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, water pumps) of advanced electrolysis systems.

Fiscal Year (FY) 2016 Objectives

- Test NREL's variable flow drying technique on large active area polymer electrolyte membrane (PEM) stacks.
- Continue long-duration testing on the three 10 kW PEM stacks from Proton OnSite, comparing decay rates of variable operation versus constant powered operation.
- Create a design package for an electrolyzer that is operated entirely on direct current (DC) enabling easy coupling with renewable electricity sources.

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Production section (3.1.5) of the Fuel Cell Technologies Office Multi-Year Research, Development and Demonstration Plan.

(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 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 Fuel Cell Technologies Office 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_2 (76% LHV, lower heating value) by 2015
    - NREL validated Giner PEM stack efficiency in 2013 to be 73.6% (LHV) at 15,00 mA/cm^2, 80°C, 390 psig
  - 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 2016 Accomplishments

- NREL demonstrated 2.5% hydrogen savings using their variable drying technique compared to typical fixed orifice drying.
- Stack failure led NREL to prematurely finalize long-duration testing of three 10 kW PEM stacks inside a Proton H-Series Electrolyzer.

- NREL identified balance of plant differences in a typical electrolyzer versus an electrolyzer that runs entirely on DC power.
- NREL continued to report on system and stack failures.

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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. PEM electrolyzer manufacturers have scaled up their systems into the megawatt range to improve system energy efficiency and capital cost. Along with capital cost reductions and efficiency improvements, low temperature electrolyzers are beginning to be deployed at utility-scale and are capable of advanced grid integration functionality as well as integrated into networks containing high penetration of renewable electricity sources. An integrated system with advanced sensing and communications will enable grid operators to take advantage of the controllable nature and fast response 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 60 kWh per kilogram. 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 research, development, and demonstration project aim to benefit the hydrogen-based industry and relevant stakeholders as the market for this hydrogen production equipment expands. Results from the project have demonstrated opportunities to improve efficiency and capital cost of an integrated renewably coupled electrolysis system.

The research now being conducted at NREL's Energy Systems Integration Facility is advancing the integration of renewable electricity sources with state-of-the-art electrolyzer technology. Real-world data from 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

Long-Duration Testing

NREL completed side-by-side testing and comparison of stack voltage decay rates between constant and variable power operation on PEM stacks. Six 10 kW 34-cell stacks were tested from November 2010 to October 2015. The stacks operated three at a time inside an H-Series PEM electrolyzer from Proton OnSite. During the five years of testing, the electrolyzer was operated for over 17,000 h resulting in 39% utilization over that time period.

Through the duration of testing, four of the stacks operated with a variable (e.g., renewable) profile and two of the stacks operated with a constant profile (control). The variable profile used ramps the stack current randomly up and down but maintains an average stack current of 80% of full rated current (full rated current 150 A, 80% of full rated current 120 A). To maintain a fair comparison, NREL sets the constant stack current to a constant value of 80% of full current. The stacks are operated in steady-state full-current mode (150 A) for a period of time (typically 100–200 h) to obtain a stack decay rate (μV/cell-h) comparison. Figure 1 shows the three different types of stack operation throughout the five years of testing.

Decay rate was determined using NREL's technology validation program tool that was developed to find decay rate of fuel cell stacks in material handling equipment and fuel cell electric vehicles. The tool tracks current and voltage performance over the duration of testing and uses curve fitting techniques to determine decay rates at certain points in time. The tool allows for all of the data sets over the

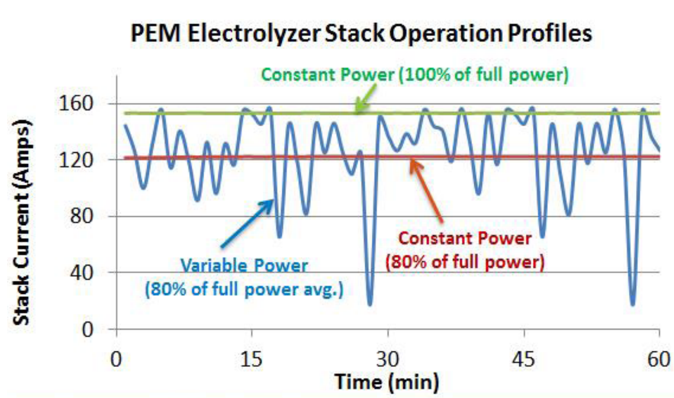

FIGURE 1. Stack operation for long-duration testing

17,000 h of testing to be analyzed at once using MATLAB as the software platform. Table 1 shows the decay rate results from the five years of testing.

