NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Fuel Cell MEA Manufacturing R&D

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MN001

Overview

Timeline

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

Budget (incl. LBNL)

Total project funding to date
- $4,862,000

Funding received in FY10
- $891,000

Funding received in FY11
- $700,000

Barriers

Barrier	Target
B: Cost - fuel cell	$45/kW (2010) at 500,000 stacks/yr
F: Low levels of quality control - manufacturing	50x stack cost reduction

Funded Partners

Lawrence Berkeley National Laboratory
Colorado School of Mines
Hawaii Natural Energy Institute
New Jersey Institute of Technology
DJW Technology

Relevance

	MYRD&DP Milestones
2011	Develop prototype sensors for quality control of MEA manufacturing
2012	Develop continuous in-line measurement of MEA fabrication
2013	Demonstrate sensors in pilot-scale applications for manufacturing MEAs
2013	Establish models to predict the effect of manufacturing variations on MEA performance

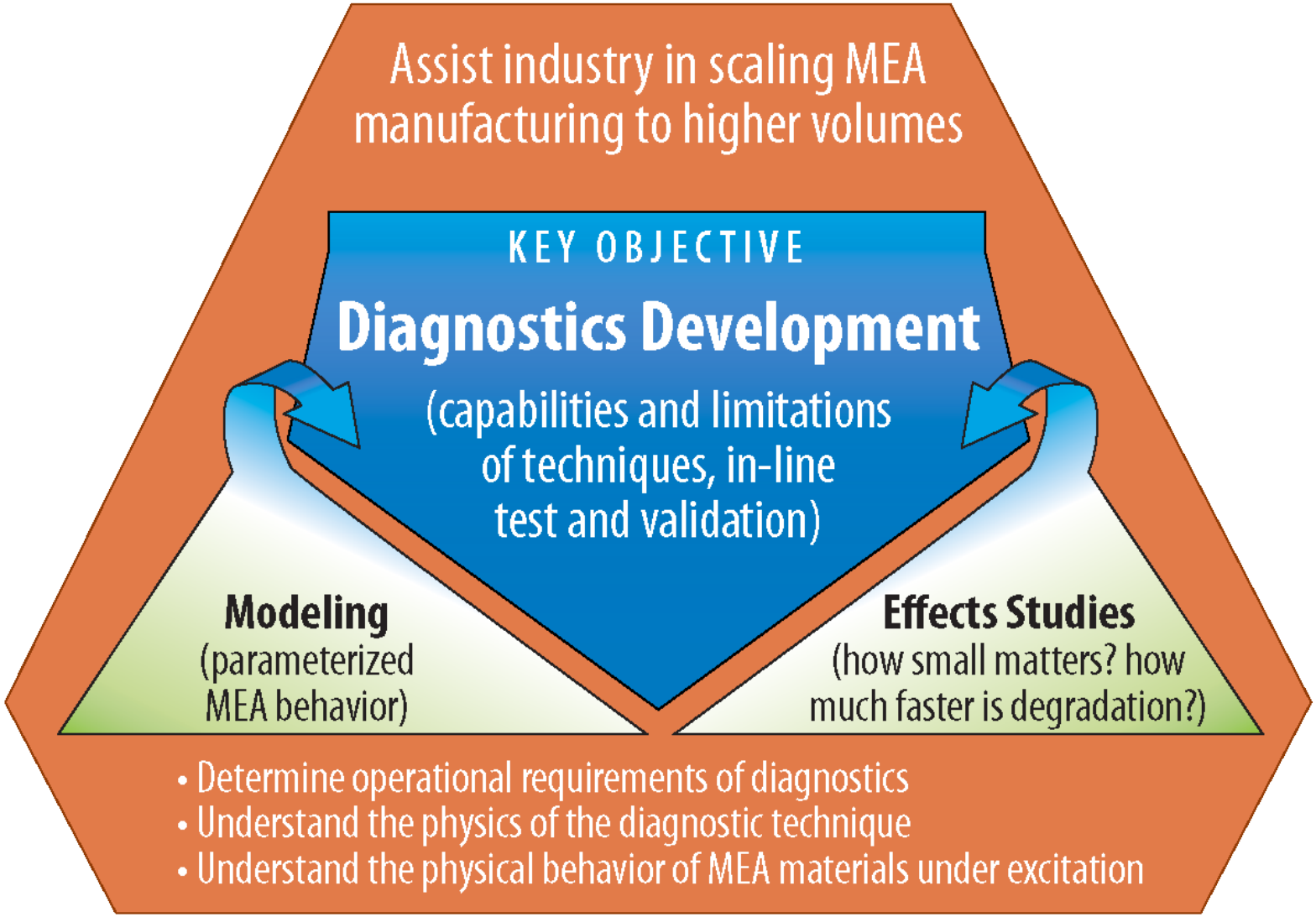
	Project Objectives
1	Evaluate and develop in-line diagnostics for MEA component quality control, and validate in-line
2	Investigate the effects of manufacturing defects on MEA performance and durability to understand the accuracy requirements for diagnostics
3	Integrate LBNL modeling to support diagnostic development and implementation

NREL is additionally providing up-to-date analyses of the manufacturing capabilities and readiness of the fuel cell industry to further support DOE's Manufacturing and Market Transformation program elements. This effort is performed in response to DOE's specific request.

