VI.1 Fuel Cell Membrane Electrode Assembly Manufacturing R&D

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- Rensselaer Polytechnic Institute, Troy, NY
- 3M, St. Paul, MN
- Arkema Inc., King of Prussia, PA
- Ballard Material Products, Lowell, MA
- BASF Fuel Cells, Somerset, NJ
- General Motors, Honeoye Falls, NY
- Johnson Matthey Fuel Cells, Sonning Common, Reading, U.K.
- Proton OnSite, Wallingford, CT
- W.L. Gore and Associates, Elkton, MD
- National Institute of Standards and Technology, Gaithersburg, MD

Project Start Date: July 16, 2007
Project End Date: Project continuation and direction determined annually by DOE

Fiscal Year (FY) 2011 Objectives

NREL and its collaborators are developing capabilities and acquiring knowledge for in-line quality control during manufacturing of polymer electrolyte membrane (PEM) fuel cells. We are focusing on membrane electrode assembly (MEA) components (membranes, coated electrodes, and gas diffusion media) in the transition to high-volume manufacturing methods. Our main tasks are to:

- Evaluate and develop in-line diagnostics for MEA component quality control and validate diagnostics in-line.
- Investigate the effects of MEA component manufacturing defects on MEA performance and durability to understand the required performance of diagnostic systems and contribute to the basis of knowledge available to functionally determine manufacturing tolerances for these materials.
- Use established models to predict the effects of local variations in MEA component properties, and integrate modeling of the operational and design characteristics of diagnostic techniques into the design and configuration of in-line measurement systems.

These objectives have strong support from our industry partners. Our specific development activities have been and will continue to be fully informed by direct input from industry. As new technologies emerge and as the needs of the industry change, the directions of this project will be adjusted. Additionally, in support of DOE's expanded scope, we have initiated activities to understand quality control needs for high-temperature fuel cell production and assess relevant inspection technologies.

Technical Barriers

This project addresses the following technical barriers, from the Manufacturing section (3.5) of the Hydrogen, Fuel Cells and Infrastructure Technologies Program's Multi-Year Research, Development and Demonstration Plan:

(A) Lack of High-Volume Membrane Electrode Assembly (MEA) Processes
(F) Low Levels of Quality Control and Inflexible Processes.

Contribution to Achievement of DOE Manufacturing Milestones

This project contributes to the achievement of the following DOE milestones, from the Manufacturing section (3.5) of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- **Milestone 1**: Develop prototype sensors for quality control of MEA manufacturing (4Q, 2011).
- **Milestone 2**: Develop continuous in-line measurement for MEA fabrication (4Q, 2012).
- **Milestone 3**: Demonstrate sensors in pilot-scale applications for manufacturing MEAs (4Q, 2013).
- **Milestone 4**: Establish models to predict the effect of manufacturing variations on MEA performance (4Q, 2013).

FY 2011 Accomplishments

NREL accomplished the following in FY 2011:

- Developed continuous process prototype test-beds to enable initial validation of diagnostic techniques with moving substrates (simulating in-line measurement).

- Demonstrated the operation of our infrared diagnostic system with direct current excitation (IR/DC) with moving gas diffusion media (GDM) and catalyst-coated membrane (CCM) sheet materials.
- Integrated LBNL modeling of the operational and design characteristics of the IR/DC technique into the design process for the in-line configuration of the diagnostic system.
- Developed a second infrared-based technique using reactive gas excitation to measure the spatial uniformity of electrodes on porous substrates, i.e., gas diffusion electrodes.
- Demonstrated the operation of our optical reflectometer diagnostic for areal membrane thickness imaging and defect identification with moving membrane sheet materials.
- Performed studies on the effects of MEA component defects, using single and segmented cells, including electrode thin spots, voids, and mud-cracks, and GDM polytetrafluoroethylene (PTFE) uniformity.
- Installed and commissioned a segmented cell system, using a 3M-developed design with 121 segments, to enable spatially resolved studies of the effects of as-manufactured defects in MEA components.
- Demonstrated the feasibility of using our optical diagnostic platform to make measurements of tape-cast solid oxide fuel cell layer uniformity.
- Continued collaboration with our industry partners, including three of DOE's competitively awarded manufacturing research and development (R&D) projects, in accordance with our project charter.
- Developed industry relationships and gained an understanding of quality control needs for the manufacture of high temperature cells.

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Introduction

In FY 2005-2007, NREL provided technical support to DOE in developing a new key program activity: manufacturing R&D for hydrogen and fuel cell technologies. This work included a workshop on manufacturing R&D, which gathered inputs on technical challenges and barriers from the fuel cell industry, and subsequent development of a roadmap for manufacturing R&D. In late FY 2007, NREL initiated a project to assist the fuel cell industry in addressing these barriers, initially focusing on in-line quality control of MEA components. The project is utilizing the unique and well-established capabilities of NREL's National Center for Photovoltaics for developing and transferring diagnostic and process technology to the manufacturing industry.

