II.E.1 PEM Electrolyzer Incorporating an Advanced Low-Cost Membrane

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Subcontractors:
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- Parker Hannifin Ltd domnick hunter Division, Hemel Hempstead, United Kingdom

Project Start Date: May 1, 2008
Project End Date: April 30, 2012

Fiscal Year (FY) 2011 Objectives

Develop and demonstrate advanced low-cost, moderate-pressure proton exchange membrane (PEM)-based water electrolyzer system to meet DOE targets for distributed electrolysis:

- Develop high-efficiency, low-cost membrane
- Develop long-life cell-separator
- Develop lower-cost prototype electrolyzer stack and system
- Demonstrate prototype at the National Renewable Energy Laboratory (NREL)

Technical Barriers

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

(G) Cost - Capital Cost
(H) System Efficiency

Technical Targets

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

Characteristics	Units	2012/2017 Target	GES Status
Hydrogen Cost	\$/kg H_2	3.70/<3.00	4.66*
Electrolyzer Capital Cost	\$/kg H_2	0.70/0.30	0.60
Electrolyzer Energy Efficiency	% (LHV)	69/74	75**

*Using H2A model rev 2.1.1. A cost of \$1.80 is included for H_2 compression, storage, and delivery
** Stack efficiency; System efficiency ~68%
LHV – lower heating value

FY 2011 Accomplishments

Membrane

- Demonstrated enhanced dimensionally stable membrane (DSM™) performance (>Nafion® 1135 membrane).
- Completed 5,000-hour life-test with DSM™ (@80°C).
- DSM™ operating lifetime estimated at 55,000 hours.
- Reduced membrane support costs by one order of magnitude in the past year.

Cell-Separator

- Demonstrated reduced hydrogen embrittlement in titanium/carbon cell-separator.
- Projected longevity of the carbon/titanium cell-separators (>60,000 hours).

Electrolyzer Stack and System Design

- Completed fabrication of electrolyzer stack utilizing low-cost components.
- Reduced electrolyzer stack costs by 60% over a four year period.
- Completed fabrication of electrolyzer system incorporating a high-efficiency hydrogen dryer.
- Completed extensive safety review of electrolyzer system.
- Completed modeling of electrolyzer capital and operating costs; performed economic analysis using the DOE H2A model illustrating cost-reductions.

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Introduction

The DOE has identified hydrogen production by electrolysis of water at forecourt stations as a critical technology for transition to the hydrogen economy, and as the hydrogen economy matures, for hydrogen production at centralized locations using renewable energy sources. However, state-of-the-art electrolyzers are not economically competitive for forecourt hydrogen production due to their high capital and operating costs. The cost of hydrogen produced by present commercially available electrolysis systems is estimated to be \$5.20/kg-H_2, considerably higher than the DOE target of \$3.70/kg-H_2 by 2012 [1]. Analysis of electrolyzer systems performed by GES and others using the DOE H2A model indicate that the major cost elements are the cost of electricity, the capital costs of electrolyzer stacks and systems, and the high cost of hydrogen compression, storage, and delivery.

GES has developed PEM-based electrolyzer technology that operates at differential pressure 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 coolant, is introduced into the oxygen side at near-atmospheric pressure. The goals of the project are to reduce the cost of the stack and system, improve electrolyzer efficiency, and to demonstrate electrolyzer operation at moderate pressure.

