VII.8 Hydrogen Filling Station*

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- UNLV Chemistry Department, Las Vegas, NV
- Distributed Energy Systems, Wallingford, CT
- National Renewable Energy Laboratory, Golden, CO
- Altairnano, Reno, NV
- Hydrogen Solar, Las Vegas, NV

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Project End Date: December 31, 2008
(Including amendments)

*Congressionally directed project

Objectives

1. Design, install and analyze operation of a hydrogen generation and vehicle fueling system using electrical energy furnished by solar energy and grid power.
2. Enhance the system by designing, testing and implementing a high-pressure electrolysis hydrogen production and dispensing system and convert another vehicle.
3. Develop and optimize nano-crystalline thin films to maximize the efficiency of photo-catalytic reaction of sunlight to generate hydrogen at low manufacturing cost.
4. Perform outreach activities to constituencies.
5. Photoelectrochemical (PEC) hydrogen production using nanotechnology processes.
6. Research for higher efficiency proton exchange membrane (PEM) technology.

Technical Barriers

This project addresses the following technical barriers from the Technology Validation Section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan as well as issues in production and safety:

(A) Lack of Fuel Cell Vehicle Performance and Durability Data
(C) Lack of Hydrogen Refueling Infrastructure Performance and Availability Data
(D) Maintenance and Training Facilities
(E) Codes and Standards
(H) Hydrogen from Renewable Resources

Contribution to Achievement of DOE Technology Validation Milestones

This project will contribute to achievement of the following DOE milestones from the Technology Validation section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- **Milestone 7:** Validated refueling time of 5 minutes or less for 5 kg of H_2 (1 kg/min) at 5,000 psi through the use of advanced communication technology. (4Q, 2007)
- **Milestone 8:** Fuel cell vehicles demonstrate the ability to achieve 250 mile range without impacting passenger cargo compartment. (4Q, 2008)
- **Milestone 10:** Validate fuel cell vehicle's 2,000-hour fuel cell durability, using fuel cell degradation data. (4Q, 2009)
- **Milestone 22:** Five stations and two maintenance facilities constructed with advanced sensor systems and operating procedures. (4Q,2006)
- **Milestone 23:** Total of 10 stations constructed with advanced sensor systems and operating procedures. (1Q, 2008)
- **Milestone 24:** Validate a hydrogen cost of $3.00/gge (based on volume production). (4Q, 2009)
- **Milestone 27:** Establish standard cell and testing protocols for PEC materials for validation efficiencies. (4Q, 2007)

- **Milestone 28:** Validate the cost of compression, storage, and dispensing at refueling stations and stationary power facilities to be $0.80/gge of hydrogen. (4Q, 2013)
- **Milestone 35:** Validate $1.60/gge hydrogen cost from biomass and $3.10/kg for renewable/ electrolysis (untaxed) at the plant gate. (4Q, 2014)

