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

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- Colorado School of Mines, Golden, CO
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- 3M, St. Paul, MN
- Arkema Inc., King of Prussia, PA
- Ballard Materials Products, Lowell, MA
- BASF Fuel Cells, Somerset, NJ
- Johnson Matthey Fuel Cells, West Chester, PA
- W.L. Gore and Associates, Elkton, MD

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## Objectives

NREL and its collaborators are developing capabilities and knowledge related to in-line quality control that will assist manufacturers of polymer electrolyte membrane fuel cell (PEMFC) membrane electrode assembly (MEA) components (membranes, coated electrodes, and gas diffusion media) transition to high volume manufacturing methods. Our main tasks are:

- 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.
- Further refine and validate models to predict the effects of local variations in MEA component properties.

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.

## Technical Barriers

This project addresses the following technical barriers from the Manufacturing section (3.5) of the Hydrogen, Fuel Cells and Infrastructure Technologies Program 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 is contributing to 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)

## Accomplishments

NREL has accomplished the following:

- Established a diagnostic development platform based on an NREL-developed optical diagnostic system used in continuous photovoltaics manufacturing.
- Demonstrated two-dimensional (2D) membrane thickness measurement and defect imaging on membrane samples of different types and with different as-manufactured defects.
- Performed initial experiments indicating the potential to use the NREL-developed optical diagnostic to measure platinum in electrodes.
- Established test methodologies to quantify the effects of defects on MEA performance.

- Demonstrated the feasibility of using segmented-cell test equipment and methods to obtain spatially resolved information about the effects of defects.
- Used LBNL models to qualitatively explain key behaviors of MEAs with defects.
- Initiated collaboration with two of DOE's competitively awarded manufacturing research and development (R&D) projects, in accordance with our project charter.

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## Introduction

In Fiscal Years 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 relying on and 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 previously by evaluating, developing, and validating (in-line) diagnostics that will support the use of high volume manufacturing processes for the production of MEA component materials. Prioritization of this work is based on inputs from our industry partners on critical manufacturing quality control needs. We are focusing on diagnostic capabilities not addressed by commercially available in-line systems. Understanding 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 identify threshold values of size and/or extent of each important type of variability or defect. Threshold values are being elucidated by statistically designed experiments using MEA components with created defects, e.g., by laser or ion bombardment methods, of defined size or extent. These results will be validated by MEAs with components having actual as-manufactured defects of similar scale. Key behaviors identified by these tests are being modeled to provide additional understanding and, where modeling capabilities are lacking, additional refinement will be made so that predictive capabilities for the identified effects of defects are developed.

## Results

A new diagnostic development platform, based on an NREL-developed optical instrument used in continuous manufacturing of photovoltaic cells, was established for fuel cell MEA component materials. Work in the past year using this platform led to the demonstration of 2D thickness imaging and defect identification on polymer electrolyte membranes of different types and with different as-manufactured defects. Figures 1 and 2 provide examples of this measurement on membrane samples with actual

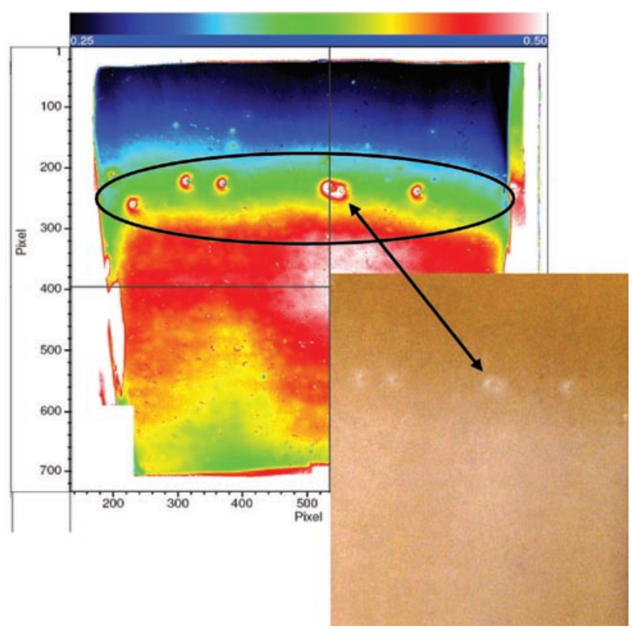


**FIGURE 1.** 2-dimensional image of a PEMFC membrane sample measured with the NREL device (corresponding optical image in inset). The image shows bubble defects and a color shift in the sample. An area of ~3″ by 3″ is shown.