Collaborations

- Industry partners: **3M, Arkema, Ballard Material Products, BASF, Johnson-Matthey, W.L. Gore, GM**
- **NREL Hydrogen Center**: Guido Bender, Niccolo Aieta, Michael Penev, Huyen Dinh, Michael Ulsh
- **NREL National Center for Photovoltaics/New Jersey Institute of Technology**: diagnostics development
- **LBNL**: model development and integration
- **NIST**: project partner
- **Colorado School of Mines**: test method development and defect analysis
- **Hawaii Natural Energy Institute**: segmented cell development and defect analysis
- **DJW Technology**: manufacturing assessment
- **Rensselaer Polytechnic Institute**: collaboration on cost-shared project
- **Georgia Tech**: collaboration on membrane casting process and defect detection

Approach


Assist industry in scaling MEA manufacturing to higher volumes
KEY OBJECTIVE
Diagnostics Development
(capabilities and limitations of techniques, in-line test and validation)
Modeling
(parameterized MEA behavior)
Effects Studies
(how small matters? how much faster is degradation?)
• Determine operational requirements of diagnostics
• Understand the physics of the diagnostic technique
• Understand the physical behavior of MEA materials under excitation

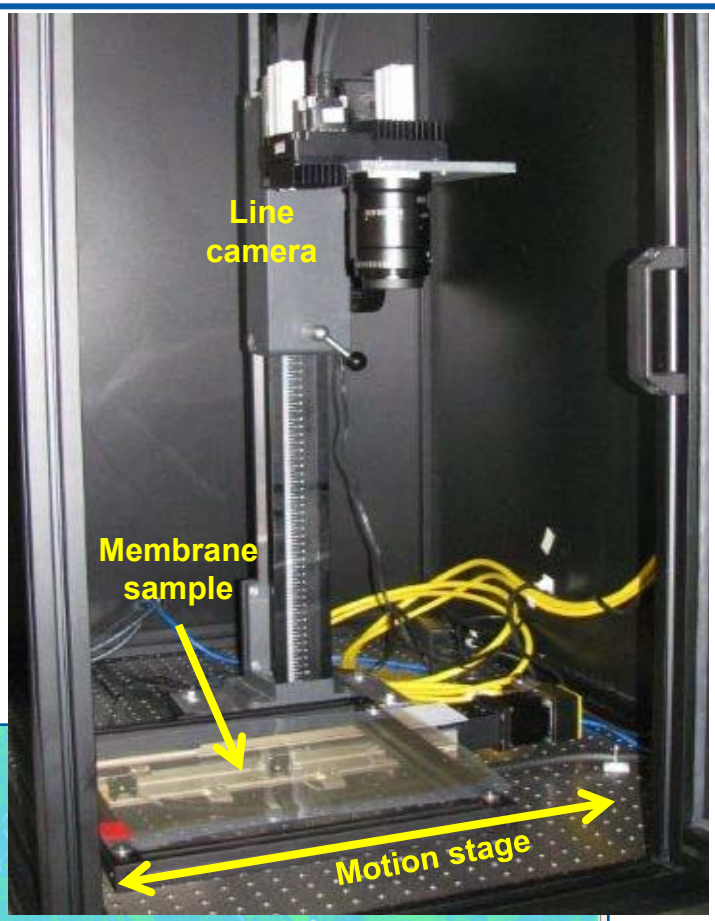
Approach – AOP Milestones

Date	Milestone/Deliverable	Complete
4/10	Research web-line commissioned	100%
7/10	Complete baseline automation study of CHP fuel cell manufacturing	100%
12/10	Complete revised MRA report on fuel cell systems and stacks for backup power and MHE	100%
4/11	Select first IR-based diagnostic concept for design and installation on web-line	100%
9/11	In-line validation of membrane diagnostic	25%
9/11	Go/No-go decision for further development of optical diagnostic for platinum measurement	25%

Technical Accomplishments: Diagnostics

Optical Reflectometer web-line prototype

- "Pre-web-line" system
  - Understand operation of camera and data acquisition with substrate motion
  - Verify functionality prior to use of resources for web-line
- Line-scan camera (12" wide FOV)
  - Faster and less data intensive than "2D" camera
  - High resolution (25 μm at 12" FOV)
- 1D motion stage and sample frame

