II.E.4 Renewable Electrolysis Integrated System Development and Testing

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Project End Date: Project continuation and direction determined annually by DOE

Fiscal Year (FY) 2011 Objective

- Optimize the coupling between wind and solar electric resources and the hydrogen-producing stacks of commercially available electrolyzer systems.
- Quantify performance differences between variable and constant current operation of electrolyzer stacks and systems.
- Collaborate with industry and utilities to advance the commercialization of integrated renewable electrolysis systems.
- Demonstrate the technical readiness of DOE-awarded advanced electrolysis systems.

Technical Barriers

This project addresses the following technical barriers from the Production section (3.1) of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

(G) Capital Cost
(H) System Efficiency
(J) Renewable Electricity Generation Integration

Technical Targets

Results from the project demonstrate improved system efficiency and offer opportunities to reduce capital costs by reducing redundant components in a renewable-coupled system. Previously, testing conducted under this project of a DOE-awarded system, from Giner Electrochemical Systems, demonstrated small-scale (16-kW) electrolyzer system energy efficiency of 55% (lower heating value, LHV). The current (2009) state-of-the-art cost for delivered hydrogen from electrolysis for a forecourt refueling station ranges from \$4.90/kg-H_2 to \$5.70/kg-H_2 dispensed at the pump, with a base-case estimate of \$5.20/kg-H_2. This base-case estimate of \$5.20/kg-H_2 includes an electrolysis production cost of \$3.32/kg-H_2 and compression, storage and dispensing costs of \$1.88/kg-H_2. These costs are evaluated using Energy Information Administration Annual Energy Outlook 2005 High A Case industrial electricity costs (\$0.053/kWh on average) [1]. In the coming year, this project will test the performance of two DOE-awarded systems to demonstrate their technical readiness for improved stack efficiency and higher pressure (>2,500 psig) hydrogen product directly from the electrolyzer stack. Based on information provided by electrolyzer suppliers for their state-of-the-art technologies, both alkaline and polymer electrolyte membrane (PEM) electrolyzers are now capable of producing hydrogen using less than 50 kWh/kg, representing a lower heating value efficiency of greater than 67% [1].

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

Characteristics	Units	2012 Target	Status
Hydrogen Cost	\$/gge	3.70	4.90-5.70
Electrolyzer Energy Efficiency	% (LHV)	69	67-75

gge – gasoline gallon equivalent

FY 2011 Accomplishments

- Completed Fuel Cell Technologies Program milestone for Hydrogen Fuel R&D for Quarter 1: “Complete testing (300 hours) of multiple commercial electrolysis stacks into a wind-to-hydrogen system to characterize the impacts of the power electronics interface and varying wind power input on electrolyzer performance and cost of renewable-based hydrogen production.”
  - Conducted varying current stack testing continuously for more than 3,800 hours by the end of July 2011.
  - The testing revealed that the duration of full-current steady-state operation embedded between long-duration, varying-current wind profile operation influences the anode catalyst oxidation state and may have a role in transient voltage behavior.
- Demonstrated 10% efficiency improvement by combining direct-coupled photovoltaic (PV) and power converter-to-stack operation based on solar irradiance.
- Installed new test facility and power switch gear at the Wind-to-Hydrogen (Wind2H2) project to support testing of DOE-awarded electrolyzer systems in FY 2012.

- Installed refurbished alkaline stack and balance-of-plant components enabling side-by-side comparison testing of similarly sized competing electrolyzer technologies.
- Completed initial hourly analysis of central wind electrolysis production facility (50,000 kg/day). See project II.E.6, "Hour-by-Hour Cost Modeling of Optimized Central Wind-Based Water Electrolysis Production".

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Introduction

Renewable electrolysis is inherently distributed, but large-scale wind and solar installations are becoming more common and will take advantage of economies of scale. Life cycle assessments of large-scale wind turbines, for example, show payback for the greenhouse gas emissions required to manufacture the equipment in about nine months [2]. 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 improve system efficiency and lower the capital costs of this near-zero carbon pathway.

Approach

The Xcel Energy/NREL Wind2H2 project is advancing the integration of renewable electricity sources with state-of-the-art electrolyzer technology. Real-world data from daily system operation are revealing opportunities for improved system design and unique hardware configurations to advance the commercialization of this technology. Lessons learned and data-driven results provide feedback to the analytical and modeling components of this project [3].

