II.B.1 Renewable Electrolysis Integrated Systems Development and Testing

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

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) 2014 Objectives

- Baseline first 2,000 hours of constant powered testing on two Proton OnSite proton exchange membrane (PEM) electrolyzer stacks and run variable testing to 5,000 hours comparing stack decay rates of the two operational modes
- Improve system efficiency and operation cost to the electrolyzer end-user by:
  - Testing NREL's novel drying technique to reduce drying losses below 3.5%
  - Demonstrating electrolyzer's capability to participate in grid ancillary services
- Report on industry collaborations to ensure research goals align with industry needs

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 (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 MYRD&D Plan:

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

- Stack Efficiency:
  - 44 kWh/kg H_2 (76% lower heating value, LHV) by 2015
  - 43 kWh/kg H_2 (78% LHV) by 2020
- System Efficiency:
  - 46 kWh/kg H_2 (73% LHV) by 2015
  - 44.7 kWh/kg H_2 (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 the plant gate. By 2020, reduce the cost of central production of hydrogen from water electrolysis using renewable power to ≤\$2.00/gge at the plant gate.

FY 2014 Accomplishments

- Completed 2,000 hours of constant-powered testing on two Proton OnSite PEM electrolyzer stacks. Decay rate for both stacks was at 9.5 (μV/cell-h).
  - On-going testing to 5,000 hours with one stack operating with a variable-powered profile and the other remaining with a constant powered profile
  - Decay rates expected to continue to decline below the 9.5 (μV/cell-h) as more hours are put on the stacks

    - A new generation PEM electrolyzer stack from Proton OnSite has been procured and will be installed late FY 2014 which will allow comparison of a newer generation of stack from Proton OnSite.
- Demonstrated hydrogen production moisture content and drying losses of a commercially available electrolyzer (Proton OnSite H-Series, 13 kg/day, 40 kW). This testing provides a baseline to inform design and implementation of NREL's novel drying technique aiming to reduce drying losses below 3.5% of rated flow.
    - Baseline results indicated drying losses of 11% at full stack power, 14% at 80% of rated stack power, and 18% at 60% of rated stack power
- Demonstrated PEM electrolyzer's ability to quickly respond and closely match a command signal sent from grid to participate in grid ancillary services
- By end of FY 2014: Report on current and potential industry partnerships including how future work will correspond with projects for industry formed through other internal NREL projects (e.g., INTEGRATE)

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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 megawatt range to improve their system energy efficiency. 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. 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. 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.

APPROACH

Results and insights gained from this RD&D project aim to benefit the hydrogen industry and relevant stakeholders as the market for water electrolyzers 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 and Energy Systems Integration Laboratory 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 operation 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 on both grid and renewable electricity sources.

RESULTS

Stack Decay Comparison: Variable Versus Constant Powered

NREL is conducting side-by-side testing and comparison of stack voltage decay rates between constant and variable power operation of electrolyzer stacks. Two 34-cell stacks for the H-Series PEM electrolyzer from Proton Onsite were obtained in June 2013. The stacks were operated in a constant full-powered mode for the first 2,000 hours of their lifetime to obtain baseline decay rate at constant power. Table 1 shows the stack decay rates for both stacks after 2,000 hours of operation. The stacks showed the same decay rate over the first 2,000 hours so it was determined to start operating one in variable mode while the other stays at constant power for a decay rate comparison.

TABLE 1. Stack Decay Rate of two Proton OnSite 10-kW Stacks after 2,000 Hours of Operation

Stack Operating Mode	Stack Identifier	Decay Rate (μV/cell-h)
Constant Power	Stack A	9.5
Constant Power	Stack B	9.5

A varying wind power profile is currently being run on one of the stacks to achieve a milestone of 5,000 hours of total operation (2,000 hrs constant powered with 3,000 variable-powered hours versus 5,000 constant-powered hours). NREL has procured a third stack from Proton OnSite to allow comparison of newer stack technology operating alongside an older stack, both running on variable power. Once the stack from Proton OnSite is installed, it will be operated at constant power for the first 2,000 hours, like the other two, before being switched to variable-powered operation.