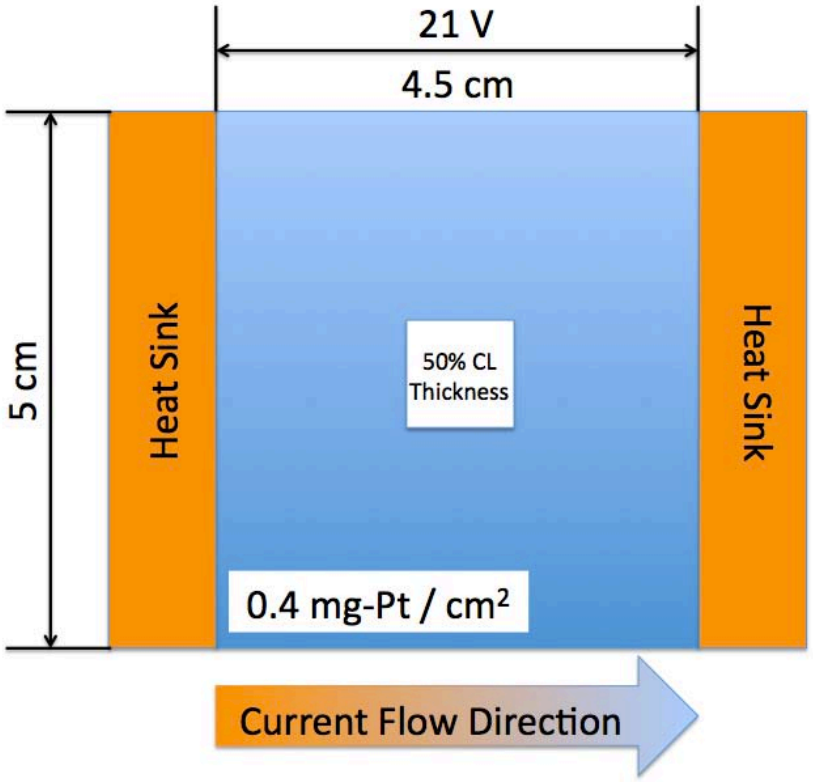


- 6"x2" image taken at 25 ft/min
- LT-PEM membrane
- Color indicates variability

Technical Accomplishments: IR/DC Diagnostics

IR/DC technique and implementation criteria

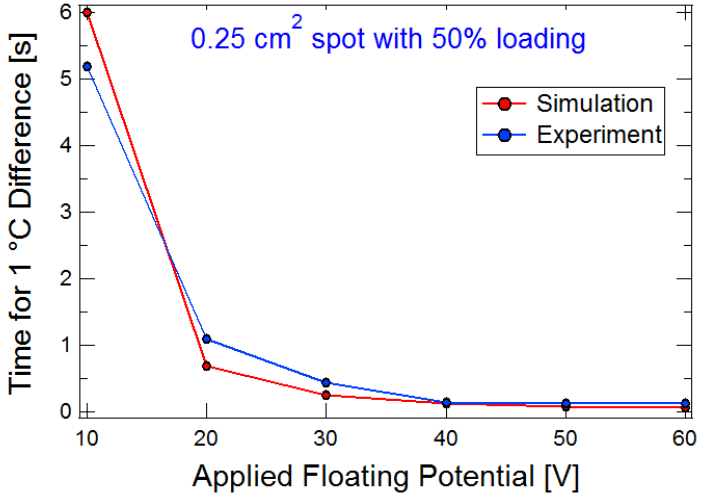
- Current methods (e.g., XRF) provide point data, which is averaged across and down web
- IR/DC provides areal imaging of catalyst layer (CL) uniformity
- DC excitation of CCM causes thermal response
- Defects change CL resistance, thus altering the thermal response
- IR camera provides rapid, quantifiable 2D data
- Development criteria
  - Rapid response
  - Size and loading sensitive
  - Non-destructive
  - Amenable to continuous process

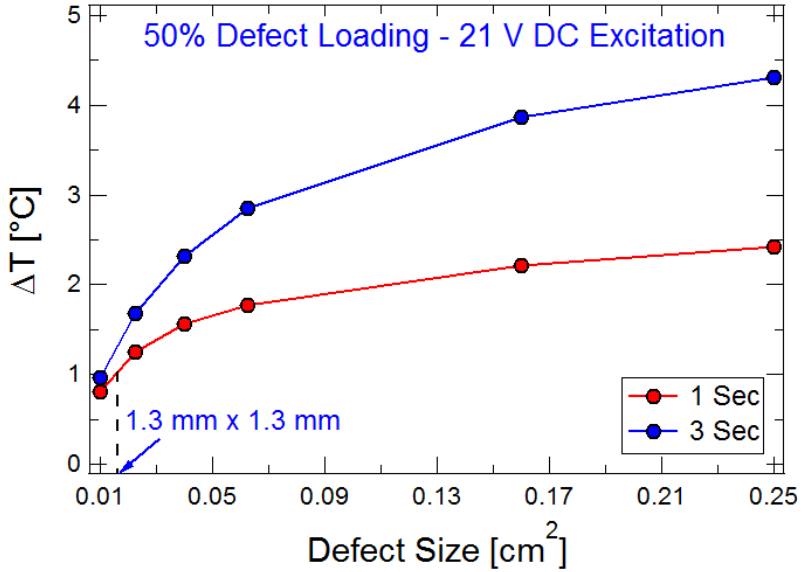


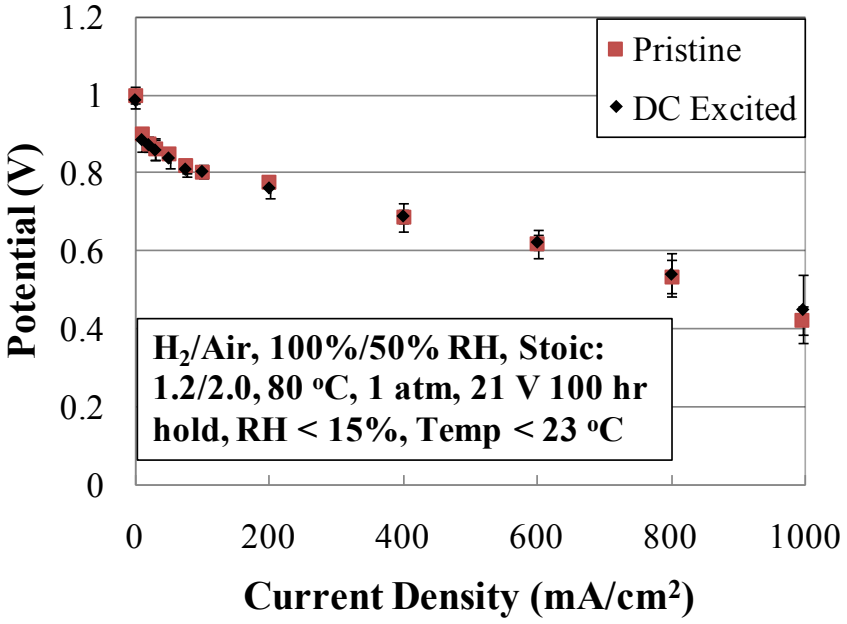
Technical Accomplishments: IR/DC Diagnostics