TABLE 1. Decay Rate on Six 10 kW PEM Stacks

Profile Type	Total Hours	Decay Rate (µV/cell-h)
Variable	7,257	13.3
	10,112	1.0
	10,014	0.1
	4,330	-10.1
Constant	7,257	30.2
	12,069	2.1

The decay rate comparison showed no significant difference between variable and constant power operation. The research also demonstrated the importance of maintaining the electrolyzer balance of plant as premature failure of the electrolyzer stacks became a limiting factor for this testing. NREL worked with Proton to evaluate a stack to understand why it was exhibiting higher than expected voltage – a second stack performing properly was sent along as the control. Proton found both stacks to be within the factory acceptance levels using multiple tests at their facility. However, they also found a high concentration of silica in residual water shipped in the stacks. NREL inspected the electrolyzer balance of plant and found that dirt and dust from a passive open vent may have entered the electrolyzer generator compartment and contaminated the water. Further analysis performed by NREL on the system data, found that multiple unexpected facility power interruptions may also have contributed to the abnormal stack voltages that led to abrupt electrolyzer shutdowns. In this case, electrolyzer balance of plant issues seems to be the main driver of stack decay rate, regardless of variable or constant operation.

Variable Flow Drying

NREL completed baseline characterization and testing of a hydrogen drying approach that aims to reduce hydrogen drying losses under variable stack power (e.g., renewable) electrolyzer power profiles. The new drying approach aims to improve electrolyzer system efficiency to help achieve the DOE goal of 44 kWh/kg by 2020. NREL's variable hydrogen drying flow approach was implemented on a pressure swing adsorption (PSA) dryer attached to the output of the NREL designed and built electrolyzer stack test bed located in the Energy Systems Integration Laboratory in Golden, CO. The electrolyzer stack test bed operated under five different variable profiles with a 120 kW PEM electrolyzer stack from Proton OnSite. Performance of the PSA dryer system was monitored with multiple dew point sensors to track the parts per million by volume (ppmv) of water vapor in the hydrogen; a water content of less than 5 ppmv is required by SAE J2719 standard, which defines the Hydrogen Fuel Quality for Fuel Cell Vehicles.

Data was collected on multiple variable stack power profiles (e.g., photovoltaic, wind) with the PSA drying system set to lose 3.5% of rated hydrogen output for desiccant regeneration. This technique, referenced as fixed orifice, was the control variable for this testing. NREL's variable flow approach aims to maintain drying losses at 3.5% of actual hydrogen output flow, instead of a constant 3.5% of rated hydrogen flow. In the NREL system, the rated hydrogen flow is 2.16 kg/h and 3.5% of the rated flow equates to a loss of 0.076 kg/h or 1.8 kg in a 24-hour period. If the system is losing 3.5% of rated hydrogen flow (fixed orifice technique) the hydrogen lost is always 0.076 kg/h regardless of the hydrogen production flowrate. On the other hand, 3.5% of hydrogen output flow refers to the system maintaining a 3.5% loss based on the actual hydrogen flow from the stack. If the stack is being operated under variable power, the drying system would adjust and only lose 3.5% of the hydrogen output flow, saving hydrogen in the process (variable hydrogen drying flow technique). This testing provides a comparison of the two techniques in a PSA drying system.

The test results show that there was no measurable difference in hydrogen quality from the fixed orifice operation compared to the variable flow technique. Furthermore, NREL's variable drying approach saved between 2–10% of the produced hydrogen versus the typical fixed orifice approach. The large range of savings is a function of the type of variable power profiles that the stack was operated at during the testing. If the stack power profile calls for a majority of time at lower power levels, then the hydrogen savings increases significantly. The total hydrogen savings between the two approaches, based on the stack power profiles used through this testing, were equivalent to saving 1 kg of hydrogen for every 40 kg of hydrogen produced or 2.5% hydrogen savings.

DC System Design

NREL is creating a design package for an electrolyzer that operates solely on DC. The electrolyzer is being designed for off-grid operation that would be directly coupled with renewable electricity sources. NREL leveraged the bill of materials that was created for the electrolyzer stack test bed as the base for the DC electrolyzer design. Reviews of the design have been on-going between team members and significant progress has been made on the uniqueness of this system compared to other systems. Replacing typical alternating current balance-of-plant components with DC components allows for a comparison of cost and efficiency between the two types of equipment. NREL plans on completing the design of the system by the end of FY 2016.

CONCLUSIONS AND FUTURE DIRECTIONS

- Finalize the design for the DC balance of plant standalone renewable electricity electrolyzer system.
- Monitor and analyze in situ performance of cell voltages of a 50- and 100-cell stack under variable conditions.
- Continue developing and testing hydrogen drying techniques and materials to improve system efficiency.

FY 2016 PUBLICATIONS/PRESENTATIONS

1. Harrison, K. "Large Active Area Electrolyzer Stack Test Bed – Design, Data, and Development," 228th Electrochemical Society Meeting. Phoenix, Arizona. October 2015. (presentation)

2. Harrison, K. "Lifetime Prediction of PEM Water Electrolysis Stacks Coupled with RES." 2nd International Workshop, Durability, and Degradation Issues in PEM Electrolysis Cells and its Components. Freiburg, Germany. February 2016. (presentation)

3. Harrison, K. "Renewable Electrolysis – Systems Integration and Optimization." Solar Fuel Generation – PV and Electrolysis Workshop. Institute of Energy Conversion, University of Delaware Energy Institute. February 2016.

1. Peters, M.; Harrison, K; Dinh, H.; Terlip, D.; Kurtz, J.; Martin, J. "Renewable Electrolysis Integrated System Development & Testing." DOE Annual Merit Review and Peer Evaluation Meeting. June 2016. (presentation)