

## II.E.3 PEM Electrolyzer Incorporating an Advanced Low-Cost Membrane

Monjid Hamdan (Primary Contact),  
 Tim Norman  
 Giner Electrochemical Systems, LLC (GES)  
 89 Rumford Ave.  
 Newton, MA 02466  
 Phone: (781) 529-0526; Fax: (781) 893-6470  
 E-mail: mhamdan@ginerinc.com

DOE Technology Development Manager:  
 Roxanne Garland  
 Phone: (202) 586-7260; Fax: (202) 586-2373  
 E-mail: Roxanne.Garland@ee.doe.gov

DOE Project Officer: Paul Bakke  
 Phone: (303) 275-4916; Fax: (303) 275-4753  
 E-mail: Paul.Bakke@go.doe.gov

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### Subcontractors:

- Virginia Polytechnic Institute and State University, Blacksburg, VA
- Parker Hannifin Ltd domnick hunter Division, Hemel Hempstead, United Kingdom

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 Project End Date: April 30, 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 Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

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

Technical targets for this project are shown in Table 1.

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

Characteristics	Units	2012/2017 Targets	GES Status
Hydrogen Cost	\$/kg H <sub>2</sub>	3.70/<3.00	3.97*
Electrolyzer Capital Cost	\$/kg H <sub>2</sub>	0.70/0.30	1.47
	\$/kW <sub>e</sub>	400/125	<500
Electrolyzer Energy Efficiency	% (LHV)	69/74	68**

\*using H2A model rev 1.0.11; \*\*75% for a single cell  
 LHV - lower heating value

### Accomplishments

- Membrane
  - Demonstrated enhanced dimensionally stable membrane (DSM™) performance. (> Nafion® 1135 membrane).
  - Completed 1,000-hour life-test with DSM™ (@80°C).
  - Projected DSM™ operating lifetime to be approximately 55,000 hours.
- Cell-Separator
  - Demonstrated performance of a low-cost titanium/carbon cell-separator.
  - Confirmed longevity of the carbon/titanium cell-separators.
- Preliminary Electrolyzer System Design Review
  - Completed process and instrumentation diagram (P&ID), process flow diagram (PFD), and system control diagrams.
  - Completed an extensive safety review of electrolyzer system.
  - Completed modeling of electrolyzer capital and operating costs; performed economic analysis using the DOE H2A (rev. 1.0.11) model illustrating cost reductions.



### Introduction

The DOE has identified hydrogen production by electrolysis of water at forecourt stations as a critical technology for transition to hydrogen powered vehicles. As hydrogen fuel cell vehicle market penetration increases water electrolysis for hydrogen production at

centralized locations using renewable energy sources will be a part of a hydrogen infrastructure. 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 \$4.80/kg-H<sub>2</sub>, considerably higher than the DOE target of \$3.70/kg-H<sub>2</sub> 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 and the high capital costs of electrolyzer stacks and systems.

GES has developed a PEM-based electrolyzer technology that generates hydrogen at moderate to high pressure directly in the electrolyzer stack. The GES technology maintains a high-differential pressure across the PEM, so that oxygen is evolved at near-atmospheric pressure while the hydrogen is produced at elevated pressure.

The goals of the project are to reduce stack and system cost to improve electrolyzer efficiency and to demonstrate electrolyzer operation at moderate pressure.

## Approach

To reduce the cost of operating PEM-based electrolyzers, GES is improving electrolyzer stack efficiency through development of an advanced high efficiency, dimensionally stable membrane (DSM™). In addition, an effort has been placed on reducing the cost of the electrolyzer stack via the development of a low-cost, long-life, bipolar stack cell-separator. Further reductions in system capital costs are also obtained by applying commercial production methods to the 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<sub>2</sub>/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 2012 DOE cost targets for hydrogen production, assuming high-volume production. This will provide competitively priced hydrogen for delivery at forecourt stations to enable the transition to hydrogen-powered vehicles.

## Results

**DSM™ Membrane Performance:** To improve electrolyzer efficiency, and thereby reduce operating and capital costs, GES is developing 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 because the membrane support minimizes changes in membrane dimensions (swelling/contraction) under high-pressure operation and with changes in water content. Performance and durability of the advanced high-efficiency DSM™ was demonstrated in full-size (160-cm<sup>2</sup> active area) electrolyzer hardware at an elevated temperature of 80°C and differential operating pressure of 300 psid for a period of 1,000 hours, simulating operation in an actual electrolyzer system.