Technique is rapid and non-destructive

- Long term (100 hrs) DC excitation shows no loss in initial performance
- Actual response times are few seconds or less
- Predictive modeling quantified detection limits as a function of excitation time and magnitude



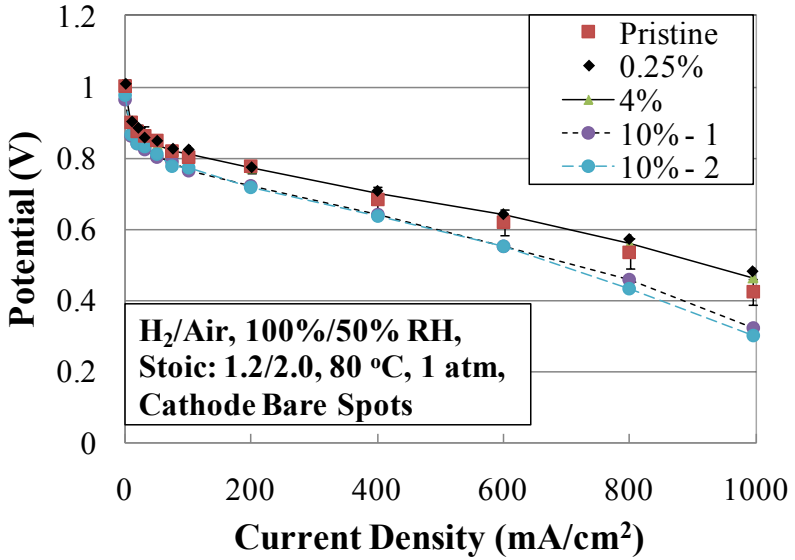


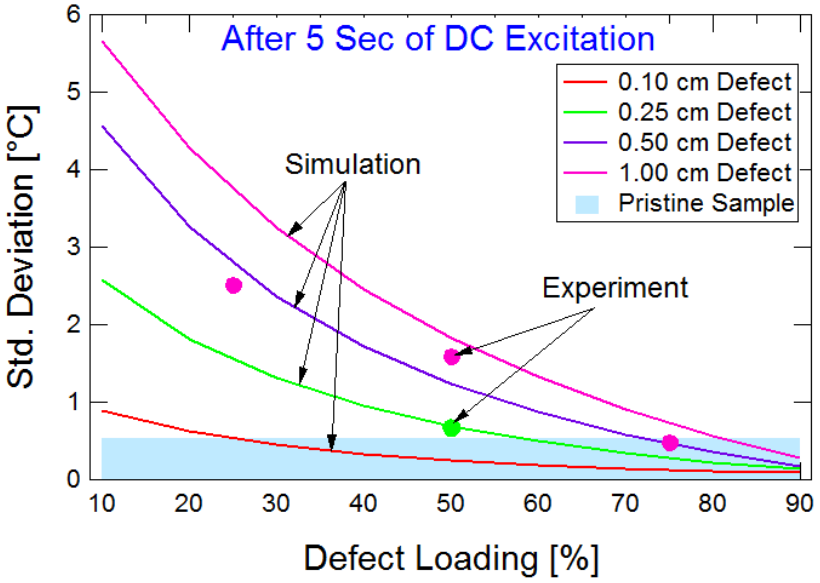


Technical Accomplishments: IR/DC Diagnostics

Technique is sufficiently sensitive to defect size and loading

- Initial performance testing shows little effect of bare spots <10% active area
- Experimental assessment of sensitivity to date
  - Defect size: ≥ 6.25 mm^2
  - Loading variations: ≥ 10% (at nominal 0.45 mg Pt/cm^2)
- Modeling predicts temperature rise as a function of defect size and loading
- Diagnostic sensitivity is higher than the measured sensitivity of initial performance to defect size and loading

