III.6 Electrochemical Hydrogen Compressor

Ludwig Lipp (Primary Contact), Pinakin Patel
FuelCell Energy, Inc. (FCE)
3 Great Pasture Road
Danbury, CT 06813
Phone: (203) 205-2492
Email: llipp@fce.com

DOE Managers
Erika Sutherland
Phone: (202) 586-3152
Email: Erika.Sutherland@ee.doe.gov
David Peterson
Phone: (720) 356-1747
Email: David.Peterson@ee.doe.gov

Contract Number: DE-EE0003727

Subcontractor
Sustainable Innovations, LLC, Glastonbury, CT

Start Date: July 15, 2010
End Date: October 14, 2014

Overall Objectives

- Demonstrate the capability of electrochemical hydrogen compression (EHC) technology to meet the DOE targets for small compressors for refueling sites.
- Quantify EHC cell performance and durability.
- Reduce capital cost to demonstrate the potential to meet DOE cost targets for hydrogen compression, storage, and delivery.

Fiscal Year (FY) 2014 Objectives

- Develop a solid-state EHC building block capable of compressing 2 lb/day hydrogen from near-atmospheric pressure to 2,000-3,000 psi.
- Scale up the EHC stack active cell area by >100%.
- Increase compression efficiency (isentropic) to 73% (DOE 2015 Target).

Technical Barriers

This project addresses the following technical barrier from the Hydrogen Delivery section (3.2) of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan:

- (B) Reliability and Costs of Gaseous Hydrogen Compression

Technical Targets

Technical targets are presented in Table 1.

TABLE 1. FCE Progress towards Meeting Technical Targets for Small Compressors for Fueling Sites [1]

Characteristic	Units	DOE 2015 Target	FCE Status
Reliability	-	Improved	>10,900 hours
Compressor Efficiency	%	73% isentropic	<5 kWh/kg at 200 bar
Losses (% of H_2 throughput)	%	0.5	1
Uninstalled Capital Cost	$	400,000	300,000 projected for EHC stack
Outlet Pressure Capability	bar	860	Up to 880
Contamination	-	Varies by design	None

FY 2014 Accomplishments

- Design: Reduced electrochemical compressor cell part count by ~75% compared to baseline design (Figure 1).
- EHC Stack Scale Up: Scaled up stack height in 185 cm^2 design from one to eight cells.
- Hydrogen Capacity: Increased EHC capacity to 2 lb/day, meeting a major program goal (Table 2).
- Capital Cost: Achieved 60% decrease in single production unit cost compared to baseline design by lowering part count and increasing the cell active area.

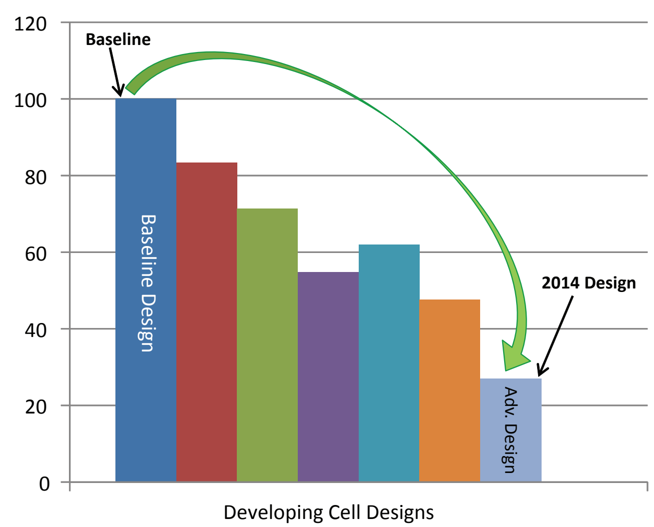

FIGURE 1. Decreased Cell Part Count for EHC Cost Reduction

- Efficiency: Validated lower specific energy consumption of <5 kWh/kg H_2 at 3,000 psi in 185 cm^2 design (Figure 2).
- Durability: Demonstrated >10,900 hour operation in larger area 185 cm^2 cell at >95% hydrogen recovery (Figure 3).

