III.6 Electrochemical Hydrogen Compressor

Ludwig Lipp (Primary Contact), Pinakin Patel
FuelCell Energy, Inc.
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
Dave Peterson
Phone: (720) 356-1747
Email: David.Peterson@go.doe.gov

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Sustainable Innovations, LLC, Glastonbury, CT

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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) 2013 Objectives

- Develop a solid-state EHC building block capable of compressing hydrogen from near-atmospheric pressure to 2,000-3,000 psi.
- Scale up the EHC 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

This project is directed at developing a solid-state EHC. The EHC is an enabling device for low-cost hydrogen delivery. Goals include the following:

- Single-stage compression of hydrogen from near-atmospheric pressure to 2,000-3,000 psi.
- Multi-stage compression of hydrogen from near-atmospheric pressure to 6,000-12,000 psi.
- Ensure no possibility of lubricant contamination of the hydrogen from compression (DOE 2020 target).
- Reduce EHC specific energy consumption.
- Scale up EHC to a capacity of 2 lb/day H_2.

The ultimate goal of the project is to meet the DOE targets for small compressors [1].

FY 2013 Accomplishments

- Design: Reduced EHC cell part count by >50% through design innovations.
- Hydrogen Flux: Increased operating current density (and therefore hydrogen flux) by ~3x over the 2010 baseline.
- EHC Scale-Up: Achieved >2x increase in cell active area by scaling up from 81 to 185 cm^2.
- Capital Cost: Achieved 50% decrease in single production unit cost through lowering part count and increasing the current density and active area to increase the production rate while lowering the total cells per stack.
- Efficiency: Reduced specific energy consumption at 3,000 psi to <5 kWh/kg H_2.
- Durability: Demonstrated 10,000 hour operation at >95% hydrogen recovery.

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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 12,000 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 EHC.

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.
- Develop a multi-stage system concept for compression to 6,000-12,000 psi.

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 focus of this year's efforts was to reduce the capital cost of the EHC building block design for 2,000-3,000 psi hydrogen product pressure. This was addressed by a multi-pronged approach of reduced cell part count, active area scale-up and increased current density. A number of design innovations were conceived, translated into a cell design, fabricated and individually tested in 81-cm^2 cells. The most successful changes were combined into the 2013 design, as shown in Figure 1. It features a >50% reduction compared to the baseline design. Mass manufacturability is an important criterion that was taken into account in the selection of the improved component designs. Simultaneously, the cell active area was scaled up by >100% from 81 cm^2 to 185 cm^2. The 185 cm^2 design has been validated for >1,000 hours of operation in a single cell. Validation at the stack level is planned for FY 2014.

The current density has been steadily increased in the project through improvements in cell design and materials. Figure 2 shows a 3-fold increase in current density over the 2010 baseline EHC. Since the hydrogen flux through the EHC is directly proportional to the current density, it enables higher hydrogen capacity from the same size EHC hardware. This equates to a proportional reduction in EHC capital cost.

