Fuel Cell MEA Manufacturing R&D

National Renewable Energy Laboratory

Michael Ulsh

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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.
Overview

Timeline
Start: July 2007
End: TBD
% complete: N/A

Budget
Funding received in FY11
- $770,000 (includes $100,000 to LBNL)
Planned funding in FY12
- $575,000 (includes $75K to LBNL)

Barriers

<table>
<thead>
<tr>
<th>Barrier</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>B: Cost - fuel cell</td>
<td>$15/kW (2017) at 500,000 stacks/yr</td>
</tr>
<tr>
<td>F: Low levels of quality control - manufacturing</td>
<td>50x stack cost reduction</td>
</tr>
</tbody>
</table>

Funded Partners
Lawrence Berkeley National Laboratory
Colorado School of Mines
Hawaii Natural Energy Institute
New Jersey Institute of Technology
DJW Technology
## MYRD&DP Milestones

<table>
<thead>
<tr>
<th>Year</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>Develop prototype sensors for quality control of MEA manufacturing</td>
</tr>
<tr>
<td>2012</td>
<td>Develop continuous in-line measurement of MEA fabrication</td>
</tr>
<tr>
<td>2013</td>
<td>Demonstrate sensors in pilot-scale applications for manufacturing MEAs</td>
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<tr>
<td>2013</td>
<td>Establish models to predict the effect of manufacturing variations on MEA performance</td>
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## Project Objectives

1. Evaluate and develop in-line diagnostics for MEA component quality control, and validate in-line

2. Investigate the effects of manufacturing defects on MEA performance and durability to understand the accuracy requirements for diagnostics

3. Integrate LBNL modeling to support diagnostic development and implementation
Relevance

• Quality control needs for scale-up of cells and cell component manufacturing confirmed by industry at recent government activities
  o NREL/DOE H₂ & Fuel Cell Manufacturing R&D Workshop, August 2011
  o ONR/ACI/Montana Tech Manufacturing Fuel Cell Manhattan Project, 2010-2011
• Both activities also highlighted the need to better understand the effects of defects on performance and durability of low temperature systems
  o Defines sensitivity requirements for diagnostics
  o Leads toward better production tolerances and lower costs
Collaborations

- NREL National Center for Photovoltaics/New Jersey Institute of Technology: diagnostics development
- LBNL: model development and integration
- Colorado School of Mines: diagnostic development, test method development and defect analysis
- Hawaii Natural Energy Institute: segmented cell development and defect analysis
Approach

- Understand quality control needs from industry partners and forums
- Develop diagnostics
  - Use modeling to guide development
  - Use in-situ testing to understand the effects of defects
- Validate diagnostics in-line
- Transfer technology

<table>
<thead>
<tr>
<th>Date</th>
<th>Milestone/Deliverable</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/11</td>
<td>Demonstrate optical diagnostic for membranes on web-line</td>
</tr>
<tr>
<td>9/11</td>
<td>Go/No-go decision for further development of optical diagnostic for platinum measurement → Conditional No-Go</td>
</tr>
<tr>
<td>6/12</td>
<td>Demonstrate IR/DC diagnostic for CCMs &amp; GDLs on web-line</td>
</tr>
<tr>
<td>9/12</td>
<td>Compare model &amp; experiment for IR/RFT and determine critical parameters</td>
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</tbody>
</table>
# Current NREL Diagnostics Overview

<table>
<thead>
<tr>
<th>Material</th>
<th>Defect</th>
<th>Examples</th>
<th>Detection</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Membrane</td>
<td>Thickness variation, pinholes, bubbles, etc.</td>
<td><img src="image1.png" alt="Image" /></td>
<td>Optical reflectometer</td>
<td>Demonstrated on web-line</td>
</tr>
<tr>
<td>GDL</td>
<td>Scratch, agglomerate, fibers</td>
<td><img src="image2.png" alt="Image" /></td>
<td>IR/DC</td>
<td>Demonstrated on web-line</td>
</tr>
<tr>
<td>Electrode</td>
<td>Thickness/loading, voids, agglomerates</td>
<td><img src="image3.png" alt="Image" /></td>
<td>CCM: IR/DC, GDE: IR/RFT</td>
<td>Demonstrated on web-line, bench-top</td>
</tr>
<tr>
<td>MEA</td>
<td>Shorting</td>
<td><img src="image4.png" alt="Image" /></td>
<td>Through-plane IR/DC</td>
<td>Demonstrated on bench-top with moving substrate</td>
</tr>
</tbody>
</table>

