II.H.1 Low-Cost, High-Pressure Hydrogen Generator

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Objectives

- Develop and demonstrate a low-cost, high-pressure water electrolyzer system for hydrogen production
  - Decrease number of compression stages required
  - Reduce capital costs to meet DOE targets
  - Demonstrate a 3,300 scfd high-pressure electrolyzer operating on a renewable energy source
- Public outreach and education

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Generation by Water Electrolysis section (3.1.4.2.2) of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(G) Capital Cost
(H) System Efficiency
(I) Grid Electricity Emissions
(J) Renewable Integration
(K) Electricity Costs

Technical Targets

Giner Electrochemical Systems (GES) Progress Toward Meeting DOE Targets for Hydrogen Production by Electrolysis (Forecourt Station, 1,500 kg/day)

Electrolyzer Parameter	DOE 2010 Target	GES Status
Electrolyzer Cell Efficiency (% LHV)	76	73.5
Electrolyzer Stack+BOP Capital Cost ($/kg H_2)	0.39	0.90
Cost of Hydrogen Produced ($/kg H_2)	$2.85	$3.97[1]

[1]at an industrial electricity cost of $0.05/kWh

Accomplishments

- Stack Cost Reduction
  - Evaluated lower-cost materials and fabrication methods for cell components
  - Reduced the part count per repeating cell from 40 parts in 2002 to 16 in 2006
- Improved Stack Efficiency
  - Demonstrated the performance advantage of an advanced high-efficiency, high-strength membrane in a full-size single-cell
- Continued modeling of electrolyzer capital and operating costs; performed economic analysis using the DOE H2A model.

Introduction

Electrolysis of water, particularly in conjunction with renewable energy sources, is a potentially cost-effective and environmentally friendly method of producing hydrogen at dispersed sites. However, state-of-the-art electrolyzers are not economically competitive for forecourt hydrogen production due to their high capital and operating costs. In addition, the output hydrogen pressure from present electrolyzers is generally limited to 200 psi, requiring a multi-stage mechanical compressor to increase the hydrogen pressure to the 6,250 psi or greater required for storage and/or dispensing to fuel cell powered automobiles. Reducing the number of compression stages required would increase the efficiency and reliability of electrolysis systems.

GES has developed differential pressure technology for producing hydrogen at high pressure directly in the electrolyzer stack, while oxygen is evolved at near-atmospheric pressure. The goal of the present DOE project is to reduce the cost of the stack and system, while increasing the hydrogen pressure in the electrolyzer stack.

Approach

GES is evaluating alternative materials and designs for stack components to reduce cost and increase the operating pressure. Improving electrolyzer electrochemical performance reduces cost by decreasing the number of cells required to produce a given quantity of hydrogen, while maintaining high efficiency. Performance is being improved through development of an advanced high-strength, low-resistance membrane. To further reduce cost, GES is evaluating advanced system concepts.

Results

The effort this year focused on continuing reduction of the stack capital cost. Based on the projected cell costs and potential for cost savings, five cell components were selected for focused cost reduction, as described below.

Anode-Side Membrane Support Structure (ASMSS)

In the present electrolyzer, the ASMSS is a complex structure consisting of nine layers of metallic components, with each layer processed and assembled by hand. This structure has the highest parts count and labor requirements of the cell components. To reduce the labor cost, GES is working with vendors to identify cost-effective methods of fabricating a single-piece component having the required properties and tolerances. In preliminary testing a single-piece ASMSS demonstrated acceptable pressure drop and stable electrolyzer performance over several hundred hours of operation.

Cell Frames

Development of a lower cost method of fabricating cell frames was continued. Each cell contains two thermoplastic frames to conduct fluids into and out of the active parts of the cell and to help contain the pressure loads. These parts are very expensive due to the required high precision and time-consuming machining operations. Several concepts for eliminating the machining steps were developed and tested on small scale coupons; further development of two methods will be pursued. Successful development of a low-cost frame is expected to reduce the cost/cell by 40%.

Cell Separator

The cell separator is a gas-impermeable conductive sheet that separates the hydrogen and oxygen compartments in the bipolar stack. The separator must be highly conductive, as well as resistant to hydrogen embrittlement and to corrosion in an oxidizing environment. The proven GES high-pressure electrolyzer uses a complex multi-layer separator incorporating a conductive compliant member and sheets of niobium and zirconium metal. Zirconium is used due to its high resistance to hydrogen embrittlement.

