III.10 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 Manager
Erika Sutherland
Phone: (202) 586-3152
Email: Erika.Sutherland@ee.doe.gov

Contract Number: DE-EE0003727

Subcontractor
Sustainable Innovations, LLC, Glastonbury, CT

Start Date: July 15, 2010
End Date: July 14, 2015

Overall Objectives

- Demonstrate 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 potential to meet DOE cost targets for hydrogen compression, storage and delivery

Fiscal Year (FY) 2015 Objectives

- Scale up the EHC stack height to increase hydrogen capacity
- Demonstrate taller stack performance stability at 3,000 psi for 1,000 hours
- Demonstrate long-term durability of EHC cells

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 for EHC are presented in Table 1.

TABLE 1. Progress Made Towards Meeting Technical Targets for Small Compressors for Fueling Sites [1]

Characteristic	Units	DOE 2015 Target	FCE Status
Reliability	-	Improved	20,000 h§&
Compressor Efficiency (Isentropic)	%	73%	75%§#
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

§For compression from 3 to 208 bar; ^3 bar inlet pressure; &0.1 kg H_2/d; #0.3 kg H_2/d; *<0.01 kg H_2/d

FY 2015 Accomplishments

- EHC Stack Scale-up: Scaled up stack height in 81 cm^2 design from five to 30 cells (Figure 1)
- EHC Cell Reproducibility: Reduced cell-to-cell variability by >70% in the past year (>90% in the program) (Figure 2)
- EHC Stack Pressure Capability: Increased stack hydrogen product pressure by 50% from 3,000 to 4,500 psi
- Stack Durability: Validated 4,500 psi product pressure in 30-cell stack for >1,500 hours, exceeding the program target by >50% (Figure 3)
- Cell Durability: Demonstrated 20,000 hours operation in larger area 185 cm^2 cell at >95% hydrogen recovery (Figure 4)

✧ ✧ ✧ ✧ ✧

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, on-board 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 program goals consists of the following major elements:

- Increase stack performance by improving reproducibility of cell performance during pressurized operation
- 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.

FIGURE 1. EHC 30-cell stack (81 cm^2 design)

RESULTS

A major activity this year was to increase the EHC stack height to demonstrate the suitability of the architecture for building taller stacks with increased hydrogen flux. The 81 cm^2 cell design was improved to increase the manufacturing yields of key components and to reduce their cost. In addition, altered fabrication methods and procedures enabled fabrication of cell components with improved tolerances. New assembly equipment was put in place to enable stacking more than five to ten cells. New tooling and assembly fixturing was developed during attempts to increase stack height. Figure 1 shows successful implementation of these improvements in a 30-cell stack.

The stack was designed for a hydrogen product pressure of 4,500 psi, which is 50% higher than previous stacks. It was proof tested at 6,750 psi to ensure safety during operation. With this stack a new record was established in terms of the combination of taller stack (30 cells) and pressure capability (4,500 psi). After conditioning and parametric testing, the hydrogen product pressure was gradually increased to the design pressure of 4,500 psi. The cell-to-cell performance was over 70% lower compared to a stack tested during the previous FY, as shown in Figure 2. This performance is ascribed to the design and fabrication improvements described in the previous paragraph, as well as improved system controls enabled by a new test station developed for taller stack testing. Figure 2 also shows an improvement

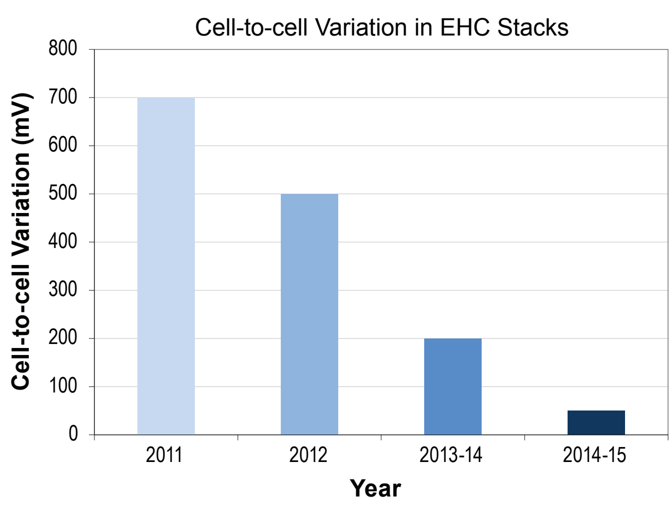

FIGURE 2. Cell-to-cell variability reduced by >70%

of >70% in cell-to-cell variation over the course of this program.

The 30-cell stack was endurance tested for 1,500 hours at 4,500 psi, as shown in Figure 3. The program milestone was to demonstrate 1,000 hours of performance stability in the 30-cell stack operating at 3,000 psi. Thus, the milestone was exceeded by 50% in both product pressure and duration.