*Scope modified according to industry input*
Technical Accomplishments: Optical Diagnostic

Web-line demonstration
• Thickness imaging, discrete defect detection
• Equipment details
  • Linescan camera (12” field of view)
  • Fiber optic light source with cylindrical lens
  • Encoder for camera timing
  • High performance computer
  • NREL-developed software
• Demonstrated defect detection on PEM membrane at 30 foot per minute
  • Bubbles, scratches, divots
  • Defects ~10-100 µm

Membrane sample spliced into carrier web, moving at 30 ft/min
Technical Accomplishments: Optical Diagnostic

Solid oxide cell defect detection

- Detection of electrolyte defects is critical
- Studied fired anode+electrolyte half-cells known to have defects on electrolyte surface
  - 10 µm to 3 mm in dimension
  - Up to ~5 µm depth
- Detected defects with standard equipment setup
  - Applicable to high-rate or in-line measurement

Cell dimensions = 98 x 154 mm
Technical Accomplishments: IR/DC Diagnostic

Web-line set-up

- Installed IR camera, bench-top roller, and excitation source on web-line
- Created defects manually
  - Square scratches from 0.04 – 2 cm²
  - Surface cuts from 5 – 20 mm long, of different orientation (0°, 45°, 90°)
Technical Accomplishments: IR/DC Diagnostic

Web-line demonstration: GDLs

- Used rolls of MPL coated GDL
  - Fabricated by Ballard Material Products
- Ran at 10 and 30 foot per minute
- Ran at speeds up to 100 foot per minute on bench-top roller
- Nominal detection criteria was ΔT of > 1°C
- Detected all defects
- Data processing enhances detection

[Image of web-line demonstration data showing a scratch in MPL at 30 ft/min with unfiltered and filtered line data.]
Technical Accomplishments: IR/DC Diagnostic

Web-line demonstration: CCMs

- 2’ x 6” one-side catalyst-coated membrane sheet
  - Fabricated by Ion Power
  - Spliced into PET carrier web
- Ran at **10, 30, and 60 foot per minute**
- Ran at speeds up to 100 foot per minute on bench-top roller
- Nominal detection criteria was $\Delta T$ of $> 1^\circ$C
- Detected all defects except surface cuts in the direction of motion (0°)
  - Improvements under development
  - Data processing enhances detection
Technical Accomplishments: IR/DC Diagnostic

Demonstration of through-plane measurement for MEA shorts

- Studied 50 cm² MEAs with optically invisible shorting defects
- Detected various defect types leading to shorting
  - Membrane pinholes
  - GDL fiber protrusion and other surface defects
  - Catalyst agglomerates
- Demonstrated technique on bench-top roller system at speeds of 30 foot per minute and higher
  - Technique promising for high-rate or in-line measurement
Technical Accomplishments: IR/RFT Diagnostic

IR / Reactive Flow Through technique

• Operation
  - Gas diffusion electrodes (GDE)
  - Flow 0.4% H₂/0.2% O₂ in N₂ through media
  - Measure heat signature with IR camera

• Experimental and numerical studies of pristine samples to understand thermal response
  - Effect of electrode loading
  - Effect of gas flow rate

Technical Accomplishments: IR/RFT Diagnostic

- IR / Reactive Flow Through technique
- Gas Inlet Manifold
- Gas Outlet Manifold
- Gas Diffusion Media
- IR Camera
- Heat Signature

Graphs showing data with labels:
- Measured
- Simulation

- Q = 1500 sccm

- ΔT [°C] vs. Gas Flow Rate [sccm]
- Temperature [°C] vs. Loading [mg/cm²]

0.256 mg/cm²
0.086 mg/cm²
Technical Accomplishments: IR/RFT Diagnostic

IR / Reactive Flow Through technique

- Experimental and numerical studies of defect samples to understand thermal response
  - Response time
  - Defect size (0.0625 – 2 cm²) and reduction in loading (25 – 100%)
- Predictive modeling to assess thermal response under other conditions of interest
  - Effect of higher H₂ concentrations & defect reduction in loading
  - Understand limitations of technique
  - Guidance for future experimentation and transition to moving substrates