Approach

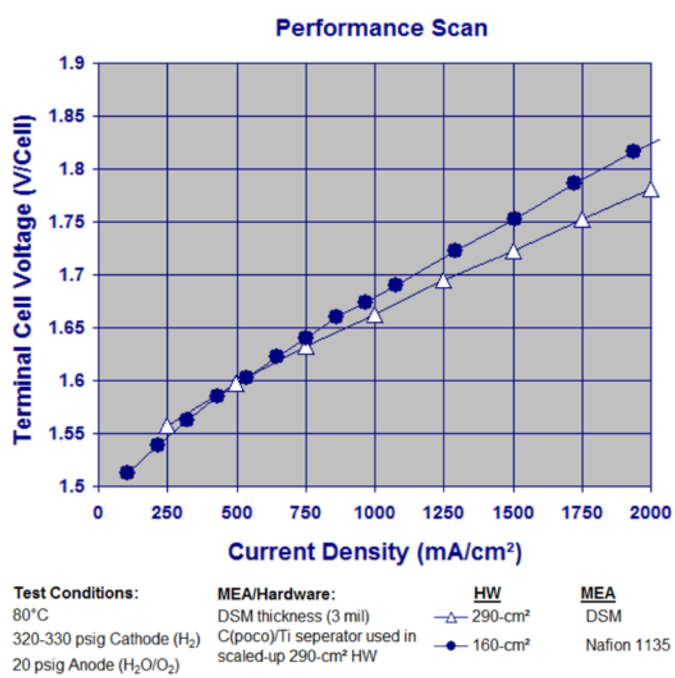
To reduce the cost of PEM-based electrolyzers, GES is improving electrolyzer stack efficiency and reducing stack cost through development of an advanced low-cost, high-strength, membrane using a perforated polyimide support imbibed with perfluorosulfonic acid (PFSA) ionomer. GES is also reducing stack capital cost and increasing stack life through development of a long-life bipolar stack cell-separator, decreasing stack costs by initiating scale-up to a larger active area, and reducing the system capital cost by applying commercial production methods to PEM-based electrolyzer systems. In each of the key development areas, GES and its team members are conducting focused development of advanced components in laboratory-scale hardware, followed by life-testing of the most promising candidate materials. The project will culminate in fabrication and testing of an electrolyzer system for production of 0.5 kg-H_2/hr and validation of the electrolyzer stack and system in testing at NREL.

Successful development of the advanced electrolyzer stack and system will result in a high-efficiency; low-capital-cost electrolyzer that will meet the DOE cost targets for hydrogen production, assuming high-volume production. This will provide competitively priced hydrogen for delivery at forecourt stations to enable transition to the hydrogen economy.

Results

DSM™ Membrane Performance: To improve electrolyzer efficiency, GES has developed an advanced supported membrane having an ionic resistance comparable to that of a 0.0020- to 0.0035-inch-thick Nafion® membrane, but having significantly improved mechanical properties. This advanced membrane is referred to as a dimensionally stable membrane (DSM™) due to the membrane support that minimizes changes in dimensions (swelling/contraction) under high-pressure operation and with changes in water content. The support structure utilized in the development of the DSM™ consists of a polyimide (Kapton®) base film with a definable open pattern. The support structure is then imbibed with 1100-equivalent-weight (EW) PFSA ionomer to a thickness of 2 to 3 mil (0.002-0.003”). Initially the membrane support structures were fabricated using a laser-drilling procedure. A more cost-effective technique of fabricating the support structures via chemical-etching has recently been implemented by GES, reducing the cost of the membrane by one order of magnitude.

Polarization scans of the DSM™ were conducted in scaled-up, full-size electrolyzer hardware through a current density range of 0-2,000 mA/cm², a differential pressure of 300 psid, and temperature of 80°C. Results are compared to Nafion® 1135 membrane with similar cathode and anode electrode structures, Figure 1. During testing, the DSM™ exceeded the criterion for performance: exhibiting lower cell voltages and thus higher cell efficiencies than that of a Nafion® 1135 membrane.



HW - hardware; MEA - membrane electrode assembly

FIGURE 1. Performance Scans: DSM™ vs. Nafion® 1135

Durability of the DSM™ was also demonstrated in the scaled-up, hardware via fluoride release rate (FRR) measurements at constant-current operation. Since PFSA ionomer is used as the membrane material and in the binder for the catalyst layer, the loss of fluoride is used as a measurement of membrane degradation. An FRR rate of 3.7 µg F^- ion/hr or less than 10 micrograms F^- ion/liter (<10 ppb) was present in the cathode effluent (electro-osmotically transported water) at the end of the 1,000-hour life test. Based on electrolysis FRR results, the lifetime of the DSM™ is projected to be between 45,000 and 55,000 hours, which exceeds the durability requirements of the electrolyzer system. In addition to its durability, the DSM™ exhibits high cell efficiencies in the range of 75% LHV (88.8% higher heating value) at an operating current density of 1,500 mA/cm².

