

## II.A.2 Renewable Electrolysis Integrated Systems Development and Testing

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electricity needs to be less than or equal to half the current average grid price of electricity.

This project addresses the following technical barriers from the Fuel Cell Technologies Office 2012 Multi-Year Research, Development, and Demonstration (MYRD&D) Plan, section 3.1.5:

- (G) System Efficiency and Electricity Cost
- (J) Renewable Electricity Generation Integration (for central production)
- (M) Control and Safety

### Technical Targets

This project is conducting applied research, development, and demonstration (RD&D) to reduce the cost of hydrogen production via renewable electrolysis for both distributed and central production pathways to help meet the following DOE hydrogen production and delivery targets found in the 2012 Multi-Year Research, Development, and Demonstration Plan:

Technical Targets: Central Water Electrolysis using Green Electricity (Table 3.1.5)

- Stack efficiency:
  - 44 kWh/kg H<sub>2</sub> (76% lower heating value, LHV) by 2015
  - 43 kWh/kg H<sub>2</sub> (78% LHV) by 2020
- System efficiency:
  - 46 kWh/kg H<sub>2</sub> (73% LHV) by 2015
  - 44.7 kWh/kg H<sub>2</sub> (75% LHV) by 2020
- By 2015 reduce the cost of central production of hydrogen from water electrolysis using renewable power to \$3.00/gasoline gallon equivalent (gge) at plant gate. By 2020, reduce the cost of central production of hydrogen from water electrolysis using renewable power to ≤\$2.00/gge at plant gate.

### Overall Objectives

- Collaborate with industry to research, develop, and demonstrate improved integration opportunities for renewable electrolysis systems for energy storage, vehicle refueling, grid support, and industrial gas end-uses.
- Design, develop, and test advanced experimental and analytical methods to validate electrolyzer stack and system efficiency; including contributions of sub-system losses (e.g., power conversion, drying, electrochemical compression) of advanced electrolysis systems.

### Fiscal Year (FY) 2013 Objectives

- Quantify stack, system efficiency, and hydrogen drying losses of the DOE-awarded electrolyzer system from Giner/Parker Hannifin.
- Demonstrate and compare 10,000 hours of variable (i.e., wind-profile) and constant power operation of proton exchange membrane (PEM) electrolyzer stacks and determine decay rates.

### Technical Barriers

Electrolysis presents the opportunity for non-carbon-emitting hydrogen production when a renewable electricity source such as wind, solar, or hydropower is used. To be cost competitive, however, R&D is necessary to reduce electrolysis capital and operating costs, and the cost of

### FY 2013 Accomplishments

- Installed, commissioned and completed 200 hours of operation of advanced high-efficiency electrolyzer system from Giner/Parker Hannifin.
  - First 100 hours of operation were completed by the end of June 2012, completing an FY 2012 EE-1 Joule Milestone.
  - Subsequently, the 12 kg/day electrolyzer system was moved from the National Wind Technology

Center to the Energy Systems Integration Facility in Golden, CO.

- Operated PEM electrolyzer stacks over 10,000 hours with variable wind profile to compare stack decay rate with that of a stack operating under constant power.



## INTRODUCTION

The capital cost of commercially available water electrolyzer systems, along with the high cost of electricity in many regions, limits widespread adoption of electrolysis technology to deliver low-cost hydrogen production. PEM electrolyzer manufacturers are working to scale up into the MW range to reduce their system energy efficiency to better compete with alkaline. Along with capital cost reductions and efficiency improvements, both technologies are developing utility-scale electrolyzers capable of advanced grid integration functionality and better integration with renewable electricity sources. Electrolytic production of hydrogen, where fossil fuels are the primary electricity source, will not lead to significant carbon emission reduction without carbon sequestration technologies.

Renewable electrolysis is inherently distributed, but large-scale wind and solar installations are being planned to take advantage of economies of scale and achieve system-level energy efficiencies less than 50 kWh/kg. Renewable electricity sources, such as wind and solar, can be closely, and in some cases directly, coupled to the hydrogen-producing stacks of electrolyzers to reduce energy conversion losses and capital costs investment of this near-zero-carbon pathway.

