II.A.6 Unitized Design for Home Refueling Appliance for Hydrogen Generation to 5,000 psi

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Overall Objectives

Design and demonstrate subsystems for a unitized proton electrolyte membrane (PEM)-based electrolyzer system for residential refueling at 5,000 psi to meet DOE targets for a home refueling appliance (HRA).

Fiscal Year (FY) 2013 Objectives

- Design, fabricate, and evaluate 5,000 psig electrolyzer stack
- Fabricate and demonstrate 5,000 psi electrolyzer system

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Production section of the Fuel Cell Technologies Office Multi-Year Research, Development and Demonstration (MYRDD) Plan [1]:

(F) Capital Cost

(G) System Efficiency and Electricity Cost

Technical Targets

The technical targets for this project are listed in Table 1.

TABLE 1. Giner Progress toward Meeting DOE Targets for Hydrogen Production

Characteristics	Units	2015 Targets[a]	Giner Status
Total Hydrogen Production Cost	$/kg H_2	3.90[b]	3.98[c]/4.64[d]
Electrolyzer Capital Cost	$/kg H_2	0.50	1.05
Electrolyzer Stack Efficiency	% (LHV) (kWh/kg)	76 (44)	72[e] (47)[e]

[a] 2012 Hydrogen Production MYRDD Plan; [b] Includes delivery (compression, storage, and dispensing); [c] Based on H35 refueling; [d] Based on H70 refueling; [e] Isothermal Compression at 5,000 psig adds ~5 kWh/kg; LHV – lower heating value.

FY 2013 Accomplishments

- Membrane Development Completed
  - Developed and evaluated high-pressure, high-strength membranes compatible with 5,000 psi operation
  - Membranes exhibit high mechanical stability and improved sealing under high operating pressure
- Electrolyzer Stack Design
  - Completed fabrication of 20-cell electrolyzer stack
  - Successfully operated electrolyzer stack at a pressure of 5,000 psig
- Electrolyzer System
  - Unitize breadboard system design and fabrication complete:
  - Determined cost of hydrogen directly in stack:

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INTRODUCTION

U.S. automakers have invested significant resources in the research and development of hydrogen fuel cell vehicles. However, to enable the widespread use of fuel cell vehicles, an additional major investment will be required to construct an infrastructure for hydrogen production and delivery to fueling stations. In order to facilitate this transition, it has been recommended that high-pressure hydrogen, generated at 5,000 psig for home refueling of fuel cell vehicles, be implemented as an intermediary approach. An improved, low-cost process for producing high-pressure hydrogen from water by electrolysis will significantly advance the development of the hydrogen economy, providing hydrogen for fuel cell vehicles at a price competitive with that of gasoline on a per-mile basis. The ability to produce hydrogen economically, the relatively low capital cost of the electrolyzer unit, and the low maintenance cost of the unit will allow widespread distribution of hydrogen home fueling appliances deemed necessary for the introduction of fuel cell vehicles.

The project focuses on the development of high-pressure, low-cost electrolyzer stack and balance-of-plant (BOP) components. Giner has a matured PEM-based electrolyzer 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 coolant, is introduced into the anode (O_2) side of the electrolyzer at near atmospheric pressure; high-pressure hydrogen is removed from the cathode or product side. In addition to reliability, and long maintenance intervals, safety is also a primary concern in this design due to the flammability and reactivity concerns of hydrogen and oxygen.

APPROACH

Giner recently completed a multi-year development project for DOE that reduces commercial PEM-based electrolyzer costs while simultaneously raising the efficiencies of water electrolyzer systems that operate in a moderate pressure range of 400 psi. Future extension of this technology to pressures of 5,000 psig is feasible with modifications to the electrolyzer stack, providing the ability to safely operate in a differential hydrogen/oxygen pressure mode. Based on an innovative electrolyzer stack concept and recent developments in high-strength membranes, Giner has designed a PEM-based water electrolyzer system for home refueling applications that will be able to deliver hydrogen at pressures of 5,000 psi. High-pressure hydrogen can be generated in low-cost moderate-pressure electrolyzer stacks by means of external reinforcement to the individual cell frames. Utilizing external cell reinforcement eliminates the need for bulky and costly stack parts and facilitates a method for fabricating an electrolyzer stack and system that can safely operate at 5,000 psi. In addition, a reduction of major system components and system cost is realized.

