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

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Subcontractor
Spectrum Automation Controls, Arvada, CO

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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) 2015 Objectives

- Compile detailed information on multiple hydrogen drying techniques used in electrolyzers
- Test NREL's variable flow drying technique on large active area polymer electrolyte membrane (PEM) stacks provided to NREL as part of the Integrated Network Testbed for Energy Grid Research and Technology Experimentation (INTEGRATE) project
  - Drying apparatus will be procured through INTEGRATE with instrumentation and data collection/analysis happening as part of the Integrated Systems Development and Testing FY 2015 funding
- Continue long-duration testing on the three 10-kW PEM stacks from Proton OnSite, comparing decay rates of variable operation versus constant powered operation

Technical Barriers

This project addresses the following technical barriers from the Fuel Cell Technologies Office 2012 Multi-Year Research, Development, and Demonstration (MYRDD) 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 MYRDD plan (2011–2020).

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/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

FY 2015 Accomplishments

- The project team designed, instrumented, and commissioned a pressure swing adsorption drying system capable of drying hydrogen to the SAE J2719 fueling standard. The dryer is capable of handling hydrogen flow rates up to 135 kg/day and pressures up to 1,000 psig.
  - NREL modified the hydrogen dryer by adding two linear actuated valves to optimize hydrogen drying losses under variable stack power operation.
- By the end of FY 2015, we will finalize a report on NREL's variable flow drying technique by finishing data

collection and analysis of variance (ANOVA) on data collected.

- The Energy Systems Integration Facility electrolyzer stack test bed was commissioned through the INTEGRATE project, expanding NREL's capabilities to perform large active area stack and balance of plant testing.
  - The electrolyzer stack test bed provides a test platform that the Renewable Electrolysis Integrated Systems Development and Testing project will be able to use for years to come to test PEM electrolyzer stacks (up to 500 kW) under variable or renewable power operation.

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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 increase system energy efficiency and reduce capital cost. Along with capital cost reductions and efficiency improvements, both alkaline and PEM 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 the energy conversion losses and capital cost investment of this near zero carbon pathway.

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 renewable-coupled electrolysis system.

The Xcel Energy/NREL Wind-to-Hydrogen and Energy Systems Integration Laboratory RD&D project is helping to advance 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 adoption 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

Variable Flow Drying Technique

The main focus for this project in FY 2015 was looking into system efficiency improvements of hydrogen dryers under a variable or renewable profile. NREL's variable flow drying approach aims to reduce hydrogen drying losses through electrolysis to an equal percentage of stack flow. The testing compares the variable flow drying technique versus the standard orifice operation under variable and renewable profiles. In FY 2015, NREL tested two types of photovoltaic profiles, a wind profile, and two different regulation profiles. An ANOVA will be used to compare the two techniques using dew point sensors to track hydrogen quality. The variable flow approach will aim to keep drying losses at 3.5% of stack flow. Commercially available electrolyzer systems have typical hydrogen losses in the 5–10% range; this project aims to reduce those down to 3.5%. An annual milestone report summarizing key findings from the drying testing and results of the ANOVA will be published at the end of FY 2015. Figure 1 shows the hydrogen drying system, and Figure 2 shows four of the five profiles used in variable mode.

The most common form of hydrogen dryer used in today's electrolyzers is a pressure swing adsorption (PSA) dryer. The goal of the dryer is to dry the hydrogen to less than five parts per million by volume (ppmv) of H_2O in H_2. The 5 ppmv threshold is set by SAE J2719, which is the hydrogen fuel quality standard adopted for light-duty fuel cell vehicles.