Large-scale hydrogen production using renewable electricity is well positioned to produce near-zero-greenhouse-gas-emission vehicle fuel in the coming years as hydrogen-powered fuel cell electric vehicles are introduced into the marketplace. An integrated system with advanced sensing and communications will enable grid operators to take advantage of the controllable nature of distributed and central water electrolysis systems to maintain grid stability.

## APPROACH

Results and insights gained from this RD&D project aim to benefit the hydrogen-based industry and relevant stakeholders as the market for this equipment expands. Results from the project have demonstrated opportunities to improve efficiency and capital cost of an integrated renewably coupled electrolysis system.

The Xcel Energy/NREL Wind-to-Hydrogen collaborative RD&D project is advancing the integration of renewable electricity sources with state-of-the-art electrolyzer technology. Real-world data from 24/7 daily

operations are demonstrating opportunities for improved system design and novel hardware configurations to advance the commercialization of this technology. Lessons learned and data-driven results provide feedback to industry and to the analytical components of this project. Finally, this project provides independent testing and verification of the technical readiness of advanced electrolyzer systems by operating them from the grid and renewable electricity sources.

## RESULTS

### Advanced Electrolyzer Testing

The DOE-awarded electrolyzer system was delivered to NREL in June 2012. The system was promptly installed, commissioned, and operated for 100 hours to achieve a DOE EE-1 Joule Milestone by the end of June.

Giner predicted that the system would produce a kilogram of hydrogen using 54 kWh of electricity. The electrolyzer control system monitors the internal pressure of the hydrogen and varies stack current to maintain 390 psig. Because of the continuous slewing of stack current, instantaneous measurements are binned and averaged, typically based on stack temperature.

Stack temperature is determined by averaging the input and output de-ionized water measurements. In addition to stack in/output temperature, NREL also instrumented the electrolyzer with the following sensors: alternating current (AC) input and voltage and stack current and voltage. Hydrogen product from the electrolyzer system was measured using an NREL designed and built volumetric mass flow device. Stack efficiency is determined based on stack voltage, temperature, and operating pressure.

The stack, designed and built by Giner, operates at 390 psig and achieved 87% (higher heating value, HHV), 73.6% (LHV) efficiency at 1,500 mA/cm<sup>2</sup> and 80°C (Figure 1). The balance of plant, designed and built by Parker Hannifin, achieved an overall system efficiency of 64.8 kWh/kg at

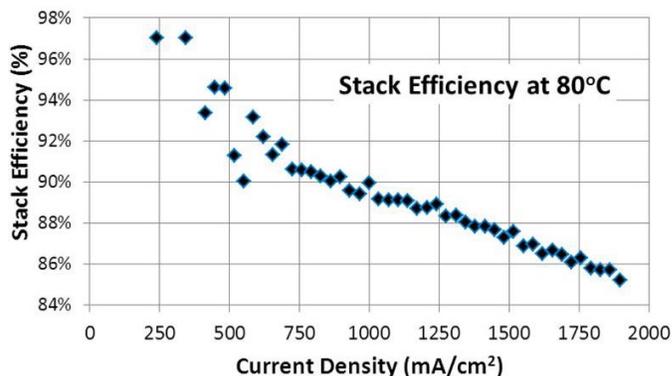


FIGURE 1. Stack Efficiency (HHV) based on Current Density

1,600 mA/cm<sup>2</sup>. Approximately 10 kWh/kg of this specific energy requirement is attributed to lower-than-expected efficiency of the AC to direct current (DC) power supplies.

Hydrogen product from commercial electrolyzer systems is routinely dried to -20°C dew point and below. Hydrogen drying losses have been reported for these systems in the 5–10% of the rated product flow from the stacks based on full stack current. These drying losses directly reduce the system efficiency because the hydrogen used to regenerate the desiccant drying beds is vented from the system.