RESULTS

Membrane Evaluation: Utilizing supported dimensionally stable membrane (DSM™) membranes developed at Giner, the performance of the PEM electrolyzer stack can be optimized for a selected operating pressure and temperature. DSM™ membranes were fabricated with thickness ranging from 1 to 20 mils. Gas permeation data obtained during single-cell testing at various operating pressures and temperatures indicates that improved membrane efficiency is obtained while operating the electrolyzer stack in a differential pressure mode (hydrogen pressure over oxygen pressure) as opposed to balanced pressure in which both hydrogen and oxygen gases are generated at the same pressure. Based on membrane gas permeation (Faradaic losses), and membrane voltage efficiency, the cost of electrochemical hydrogen compression in the stack was determined to be 4 to 6 $kWh_e/kg\text{-}H_2$. At an operating pressure of 5,000 psi and 80°C, the optimal membrane thickness was determined to be between 7 and 10 mils operating in the current density range of 1,000 to 1,500 mA/cm^2. The supported membranes also demonstrated significant improvements in membrane creep property and mechanical stability during high differential pressure operation of 5,000 psi.

Electrolyzer Stack Fabrication: The HRA has been designed for on-demand operation. The system is designed with a 2.3-kWe, 20-cell electrolyzer stack (Figure 1), providing a vehicle tank fill of 0.5 kg of hydrogen over a 12-hour period. This will provide 30 miles of driving range based on current fuel cell vehicle fuel economy estimates of 60 miles/kg-H_2. Differential pressure operation required redesign of the electrolyzer stack hardware. Giner's initial design included the use of a pressure containment dome; the gas pressure in the pressure dome is matched to that of the electrolyzer's hydrogen and oxygen product streams to provide external stack reinforcement. In 2012, Giner developed a modified stack design that utilizes a metal containment ring externally attached to the electrolyzer-stack's cathode (H_2) cell frames. The simplified design eliminates the need for a containment dome; in addition, this technique enables high pressure operation with the use of low- and moderate-pressure PEM-based electrolyzer stacks without the need for expensive internal cell reinforcement or metal frames. The low cost of the electrolyzer stack is maintained by utilizing previously designed injection molded thermoplastic cell frames and cell components.

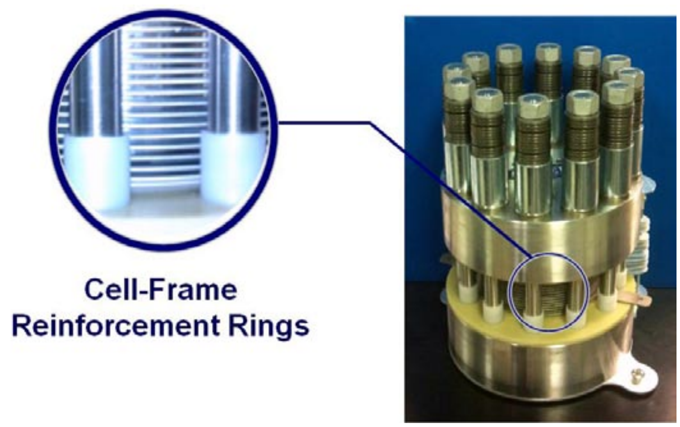

FIGURE 1. High-Pressure PEM Electrolyzer Stack with Reinforced Cell Frames (20-Cell Stack)

In addition to the use of external cell-frame reinforcement, the electrolyzer stack includes several modifications developed under a separate DOE project that further reduce stack cost. This includes: (1) an overall decrease in the parts count per cell, (2) a 75% reduction in anode and cathode catalyst loadings, (3) molded thermoplastic cell frames, resulting in a cost reduction of 95% as compared to machining this component, (4) a reduction in cell frame thickness, thus reducing the anode and cathode support materials and costs, and (5) a modified anode membrane support material that enables high pressure operation of 5,000 psi. The stack was successfully operated in 8- to 12-hour intervals at hydrogen pressures of 5,000 psi. The average cell performance is shown in Figure 2 for various operating pressures and temperatures. The power consumption of the electrolyzer stack was measured at 51.8 $kWh_e/kg\text{-}H_2$ while operating at a pressure of 5,000 psi and a current density of 1,200 mA/cm^2.

5,000 psi "Unitized" Electrolyzer System for Home Refueling: The HRA shown in Figure 3 features: (1) a 20-cell differential pressure electrolyzer stack that produces hydrogen at up to 5,000 psi and oxygen at ambient pressure, (2) a water tank, sized for approximately 12 hours of electrolyzer operation at rated power levels, (3) an integrated deionized water loop used to maintain water purity and temperature control of the electrolyzer stack during operation, (4) a small hydrogen dryer to maintain a hydrogen gas dew point of <-40°C, (5) sensors for monitoring the production gases to detect/prevent formation of flammable mixtures, and (6) the integration of electrolyzer subsystems to minimize the number of BOP components. An automated control system also provides safe automated operation.