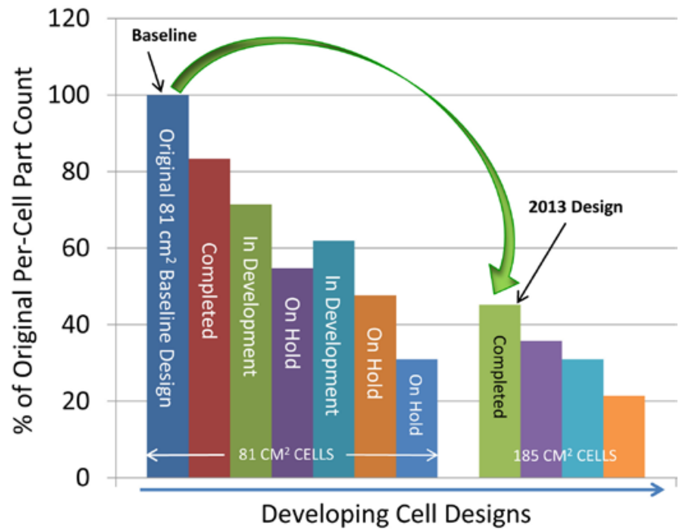

FIGURE 1. >50% Decrease in Cell Part Count for EHC Cost Reduction

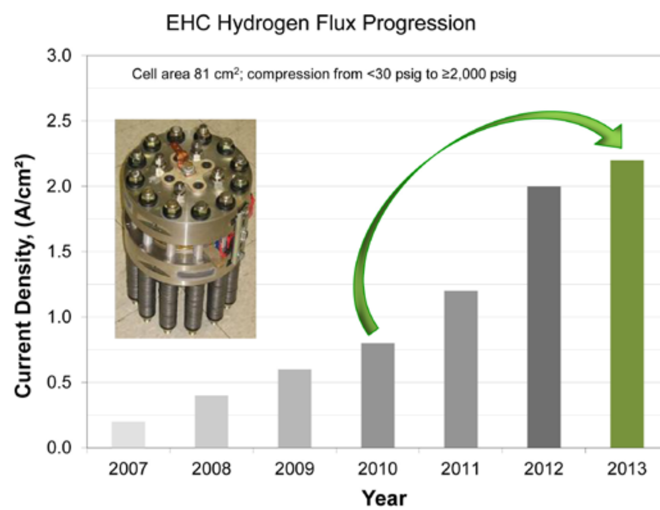

FIGURE 2. Increased Operating Current Density by ~3x over the 2010 Baseline

Overall, a >50% decrease in single production unit cost was achieved through the above improvements.

The EHC efficiency is measured by the hydrogen recovery as well as the specific energy consumption. Figure 3 shows the specific energy consumption of a number of recent EHC cells. In previous years efforts were centered at 2,000 psi. This year's focus was on reducing the specific energy consumption at a product pressure of 3,000 psi (with a hydrogen feed of 30 psi or less). Figure 3 shows a stepwise reduction in specific energy consumption at 3,000 psi from ~8 kWh/kg to <5 kWh/kg H_2. The reduction is attributed to improved cell design as well as refined operating procedures.

Durability and reliability are significant barriers for mechanical compressors, and major incentives for pursuing

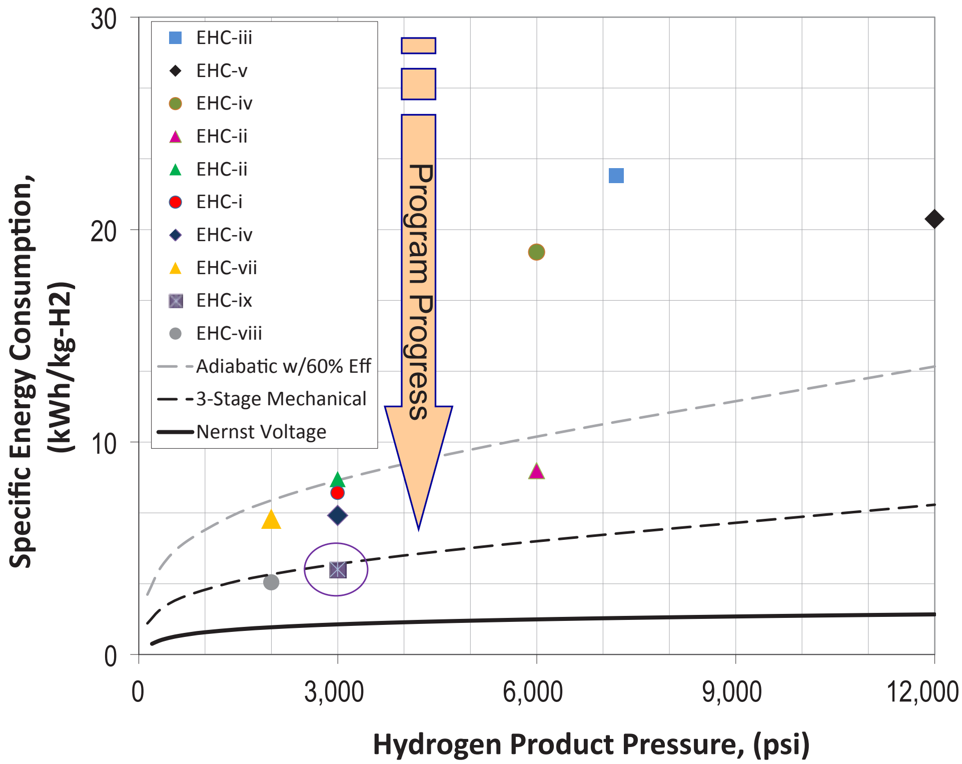

FIGURE 3. Reduced Specific Energy Consumption at 3,000 psi to <5 kWh/kg H_2

electrochemical compression. Therefore, emphasis was placed on endurance testing the EHC. A cell that began operation in FY 2012 continued to run in FY 2013, accumulating 10,000 hours of operation, as shown in Figure 4. Its hydrogen recovery was in excess of 95%. After initial fluctuations the cell performance was quite stable. Therefore, EHC is expected to be able to meet the DOE target for high compressor reliability.