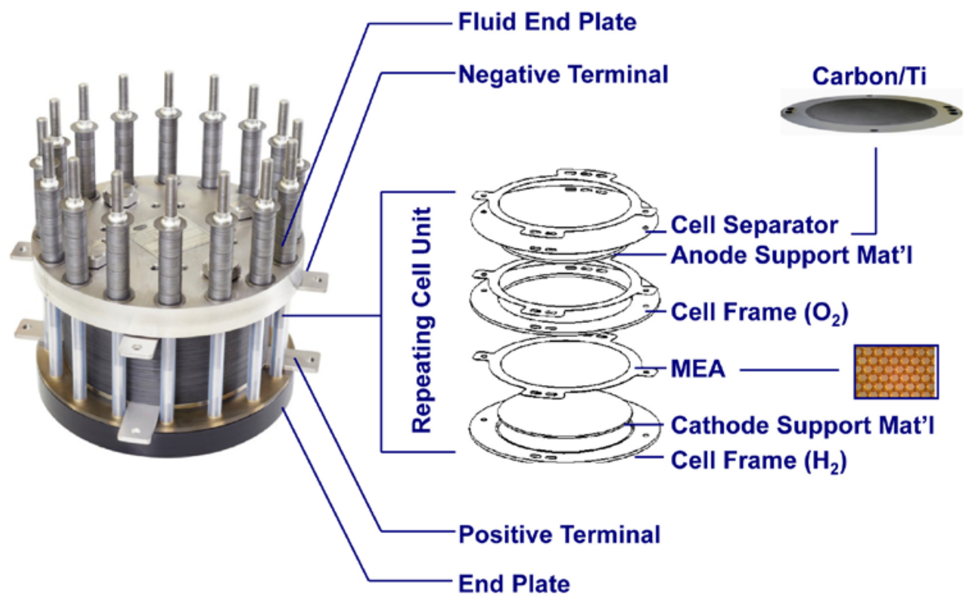


FIGURE 2. Low-Cost Electrolyzer Stack

Cell-Separator Development: 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. GES's legacy high-pressure naval electrolyzers use a complex multi-layer cell-separator incorporating a conductive compliant member and sheets of niobium and zirconium metal. Zirconium is used due to its high resistance to hydrogen embrittlement. GES has previously evaluated a low-cost, dual-layer titanium cell-separator. Although performance was comparable to that of niobium/zirconium cell-separators, lifetimes were limited to 5,000 hours due to hydrogen embrittlement.

The most promising approach for long-term implementation has been achieved by coating titanium with a low-cost electrically conductive, embrittlement-resistant carbon coating. The challenge was the development of a pinhole-free, highly adherent coating with the required characteristics. Under the cell-separator development task, GES demonstrated performance of a carbon/titanium cell separator in scaled-up 290-cm² electrolyzer stack hardware. Performance is comparable to that of the niobium-zirconium separator. In addition, life expectancy of the carbon/titanium separator, determined via hydrogen-uptake analysis over a 1,000-hour period, indicates lifetimes exceeding the 50,000-hour system requirement.

