III.12 Development of Highly Efficient Solid-State Electrochemical Hydrogen Compressor

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Sustainable Innovations, LLC, Glastonbury, CT

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Objectives

- Demonstrate feasibility of a solid-state electrochemical hydrogen compressor (EHC) capable of compressing hydrogen from near-atmospheric pressure to 2,000 psi.
- Increase the cell performance (reduce power consumption, improve compression efficiency) while lowering the cost compared to previous designs.
- Study thermal and water management to increase system reliability and life.

Technical Barriers

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

(B) Reliability and Costs of Hydrogen Compression

Technical Targets

This project is directed at demonstrating the feasibility of solid-state electrochemical hydrogen compression. The EHC is an enabling device for low-cost hydrogen delivery. Phase I goals are as follows:

- Compress hydrogen from near-atmospheric pressure to 2,000 psi.
- Demonstrate performance stability at 2,000 psi for 50 hours.
- Demonstrate hydrogen recovery efficiency of 95%.
- Demonstrate 10 pressure cycles to 2,000 psi.

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

Accomplishments

- EHC feasibility successfully demonstrated.
- Significantly exceeded all program milestones.
- Compression Mode Operation: Increased capability from 600 psi to 4,500 psi in a single stage EHC cell (160:1 compression ratio).
- Operation Hours: Nearly 5,000 hours total EHC operation at different conditions.
- Pressure Cycling: Completed >1,000 pressure cycles from 100 to 3,000 psi without performance loss.
- Hydrogen Flux: Operated at 700 mA/cm^2.
- Hydrogen Recovery: Achieved 100% hydrogen recovery rate.
- Cost Reduction: Reduced Pt content by 90% without any performance loss.
- System Simplification: Demonstrated EHC operation without external humidification for >50 hours.

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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 implementation of a hydrogen economy, especially in the transportation sector where on-board storage of pure hydrogen may be 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 an efficient, low-cost, solid-state electrochemical hydrogen compressor based on polymer electrolyte membrane technology.

Approach

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

- Use of high-pressure electrolyzer experience for mechanically robust cell design.
- High current density operation to minimize the effect of hydrogen back diffusion (reduce ohmic resistance).
- Flow field design to increase hydrogen recovery efficiency.
- Reduce capital cost by reducing Pt loading, cell footprint and humidification requirements (simple system).

To this end, the approach includes the construction and evaluation of an advanced cell architecture, and the development and demonstration of critical sealing technology to contain the high-pressure hydrogen within the cathode compartment of the cell.

Results

A new cell architecture, designed and fabricated by the subcontractor, Sustainable Innovations, LLC, underwent extensive evaluation in FuelCell Energy's test facility. The focus parameter for this activity was hydrogen product pressure. The initial cell build was capable of compressing hydrogen from <30 psi to 1,450 psi, more than double the compression that our team had achieved in the 1990's with an earlier cell design. Operating parameters were varied systematically to identify favorable operating conditions. Based on the observations from several diagnostic tests, the cell was rebuilt with improved internal components thereby achieving the program goal of 2,000 psi and demonstrating a product pressure of 2,625 psi. After further improvements to the cell components, compression to 4,500 psi was achieved, as shown in Figure 1. Hence, the program goal was exceeded by more then 100%. Moreover, the DOE Fiscal Year 2010 pressure goal for forecourt compressors (5,000 psi fill pressure with 6,250 psi peak pressure [1]) was nearly achieved. The combined operating time at low pressure (<1,000 psi), medium pressure (1,000-2,200 psi) and high pressure (2,200-4,500 psi) nearly reached 5,000 hours, as shown in Figure 2. Therefore, the program goal was exceeded by almost two orders of magnitude. It can be seen that the EHC was operated at high pressure for the majority of the time, confirming the durability of this advanced cell architecture.