✧ ✧ ✧ ✧ ✧

INTRODUCTION

With the depletion of fossil fuel reserves and a global requirement for the development of a sustainable economy, hydrogen-based energy is becoming increasingly important. Production, purification, and compression of hydrogen represent key technical challenges for the widespread commercialization of hydrogen fuel cell technologies. In the transportation sector, onboard storage of pure hydrogen is required at pressures up to 10,000 psi and compression of the hydrogen fuel up to 12,700 psi.

The level of maturity of current hydrogen compressor technology is not adequate to meet projected infrastructure demands. Existing compressors are inefficient and have many moving parts, resulting in significant component wear and therefore excessive maintenance. New technologies that achieve higher operational efficiencies, are low in cost, safe, and easy to operate are therefore required. This project addresses high-pressure hydrogen needs by developing a solid-state electrochemical hydrogen compressor.

APPROACH

The approach to address the project goals consists of the following major elements:

- Increase hydrogen recovery efficiency by improving flow field design.
- Reduce capital cost by increasing the hydrogen flux.
- Reduce operating cost by improving membrane and electrode design.
- Increase compressor capacity by increasing cell active area and stack height.

To this end, the approach includes the design, fabrication and evaluation of improved cell architecture, and the development and demonstration of critical sealing technology to contain the high-pressure hydrogen within the EHC.

RESULTS

A major activity this year was to reduce the capital cost of the EHC design for 2,000-3,000 psi hydrogen product pressure. This was addressed by reducing the cell part count, as well as scaling up the cell active area and transitioning to a short stack. A number of design innovations were implemented in the advanced EHC design. The number of parts has been reduced in a stepwise process as shown in Figure 1. Compared to 2013, the number of parts was reduced by 50%. Compared to the original baseline design, a 75% reduction has been achieved. The reduced part count results in a lower cost to fabricate EHC cells. This contributes to the overall reduction in capital cost. Potential for mass manufacturability was maintained with the improved cell components. Preliminary cost projections show a stack cost of $300,000 can be achieved at 160 bar with further scale up from 185 to 400 cm^2 active area, increased current density to 2 A/cm^2, increased stack height to 10-50 cells per stack and a moderate production volume of 10,000 stacks per year. This compares favorably to the DOE FY 2015 cost target of $360,000-$400,000 for small compressors. Additional cost reduction is expected by further increasing stack height and production volume. Improved cell stack materials and components to meet these projections are under development, including repeating and non-repeating stack hardware.

To demonstrate increased hydrogen capacity, an eight-cell stack using the scaled-up 185-cm^2 hardware was fabricated. Procedures were developed to operate the stack continuously at a product pressure of 3,000 psi. A direct current up to 133 A was applied to the stack, thus achieving a capacity of 2 lb/day hydrogen, as shown in Table 2. Hence a major milestone in the project is met. The stack was operated at various conditions, reaching total operating time of >3,000 hours to date.

TABLE 2. Increased Hydrogen Capacity by 7x to Meet Project Target of 2 lb/day

Characteristic	Units	2014 Result
DC Load	A	133
Average Cell Voltage	V	0.373
Hydrogen Flux Rate	slpm	7.6
Power Input	Watts	397
Production Rate	lb H_2/day	2

The EHC efficiency is measured by the hydrogen recovery as well as the specific energy consumption. Figure 2 shows the specific energy consumption of a number of recent EHC cells. Efforts in previous years reduced the specific energy consumption to below that of state-of-the-art multi-stage mechanical compressors, first at hydrogen product pressures of 2,000 psi and then at 3,000 psi. This development was carried out in 81-cm^2 EHC hardware. This year the lowest specific energy consumption of <5 kWh/kg at 3,000 psi was reproduced in a scaled-up 185-cm^2 cell. This indicates a successful cell area scale up.