In hydrogen production facilities even small increases in system efficiency result in significant reductions in hydrogen cost. DOE is funding electrolyzer manufacturers to design and build improved stacks and system balance of plant to reduce the cost of electrolytically produced hydrogen. This project provides independent testing and verification of the technical readiness of these advanced electrolyzer systems by operating them from the grid and renewable electricity sources.

Results

We conducted side-by-side testing and comparison of stack voltage decay rates between constant and variable current operation. Two, 34-cell stacks of an H-Series PEM electrolyzer, from Proton On Site, were operated with a highly variable wind profile for more than 3,800 hours between November and July 2011. The third stack was operated over the same time with a constant stack current while having the same average current as the two variable stacks. Varying wind current profile was normally operated for hundreds of hours continuously and only interrupted to operate all three stacks at their full-current steady-state point for a few days at a time.

Table 2 summarizes these results, which are based on over 3,800 hours of combined varying wind and full-current steady-state operation through July 2011. Before delivery to NREL, the stacks under test faced severe abuse with no hydration for about a year in a warehouse without operation or attention. 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. Stack decay rates of today's PEM stacks are in the range of 2–5 µV/cell-h.

TABLE 2. Summary of Full-Current Steady-State Scans and Resulting Decay Rate

Mode	Stack Voltage (104°F)					Average Decay µV/cell-hr
	1/7/2011	2/9/2011	4/12/2011	6/10/2011	7/22/2011	
Variable	76.5	77.6	78.6	79.1	78.3	13.9
Variable	74.5	75.5	76.9	77.2	76.3	13.7
Constant	75.1	75.9	77.1	77.3	76.7	12.4
Cumulative Hours		594	1,853	3,143	3,803	

The cell membrane resistance supports the linear fitting and extrapolation to 104°F (40°C) to establish a common temperature to compare the full-current scans. The data indicate a narrow band of operation during the colder winter months and the wider temperature operating range from the April 12 full-current scan (Figure 1). We expect that hotter summer months will shift stack operating temperature to even higher temperatures, which is the reason 104°F was selected as the comparison temperature.

Original plans to operate the three stacks in full-current steady-state mode for tens of hours between the varying wind profile were quickly replaced when longer duration full-current scans revealed a change in the voltage behavior. The longer duration full-current scans suggested that the anode catalyst layer has a role in this transient voltage behavior. As a result, all future full-current steady-

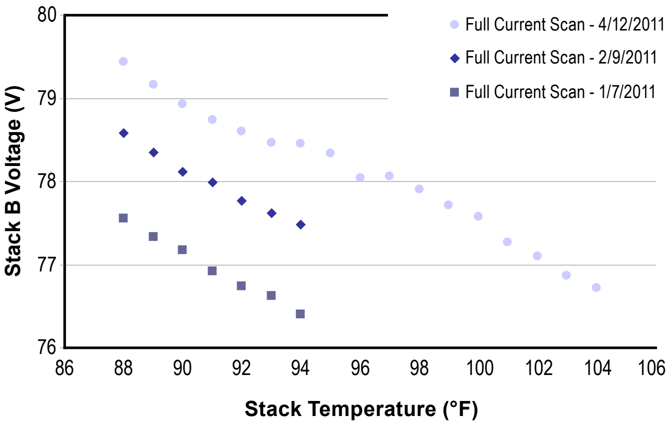

FIGURE 1. Stack B (Varying Stack) Voltage Responses During Full-Current Steady-State Operation

state scans will be run for several days. Proton On Site has suggested a brief electrolyzer shutdown between varying stack and full-current steady-state mode may provide further insight to stack voltage behavior.

The three stacks are periodically brought to their full-current steady-state operating point to enable comparison of their stack voltages at stable conditions. Input and output deionized (DI) water temperature, stack current, and voltage are monitored. DI input and output water temperatures are averaged and binned for every 1°F and the corresponding stack voltages are averaged for each bin. Stack B (varying stack) voltage responses are shown in Figure 1 for three of the full-current steady-state periods and are representative of each stack. Each stack responded similarly during these full-current steady-state operation periods.

