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

Mike Peters (Primary Contact), Kevin Harrison, Huyen Dinh
National Renewable Energy Laboratory (NREL)
15013 Denver West Parkway
Golden, CO 80401-3305
Phone: (303) 524-0864
Email: Michael.Peters@nrel.gov

DOE Manager: David Peterson
Phone: (240) 562-1747
Email: David.Peterson@ee.doe.gov

Subcontractor:
Spectrum Automation Controls, Arvada, CO

Project Start Date: October 1, 2003
Project End Date: September 31, 2017

Overall Objectives

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

Fiscal Year (FY) 2017 Objectives

- Characterize large active area stack performance by taking current-voltage (IV) curves of two state-of-the-art polymer electrolyte membrane (PEM) electrolyzer stacks.
- Develop a balance of plant (BoP) stack model that examines PEM electrolyzer system efficiency over the expected lifetime of the system.
- Explore cell performance of PEM stacks under variable power with a solid-state individual cell voltage monitoring system.

Technical Barriers

This project addresses the following technical barriers from the Fuel Cell Technologies Office 2012 Multi-Year Research, Development, and Demonstration 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 research, development, and demonstration to reduce the cost of hydrogen production via renewable electrolysis for both distributed and central production pathways and to help meet the following DOE hydrogen production and delivery targets for central water electrolysis with green electricity found in the Multi-Year Research, Development, and Demonstration Plan (2011–2020, Table 3.1.5).

Stack energy efficiency

- 44 kWh/kg H_2 (76% lower heating value [LHV]) by 2015
- 43 kWh/kg H_2 (78% LHV) by 2020

System energy efficiency

- 46 kWh/kg H_2 (73% LHV) by 2015
- 44.7 kWh/kg H_2 (75% LHV) by 2020

Hydrogen Levelized Cost

- $3.00/kg H2 at plant gate by 2015
- $2.00/kg H2 at plant gate by 2020

FY 2017 Accomplishments

- NREL obtained IV polarization curves on two large active area PEM stacks.
- NREL built a BoP model to trade performance metrics like; electrolyzer system efficiency, maintenance, stack decay rate, and system output over the expected lifetime of an electrolyzer.
- NREL commissioned an individual cell voltage analyzer that is capable of reading single cell voltages on electrolyzer stacks; up to 132 cells can be measured simultaneously.

✧ ✧ ✧ ✧ ✧

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. In response, PEM electrolyzer manufacturers have and continue to scale-up their systems into the multi 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 help 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 exist today and take advantage of economies of scale and achieve system-level energy efficiencies less than 60 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 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.

Real-world data from daily operations are demonstrating opportunities for improved system design and novel hardware configurations to advance the commercialization of this technology. The research being conducted at NREL's Energy Systems Integration Facility is advancing the integration of renewable electricity sources with state-of-the-art electrolyzer 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

Large Active Area Stack Testing

NREL obtained IV curves on their 120 kW and 250 kW PEM electrolyzer stacks and looked at stack efficiency (higher heating value, LHV, or kWh/kg) over the full current range of the stacks (100 A–1,160 A).

IV polarization sweeps were taken at:

- Temperature: 30°C, 40°C, and 50°C
- Pressure: 150 psig, 300 psig
- Stack Size: 120 kW, 250 kW

Stack efficiency based on the LHV ranged from 58–82% depending on the current density applied to the stacks. DOE's 2020 goal from their technical targets for distributed forecourt water electrolysis hydrogen production is a stack efficiency of 77% based on the LHV. Figure 1 is a graph of three IV sweeps that were completed. Both stacks are able to achieve the 77% target at relatively low current densities. Values **above** the 2020 DOE target line are the best efficiencies in this graph.

Balance of Plant Model

NREL built an electrolyzer model by measuring BoP component's power demand. NREL also measured stack performance values on three state-of-the-art large active area PEM stacks and monitored power on major BoP components. The system efficiency of NREL's electrolyzer stack test bed at the Energy Systems Integration Facility with the 250 kW stack operating at full power is 65.5 kWh/kg. This number is significantly higher than DOE's 2020 system efficiency of 44 kWh/kg, however the NREL system is smaller than the megawatt-scale systems needed to reach the DOE target. The components that make up the share of the overall system efficiency break down as follows (Figure 2):

- Stack: 79%
- Power Supplies: 15%
- Drying: 4%
- Main Direct Injection (DI) Pump: 1%
- Cooling: 0.5%
- Other: 0.5%

Characterizing PEM Stack Performance

NREL used data from previously tested stacks at NREL to obtain a general PEM stack performance curve. The data was used to find stack energy efficiency (kWh/kg) and was normalized to percent of full stack power for simplicity. A curve fit was applied to the combined stack data to determine stack efficiency as a function of rated power.