Due to the importance of a highly durable, low-cost separator, several approaches were evaluated. A near-term approach is to use a separator consisting of two metal layers. After over 700 hours of testing, the two-layer separator was in very good condition, with no evidence of corrosion or hydrogen embrittlement.

The most promising approach for longer-term implementation is bonding of titanium to a low-cost electrically conductive, embrittlement-resistant material. The challenge is development of a bonding technique that minimizes contact resistance and provides good adherence between the layers. A sample separator was fabricated and tested in a single-cell with acceptable performance, although the cell resistance was somewhat higher than typical. Further testing is required to determine the long-term stability of the bond.

Advanced Membrane

To improve electrolyzer efficiency, and thereby reduce operating and capital costs, GES is developing an advanced thin supported membrane having resistance comparable to that of a 0.002-inch thick Nafion® 112 membrane, but having significantly improved mechanical properties.

An apparatus for fabricating large pieces of the advanced membrane was designed and assembled. Membrane fabrication process parameters were developed and four pieces of advanced membrane were fabricated

The advanced membrane was successfully tested in a 160-cm^2 single-cell electrolyzer, operating at pressures up to 125 psig and at temperatures up to 80°C. As shown in Figure 1, initial performance of the advanced membrane in a membrane electrode assembly (MEA) is significantly better than that of a Nafion® 117 MEA. Testing to determine membrane performance under various conditions and membrane lifetime is underway.

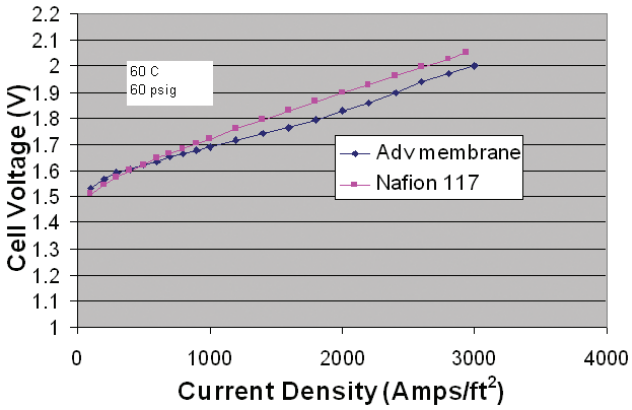

FIGURE 1. Performance of the GES Advanced Membrane

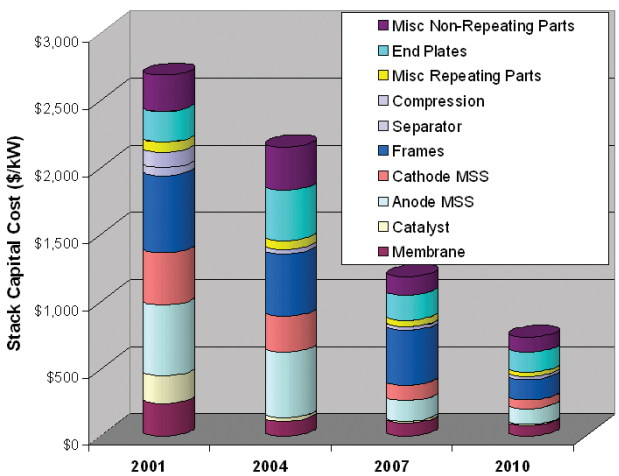

FIGURE 2. Progress in Electrolyzer Stack Cost Reduction

Stack Cost Reduction/ Decreased Parts Count

The materials and manufacturing methods developed in this project have significantly decreased the electrolyzer capital cost, as shown in Figure 2. As a result of the component development described above, the overall projected capital cost of the electrolyzer stack (designed for 330 psig operation) has decreased from greater than $2,500/kW in 2001 to approximately $1,100/kW in 2007, with a further projected decrease to $600/kW in 2010, assuming successful commercialization of the low-cost manufacturing methods and large-scale production of electrolyzer stacks.