DSM™ performance and durability were assessed by two major characterizations: fluoride release rate (FRR) and polarization performance. Since PFSA ionomer is used as the membrane material and in the binder for the catalyst layer, fluoride loss is a good measurement for PFSA ionomer degradation. An FRR rate of less than 3.0 µg F<sup>-</sup> ion/hr was measured at the end of the 1,000-hour life test. Less than 10 micrograms F<sup>-</sup> ion/L (<10 ppb) were found in the cathode side, electro-osmotically transported water. Based on the electrolysis life data and 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% lower heating value (88.8% higher heating value), operating in the cell voltage range of 1.72 V at a current density of 1,500 mA/cm<sup>2</sup> (Figure 1).

Polarization scans through a current density range of 3,000 mA/cm<sup>2</sup> were conducted to evaluate the DSM™ membrane-electrode assembly (MEA) performance under the operating conditions stated above: 80°C, 300 psid. A comparison made between DSM™ and Nafion® 1135 MEAs under similar operating conditions, cathode and anode electrode structures, and in the same

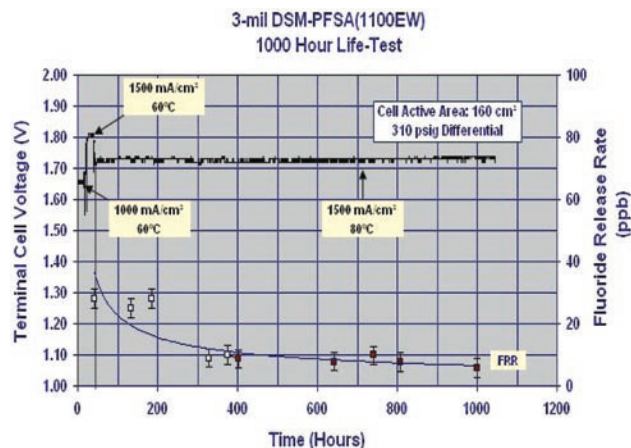


FIGURE 1. 1000-hour Life Testing of DSM™ MEA

160-cm<sup>2</sup> hardware, show that the DSM™ MEA exhibited lower cell voltages (lower power requirements) and thus higher cell efficiencies (Figure 2).

In addition to the DSM™, a second membrane approach, under development with Virginia Polytechnic Institute, is advanced Bi Phenyl Sulfone hydrocarbon membranes. Initial results obtained at GES have shown that these membranes have high efficiency, high protonic conductivity, excellent mechanical properties and high chemical stability in PEM-based electrolyzers.

**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. 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. 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 is 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 (polarization curve) of a low-cost carbon/titanium separator in 160-cm<sup>2</sup> hardware comparable in performance to a dual-layer titanium separator at 1/40<sup>th</sup> the cost of niobium-zirconium cell-separators (Figure 3). In addition, life expectancy of the carbon/titanium separator, determined via hydrogen-uptake analysis over a 500-hour period, indicates lifetimes exceeding the 50,000-hour system requirement.

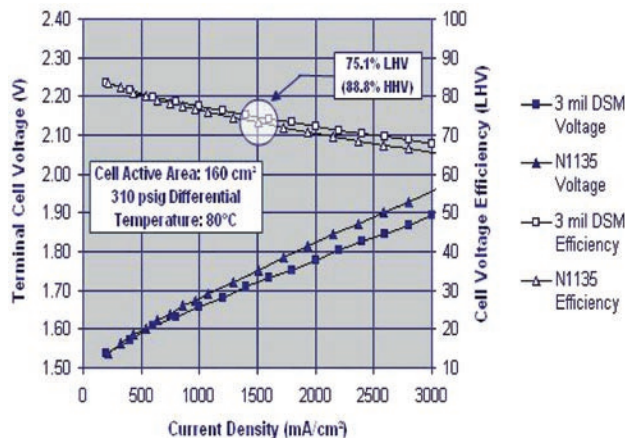


FIGURE 2. Performance and Efficiency of DSM™ vs. Nafion® 1135

**Preliminary Electrolyzer Stack and System Design:**

The materials and manufacturing methods developed in this project have significantly decreased the electrolyzer stack and system 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 \$500/kW in 2009, with a further projected decrease to <\$400/kW in 2012, assuming successful commercialization of the low-cost manufacturing methods and large-scale production of electrolyzer stacks.