Electrolyzer Stack and System Fabrication: The full-size (27-cell, 290-cm² active area) electrolyzer stack developed during this project is shown in Figure 2. The electrolyzer stack, capable of producing 0.5 kg-H_2/hr at an operating current density of 1,500 mA/cm², is designed with low-cost components. In addition to the use of chemically etched DSM™ and carbon/titanium cell-separators, the electrolyzer stack includes several modifications to GES's legacy hardware; (1) an increase in cell active area from 160 to 290 cm², effectively reducing the number of cells required to produce a given amount of hydrogen, thus reducing the stack manufacturing labor, (2) an overall decrease in the parts count per cell (from 41 to 10), (3) a 75% reduction in anode and cathode catalyst loadings, (4) molded thermoplastic cell frames, resulting in a cost reduction of 95% as compared to machining this component, (5) a 33% reduction in cell frame thickness, thus reducing the anode and cathode support materials and costs by 33%, and (6) a low-cost carbon-steel end plate. As a result of the component and membrane development during this project, the overall projected capital cost of the electrolyzer stack has decreased from greater than $1,000/kW in 2007 to <$400/kW in 2011 (Figure 3).

As shown in Figure 4, the system build, undertaken at the Parker facility, is in its advanced stages. The electrolyzer system required detailed planning with respect to system layout and fabrication sequence. Several factors, including specific codes and standards that are pertinent to hydrogen electrolyzer systems, were considered during the system layout. To meet these requirements, the system was designed with three separate compartments; the oxygen (O_2), the hydrogen (H_2), and the electrical (controller and power supply) compartments. The O_2 compartment contains the oxygen gas-phase separator, a circulating liquid pump, and the de-ionized water feed tank. The H_2 compartment encloses a novel high-efficiency (97%) hydrogen dryer assembly, high- and low-pressure hydrogen gas-phase separators, a

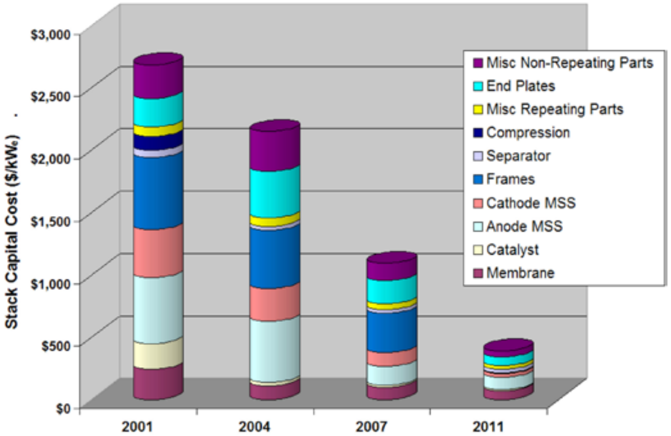


FIGURE 3. Electrolyzer Stack Capital Costs

FIGURE 4. Electrolyzer System

heat exchanger, cooling fans, and various flow valves. The electrolyzer stack is powered via a high-efficiency power supply rated at 94% located in the electrical compartment. The outside platform is also used as the staging area for the nitrogen (N_2) tanks that will provide N_2 gas for purging the electrolyzer stack during start-up and shutdown.

Conclusions and Future Directions

Significant progress has been made in DSM™ membrane development. GES has demonstrated membrane reproducibility and durability as well as a significant improvement in electrolyzer cell efficiency that exceeds the DOE's 2017 efficiency targets. In addition, development efforts conducted under this project have resulted in significant cost reductions in the PEM-based electrolyzer stacks and systems, an increase in the life of the low-cost cell-separators, and improved balance-of-plant components efficiency. The future objectives are to:

- Complete critical design review.
- Install electrolyzer stack into system.
- Assist in system start-up at Parker facilities and evaluate overall performance.
- Deliver and demonstrate the prototype electrolyzer system at NREL for validation.

FY 2011 Publications/Presentations

1. M. Hamdan, *PEM Electrolyzer Incorporating an Advanced Low-Cost Membrane.* 2011 Hydrogen Annual Program Merit Review Meeting. Presentation #pd_030_hamdan, May 11, 2011.

2. M. Hamdan, *Hydrogen Production by PEM Electrolysis.* Fuel Cell Technologies Program webinar. http://www1.eere.energy.gov/hydrogenandfuelcells/webinar_archives.html, May 23, 2011.

References

1. The Department of Energy Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan, http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/program_plan2010.pdf