A PSA drying system consists of a handful of control valves and two desiccant beds combined in parallel on the output of the H_2-H_2O separator and before the back pressure regulator. The saturated hydrogen comes out of the H_2 separator and travels through one of the desiccant tubes to dry the hydrogen. At the outlet of the active desiccant tube, some of the dry hydrogen is used to dry the inactive desiccant bed. The dry hydrogen is used as a sweeping gas to get the moisture off of the desiccant in the inactive bed. In a fixed flow system there is an orifice between the two desiccant beds that allows limited flow of hydrogen between

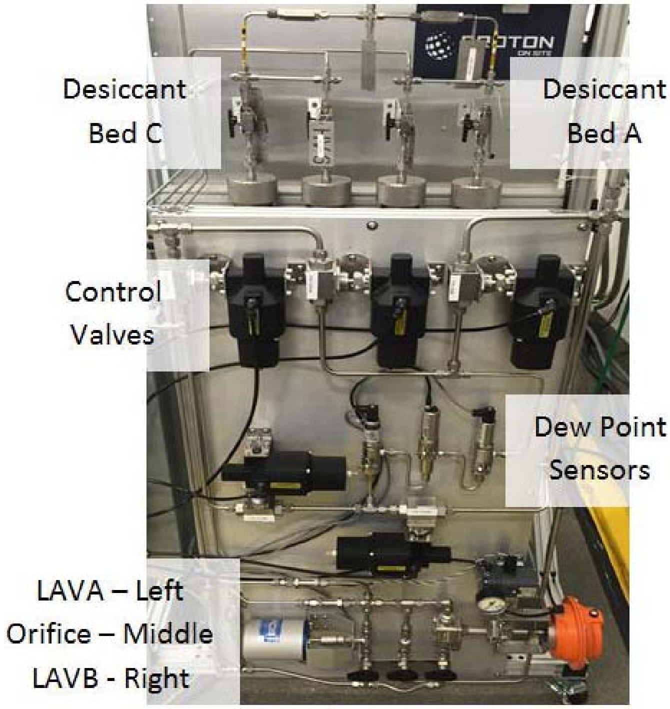


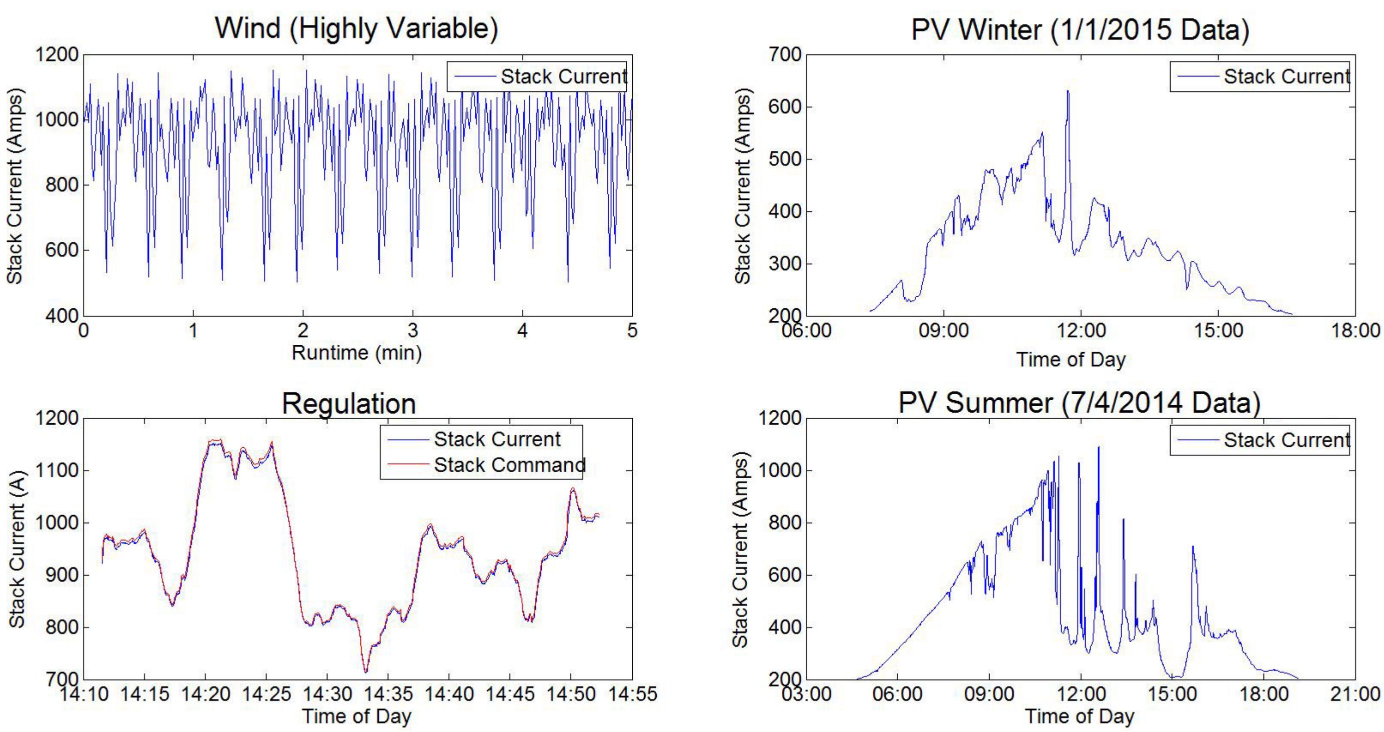
FIGURE 1. PSA dryer

the two. 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 off to the atmosphere; this is what is considered the electrolyzer drying losses.

The fixed orifice drying system, employed in commercially available electrolyzer systems today, allows a constant flow of hydrogen to be lost through the orifice independent of how much hydrogen the stack is producing. This approach is not optimal in an electrolyzer system operating with variable stack power, because the percentage of hydrogen lost will increase as stack power drops below maximum operating power. During renewable operation of an electrolyzer the stack is operated below full power most of the time, which means the hydrogen flow rate is less than when it is operated at full power; however, the same amount of hydrogen will be lost through the fixed orifice during the drying process. With a fixed orifice dryer, if the flow decreases while still losing the same amount of hydrogen, there is a higher percentage of hydrogen lost to drying.

PEM Electrolyzer Long Duration Testing Update

NREL is conducting side-by-side testing and comparison of stack voltage decay rates between constant and variable power operation. Three 34-cell stacks (labeled A–C) for