During the milestone testing, NREL intercepted this hydrogen drying vent from the Giner/Parker Hannifin electrolyzer system and measured the flow rate using two different methods. Both methods provided reasonably close measurements of the drying loss. First, a hydrogen mass flow sensor measured 11–12 grams per hour of hydrogen loss from the drying system. Although the hydrogen from the vent was dried using desiccant prior to the sensor, this measurement is slightly in question because it is a thermally-based technology and any entrained water vapor will disrupt the measurement.

The second method used a 5.9-liter flask and a timer. The amount of time and volume of gas was repeatedly measured to a range of 15.2–15.6 grams per hour. Giner predicted a drying loss of 18 grams per hour. The measured loss represents about 3.5% drying loss based on full stack current of 505 amps DC.

#### Variable vs. Constant Power Stack Operation

NREL is conducting side-by-side testing and comparison of stack voltage decay rates between constant and variable power operation. Two 34-cell stacks of an H-Series PEM electrolyzer from Proton Onsite were operated with a highly variable wind profile, achieving a total of over 10,000 hours of operation between November 2010 and March 2013. A third stack was operated over the same time with constant stack power. All three stacks were operated with the same average current.

A varying wind power profile is run on the stacks for hundreds of hours continuously and only interrupted to operate all three stacks at their full-current point for a few consecutive days to enable comparison of their steady-state voltage. Table 1 summarizes the results over 7,500 hours of operation and shows one of the variable stacks exhibiting a slightly higher decay rate than that of the constant current stack. The other variable-powered stack's decay rate is significantly higher than the others. That stack failed shortly after this 7,500 hour test was completed.

At the beginning of the 7,500 hour test, the stack's operational modes were randomly selected. Because of this, the two remaining stacks in the test were swapped and the test restarted. The reason for swapping the two stacks was to eliminate any random systematic error in stack

Table 1. Average Cell Decay Rates by Operational Mode

Mode	Average Decay $\mu\text{V}/\text{cell-h}$
Variable	16.7
Variable	9.7
Constant	9.2
Hours	7,538

manufacturing. Unfortunately, after the first 2,500 hours (~10,000 hours total) after swapping their operational modes another stack failed and the test was halted. Since these stack failures, Proton Onsite has provided two newer replacement stacks (manufactured in 2008) and the variable versus constant power testing is continuing.

It is important to note that before delivery to NREL, that all three of the original electrolyzer stacks faced severe abuse with no hydration for about a year in a warehouse. Furthermore, this testing is intended only to reveal relative stack decay rates between a variable wind profile and constant current operation, if there is any difference. Normal stack decay rates of today's PEM stacks from Proton Onsite are between 2–5  $\mu\text{V}/\text{cell-h}$ .

## CONCLUSIONS AND FUTURE DIRECTION

NREL completed a DOE EE-1 Joule Milestone by installing, commissioning and operating an advanced electrolyzer from Giner and Parker Hannifin. The PEM electrolyzer included a high efficiency stack operating at 390 psig. Stack efficiency was determined to be 73.6% (LHV) versus the DOE's 2015 target of 76% (LHV). The system consumed 64.8 kWh/kg but 10 of those kWhs were attributed to higher-than-expected power supply conversion losses. The DOE 2015 target for system efficiency is 46 kWh/kg, noting that this would be expected of large MW-scale electrolyzers. The Giner/Parker Hannifin electrolyzer produces 12 kg/day while requiring 30-35 kW of electrical power. Hydrogen drying losses were determined to be 3.5%, based on the full rated hydrogen flow from the stack.

Three PEM electrolyzer stacks were operated in variable and constant power modes. Over 10,000 hours of operation were achieved before the test was halted due to two stack failures. All three of the original electrolyzer stacks faced severe abuse with no hydration for about a year in a warehouse. Two newer stacks (manufactured in 2008) were provided by Proton Onsite and are now under test.

In the coming year the team will complete the following:

- Complete testing of novel hydrogen drying process and show potential improvement of system efficiency.
- Achieve over 4,000 hours of variable versus constant power stack operation to determine if variable stack operation causes a different decay rate than constant power mode.