Baseline Testing for Variable Flow Drying Technique

A dual-bed pressure swing absorption drying system consists of a handful of control valves and two desiccant beds combined in parallel at the output of the H_2/H_2O phase separator. A back-pressure regulator maintains constant pressure on the pressure swing absorption system and stack. The water vapor saturated hydrogen comes out of the hydrogen phase separator and travels through one of the desiccant tubes; the goal of the first tube is to dry the hydrogen to less than 5 parts per million by volume (ppmv) of H_2O in H_2. At the outlet of the desiccant tube being used for drying, an orifice allows a percentage of dry hydrogen to sweep out (dry) the bed being regenerated (inactive bed). The orifice between the two desiccant beds allows a fixed amount of hydrogen to flow and dry the inactive bed. The flow of dry hydrogen through the inactive bed is a function of the orifice size and the back pressure regulator setting. The hydrogen used to dry the desiccant bed is not recoverable and is vented out of the system; this is what is considered the electrolyzer drying losses.

The typical drying approach results in the same amount of hydrogen being lost regardless of the stack power. This approach decreases system efficiency at lower than rated stack power levels because the amount of hydrogen lost due to drying is a higher overall percentage of the flow rate. This concept was validated experimentally using NREL's Proton OnSite H-Series and is described in Table 2. The table shows the drying losses as a percentage of rated hydrogen flow at three stack power levels. As expected, the drying losses are constant at 0.07 kg/hr for each test. However, when stack power is being decreased, the product hydrogen flow decreases, and thus there is a higher percentage of drying loss.

TABLE 2. Proton OnSite H-Series Drying Losses with Variable Stack Power

Drying Losses	100% Stack Power	80% Stack Power	60% Stack Power
Flow (kg/hr)	0.07	0.07	0.07
% of Rated Flow	11	14	18

* Relatively Small Sample Size n = 5 for each test

SAE International (SAE) J2719 sets standards for fuel quality for station providers in the hydrogen dispensing market; they have set their standard for moisture content to less than 5 ppmv H_2O so for hydrogen vehicle fueling applications the electrolyzer drying system must be able to achieve this specification. Dry hydrogen ensures that impurities are not delivered to fuel cell units when the hydrogen is converted back to electricity.

The electrolyzer output was instrumented with a dew point sensor, pressure gauge, pressure transducer and resistive temperature device to measure the parameters needed to calculate moisture content in the hydrogen. First, a series of start-ups was tested to determine how quickly the electrolyzer reached the SAE J2719 tolerance. During this testing the electrolyzer consistently provided hydrogen below the 5 ppmv tolerance in less than 5 minutes. The second test looked at the hydrogen output moisture content versus stack current. It was established that the moisture content was unaffected by stack current, however, drying losses increased as a percentage as stack current dropped. Figure 1 shows a graph of three stack current levels (blue) and the resulting hydrogen moisture content (red).

NREL's variable flow drying technique aims to reduce the percentage of hydrogen lost due to drying by replacing the fixed orifice between the two desiccant beds with a variable flow orifice. Unlike the fixed flow orifice which allows the same amount of flow through the inactive