Durability and reliability are significant barriers for mechanical compressors, and major incentives for pursuing electrochemical compression. Therefore, emphasis was

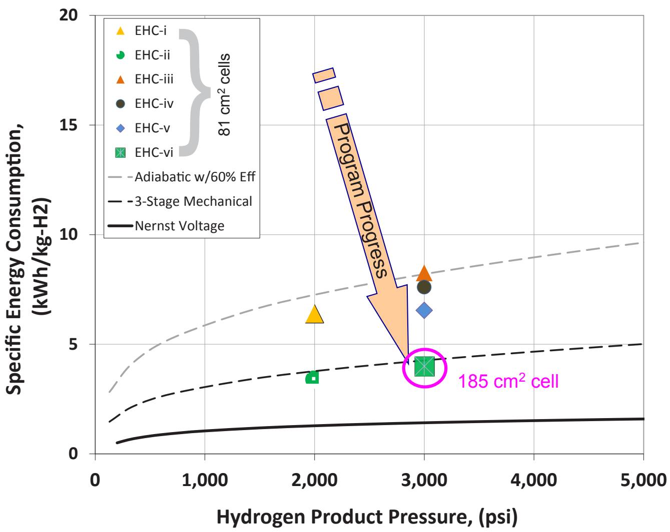

FIGURE 2. Maintained Lower Specific Energy Consumption at 3,000 psi in Scaled-Up EHC (185 cm^2 active area)

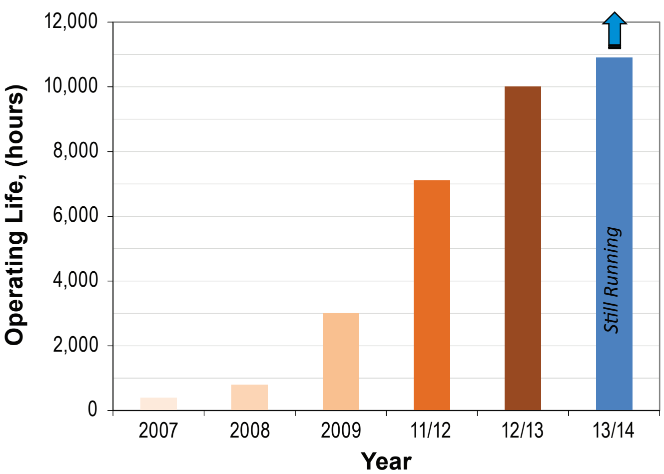

FIGURE 3. 10,900 Hour Endurance Demonstrated in Scaled-Up EHC at >95% Hydrogen Recovery

placed on endurance testing the EHC. 81-cm^2 cells were operated up to 10,000 hours at 3,000 psi, as reported in the last annual progress report. This year, a 185-cm^2 cell has reached 10,900 hours of operation, as shown in Figure 3. Its hydrogen recovery was in excess of 95%. Cell operation is continuing. This result is further confirmation of the robustness of the EHC, even with increased cell active area. Therefore, EHC is expected to be able to meet the DOE target for high compressor reliability.

CONCLUSIONS AND FUTURE DIRECTIONS

The EHC capacity has been increased by a factor of seven to meet the project target of 2 lb/day hydrogen. The cell part count was reduced by 50% to 25% of the original baseline cell, in an effort to reduce EHC capital cost. A specific energy consumption below that of state-of-the-art mechanical compressors has been maintained with the scaled-up cell hardware. Durability of the scaled-up cell architecture has been demonstrated in a 10,900 hour test, confirming its robustness. The following summarizes critical performance parameters that were advanced during this reporting period:

Parameter	2013 Value	2014 Value
Percent of Original Part Count	50	25
EHC hydrogen capacity	0.3 lb/day	2 lb/day
Specific energy consumption at 3,000 psi	<5 kWh/kg in 81 cm^2	<5 kWh/kg in 185 cm^2
Endurance	10,000 hours	10,900 hours

Future efforts will include continued endurance testing of a 185-cm^2 EHC cell, as well as fabrication and testing of a taller EHC stack.

FY 2014 PUBLICATIONS/PRESENTATIONS

1. L. Lipp, "Electrochemical Hydrogen Compressor", 2014 DOE Hydrogen Program Merit Review and Peer Evaluation Meeting, Washington, DC, June 16–20, 2014.

REFERENCES

1. DOE Office of Energy Efficiency and Renewable Energy (EERE) Fuel Cell Technologies Office Multi-Year Research, Development and Demonstration (MYRD&D) Plan, Table 3.2.4 "Technical Targets for Hydrogen Delivery Components", section on Small Compressors, page 3.2-16.