In addition to the overall decrease in parts count per cell and the use of low-cost cell-separators, the preliminary stack design shown in Figure 4 includes two major modifications to the previous hardware; (1) an increase in cell active area from 160 to 290 cm<sup>2</sup> and (2) the use of a pressurized dome that encloses the electrolyzer stack, which strengthens the stack assembly and provides personnel and equipment protection in the unlikely event of failure. Larger cell active areas reduce the number of cells required to produce a given amount of hydrogen, and thus reduces the stack manufacturing labor and the materials scrap rate. The addition of a *pressurized dome* makes the electrolyzer stack and system a more commercially viable product. Pressure sensors attached to the dome will monitor any decrease/increase in pressure, indicating stack leakage, and the system can then be shut down safely.

GES electrolyzer system designs and Parker Hannifin Ltd. (Parker) hydrogen generator designs have been reviewed and the appropriate aspects of

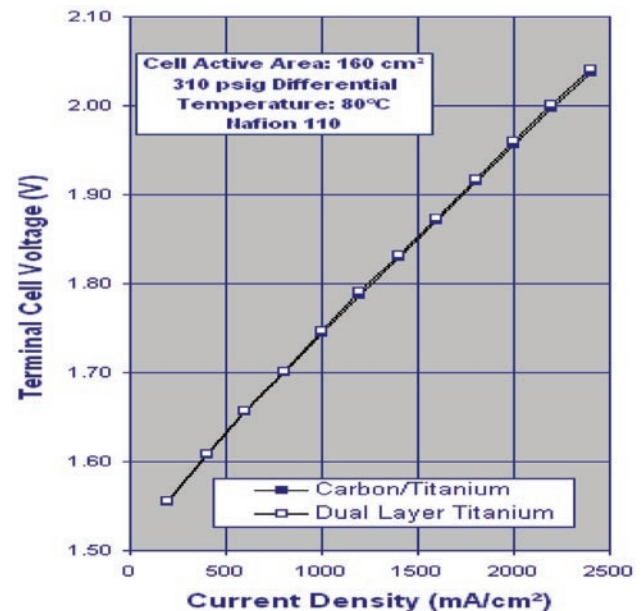
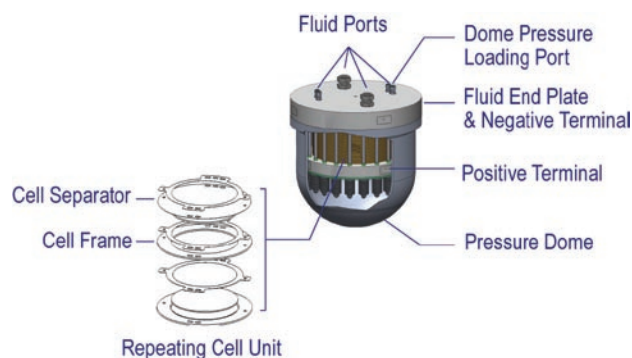


FIGURE 3. Performance Scans: Carbon/Titanium vs. Dual-Layer/Titanium



**FIGURE 4.** Preliminary Stack Design

these designs incorporated into the prototype system design with a focus on eliminating and replacing costly components and improving balance-of-plant (BOP) efficiency. Our subcontractor, Parker has completed the PFD and P&ID, as well as the control logic diagrams. As part of the preliminary system design review, an extensive safety management plan addressing both the electrolyzer system and manufacturing area, where the system will be fabricated and tested, has been completed by Parker.

## Conclusions and Future Directions

Significant progress has been made in DSM™ development. GES has demonstrated membrane reproducibility and durability as well as a significant improvement in electrolyzer cell efficiency. In addition, development efforts conducted under this project have

resulted in the reduction in the cost of the moderate-pressure PEM-based electrolyzer systems, an increase in the life of the low-cost cell-separators, and improved BOP components efficiency. The future objectives are to:

- Continue development of low-cost, high-efficiency membrane and cell-separator:
  - Scale-up of membrane and cell-separator to larger active areas (290 cm<sup>2</sup>).
- Complete electrolyzer stack and system preliminary designs.
- Fabricate a deliverable electrolyzer stack and system.
- Demonstrate prototype system at NREL.

## FY 2009 Publications/Presentations

1. M. Hamdan, *Hydrogen Production Cost*. Hydrogen Production Cost Estimate Using Water Electrolysis Review Panel. Web Based Presentation – NREL. January 28, 2009.
2. M. Hamdan, *PEM Electrolyzer Incorporating an Advanced Low-Cost Membrane*. 2009 Hydrogen Annual Program Merit Review Meeting. Presentation #pd\_21\_hamdan, May 20, 2009.

## References

1. Multi-Year Research, Development and Demonstration Plan. Hydrogen Production. DOE, Pg 3.1-14 <http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/pdfs/production.pdf>.