II.C.2 Low-Cost, High-Pressure Hydrogen Generator

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Objectives

- Develop a low-cost, moderate-pressure proton exchange membrane (PEM) water electrolyzer system for hydrogen production
  - Reduce capital costs to meet DOE targets
  - Increase electrolyzer efficiency to reduce operating costs
- Demonstrate 1,200 psig electrolyzer
- Field test 0.25 kg H_2/hr electrolyzer system at the National Renewable Energy Laboratory (NREL)
- Public outreach and education

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Production Section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(G) Cost - Capital Cost

(H) System Efficiency

(J) Renewable Electricity Generation Integration

Technical Targets

TABLE 1. GES Progress toward Meeting DOE Targets for Distributed Electrolysis Hydrogen Production

Characteristics	Units	2012/2017 Targets	GES Status
Hydrogen Cost	$/gge	3.70/<3.00	4.76
Electrolyzer Capital Cost	$/gge	0.70/0.30	2.19
	$/kW	400/125	987
Electrolyzer Energy Efficiency	% (LHV)	69/74	64

Accomplishments

- Stack cost reduction
  - Continued development of 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
  - Reduced stack capital cost by >40%
- Improved stack efficiency
  - Demonstrated stable performance of an advanced high-efficiency, high-strength membrane in a full-size single-cell; efficiency is 72% lower heating value (LHV) at 2,000 mA/cm^2
- Continued modeling of electrolyzer capital and operating costs; performed economic analysis using the DOE H2A model
- Modified stack and system for field-testing at NREL

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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, present electrolyzer systems generally require 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 would increase the efficiency and reliability of electrolysis systems.

GES has developed differential pressure technology for producing hydrogen at moderate to high pressure directly in the electrolyzer stack, while oxygen is evolved at near-atmospheric pressure. In this system, liquid water, which is a reactant as well as a coolant, is introduced into the oxygen side at near atmospheric pressure. The goals of the present DOE program are to reduce the cost of the stack and system, demonstrate electrolyzer operation at moderate pressure and determine the optimum operating pressure for low-cost hydrogen production.

Approach

GES developed lower-cost cell components through design simplification, development of less expensive materials, and development of lower-cost fabrication methods. The cost of the electrolyzer stack was also reduced by improving the electrochemical performance, which decreases the number of cells required to produce a given quantity of hydrogen, while maintaining high efficiency. Performance was improved through development of an advanced high-strength, low-resistance membrane. To further reduce cost, GES evaluated advanced system concepts.

Results

The effort this year focused on continued development of low-cost stack components through development of alternate materials and fabrication methods. Based on previously reported results and updated cost studies, development was focused on the three critical stack components discussed below. Development of the advanced high-efficiency membrane was continued. An electrolyzer stack and system were modified for delivery to NREL for field-testing.

Anode-Side Membrane Support Structure (ASMSS)

In prior designs, the ASMSS was 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. Last year, we developed a preliminary design for a single-piece component having the required properties and tolerances. This year several methods of fabricating the single-piece ASMSS were evaluated, and one ASMSS demonstrated acceptable pressure drop and good performance in a full-size (160 cm^2 active area) single-cell test.

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. The preliminary feasibility of a low-cost fabrication method that eliminates the machining steps was demonstrated. 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 naval 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.

Development of a highly durable, low-cost separator was continued. The most promising approach for long-term implementation is coating titanium with a low-cost electrically conductive, embrittlement-resistant material. The challenge is development of a pinhole-free, highly adherent coating with the required characteristics. Two coatings, a carbon-based material and a metal oxide, were evaluated, but neither coating was pin-hole free, resulting in hydrogen embrittlement of the underlying titanium. Further development is required to eliminate porosity of the electrically conductive coatings or films to protect titanium from embrittlement,

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. This advanced membrane is referred to as a dimensionally stable membrane (DSM) because the membrane support minimizes changes in membrane dimensions (swelling/contraction) with changes in water content.

We previously reported that initial performance of a DSM in a full-size, single-cell electrolyzer was significantly better than that of a Nafion® 117 membrane. This year, we conducted preliminary life-testing of the DSM in a continuously operating electrolyzer cell. As shown in Figure 1, the performance of the DSM cell was stable after 300 hours of operation at 60°C. No indication of membrane degradation was observed during cell tear-down.