PV - photovoltaic

FIGURE 2. Variable and renewable stack profiles

the H-Series PEM electrolyzer from Proton OnSite were obtained in FY 2015. Two of the stacks (A and B) have 6,500 hours of operation to date and one of the stacks (Stack C) has 3,500 hours of operation. Stacks A and C are being operated in variable mode and Stack B is being operated in a constant power mode. Stack decay rates are being tracked and Table 1 shows a snapshot of decay rates that was reported at the 2015 DOE Annual Merit Review, at that time Stack C was only being operated in constant power mode. The table shows slightly higher decay rates than expected, with no significant difference observed between the two operating modes. In past testing Proton OnSite has stated that the decay rates should be better than 9 microvolts per cell-hour (μV/cell-h); however, the testing so far has indicated a slightly higher decay rate than expected.

TABLE 1. Snapshot of Stack Decay Rates

Operating Mode	Stack Identifier	Decay Rate (μV/cell-h)
Variable Power	Stack A	11.5
Constant Power	Stack B	12.6
Constant Power	Stack C	21.6

Long duration testing of the three stacks will continue through the end of FY 2015. When the goal of 7,500 hours is met, the stack decay rates at that time will be reported again.

Electrolyzer Stack Test Bed

The electrolyzer stack test bed located in the Energy Systems Integration Laboratory was designed, built, and commissioned in FY 2014/FY 2015. The test bed was funded under NREL's INTEGRATE task and was commissioned in September 2014 as a collaboration with Giner, Inc. The stack test bed features a modular design that allows testing of different PEM electrolyzer stacks (up to 500 kW) and electrolyzer balance of plant components. The test bed provides an essential platform for this project looking at both stack performance and system efficiency improvements under renewable operation as electrolyzer stacks scale up to the megawatt size.