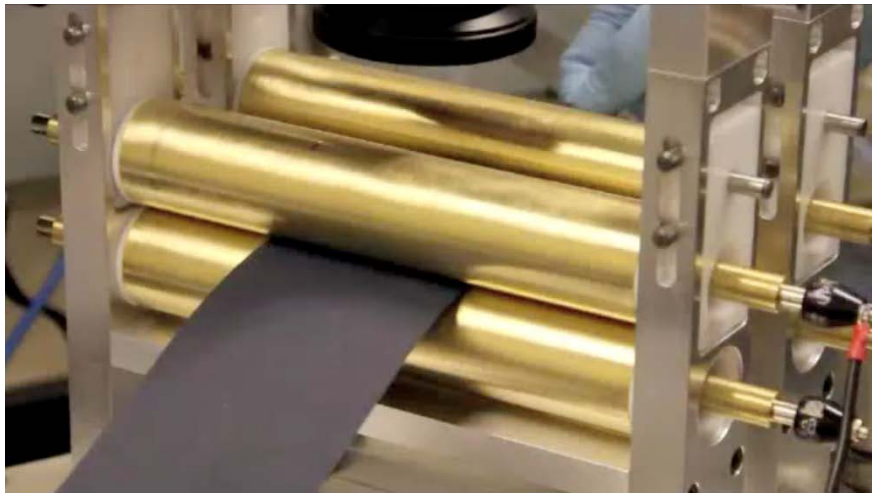


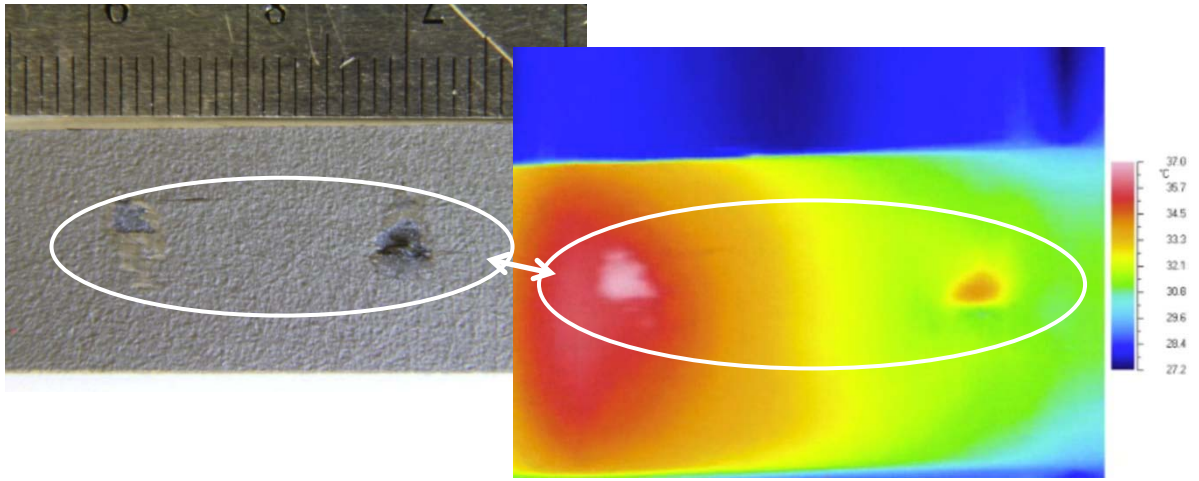


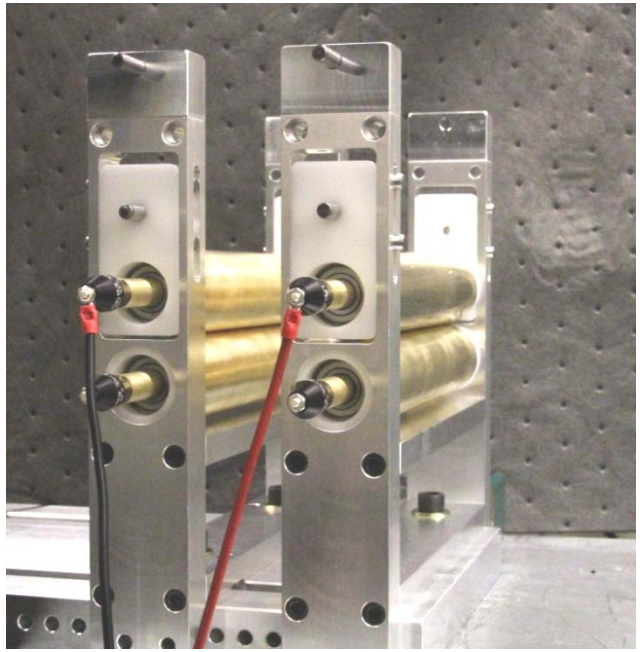
Technical Accomplishments: IR/DC Diagnostics

Bench-top roller system proves feasibility with moving substrate

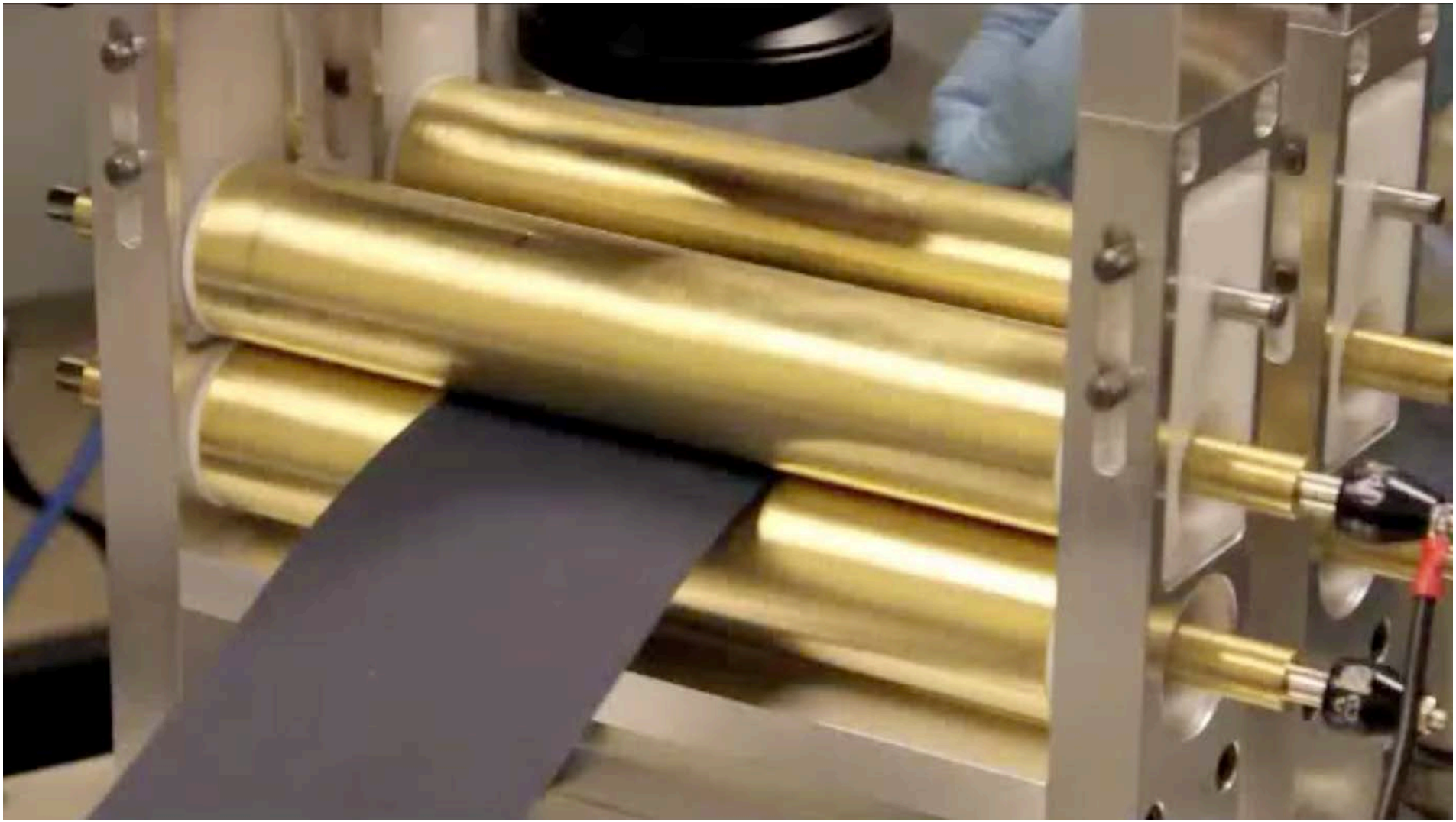
- First step toward in-line implementation
- Evaluated rolling electrical contacts
- Evaluated response time as a function of excitation and roller configuration
- Developed understanding of technique prior to investment for web-line implementation