The reactant water is supplied to the anode side of the electrolyzer stack at ambient pressure. Oxygen generated on the anode side of the electrolyzer stack is then separated from water in the oxygen gas separator which also serves as the water reservoir. Water is circulated from the oxygen gas separator to the anode of the electrolyzer stack and back to the oxygen gas separator. The circulating pump operates at low differential pressure, as it must only overcome the pressure drop in the feed loop. During electrolyzer operation water is transferred from the anode side of the electrolyzer stack to the cathode side due to electrically-osmotic transport. Water loss due to electro-osmotic drag is collected in the hydrogen gas phase separator and returned to the electrolyzer feed loop after it has been degassed. Hydrogen generated on the cathode side is then passed through a regenerative dryer consisting of dual desiccant columns.

At the end of the electrolysis cycle, which occurs when the water in the HRA system is nearing depletion, power is no longer available, or at a predetermined time or pressure, the electrolyzer system is shut down. In addition to the normal end-of-cycle operation, the control system automatically shuts down electrolyzer operation when abnormal conditions are detected. The conditions that trigger

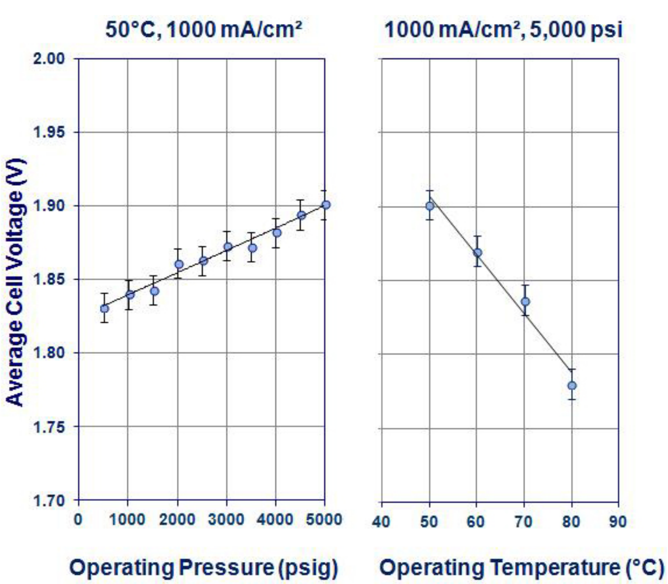

FIGURE 2. Cell Performance under Various Operating Conditions

FIGURE 3. Electrolyzer (HRA) System

electrolyzer subsystem shut down include: low water in the electrolyzer feed loop, low water flow rate, high temperatures (>80°C), over pressure (>5,000 psig), and gas detection alarms. In addition, any cell in the electrolyzer stack exhibiting a low or high cell voltage will activate a system shutdown.

CONCLUSIONS AND FUTURE DIRECTIONS

The stack and system design incorporates numerous cost-saving (and reliability enhancing) simplifications. These design features eliminate the need for bulky and costly stack and system parts, and facilitate a method for producing a low-cost electrolyzer system that can safely operate at a hydrogen pressure of 5,000 psi in a residential setting. The technology is capable of providing onsite residential hydrogen refueling at a cost that meets the DOE 2015 target of \$3.90/kg-H_2 for vehicles that have H35 (6,250 psi) refueling requirements. In addition, the hydrogen production costs for H70 (12,688 psi) refueling, have been estimated at \$4.64/kg-H_2.

Work on this project has been completed, however Giner will continue to investigate methods that further reduce cost and improve the efficiency of high-pressure PEM-based electrolyzer stacks and systems. Giner believes that future challenges for high-pressure PEM electrolysis include:

- Scale up of high-pressure stack technology to 50 cells per stack (or higher)
- Improve pressure capabilities of stacks (to 12,688 psi) for H70 refueling
- Develop membranes with reduced gas permeability (improve membrane efficiency)

FY 2013 PUBLICATIONS/PRESENTATIONS

1. M. Hamdan, *PEM Electrolyzer Incorporating an Advanced Low-Cost Membrane.* 2013 Hydrogen Annual Program Merit Review Meeting, Presentation #pd030, May 15, 2013.

2. T. Norman, and M. Hamdan, *Unitized Design for Home Refueling Appliance for Hydrogen Generation to 5,000 psi.* 2013 Hydrogen Annual Program Merit Review Meeting. Presentation #pd065, May 15, 2013.

REFERENCES

1. 2012 Multi-Year Research, Development and Demonstration Plan. Hydrogen Production. DOE, Pg 3.1-14 (http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/pdfs/production.pdf)