Accomplishments

- Developed a new 30 barg (435 psig) hydrogen generator for increased capacity and efficiency at the Las Vegas Valley Water District (LVVWD) Filling Station. Work enabled an increase in throughput of over 6 times vs. the original HOGEN RE with the same mechanical compressor and similar footprint.
- Designed an optimized membrane electrode assembly (MEA) based on advanced catalyst and membrane components which demonstrated a 10% increase in stack efficiency.
- Quantified the power consumption of system components to identify opportunities for improved system efficiency and modeled the interaction of electrolyzer size with renewable energy source output. The model predicts optimal utilization when using the electrical grid as a buffer.
- Designed and installed a data acquisition system to monitor the operation of the upgraded filling station. Sensors were placed at the station to monitor weather conditions, energy use by the filling station equipment, energy generated by the solar photovoltaic array, and the amount of hydrogen produced at the station.
- A computer model was created to simulate the energy production and use at the station, as well as how vehicle usage affects the energy and hydrogen balance at the station.
- Established trouble shooting techniques for the filling station's equipment systems.
- Conducted tour of the station for the Alternative Fuels & Vehicles National Conference and Expo 2008, congressional representative, a presidential candidate, DOE staff, national laboratory researchers, and international researchers working on hydrogen projects. Media and news organizations were hosted at the station and several news articles were filmed about the station and related hydrogen research.
- Identified and corrected problems associated the battery charging and converters on the Taylor Dunn hybrid electric/fuel cell vehicle (FCV) in use at the LVVWD.
- Identified and corrected problems associated with performance and fuel economy on the Polaris single-cylinder gasoline powered vehicle which was converted to run on hydrogen at the LVVVWD.
- Continued work on the Ford F-250 pickup, an eight-cylinder internal combustion engine, which has been converted to be powered by hydrogen.
- Fabricated prototype parts for a large-scale cell stack with six times the active area of the current design. Designed and fabricated a large-scale test stand to operate large area cell stack. Computational fluid dynamics modeling of the bipolar plate design demonstrated improved uniformity of fluid flow.
- Developed an electrochemical model which was utilized to calculate the impact of stack and system improvements on the cost of hydrogen in $/kg. Based on the model, a fully optimized system based on the research completed is expected to meet the near term, small-scale, distributed hydrogen generation DOE targets of $5/kg.
- Completion of design and installation of sun test facility including the completion of test cells.
- Design of parametric study.
- Demonstrated record setting PEC performance at two independent solar test laboratories, exhibiting an optimum 35 mA/cm^2-1.2 V_{bv} photo current density which is ten times the WO_3 PEC performance at the bias voltage reported in 2006.
- Innovated PEC water splitting cells to eliminate the use of chemically active electrolytes by applying pure water and a PEM for cell operations.

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Introduction

PEM electrolysis for onsite generation of hydrogen from water has been shown to be a clean, attractive alternative to delivered hydrogen for certain applications such as generator cooling and analytical instrumentation. However, to compete long-term as a backup power and fueling option, the electrolyzer cost needs to be reduced. One method of decreasing cost is to increase efficiency, so that the production rate is increased for the same quantities of catalyst and membrane. Another method is through decreasing the capital cost of the components. Several areas of opportunity were identified as part of this project. The testing of various PEC devices and materials is a major step towards bringing clean and cost effective solar hydrogen production to enable a hydrogen economy.

The overall goals of this project were 1) to upgrade the LVVWD filling station to 400 psig operation; 2) establish monitoring systems for the station and vehicle; 3) to continue maintenance on existing converted vehicles; 4) to finish the conversion of the third vehicle; 5) to conduct fundamental research to improve the cost, efficiency, and durability of PEM electrolysis; 6) establish and test an on-sun facility; and 7) to continue work on the deployment of nano technologies to resolve critical PEC water splitting issues. The LVVWD filling station was successfully upgraded to the target pressure, and related system monitoring was established. Vehicle conversions were advanced and a third vehicle is close to completion. Significant work was accomplished to advance understanding of PEM electrolysis and provide direction for improved efficiency and durability. A large active area test stand and prototype large active area parts were also fabricated in order to begin proving feasibility of larger units in order to decrease the cost of hydrogen. Additional work on testing PEC devices and materials was performed.

Approach

The basis for Phase III of the LVVWD Filling Station (Figure 1) upgrade began with a HOGEN H6M industrial hydrogen generator and associated chiller designed to operate indoors at 200 psi (~15 barg). It was then modified to meet the higher generation pressure requirements and repackaged into a NEMA4-style enclosure. Overall endurance and cyclical testing were performed on key components to verify and validate the design requirements. A site plan was developed with the end customer, LVVWD, and UNLV Research Foundation engineers to keep modification of the site to a minimum.

To monitor the performance of the equipment at the HFS, a data acquisition system was installed. Sensors were placed at the station to monitor weather conditions, energy use by the filling system equipment, energy generated by the solar photovoltaic (PV) array, and the amount of hydrogen produced at the station. The data from each sensor installed at the filling station is collected and stored by a data logger each minute. In addition to providing real-time data to UNLV for performance monitoring, UNLV generates plots for display on the internet. This allows the public to view the weather conditions and performance of the station. The Web address is: www.hydrogen.unlv.edu/HFS.html.