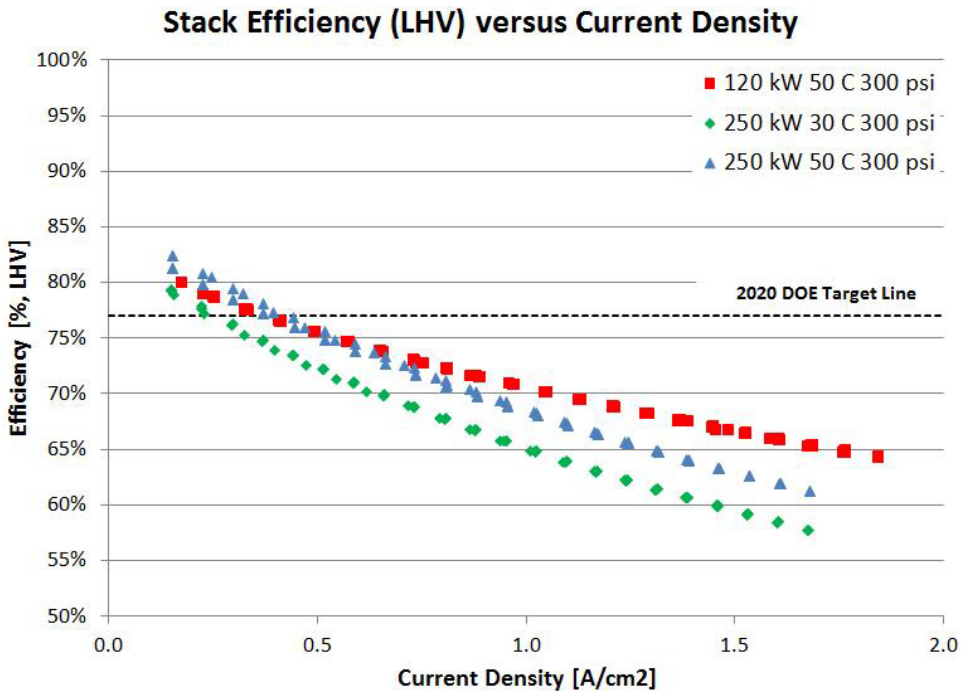

FIGURE 1. Stack efficiency (LHV) versus current density

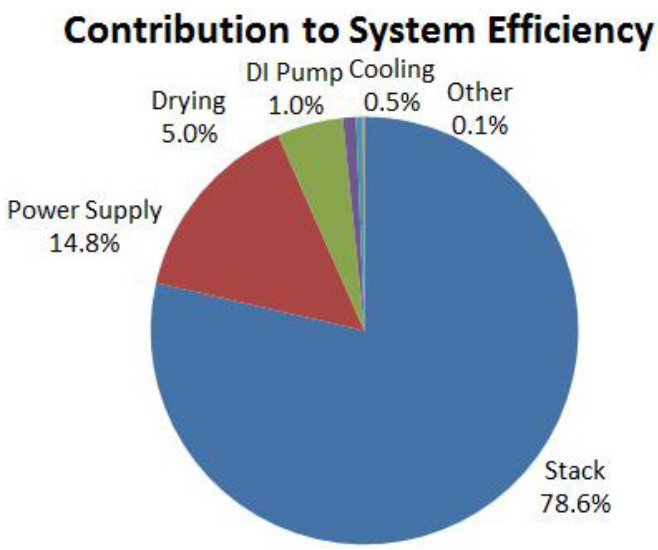

FIGURE 2. Electrolyzer system efficiency by sub-system

Power Supply Efficiency

NREL measured the efficiency on their alternating current (AC) to direct current (DC) power supplies that feed the electrolyzer stack test bed by instrumenting both the AC and DC sides of the power supply with power transducers. The power supply efficiency ranged from 85% (33% load) to 89% (100% load), which is a lower efficiency than was previously assumed. The AC power versus DC power scales linearly and allows the model to account for added AC load based on the power supply efficiency. Based on the model, for a 250 kW system operating at full power the power supply will add approximately 10 kWh/kg or ~15% to the overall system efficiency.