Defects in MEA components differ in type and extent depending on the fabrication process used. The effects of these defects also differ, depending on their size, location in the cell relative to the reactant flow-field, cell operating conditions, and which component contains the defect. Understanding the effects of these different kinds of defects is necessary to be able to specify and/or develop diagnostic systems with the accuracy and data acquisition/processing rates required for the speed and size scales of high-volume continuous manufacturing methods. Furthermore, predictive capabilities for manufacturers are critical to assist in the development of transfer functions and to enable assessment of the effects of material and process changes.

Approach

NREL and its partners are addressing the DOE manufacturing milestones listed above by evaluating, developing, and validating (in-line) diagnostics that will support the use of high-volume manufacturing processes for the production of MEAs and MEA component materials. Prioritization of this work is based on inputs from our industry partners on their critical manufacturing quality control needs. We are focusing on diagnostic capabilities not addressed by commercially available in-line systems, in particular evaluating methods to make areal rather than point measurements such that discrete defects can be identified. Given that specification of the required accuracy and precision of a diagnostic device to measure or identify material property variability or defects requires information about how this variability affects the functionality of the MEA, we are developing test methodologies to study the effects of size and/or extent of each important type of variability or defect. These results will additionally assist our industry partners in validating manufacturing tolerances for these materials, ultimately reducing scrap rates and cost, and improving supply chain efficiency. Finally, predictive models are being used at LBNL to understand the operational and design characteristics of diagnostic techniques by simulating the behavior of MEA components in different excitation modes. These results are being fed back to our design effort in configuring the diagnostics for in-line implementation. MEA models are also being utilized to understand the in-situ behavior of defect MEAs to guide and further elucidate experiments.

Results

Significant progress was made in moving our two diagnostic platforms, optical- and infrared-based, closer to in-line implementation. Benchtop prototype systems were designed and fabricated at NREL to enable validation of the operation and data acquisition of these techniques with a moving (as opposed to stationary) measurement target, a critical step in proving the viability of these techniques for in-line measurement. Using these systems, we successfully demonstrated the operation of the IR/DC and optical reflectometer diagnostics using GDM, CCM, and membrane sheet materials from our industry partners. Figure 1 shows the benchtop roller system used to validate

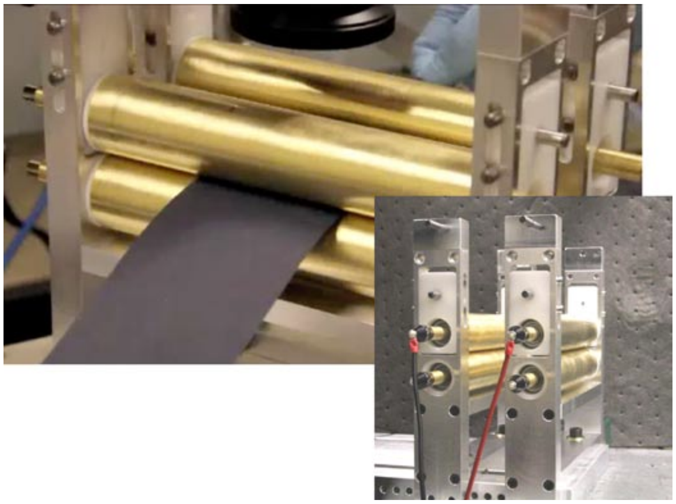

FIGURE 1. Benchtop Roller System (Inset: side view showing sliding electrical connectors.)

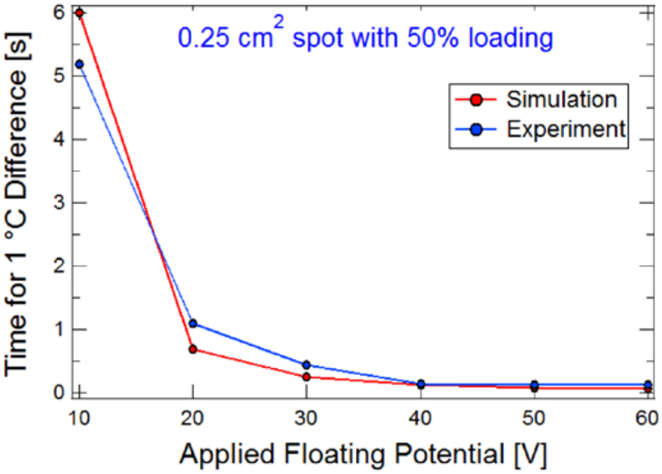

FIGURE 3. Comparison of modeling and experimental results indicating the response time for a given detection criteria and electrode defect size as a function of the DC excitation magnitude.

the IR/DC technique. Figure 2 shows an example from that validation, in this case scratch defects in a GDM sheet, and the resulting thermal response to those defects while the sheet was moving through the system. Studies were also performed to assess the response time and sensitivity, and to ensure that the technique would not damage the material during measurement. Models were developed by LBNL to assess the behavior of MEA materials during the DC excitation, enabling a full characterization of the operational space for the process, in terms of defect size and loading, detection criteria, response time, and magnitude of excitation. Figure 3 shows modeling and experimental results that indicate the response time for a given detection criteria and defect size as a function of the excitation magnitude. These simulations have fed back to the design specifications for an in-line system. We also performed in situ studies, using single and segmented cells, to determine the effect on initial performance of MEA component defects, including electrode thin spots, voids, and mud-cracks, and GDM PTFE loading.