FIGURE 1. Hydrogen Filling Station at the LVVWD

Work continued on improving performance and fuel economy of the existing converted vehicles by correcting problems related to uneven battery charging, installation of direct current (DC) to DC power converters, intake valves and injection timing, and start-up issues. In addition, the third vehicle (a Ford F-250 pickup truck) has been modified using a new design direct cylinder injection.

Research tasks revolved around optimization of the MEA materials and scale-up of the cell stack to a larger active area. Catalyst and membrane materials were evaluated vs. the baseline construction and optimized combinations were designed. Fundamental characterization was also performed in order to correlate physical properties with stack performance for better predictability of performance in the future and determine which bench tests were important to incorporate into future screening efforts. Possible techniques for manufacturing the larger active area bipolar plates were also investigated. The bipolar plate design was optimized, including computational fluid dynamics modeling in order to compare flow distribution and thermal profiles in various designs. Cell stack parts were designed and procured and prototype MEAs were fabricated and tested for conformance to specification. Key technical issues associated with the renewable energy interface for PEM electrolyzers were also evaluated.

Testing of PEC devices photoanodes under real work conditions was established through the construction of a test platform on the roof of the Thomas Beam Engineering building at UNLV (Figure 2). Cells were constructed of ¾” chlorinated polyvinyl chloride sheets. The single inlet and outlet are branched into 12 fitting manifolds to provide uniform flow over the anode and cathode. This method of securing the membrane has many advantages over the heat press method that was previously investigated. In the materials

FIGURE 2. On-Sun Testing Facility Installed on Roof of UNLV Building

area, PEC methodologies in publications utilize semi-conductive photo anodes interacting with aqueous electrolytes for water splitting and confront a number of major issues associated with solar energy conversion efficiency, operation durability and expensive material cost. Particularly, improper use of electrolyte has demonstrated detrimental effects on the electrode. The use of a PEM, on the other hand, has demonstrated a successful application in water electrolysis and been adopted as a promising means to produce renewable hydrogen upon deploying wind electricity. By the same token, incorporating solar energy may achieve the same purpose. Unlike electrolyzers driven by photovoltaic electricity, this approach directly applies photo active material in a PEC cell while utilizing PEM and pure water. Thus, it provides a short and effective path to convert solar energy into hydrogen. Because of the use of external electrical power, the electrical energy consumption must be counted when calculating solar energy conversion efficiency of the PEC cell.

Results

Hydrogen Filling Station

The outdoor enclosure for the LVVWD Filling Station was developed, configured and successfully tested. The verification testing of the 30 barg system was completed showing a calculated increase in production from 0.539 kg/hr to 0.575 kg/hr. This increase equates to a 6.5% increase in efficiency for energy consumed per kg of H_2. As of May 2008, the system has generated approximately 350 kg of hydrogen at 30 barg equating to over 650 hours of runtime. The improved station has been in operation since October with only a software upgrade and minor maintenance.

Through the design and installation of a data acquisition system, UNLV can now monitor the energy use of each piece of equipment, average and maximum wind speeds and temperatures, total solar PV array energy output, and the total amount of hydrogen produced.

The Phase III filling station has provided over five months of continuous data as of the writing of this report. The performance of the upgraded Phase III equipment from the months of January to May 2008 is summarized. Due to the fact that the converted hydrogen vehicles were still being completed, hydrogen was only used five times during this five month period. Phase III five month station performance: PV system efficiency was 10.32%; total PV energy produced was 16.75 MWh; total energy to the grid was 9.72 MWh; number of days generating hydrogen was ~5.

To show how the filling station will perform under its expected daily operational demands, hydrogen was dispensed to simulate filling a Ford F-150 pickup truck with enough hydrogen to drive 28.5 miles. During the testing, 1.5 kg of hydrogen was dispensed, and the amount of energy used during hydrogen production was recorded showing the net power flow at the filling station during the day in which the simulated vehicle fill took place. It is noted that during hydrogen production, the electrolyzer requires much more power than the solar PV array is capable of producing.