Time

The model is capable of looking at system performance over the lifetime of a system. The user inputs an expected stack decay rate and the model adjusts the stack and BoP loads over time to look at the system efficiency. The model assumes that stacks are replaced when they reach 20% degradation compared to their original voltage. For example, if the cell voltage of a cell at the beginning of life is 2 V, then the stack would be replaced when cell voltage reaches 2.4 V. Figure 3 is the output from the model that shows system efficiency over the lifetime of a system. The assumptions for this case are:

- 250 kW rated stack power
- 100 cells
- 80% yearly utilization
- 5 µV/(cell-h) degradation (i.e., stack decay rate)
- BoP is maintained and efficiency recovers with new stack install (in Year 10)

Figure 3 shows system efficiency at full stack power. In Year 0 (start) the system starts at 65.5 kWh/kg and slowly climbs until Year 10 when system efficiency hits 76.3 kWh/kg. At this point, the model assumes stack

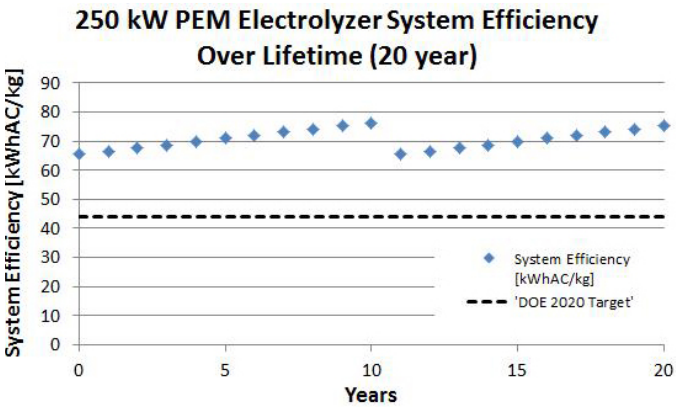

FIGURE 3. Electrolyzer system efficiency over the system lifetime

replacement and the system efficiency recovers to its original value. The model developed in this project is scalable to smaller or larger systems and is easily adjustable as more BoP or stack measurements are obtained.

Individual Cell Voltage Analyzer

NREL recently specified, procured, and implemented an individual cell voltage acquisition system that is capable of simultaneously monitoring individual cell voltages on PEM electrolyzer stacks (Figure 4). The prototype system was developed by Polyphotonics, a small business based out of Springwater, New York. The 132-channel differential voltage system utilizes a Raspberry Pi and allows for an ethernet, USB, or wireless connection to pull the data off the onboard memory.

CONCLUSIONS AND UPCOMING ACTIVITIES

- Stack and system efficiency continue to improve as systems integration and economies of scale help achieve the DOE goals.
- NREL will continue examining individual cell voltage performance under variable and constant power to inform improved integration with renewable electricity sources.
- NREL will write a final report summarizing the past 14 years as the project concludes.

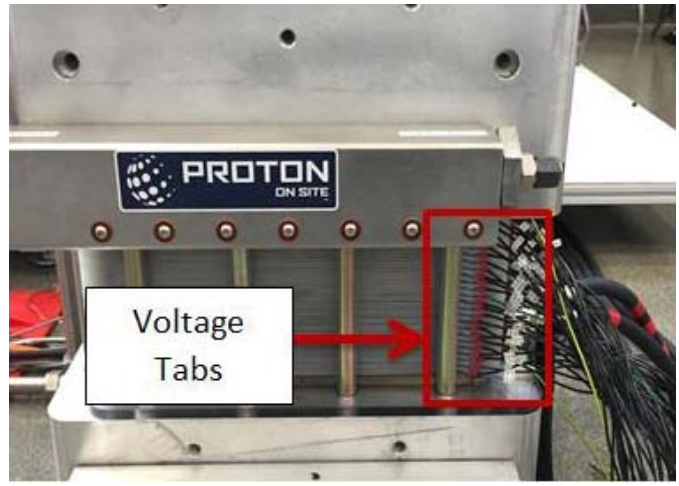

FIGURE 4. Individual cell voltage tabs for the steady-state voltage measurement device

FY 2017 PUBLICATIONS/PRESENTATIONS

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, 2017. (presentation)