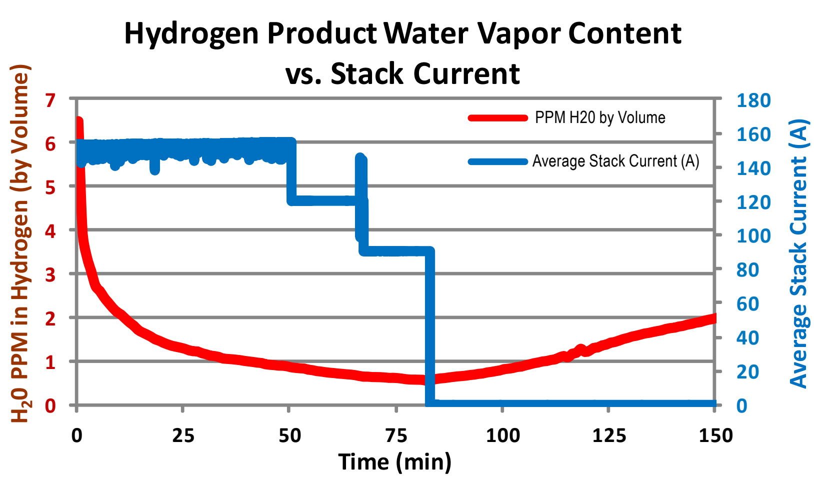

FIGURE 1. Water Vapor Content versus Stack Current

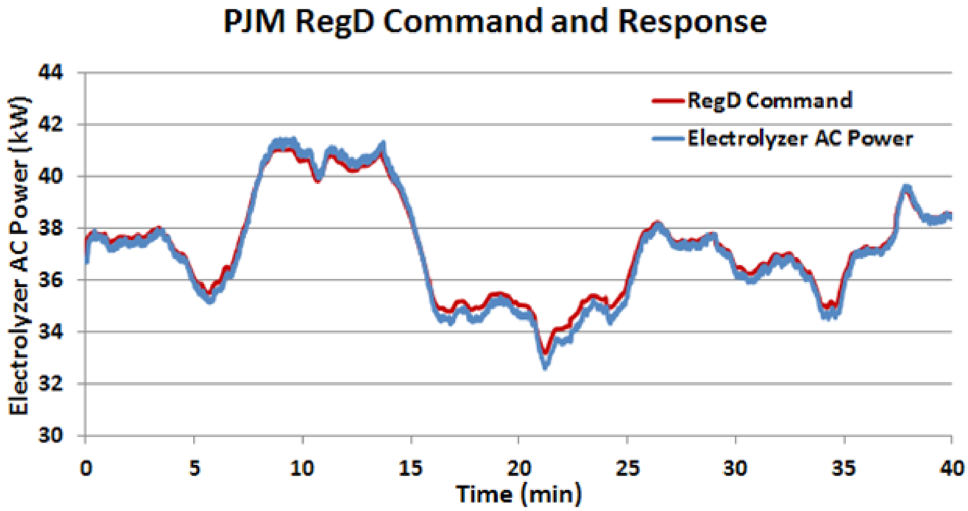

FIGURE 2 - Dynamic Regulation of Proton OnSite H-Series

desiccant bed, the variable flow orifice will be capable of adjusting with stack power to maintain the same percentage of hydrogen lost through drying. This approach will increase electrolyzer system efficiency while still maintaining the necessary hydrogen dryness required by SAE J2719.

PEM Electrolyzer Participating in Grid Ancillary Services

NREL demonstrated the ability of the Proton OnSite H-Series to react to a quickly changing command similar to those provided in grid ancillary service markets. PJM Interconnection, a regional transmission organization that coordinates the movement of electricity in 13 states and Washington D.C., has regulation tests that electricity assets need to pass before they can bid into the regulation market. The H-Series electrolyzer was tested with a standard regulation signal (RegA) and a dynamic regulation signal (RegD) both provided by PJM Interconnection. Figure 2 shows the results of the RegD dynamic regulation test which is the harder of the two tests to pass. Although results were not sent to PJM for an official grade, compared to other examples provided by PJM the electrolyzer response to the command signal was very good. This testing demonstrated that future electrolyzers should be able to bid into the regulation market, providing an additional revenue source.

CONCLUSIONS AND FUTURE DIRECTIONS

- **Conclusion:** Completed 2,000 hours of constant-powered testing on two Proton OnSite PEM electrolyzer stacks. Decay rate for both stacks was at 9.5 (μV/cell-h).
  - **Future:** Continue long-duration testing to compare constant versus variable powered operation
- **Conclusion:** Baseline results of Proton OnSite H-Series drying losses of 11% but quickly (less than 5 min) achieves the SAE J2719 moisture content tolerance
  - **Future:** Continue testing NREL variable flow drying technique aiming to reduce drying losses below 3.5% at rated power
- **Future:** Leverage other NREL projects to characterize electrolyzer system improvements, grid integration, and advanced stack efficiency

SPECIAL RECOGNITIONS & AWARDS/ PATENTS ISSUED

1. DOE special recognition awards to Chris Ainscough and Kevin Harrison for the work completed in FY 2013 on the Giner/Parker Hannifin electrolyzer testing

FY 2014 PUBLICATIONS/PRESENTATIONS

1. Harrison, K. (May 2013). “Renewable Electrolysis: Integrated System Testing.” Keynote presentation at the 2nd Annual ADvanced ELectrolysis (ADEL) International Workshop, Corsica, France, May 2013.

2. Harrison, K. (October 2013). “Integrated Systems Testing PEM/ Alkaline.” Presentation at F-Cell Conference. Stuttgart, Berlin. October 2013

3. Harrison, K. (February 2014). “Renewables and Grid Integration.” Presentation at DOE Electrolytic Hydrogen Production Workshop. Golden, CO. February 2014

4. Peters, M. & Harrison, K. (June 2014) “Innovative Drying Technique for Wind and Solar Powered Electrolysis.” ASME 2014 12th Fuel Cell Science, Engineering & Technology Conference. Boston, MA. June 2014.

5. Eichman, J., Harrison, K. and Peters, M. “Novel Applications for Electrolyzers: Providing more than just hydrogen.” NREL Publication. Under Review. Golden, CO