Additionally, it was important to monitor how quickly the filling station was able to refill its tanks after a fill. This measurement provided a way to determine the amount of use that the station can support on a daily basis. After the fill, the dispenser level dropped to 76% of its full level, and required 2.93 hours to completely refill its tanks. To produce 1.5 kg of hydrogen, the station required 113.83 kWh. This resulted in a requirement of 75.87 kWh/kg of hydrogen, and a production efficiency of 51.9%, based on the higher heating value (HHV) of hydrogen (39 kWh/kg). Phase III June 20, 2008 simulation results: mass generated was 1.50 kg; energy consumed was 113.83 kWh; PV energy produced was 46.09 kWh; production energy requirement was 75.87 kWh/kg; hydrogen production efficiency was 51.91 %.

The LVVWD has assumed the responsibility for a service contract for maintenance of the station. In addition, they have entered into a contract to expand the storage capacity of the station to 12 kg. Once this modification is complete they will expand the use of the vehicles both on site and, when the third vehicle is complete, in the community.

Vehicle Conversions

Fuel Cell Vehicle: The Taylor Dunn FCV was delivered to the LVVWD for the opening of the filling station (Figure 3). This was done after testing at the university to allow the fuel system to be filled

FIGURE 3. Taylor Dunn Hybrid Electric/Fuel Cell Vehicle

completely with 5,000 psig hydrogen and allow further testing of the vehicle systems with daily operation by the LVVWD. After delivery, the vehicle was painted and underwent inspection by the DOE Safety Review Panel. Suggestions by the panel were implemented on the vehicle before operation. During the testing at the LVVWD a few problems developed with vehicle. It was found that during operation there was uneven charging of the batteries caused by the various voltage taps required to operate the fuel cell and controls. When the batteries were low, an acceleration of the FCV would drop the voltage of the batteries enough to cause the electronic controls to shut-down temporarily and shut down the fuel cell. To solve this problem, DC to DC power converters were installed to power the components instead of using the voltage taps in the battery bank. The converters allowed for the even charging of the batteries, which would also prolong the battery life, and also kept the controls running during vehicle acceleration. The converters did cause an unreferenced floating voltage which had to be addressed with diodes and grounding. Another problem that was found during testing was the short driving duration of the vehicle at the LVVWD. These short periods would not let the fuel cell complete the warm-up cycle and switch into the power on demand cycle needed to charge the batteries. The problem was solved by LVVWD mechanics by rewiring the fuel cell controls to allow the fuel cell to run and charge the batteries while the vehicle was parked. Before rewiring the controls, the electronic control which controlled the output of the fuel cell had failed. This control used a voltage output signal of the fuel cell to control the main DC-to-DC power converter that stepped the fuel cell 48 VDC to the vehicles 72 VDC. A new circuit was designed and tested to replace the failed control and allow better adjustment of the control parameters.

Polaris Vehicle: The Polaris vehicle is a single-cylinder gasoline-powered vehicle, which was converted to run on hydrogen as part of this project. Since its conversion, UNLV has been working to optimize its performance and fuel economy. Early this year, the vehicle had start-up issues along with weak performance. The engine's characteristics were monitored with a multi-channel oscilloscope, where data was gathered from the crankshaft, camshaft, injector, and spark pulse. The acquired information from the oscilloscope helped to determine that hydrogen was being injected while the intake valves were still opened. The solution was to advance the timing 90 degrees so the injection process occurred when the intake valves were closed. This resulted in a noticeable performance drop. The drop was found to be caused by hydrogen auto-igniting due to hot spots within the combustion chamber. This was fixed by moving the injection process once again, but this time it was moved closer to the spark ignition, eliminating the chance of prematurely igniting the hydrogen. With the injection timing altered, the vehicle was able to be driven around the facility. However, the vehicle was incapable of exceeding 3,000 RPM. This dilemma was resolved by increasing the injection pressure by a factor of two. At an injection pressure of nearly 650 PSI the vehicle was able to operate freely to 5,500 RPM in neutral, and under load it was able to get up to 4,000 RPM. The next step was to improve the vehicle's start-up. It was difficult to start the vehicle without a battery charger initially, and there was also excessive back fire coming from the exhaust. The problem was found in a throttle position plug that tricked the engine control module (ECM) into thinking that the throttle was open upon start-up. This caused the ECM to think the engine was flooded, and as a result, no fuel was being injected for start-up. By eliminating the throttle position sensor, the Polaris started on every crank with no back-fire.