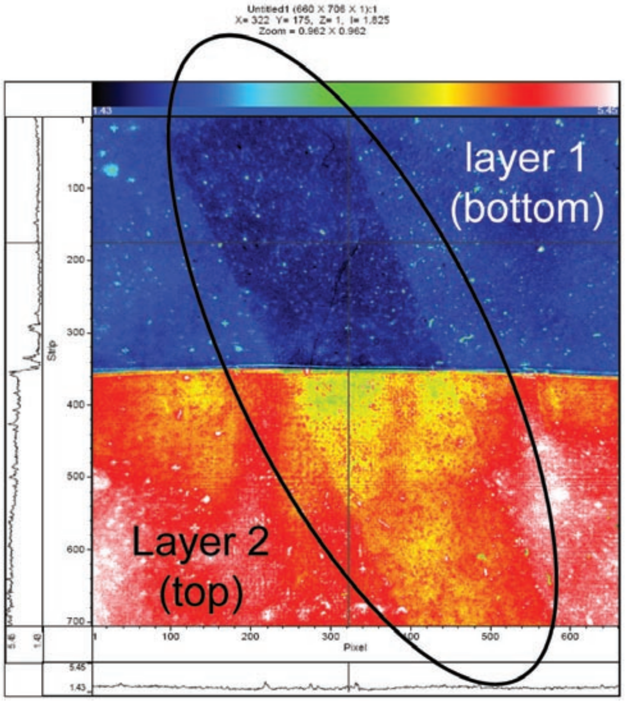


**FIGURE 2.** 2-dimensional image of membrane thickness showing "impression" defect in layer 1. The defect has an approximately 10% reduction in thickness. An area of ~3" by 3" is shown.

manufacturing defects. This capability represents an improvement over existing in-line measurement capabilities because it provides both imaging of defects and two-dimensional thickness measurement. As such, it provides the capability not only to represent the statistical variability of the membrane but to view, in real-time, actual defects. This could enable much more rapid diagnosis of the source of the defects and ultimately reduce scrap, improve reliability, and enhance customer satisfaction. Additional work with the new platform, as well with standard optical characterization data, showed that the NREL device may be useful in measuring many important MEA component properties. For example, initial experiments showed that electrode platinum content – a property deemed critically important for in-line measurement by our industry partners – can potentially be measured.

In parallel with our diagnostic development and evaluation work, we and our partners at the Colorado School of Mines and the University of Hawaii established test methodologies to quantify the effects of MEAs with defects compared to pristine MEAs. Consistent with our initial diagnostics focus on membrane thickness, we identified differential pressure (anode vs. cathode) single cell and segmented cell tests that enable comparative measurement of MEA

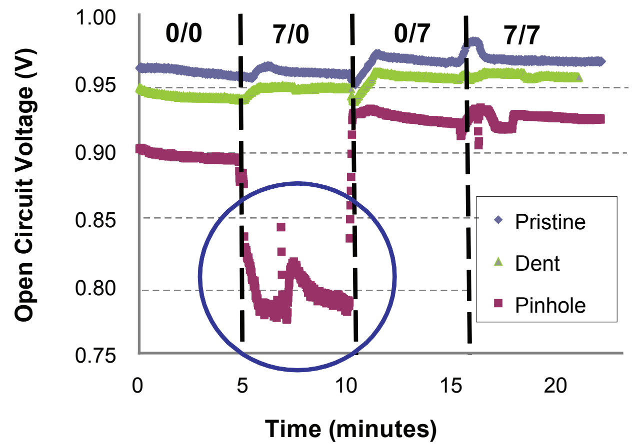


**FIGURE 3.** Open circuit voltage data from MEAs with non-Teflon® membranes under differential pressure (anode/cathode) test conditions. Membrane defects were ~1 mm in diameter.