The overall decrease in parts count per cell is a major factor in the stack cost reduction. The parts count/cell has been reduced from more than 40 parts at the beginning of this project in 2002 to the present design of 16 parts, as shown in Figure 3. In addition

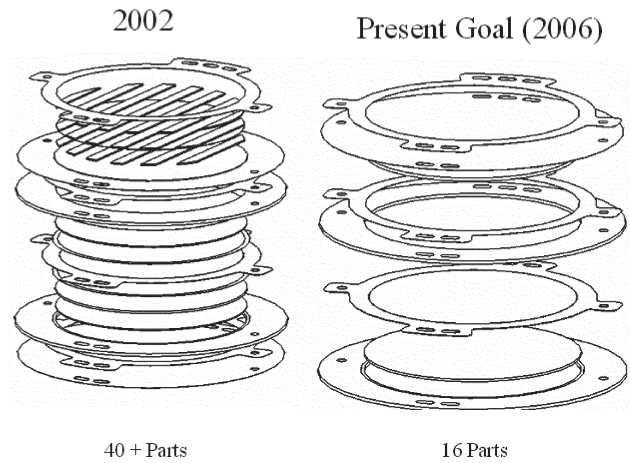

FIGURE 3. Reduction in Electrolyzer Cell Parts Count

to reducing the cost of the individual components, the reduced parts count is expected to decrease the labor required to assemble the stack by 60%.

Economic Analysis

The DOE H2A Forecourt model was used to project the cost of hydrogen produced by the advanced, low-cost proton exchange membrane (PEM) electrolyzer for forecourt filling station applications. The model is based on production of 1,500 kg H_2/day at a storage pressure of 6,250 psig. GES developed capital cost projections for the electrolyzer system based on the cost for the 500th unit, representing large-scale production of electrolyzer cells and stacks.

Using the model and capital cost assumptions, the delivered cost of hydrogen was compared for electrolyzers producing hydrogen at 330, 1,200 and 5,000 psig, with a mechanical compressor used to boost the hydrogen to the 6,250 psig storage pressure. At each pressure studied, the effect of operating current density on hydrogen cost was evaluated to understand the tradeoff between higher electricity costs (due to decreased efficiency) but lower capital costs as the design current density is increased. The relative contribution of efficiency and capital cost to the cost of hydrogen depend on the cost of electricity. Figure 4, shows that at a cost of industrial electricity of $0.05/kWh, the projected cost of hydrogen delivered at a forecourt station is less than $4/kg using an electrolyzer designed for 330 psig operation. The cost of hydrogen increases with electrolyzer design pressure due to the higher stack and system capital cost required for higher pressure operation, resulting in a projected hydrogen cost of approximately $5/kg at 5,000 psig, a 25% increase over the projected cost for a 330 psig electrolyzer.

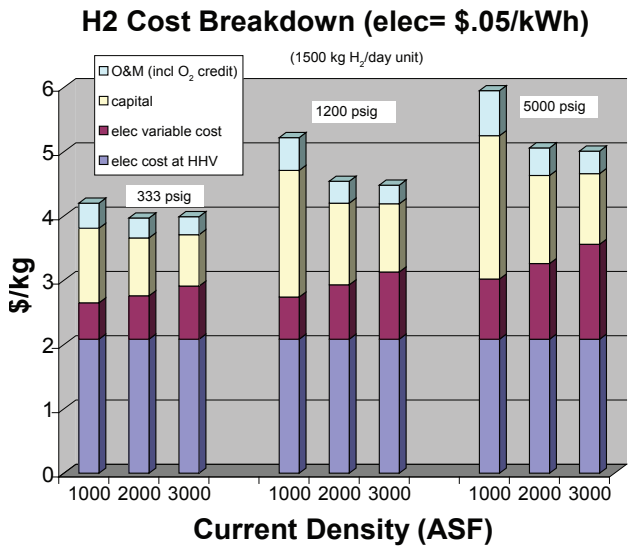

FIGURE 4. Effect of Operating Pressure and Operating Current Density on Cost of Hydrogen at a Forecourt Station

Conclusions and Future Directions

The developments in this project have resulted in a significant reduction in the cost of an electrolyzer stack. In production quantities the capital cost of the stack is projected to be approximately $600/kW.

In the remaining year of the project, GES plans to incorporate the low cost components developed under this project in an electrolyzer stack with a capacity of 3,300 scfd. If funding is available the stack will be tested at NREL

FY 2006 Publications/Presentations

1. Presentation at 2006 Hydrogen Fuel Cells Technology Infrastructure Review Meeting, C. Cropley.