Ford F-250 Pickup: The Ford F-250 pickup truck is powered by an eight-cylinder internal combustion engine, which has been converted to be powered by hydrogen. The truck is almost completely converted, with the exception of the fuel injectors and the electrical components. All components for the injector assembly have been made, including the ceramic insulators for the spark. The plan for the truck is to assemble a single injector for testing. A leak down test will be performed to ensure that there is no chance for hydrogen to escape during the injection process. Another test that will be performed is a simulation test, where normal operating conditions will be applied to the injectors to observe any irregularities throughout the RPM ranges. There are also electrical components that will be installed on the truck. Several hydrogen detectors will be installed throughout the truck, along with a siren to alert the driver in the case of a hydrogen leak. A DC-to-DC voltage booster will also be installed to step up the injector solenoid voltage from 12V DC to 24 VDC.

Thin Film Technology

Using a photo electrolyzer consisting of WO_3, Pt, PEM, water, and other auxiliary materials, tests were performed on cells fabricated using film technology in comparison with the performance of a typical PEM electrolyzer. The photo electrolyzer generated a photo current density reaching as high as 1.1 mA/cm^2 at 1.2 V_{bv} while the electrolyzer displayed virtually no current when a 1.2 V external power was applied. Using the same materials, nano photo electrolyzers (NanoPE) have been fabricated at Photon Synergy upon applying nano engineering. Solar simulator test results obtained from the novel NanoPE in comparison with its control under 1.5 AM standard illumination condition, displayed a sharp contrast in photo current density performance. NanoPE produced nearly thirty times higher photocurrent density at 1.2 V_{bv}. In order to confirm the test results, sunlight tests were conducted at solar elevation close to 1.5 AM condition. The results demonstrated consistent photo current performance at 0.8 V_{bv} and 1.2 V_{bv}. Clearly, both light sources produced consistent current-voltage (I-V) results over NanoPE and demonstrated the fact that higher efficiencies can be achieved by nano engineering. It is important to notice that this NanoPE performance has been demonstrated at two independent solar test laboratories and additional verification at the National Renewable Energy Laboratory. Further experimentation discovered that the high efficiency of NanoPE is mainly attributed to field modulated multiple exciton generation processes. A 10 nm red shift of the most population distribution in spectral responsivity was observed when the applied field was increased from 1.0 V_{bv} to 1.2 V_{bv}, suggesting a 0.1 eV excitation energy decrease in NanoPE. This is consistent with the observation that the excitation energy in NanoPE is 0.3 eV lower compared to a photo electrolyzer at 1.2 V_{bv}.

PEC

The On-Sun Test Facility has been designed and constructed. The instrumentation and control systems have been tested and are fully functional. The cells have been tested on sun and are dimensionally stable under temperature and pressure and do not leak. In addition to this, the two test units are well matched in internal resistance as well as open circuit voltage.

PEM Research

Two candidates for each component were selected for testing in combination with each other. The best membrane showed improvement with both alternative catalysts, with approximately 10% improvement in efficiency based on the HHV for hydrogen generation. A commercial MEA also showed improvement over the baseline. Correlations were observed between the fundamental electrochemical properties of the catalysts and the initial stack performance data, which enables improved understanding and design of future candidates. Information was also gathered on membrane properties which will guide selection of next generation materials.

Improvements have also been identified for design and manufacture of bipolar plates. Alternate techniques for forming bipolar plates which are recommended for further study include chemical milling, stamping, and vertical milling or machining. These techniques had good tolerance control with reasonable removal rates and lower capital cost than techniques such as laser machining. Modeling of the large active area bipolar plate design demonstrated improved flow characteristics and uniform temperature gradients vs. the baseline bipolar plate (Figure 4). These results were supported by flow experiments but still need to be validated in a fully functional cell stack.