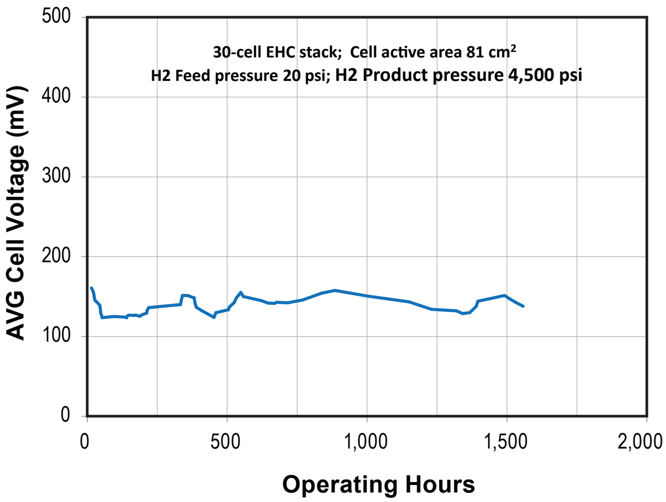

FIGURE 3. EHC 30-cell stack operation at 4,500 psi – milestone met

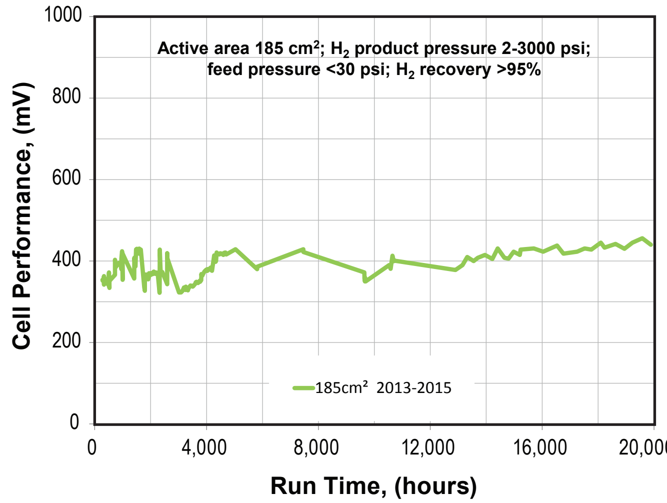

FIGURE 4. EHC 185 cm^2 single cell long-term operation at 2–3,000 psi

Over the total operating time of >4,000 hours, the stack was subjected to more than 20 pressure cycles from >3,000 psi to <30 psi. This cycling has not affected its performance, confirming the stack's robustness. Previously an EHC cell was cycled >1,000 times over that pressure range without adverse effects. The limited cycling data suggests that the pressure cycling capability was maintained in the stack scale-up to 30 cells.

Durability and reliability are significant barriers for mechanical compressors, and are major incentives for pursuing electrochemical compression. Therefore, continued emphasis was placed on endurance testing the EHC. A larger area EHC cell (185 cm^2 active area), fabricated and assembled in 2013, reached 20,000 hours of operation, compressing hydrogen from an inlet pressure of <30 psi to a product pressure of 2–3,000 psi at a hydrogen recovery rate of about 95%. As Figure 4 shows, cell performance has been quite stable, demonstrating long-term durability. This data is continued evidence of the robustness of the EHC cell architecture. Based on this data, durability well in excess of 40,000 hours is predicted. Therefore, EHC is expected to be able to meet the DOE target for high compressor reliability.

CONCLUSIONS AND FUTURE DIRECTIONS

The EHC stack height was increased from five to 30 cells. Simultaneously, the hydrogen product pressure was increased from 3,000 psi to 4,500 psi. Improvements in cell design, fabrication and assembly have resulted in a more than 70% reduction in cell-to-cell variability, resulting in improved operability. This improvement was demonstrated by running the 30-cell stack at 4,500 psi for more than 1,500 hours, with good performance stability. Durability of the scaled-up cell architecture has been demonstrated in a 20,000-hour test, confirming its robustness. The following summarizes critical performance parameters that were advanced during this reporting period:

Parameter	2014 Value	2015 Value
Number of cells in stack	5	30
EHC stack product pressure	3,000 psi	4,500 psi
Stack endurance at 4,500 psi	N/A	>1,500 hours
EHC cell endurance	10,900 hours	20,000 hours

N/A – not appliable

No additional work is planned under this project. Additional efforts are needed to further scale up the EHC stack to a building block size suitable for hydrogen refueling stations. Cost reduction opportunities include further advancing thermal management.

FY 2015 PUBLICATIONS/PRESENTATIONS

1. L. Lipp, "Electrochemical Hydrogen Compressor," 2015 DOE Hydrogen Program Merit Review and Peer Evaluation Meeting, Arlington, VA, June 8-12, 2015.

REFERENCES

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