In collaboration with Proton OnSite, NREL designed, instrumented, and commissioned a hydrogen drying system on the electrolyzer stack test bed. The hydrogen dryer is capable of handling flows up to 135 kg/day and pressures up to 1,000 psig. The dryer was procured from Proton OnSite using funds from INTEGRATE; this project funded activities such as adding control valves and dew point sensors, and programming the dryer operation. Figure 3 shows the electrolyzer test bed in the Energy Systems Integration Laboratory.

CONCLUSIONS AND FUTURE DIRECTIONS

- **Conclusion:** Testing of NREL's variable drying technique is on-going. Preliminary results indicate that 3.5% drying losses may be hard to maintain over long operation but the annual milestone report will finalize the data analysis.
- **Future direction:** We will submit an annual milestone report with an ANOVA comparing the two methods toward the end of FY 2015. Optimization of hydrogen drying will continue into FY 2016 using the electrically actuated linear actuated valve.
- **Conclusion:** Long duration constant versus variable power stack testing showed higher-than-expected stack

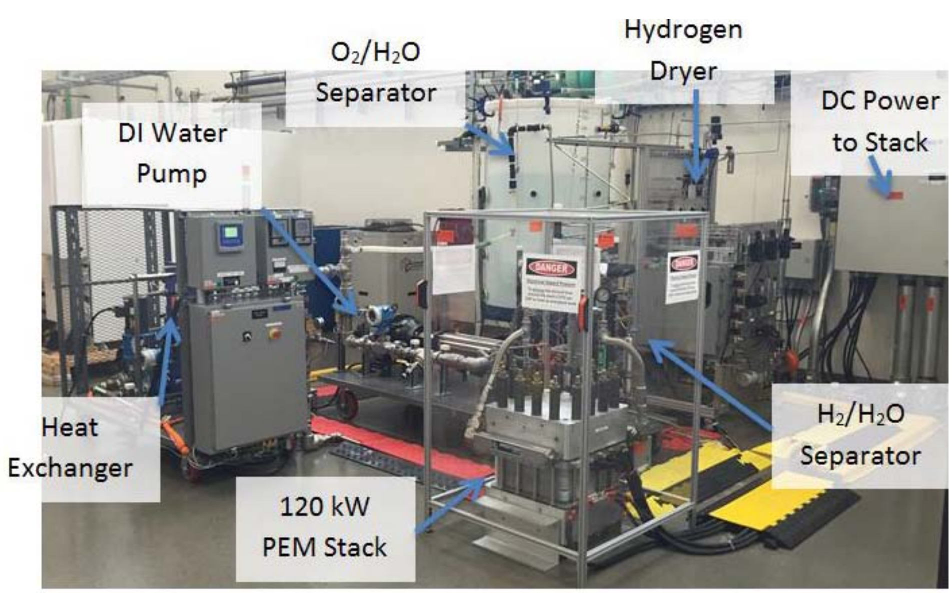


FIGURE 3. Electrolyzer stack test bed

decay rates, but no significant difference between the two methods was observed so far in the testing.

- **Future direction:** Stack testing up to 7,500 hours will continue through the end of FY 2015.
- **Conclusion:** Design, build, and commissioning of the Energy Systems Integration Laboratory electrolyzer stack test bed was completed as a collaboration with the INTEGRATE project.
- **Future direction:** The electrolyzer stack test bed will be used as a platform for renewable electrolysis testing for years to come.

FY 2015 PUBLICATIONS/PRESENTATIONS

1. Peters, Michael. "Renewable Hydrogen Production for Use in Hydrogen Fuel Cell Vehicles," Presentation at the ACT Expo, Dallas, TX, May 2015.

2. Peters, Michael, Kevin Harrison, and Danny Terlip. "Renewable Electrolysis Integrated System Development and Testing," Presentation at the DOE Hydrogen and Fuel Cells Program Annual Merit Review and Peer Evaluation Meeting, Arlington, VA, June 2015.