In system level studies, comparing the baseline power consumption data for three commercial hydrogen generators showed that the major electrical balance-of-plant (BOP) losses were in the power conversion subsystem. All of the electrolyzers investigated had BOP losses of 5-8% when the power conversion losses were ignored. When the most efficient subsystem components were considered together and scaled for a 100 kg/day unit, the system power requirement was projected to be 300 kW. The results of the integration simulations showed that power conversion efficiency for electrolysis

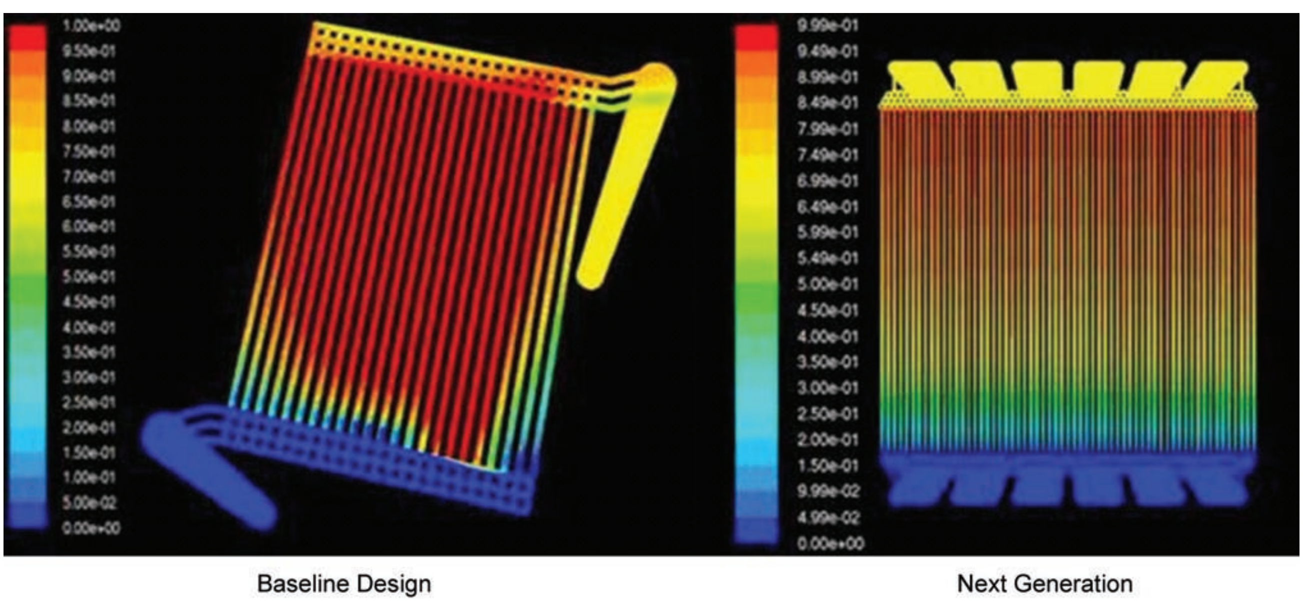

FIGURE 4. Modeling Results for Improved Bipolar Plate Designs

can be improved to 95% or better for both direct interface with renewable sources or using the grid as an interconnection.

Modeling was successfully completed for the electrochemical parameters of the cell stack as well as the capacity interaction for the entire system in relation to a renewable energy source. The electrochemical model showed that significant cost savings are achievable and enables projections for future cell stack and system improvements. Capacity modeling demonstrated that at present and into the near future, the off-grid approach to hydrogen generation is not favorable for large-scale hydrogen generation due to the capital cost of PEM-based hydrogen generation. The RE-Grid Fixed Capacity hydrogen generator is therefore the most economical approach. Incorporation of the collective work achieved in this project into the H2A model projects a cost savings of over 50% in $/kg hydrogen vs. the baseline cost as all the proposed advancements are further reduced to practice and advanced to commercialization.