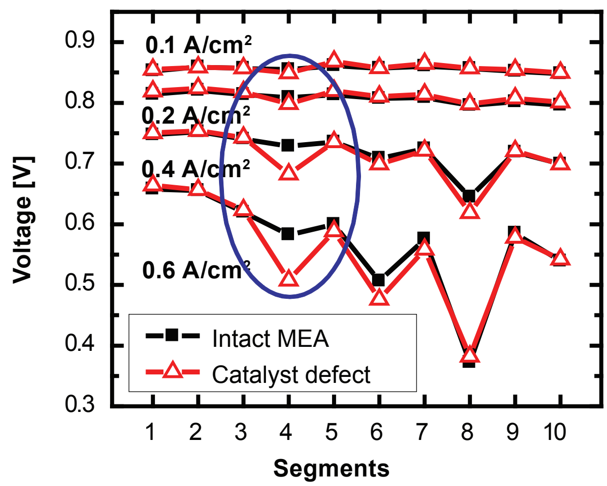


**FIGURE 4.** Segmented cell performance data from MEAs with and without anode defect (62% reduction in thickness). The defect was located in segment 4 and resulted in a local loss of performance at higher current densities.

performance with membranes having thickness defects or pinholes. Figure 3 is exemplary of this work and shows a comparison of MEAs with membrane defects to a pristine MEA. The effects of electrode defects also were studied (see Figure 4), as well as gas diffusion layer defects relating to thickness, Teflon® content, and micro-porous layer voids. Of particular note in this aspect of our work is the demonstration of the feasibility of using segmented cell hardware and methods to obtain spatially resolved information on the local effects of defects within the MEA.

## Conclusions and Future Directions

### Conclusions

- Continued support and guidance from our industry partners is critical.
- The NREL-developed optical diagnostic can be used for imaging of membrane thickness and defects. Further development of this capability will be driven by industry needs.
- Segmented cell test hardware and methods can be used to obtain spatially resolved information about the local (within the MEA) effects of defects. Further work should be undertaken to optimize the design of the hardware.
- The LBNL MEA models provide qualitative understanding of the behaviors of MEAs with component defects.

### Future Directions

- Install and commission the research web-line for in-line validation of diagnostic systems.
- Complete system-level development of selected diagnostics, based on industry partner needs, including configuring the system for wide-web use.
- Investigate the use of the NREL-developed optical diagnostic for measurement of prioritized material properties, including catalyst loading, porosity, and surface structure.
- Establish a library of performance and durability test methodologies to study the threshold values of priority defects, so that specifications for in-line diagnostics can be understood.
- Use our defect MEA testing results to validate current LBNL models and establish a predictive capability for the effects of as-manufactured defects.

## FY 2009 Publications/Presentations

**1.** "A Study of the Relationships Between PEM Fuel Cell MEA Component Manufacturing Defects and Cell Performance and Durability," Williams et al., 2008 Fall ECS Meeting, Honolulu, HI.

**2.** "Utilization of a Segmented Cell to Detect Defects in Proton Exchange Membrane Fuel Cells," Bender et al., 2008 Fall ECS Meeting, Honolulu, HI.

**3.** "NREL MEA Manufacturing R&D Project," Ulsh et al., 2008 Fuel Cell Seminar and Exhibition, Phoenix, AZ.

**4.** "Gas-Crossover and Membrane-Pinhole Effects in Polymer-Electrolyte Fuel Cells," Weber, J. *Electrochem. Soc.*, 155, B521-B531 (2008).

**5.** "PEMFC MEA Manufacturing Quality Control R&D at NREL," Ulsh et al., 2009 National Hydrogen Association Conference and Hydrogen Expo, Columbia, SC.

**6.** DOE Hydrogen Program Annual Merit Review, oral presentation, May 2009.

**7.** "A Study of the Relationships Between PEM Fuel Cell MEA Component Manufacturing Defects and Cell Performance," Williams et al., 2009 Spring ECS Meeting, San Francisco, CA.