In FY 2010, NREL conducted testing comparing the performance of direct coupling a PV array to a PEM electrolyzer stack with that of a power converter using maximum power point tracking. The electrolyzer stack operating point was intentionally aligned with that of PV array. In FY 2011, the power converter switching losses and diode reverse recovery were investigated. The direct coupling and power converter data were further analyzed to show a 10% system efficiency improvement if direct coupling were used in solar irradiances less than 500 W/m^2 and the power converter was used when higher irradiances were present (Figure 2).

Conclusions and Future Direction

Through the end of July 2011, NREL conducted more than 3,800 hours of varying wind profile stack current testing with two PEM electrolyzer stack while holding a third stack at constant current. As these results are preliminary, the testing continues.

NREL's comparison testing between direct coupling a PV array to a PEM electrolyzer stack versus a power converter using maximum power point tracking provides an opportunity to improve system efficiency. System efficiency can improve by 10% if direct coupling is used in solar irradiances less than 500 W/m^2 and the power converter is used when higher irradiances are present.

- To support the opportunity to use electrolyzers as dispatchable loads for grid support services, NREL plans to induce frequency disturbances on its 80 kW and 125 kW diesel generators using resistive step loads. Both the PEM and alkaline electrolyzers will be triggered to shed or add load to the microgrid to mitigate these frequency changes.
- Similarly, the 5 kW PEM fuel cell will be direct current coupled with the PV array to quantify its response time as clouds passing by the PV array induce load changes.
- NREL plans to test the performance of two DOE-awarded electrolyzer systems in the coming year. These advanced systems were designed and built to improve stack efficiency and high-pressure electrochemical operation of the stack.

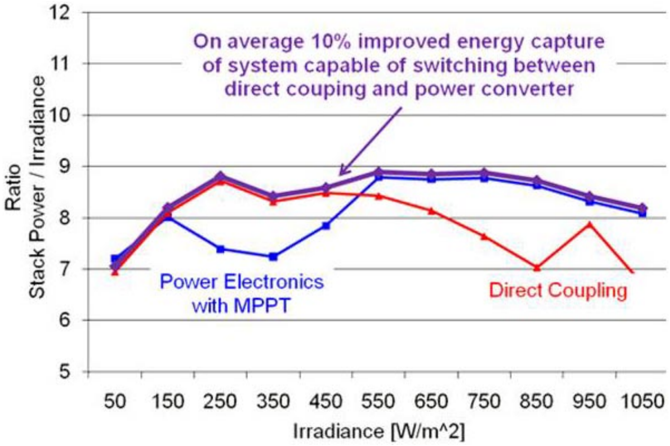

FIGURE 2. 10% Improved Energy Capture by Taking Advantage of Direct Coupling at Solar Irradiances Less Than 500 W/m^2 and Power Conversion when Irradiances are Greater

- Equipment downtime, reliability, and maintenance data will be tracked to help quantify the performance of this integrated renewable hydrogen production system.
- Multiple stack electrical isolation tests will highlight the challenges of electrical floating and bipolar stack operation. If successful, multiple stacks could be configured to take advantage of the direct current bus of large-scale variable-speed wind turbines.

FY 2011 Publications/Presentations

1. Harrison, K.; Novachek, F.; Ramsden, T.; Ainscough, C., NREL and Xcel Energy Collaboration on Wind-to-Hydrogen (Presentation); Fuel Cell and Hydrogen Energy Association Conference, February 14–16, 2011, Washington, D.C.

2. Harrison, K.W.; Remick, R.; Hoskin, A.; Martin, G.D., Hydrogen Production: Fundamentals and Case Study Summaries; NREL Report No. CP-550-47302.

References

1. Independent Panel Review, Current (2009) State-of-the-Art Hydrogen Production Costs Estimate Using Water Electrolysis, Report No.: NREL/BK-6A1-46676, September 2009.

2. Life Cycle Assessment of electricity produced from onshore sited wind power plants based on Vestas V82-1.65MW turbines, retrieved June 1, 2011 from www.vestas.com/en/about-vestas/sustainability/wind-turbines-and-the-environment/life-cycle-assessment-%28lca%29.aspx.

3. Harrison, K.; Ainscough, C.; Ramsden, T.; Saur, G. 2011. Hour-by-Hour Cost Modeling of Optimized Central Wind-Based Water Electrolysis Production. Presentation given at the DOE Annual Merit Review, May 10, 2011. www.hydrogen.energy.gov/pdfs/review11/pd085_saur_2011_p.pdf.