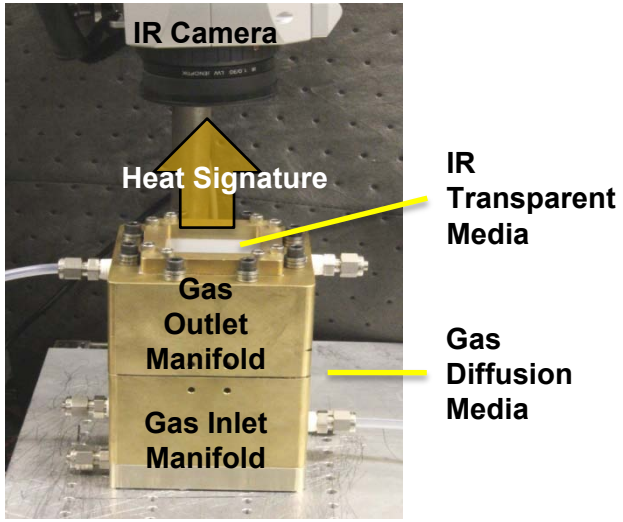
Technical Accomplishments: IR/DC Diagnostics (Video)



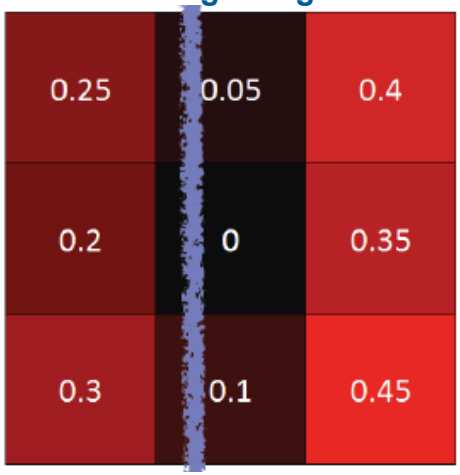
Technical Accomplishments: IR/RFT Diagnostics

IR / Reactive Flow Through technique

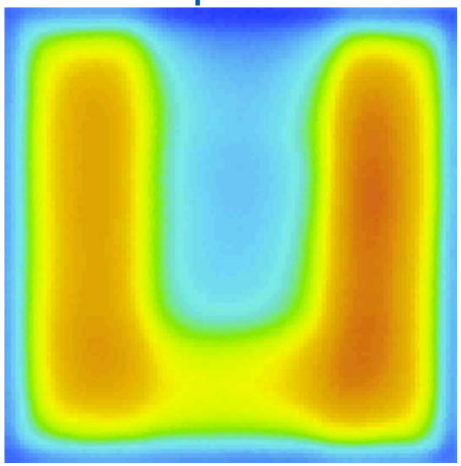
- Areal imaging of GDE catalyst layer uniformity
- Non-flammable (<25% LEL) flow of reactive gas
- Excitation by gas reacting on catalyst
- Rapid detection time (seconds)
- Demonstrated sensitivity to loading variations of 0.03 mg Pt/cm^2
- Sensitivity and detection time can be tuned to target loading