![GDE with 0.2 mg/cm² nominal loading and 1 cm² defect of 50% loading reduction](image)

![Graphs showing temperature vs. concentration and time](image)
Technical Accomplishments: HNEI Segmented Cell

Segmented cell study of GDL defects

• Question: Is a process tolerance of ±2% of PTFE content sufficient?
• Study: Insert defect over 10% of total cell area
• Results:
  o Local variation in cell performance observed and characterized (indicates need for aging)
  o No difference in total cell performance for a 4% difference in PTFE content
  o Confirmed currently applied manufacturing tolerances
• Implication: Segmented cell is a relevant tool for manufacturing studies
Technical Accomplishments: NREL Segmented Cell

Segmented cell study of electrode defects

- 121 segments over 50 cm\(^2\)
- Studied CCMs with square defects fabricated in cathode
  - 0.0625 - 2 cm\(^2\) bare spots
  - 0.2 mg/cm\(^2\) nominal loading
- Demonstrated capability to detect sub-cm\(^2\) electrode defects
- Result: Investigated defects have local performance effects
- Technique enables us to understand the required detection limits of our diagnostics
- Future work will study aging of very small defects to determine if failure points are initiated at the defect location

80°C, 100/50% RH, 1050/3500 sccm H\(_2\)/air, 150/150 kPa (an/ca)

Current density plot for 0.5 cm\(^2\) bare spot
Future Work

- Continue to refine the configuration and optimize the performance of diagnostics on web-line
- Determine if the IR/RFT diagnostic is feasible for in-line measurement of GDEs
- Prove feasibility of through-plane IR diagnostic on bench-top roller using industrially produced MEA sheets
- Continue to integrate modeling results to support diagnostic development
- Complete electrode defect study using the NREL segmented cell system
  - Identify defect size at which local performance effects are not observed
  - Perform aging studies to determine if failures develop at defect locations
- Assess industry needs and begin to evaluate other diagnostic techniques
- Complete specific partner studies and continue to support the industry
- Complete cost-benefit assessment in collaboration with Strategic Analysis, Inc.
Summary

- Relevance of activity strongly supported by DOE Manufacturing Workshop and DoD Manufacturing Fuel Cell Manhattan Project
- Demonstrated detection of CCM (electrode) and GDL/MPL defects on web-line using continuous webs at speeds of 30 foot per minute and higher
- Demonstrated detection of membrane defects on web-line using continuous webs at speeds of 30 foot per minute and higher
- Demonstrated detection of defects in multi-layer, multi-component membranes
- Demonstrated detection of defects in fired SOFC half-cells
- Demonstrated detection of MEA shorting defects with moving substrates
- Performed experimental and numerical studies to understand sensitivity, detection time, and operating characteristics of the IR/Reactive Flow Through diagnostic
- Completed segmented cell study of GDL PTFE content variability
- Performed segmented cell studies of effects of electrode defects
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TECHNICAL BACK-UP SLIDES
Technical Accomplishments: Optical Diagnostic

Gore membrane defect detection

• Studied experimental membranes for defect analysis
  • Gore PFSA ionomer + ePTFE reinforcement
  • Defects ~10-100 µm
• Detected defects with standard equipment setup
  • Applicable to high-rate or in-line measurement
Technical back-up slides: IR/DC

GDL/MPL defects

- Continuous roll of GDL with multiple MPL coatings
  - Fabricated by Ballard Material Products
  - Streak in first MPL coating, subsequently over-coated by 2nd and 3rd coatings
  - Repeating scratch (“dot”)
- Detected streak defect in first MPL layer on web-line at 10 foot per minute
  - Also detected dots
  - Did not detect streak after over-coating, indicating the streak was leveled or filled by subsequent coats
Electrode Defects

- Response to reduction in defect loading (modeling)
- Response to flowrate as a function of substrate
- Repeatability

**Run-to-Run Repeatability**

- Temperature (°C) vs. Flow Rate (sccm)

**Detectability (ΔT) as a function of substrate**

- ΔT (°C) vs. Flow Rate (sccm)
- Toray, 0.438
- Alpha, 0.467

**IR/RFT web-line concept**

- IR camera
- GDE web
- Air knife
- Motion