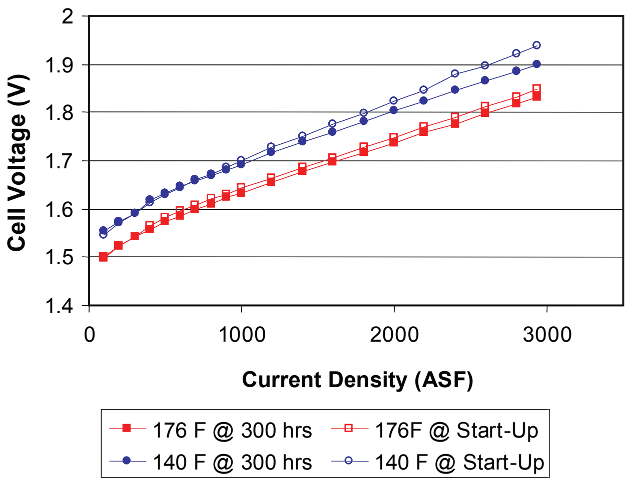

FIGURE 1. Performance of DSM Following 300 Hours of Operation

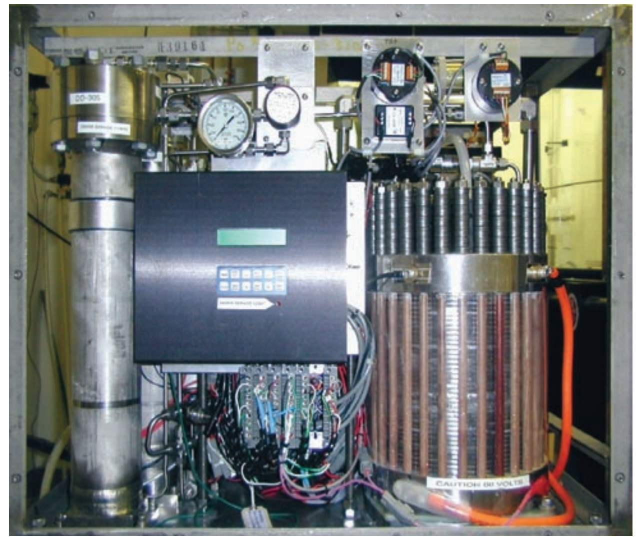

FIGURE 2. EP-1 Electrolyzer Module to be Delivered to NREL for Field-Testing

Stack Cost Reduction/Decreased Parts Count

The materials and manufacturing methods developed in this project have significantly decreased the electrolyzer capital cost. As a result of the component and membrane development conducted in this project, 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 less than $1,000/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 program in 2002 to the present design of 16 parts. In addition 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%.

Modification of Stack and System for Field Testing at NREL

To conclude the project, GES will conduct field testing of the GES EP-1 prototype electrolyzer module, Figure 2, at NREL. The EP-1 module will produce approximately 0.25 kg/hr hydrogen at pressures up to 1,200 psig. The electrolysis stack in the EP-1 module is a 28-cell stack of the EP-2 design, using the low-cost internal components developed under this project. This year the stack was modified to incorporate the recently developed two-piece cell separator to provide longer stack operating life. GES is also updating the EP-1 module to incorporate advanced system controls and is modifying the system to interface with the NREL test stand. The EP-1 module will be shipped to NREL, and GES will assist NREL in installation and testing of the module, including training of NREL personnel.

The GES EP-1 module, with a power requirement of approximately 15 kW (12.8 kW for the maximum stack input), is a good fit for the NREL test facility. NREL will test the performance of the EP-1 electrolyzer over a range of power input levels simulating input from a renewable energy source. NREL will determine the efficiency of the electrolyzer stack and module and monitor the hydrogen purity. Performance of the electrolyzer stack and module will be monitored over time. Throughout the testing at NREL, GES will review the electrolyzer data, periodically analyze water samples from the electrolyzer and provide support to NREL personnel as necessary.

Conclusions and Future Directions

The project will be concluded this year with field-testing of the electrolyzer system at NREL. Development conducted under this project has resulted in a 60% reduction in the cost of the moderate-pressure PEM electrolyzer stack. However, continued development of low-cost component and stack fabrication methods and of the high-efficiency DSM is required to meet the DOE cost and efficiency targets for hydrogen production by electrolysis.

FY 2007 Publications/Presentations

1. Presentation at 2007 Hydrogen Fuel Cells Technology Infrastructure Review Meeting, C. Cropley.