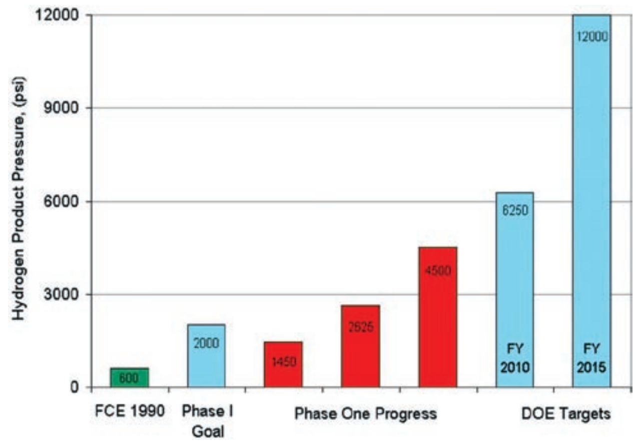

FIGURE 1. Nearly Achieved the DOE FY 2010 Pressure Goal for Forecourt Compressors

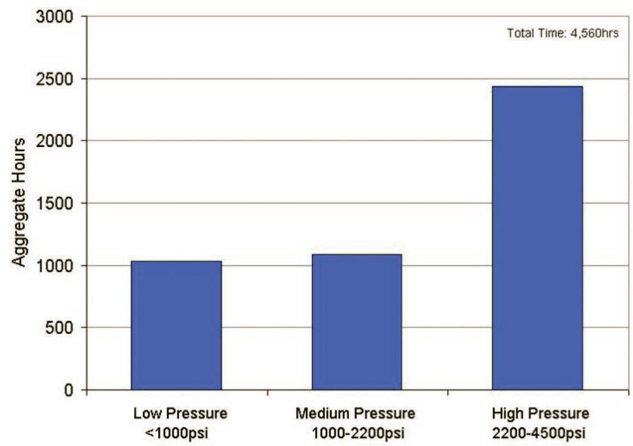

FIGURE 2. Demonstrated ~2,500 hours Durability at High Pressure

The EHC also underwent pressure cycling in the form of an accelerated durability test. Frequent pressure cycling may be expected in some applications, such as in hydrogen refueling stations, where hydrogen demand varies sharply by time of day. More than 1,000 pressure cycles from 100 to 3,000 psi were performed, as illustrated in Figure 3. No change in performance was observed, providing further validation of the robust cell design.

Conclusions and Future Direction

We have successfully demonstrated the feasibility of a solid-state EHC. In a proposed Phase II effort, further work is suggested as follows:

- Increase pressure capability of a single-stage EHC from 2,000 to 6,000 psi.
- Develop multi-cell stack design and validate in a 10-cell stack.

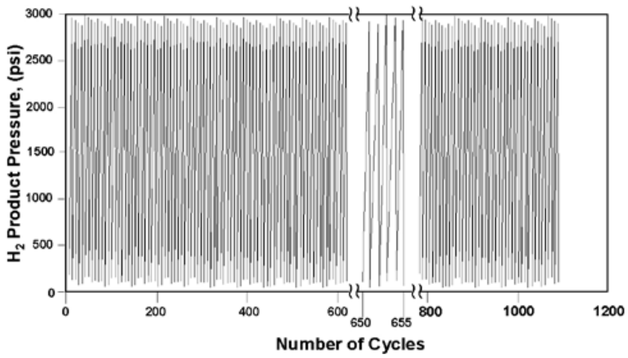

FIGURE 3. >1,000 Pressure Cycles to 3,000 psi Validates Robust Design

- Increase operating current density up to 2,000 mA/cm^2.
- Demonstrate 2 lb/day H_2 at 3,000 psi.
- Reduce power consumption to 50% of current design.
- Maintain hydrogen recovery >98%.
- Estimate capital and operating cost benefits.

FY 2008 Publications/Presentations

1. L. Lipp, "Development of Highly Efficient Solid State Electrochemical Hydrogen Compressor (EHC)", 2008 DOE Hydrogen Program Merit Review and Peer Evaluation Meeting, Washington, D.C., June 10-13, 2008.

References

1. HFCIT MYRDD Plan, Table 3.2.2 "Technical Targets for Hydrogen Delivery", section on Forecourt Compressors, page 3.2-14.