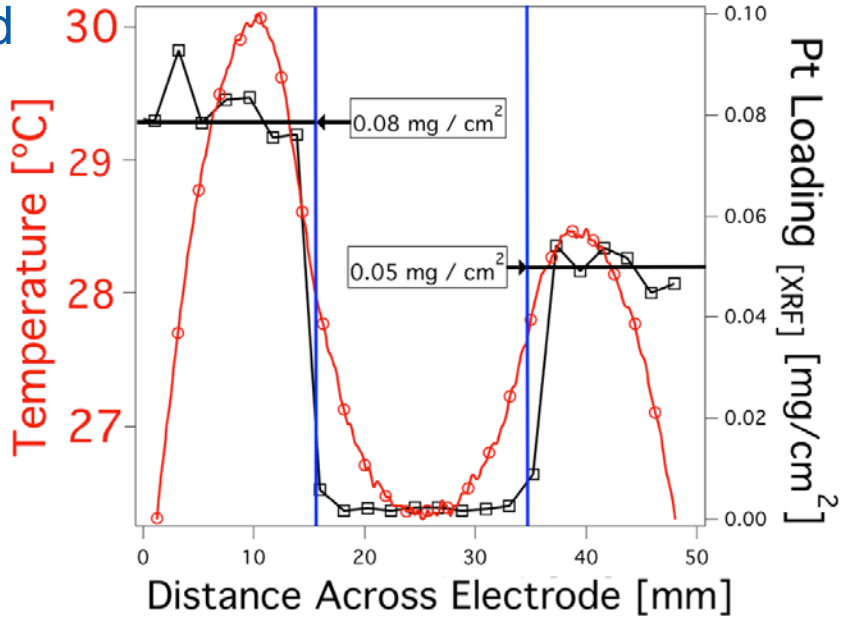


GDE loading in mg Pt/cm^2



Thermal response after 10 s





Technical Accomplishments: Defect effects studies

HNEI Hawai'i Natural Energy Institute University of Hawai'i at Mānoa

BALLARD

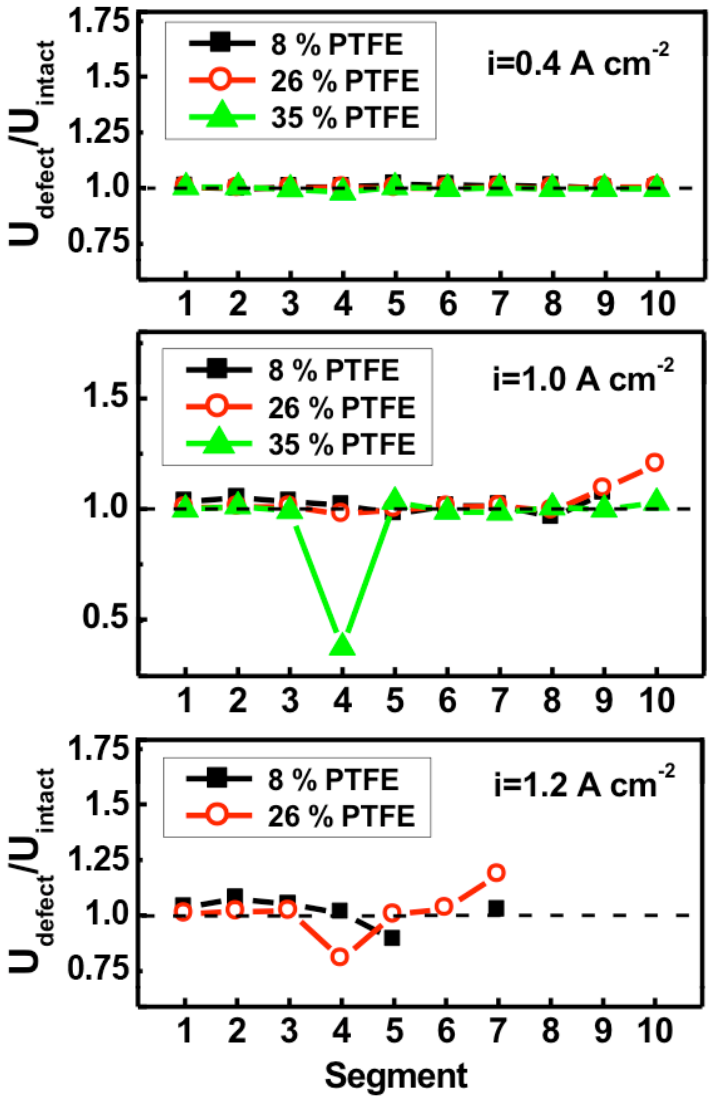
Segmented cell study of GDL defects

Materials

- BMP baseline P50T anode
- BMP baseline P50T cathode (13% PTFE)
- BMP 'defect' cathode materials (8, 17, 26, 35% PTFE) placed in segment 4
- Commercially available 100 cm^2 CCMs (0.1/0.2 mg Pt/cm^2)

Testing

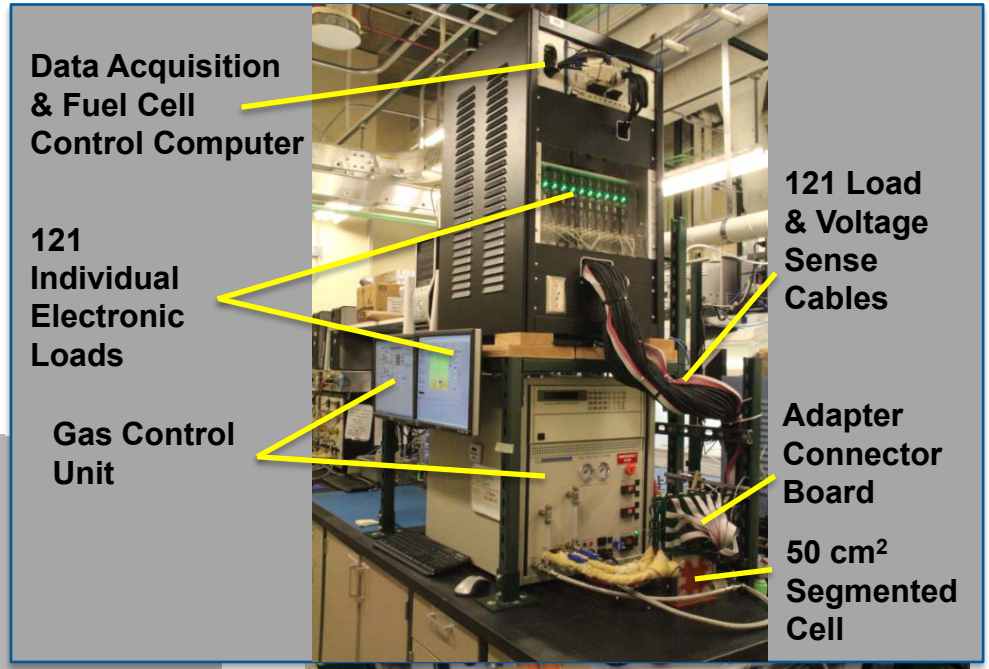
- HNEI 10 segment cell (7.6 cm^2/seg)
- Wet (100/50 %RH) and dry (32/32) conditions
- V/I and EIS spatial diagnostics
- 35% PTFE defect impacts performance at 1.0 A/cm^2
- 26% PTFE defect impacts performance at 1.2 A/cm^2
- Dry results similar to wet in testing to date
- Study is ongoing

