III.10 Electrochemical Hydrogen Compressor

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Contract Number: DE-EE0003727

Subcontractor:
Sustainable Innovations, LLC, Glastonbury, CT

Start Date: July 15, 2010
End Date: July 14, 2013

Fiscal Year (FY) 2011 Objectives

- Develop a solid-state electrochemical hydrogen compressor (EHC) building block capable of compressing hydrogen from near-atmospheric pressure to 2,000-3,000 psi.
- Study feasibility of an EHC multi-stage system capable of compressing hydrogen from near-atmospheric pressure to 6,000-12,000 psi.
- Increase compression efficiency to 95% (DOE 2015 target).

Technical Barriers

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

(B) Reliability and Costs of 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 2015 target).
- Reduce EHC specific energy consumption.
- Scale up EHC to a capacity of 2-4 lb/day H_2.

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

FY 2011 Accomplishments

- Hydrogen Pressure: reached 6,000 psi hydrogen pressure in a two-stage EHC system (Figure 1).
- Compression Efficiency: reduced specific energy consumption to <5 kWh/kg H_2 when compressing from atmospheric pressure to 2,000 psi (Figure 2).
- Hydrogen Recovery: achieved 95% hydrogen recovery in a single cell.
- Capital Cost: increased hydrogen flux from 400 to 750 mA/cm^2.

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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

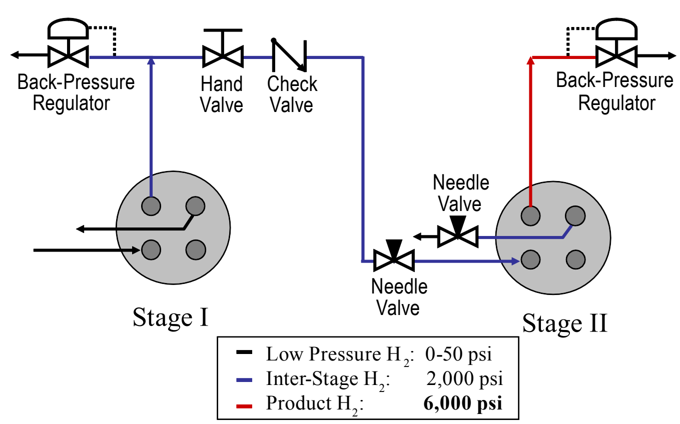

FIGURE 1. 2-Stage EHC System Concept

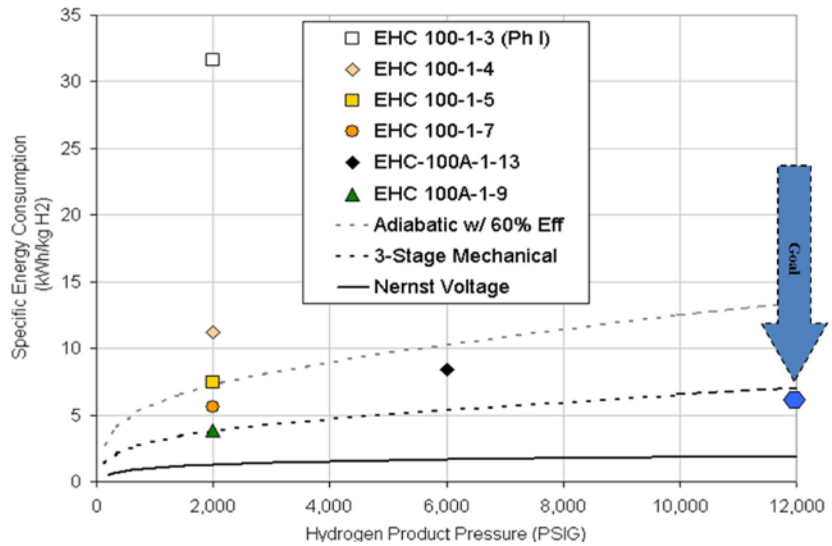

FIGURE 2. Reduction in the Specific Energy Consumption of the EHC

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 program 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 2-stage EHC system concept was developed, in order to achieve higher hydrogen pressures using existing EHC designs. The challenge was to design a system that can automatically respond to changes in pressure, inlet flow and current density, while maintaining stable operation in both stages. The system also needs to safely operate without attendants, in order to demonstrate continuous operation. The high level system configuration and control strategy that was developed in FY 2011 is shown in Figure 1. Atmospheric pressure hydrogen is fed to the low-pressure side of stage I. The pressurized hydrogen (inter-stage pressure) is then fed to the low-pressure side of the stage II EHC. A check valve prevents hydrogen from flowing back from stage II to stage I. The product hydrogen exits the stage II EHC at the desired high pressure. For safe operation of the laboratory system, this pressure is controlled by a back-pressure regulator. The concept was validated in the laboratory by compressing from atmospheric pressure to about 2,000 psi in the first stage, followed by compression to 6,000 psi in the second stage. Then it was operated for several weeks at a variety of inter-stage and product pressures, and at different hydrogen flow rates. This experience will provide a solid basis for designing a multi-stage system capable of reaching 12,000 psi, as shown in Figure 3. A product pressure of 12,000 psi is desirable in order to efficiently refuel hydrogen vehicle tanks with a maximum fill pressure of 10,000 psi. This pressure is needed to enable a driving range similar to gasoline-fueled vehicles, while preserving the passenger and cargo capacity of the vehicles.

A major challenge in the commercialization of the EHC is capital cost. One way to address this challenge is to increase the hydrogen flux by increasing the operating current density. This, however, could lead to a higher operating cost, due to increased specific energy consumption. The latter is proportional to the cell resistance. To lower the cell resistance, efforts were

FIGURE 3. Multi-Stage System Capable of Reaching 12,000 PSI

focused on lowering the bulk and contact resistances of key cell components, such as membrane and bipolar plates. Improvements to the cell design and materials enabled a reduction in specific energy consumption to below 5 kWh/kg H_2. This performance was obtained when compressing hydrogen from atmospheric pressure to 2,000 psi, as shown in Figure 2. The hydrogen recovery was as high as 95%. The improvements in membrane and bipolar plate materials also enabled the desired increase in current density, which leads to a higher hydrogen flux and therefore reduced capital cost. Continuous operation at 750 mA/cm^2 was demonstrated in a 1,000 hour test.

Conclusions and Future Directions

The feasibility of a 2-stage EHC system to increase the pressure capability has been demonstrated. Improvements in materials have resulted in an 80% increase in hydrogen flux, which translates to a lower capital cost.

Future efforts will include further improvements in cell architecture, scale up and increase in pressure capability in a multi-stage system.

FY 2011 Publications/Presentations

1. L. Lipp, "Electrochemical Hydrogen Compressor", 2011 DOE Hydrogen Program Merit Review and Peer Evaluation Meeting, Arlington, VA, May 9–13, 2011.

References

1. Fuel Cell Technologies MYRDD Plan, Table 3.2.2 "Technical Targets for Hydrogen Delivery", section on Forecourt Compressors, page 3.2–14.