CONCLUSIONS AND FUTURE DIRECTIONS

The EHC active area has been scaled up by >100%. Initial test data suggests the cell performance has been maintained in the scaled-up cell. The hydrogen flux through the EHC was increased by up to 3x, which translates to a lower capital cost. A >50% reduction in EHC cell part count also contributes to reduced cost. Durability of the EHC cell architecture has been demonstrated in a 10,000 hour test, confirming its robustness. The following summarizes critical performance parameters that were advanced during this reporting period:

Parameter	2012 Value	2013 Value
% of Original Part Count	80%	<50%
Current Density	1,200 mA/cm^2	2,200 mA/cm^2
Specific energy consumption at 3,000 psi	~8 kWh/kg	<5 kWh/kg
Endurance	6,000 hours	10,000 hours

Future efforts will include endurance testing of a 185-cm^2 EHC cell to fully validate successful active area scale-up. This will be followed by stack scale-up of the 185-cm^2 hardware to a short stack. This stack will be designed for a capacity of 2 lb/day H_2 at compression to 3,000 psi to meet the capacity objective of the project.

FY 2013 PUBLICATIONS/PRESENTATIONS

1. P. Patel and L. Lipp, "Electrochemical Hydrogen Compression (EHC)", DOE Hydrogen Compression, Storage and Dispensing Workshop, Argonne, IL, March 20, 2013.

2. L. Lipp, "Electrochemical Hydrogen Compressor", 2013 DOE Hydrogen Program Merit Review and Peer Evaluation Meeting, Arlington, VA, May 13–17, 2013.

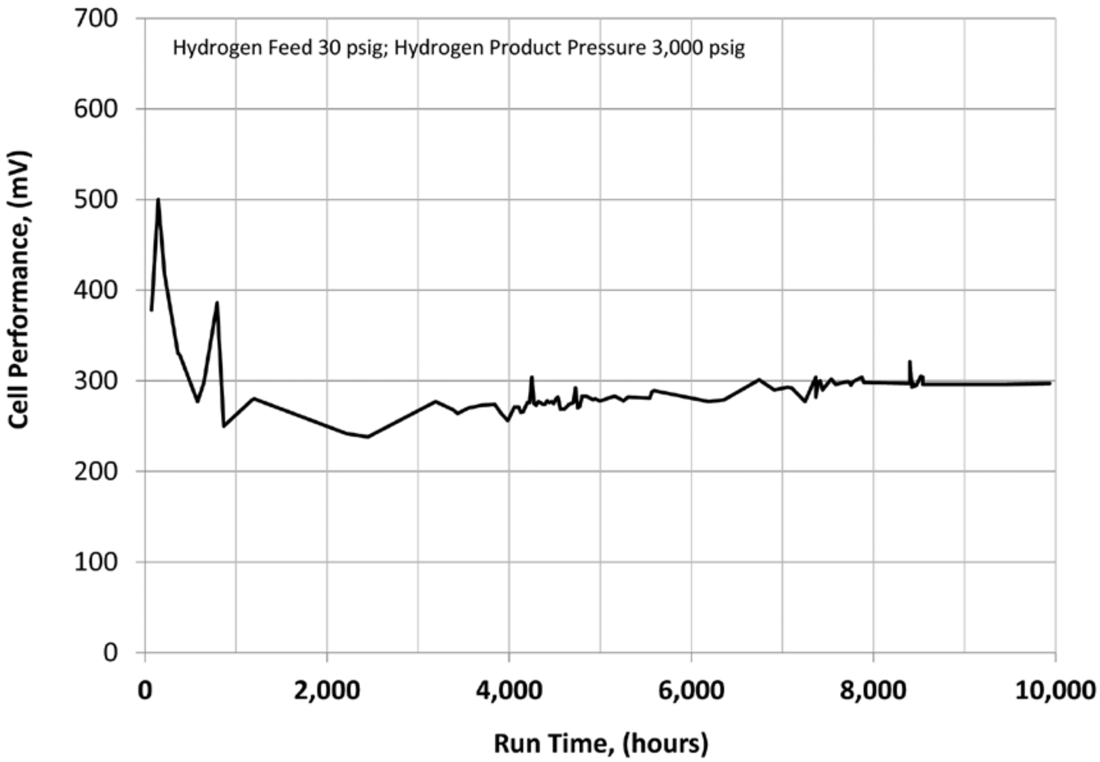

FIGURE 4. 10,000 Hour Endurance Demonstrated at >95% Hydrogen Recovery

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.