Continuing our efforts to expand the applicability of our optical reflectometer platform, we evaluated techniques to deconvolute membrane thickness from a composite measurement of a membrane still on its casting liner. This would enable the quality measurement farther forward in the manufacturing process, maximizing value. Depending on the difference in optical properties between the membrane and liner, the technique appears to be feasible. Software development to automate this calculation is ongoing. We also demonstrated the feasibility of using this diagnostic to measure the uniformity of tape-cast solid oxide fuel cell layers.

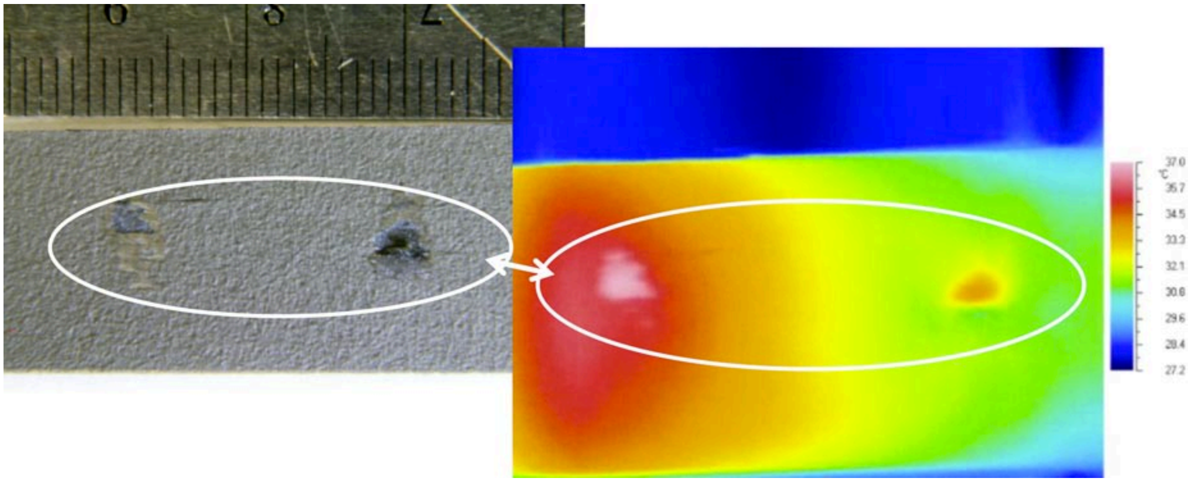

FIGURE 2. GDM sheet material with scratches and associated thermal response to those scratches, using the IR/DC technique on the benchtop roller system. The velocity of the sheet motion was approximately 10 feet per minute.

Future Directions

- Demonstrate the IR/DC and optical reflectometry diagnostics on our research web-line.
- Continue to use predictive modeling and single and segmented cell test methods to feed requirement and configuration information back to diagnostic development, device design, and detection algorithm assessment.
- Study how as-manufactured defects affect the performance of MEAs over time using standard or modified accelerated stress tests.
- Continue to work with our industry partners to ensure the relevance of our studies to their evolving needs and directions, including ongoing prioritization of diagnostic development needs.

FY 2011 Publications and Presentations

1. "IR Thermography for Quality Assessment of PEMFC Components," Aieta, Perdue, Ulsh; Advances in Materials for Proton Exchange Membrane Fuel Cell Systems, Asilomar, Pacific Grove, CA; February, 2011.

2. "New Technique for Rapid, Spatially Resolved, Detection of Pt in PEMFC Electrodes," Aieta, Bender, Perdue, Penev, Ulsh; 218th ECS Meeting, Las Vegas, NV; October, 2010.

3. "Formation and Detection of Catalyst Layer Cracks in PEMFCs," Perdue, Herring, Aieta, Dinh, Bender, Ulsh; 218th ECS Meeting, Las Vegas, NV; October, 2010.

4. "2010 Manufacturing Readiness Assessment Update to the 2008 Report for Fuel Cell Stacks and Systems for the Backup Power and Material Handling Equipment Markets," D. Wheeler and M. Ulsh, *submitted to DOE and under review*, December, 2010.

5. "A study of the adoption of automation and continuous processes in manufacturing of stationary and CHP fuel cell applications," M. Ulsh, D. Wheeler, P. Protopappas, *submitted to DOE and under review*, July, 2010.

6. "Fuel Cell MEA Manufacturing R&D," DOE Fuel Cell Technologies Program Annual Merit Review, May, 2011, Washington, DC.