Conclusions and Future Directions

During this project, significant work was accomplished to advance hydrogen production using renewable resources, vehicle development, PEC testing and thin film technology, and understanding of PEM electrolysis and provide direction for improved efficiency and durability including:

- Successfully upgraded LVVWD filling station to 30 barg operation.
- DC-to-DC power converters installed on the fuel cell vehicle to power components instead of using the voltage taps in the battery bank provide even charging of the batteries to prolong battery life.
- On the Polaris vehicle, advancement of the timing by 90 degrees provided by the intake valves to close before the injection process takes place. Increasing the injection by a factor of two allowed the vehicle to operate freely to 5,500 RPM in neutral, and under load it was able to get up to 4,000 RPM.
- During hydrogen production, the electrolyzer requires much more power than the solar PV array is capable of producing. Therefore, power is imported from the grid during this time.
- After the station was filled, the dispenser level dropped to 76% of its full level, and required 2.93 hours to completely refill its tanks. To produce 1.5 kg of hydrogen, the station required 113.83 kWh. This resulted in a requirement of 75.87 kWh/kg of hydrogen, and a production efficiency of 51.9%, based on the HHV of hydrogen (39 kWh/kg).
- Demonstrated increased MEA efficiency based on catalyst and membrane characterization.
- Successfully fabricated large active area test stand and prototype large active area parts, including improved bipolar plate.
- Quantified BOP energy losses through system analysis.
- Modeled interaction of PEM electrolysis capacity with renewable energy sources and impact of stack and system component changes on H2A model cost predictions.

Special Recognitions & Awards/Patents Issued

1. Pending US Patent: Application No. 11/821.398.

FY 2008 Publications/Presentations

1. Presentation: Embracing the New Era of Solar Hydrogen Production, Feb 2008.

2. K. Ayers, E. Anderson, J. Friedman, J. Manco, E. Styche & C. Capuano, "*Development of Advanced MEA's for PEM Water Electrolysis*," presented at the 2008 Electrochemistry Gordon Research Conference, Ventura, CA, January 6-11, 2008.

3. E.B. Anderson, K.E. Ayers, J. Manco, and E. Styche, "*Development of Advanced Catalysts for PEM Water Electrolysis*," presented at Hydrogen 2008: Materials Innovations in An Emerging Hydrogen Economy, Cocoa Beach, FL, February 24-27, 2008.

4. E. Anderson, J. Friedman, J. Manco, and K. Ayers, "*Development of Advanced MEA's for PEM Water Electrolysis*," Chapter 15 in Fuel Cells Durability and Performance, 3rd Edition, The Knowledge Press, Inc., Brookline, MA, 2008.

5. Journal: Jianhu Nie, Yitung Chen, Robert F. Boehm, and Shanthi P. Katukota, *"A photo-electrochemical model of solid polymer water electrolysis for hydrogen production,"* Journal of Heat Transfer (accepted and in press).

6. Jianhu Nie, Yitung Chen, Steve Cohen, Blake Carter, and Robert F. Boehm, *"Velocity and temperature distributions in bipolar plate of PEM electrolysis cell,"* Proceedings of ASME International Mechanical Engineering Congress and Exposition (IMECE 2007), IMECE2007-42622, November 11-15, Seattle, WA, USA, 2007.

7. Jianfei Wu, Jianhu Nie, and Yitung Chen, *"Three-dimensional fluid flow and coupled heat transfer in simplified bipolar plates,"* Proceedings of ASME International Mechanical Engineering Congress and Exposition (IMECE 2007), IMECE2007-42360, November 11-15, Seattle, WA, USA, 2007.

8. Jianhu Nie, Yitung Chen, Steve Cohen, Blake Carter, and Robert F. Boehm, *"Non-uniform velocity distributions in bipolar plate PEM electrolysis cell,"* Proceedings of 5th Joint ASME/JSME Fluids Engineering Conference, FEDSM2007-37299, July 30 - August 2, San Diego, California, USA, 2007.

9. M. Campbell, R. Hurt, S. Sadineni and R. Boehm, *A Solar Powered Hydrogen Generation and Filling Station,* Proceedings of the 37th ASES Annual Conference, May 3-8, San Diego, CA, 2008.

10. Mark Campbell, Sachin Deshmukh, Rick Hurt, Robert Boehm, *Modeling Solar Impacts on Hydrogen Production from Electrolysis,* ASME 2nd International Conference on Energy Sustainability, Aug 10-14, Jacksonville, FL, 2008.