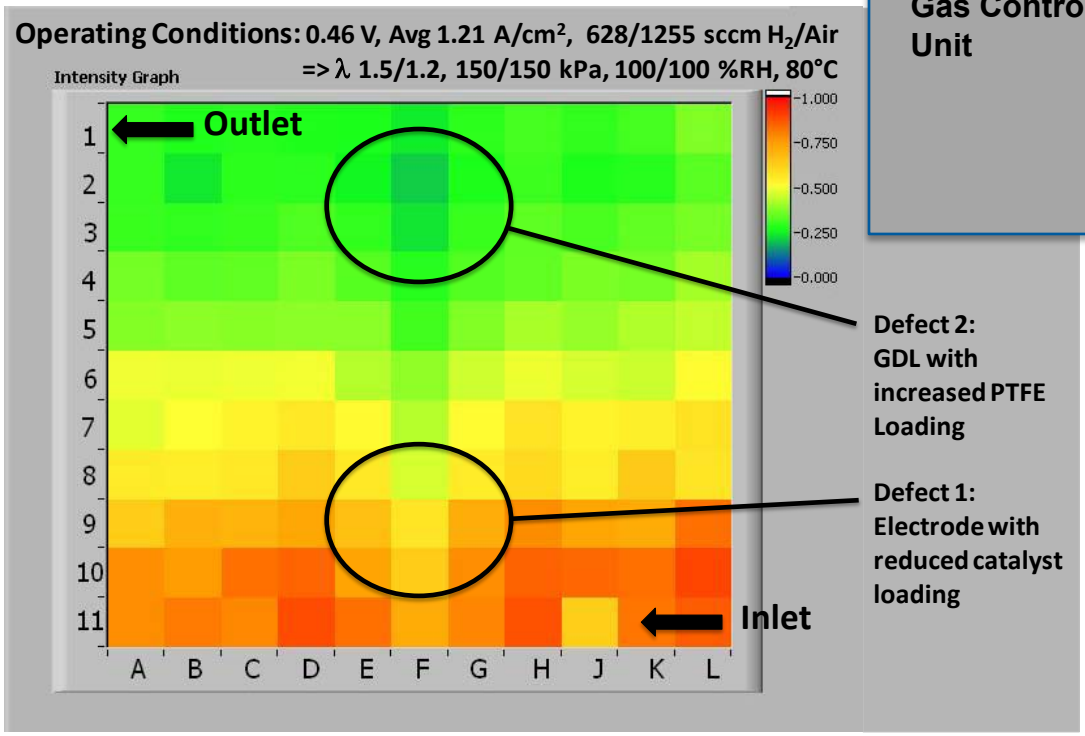


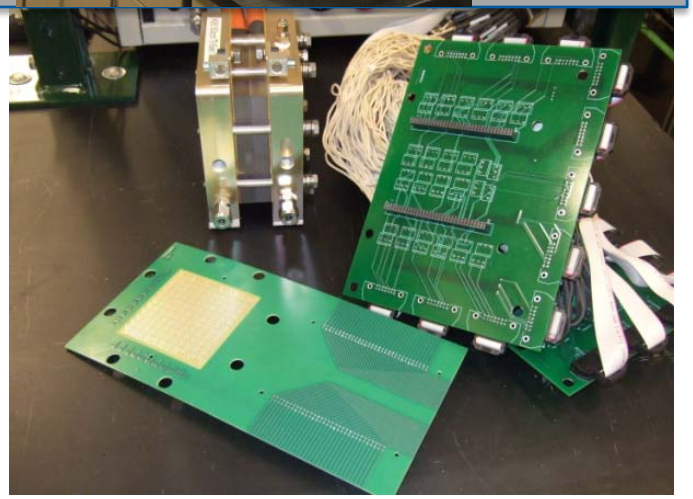
An/Ca: H_2/Air, 100/50% RH, 2/2 stoi, 48.3/48.3 kPa_g, 60°C

Technical Accomplishments: Defect effects studies

- Installed and commissioned 3M-design segmented cell system at NREL (PCB-based, 121 segment, 50 cm^2)
- Collaborating with 3M on system setup and use







Technical Accomplishments: Manufacturing Assessment

Manufacturing Readiness Assessment Update: PEM systems and stacks for forklift and backup power markets

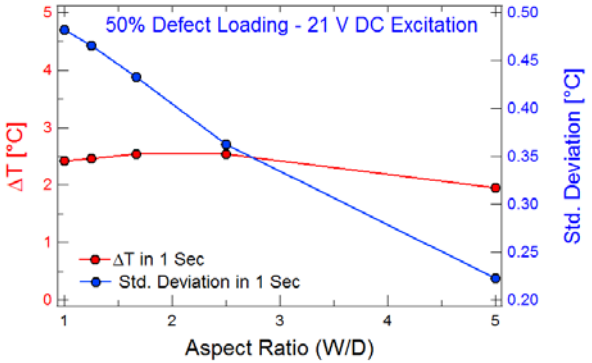
- Hydrogenics, Nuvera, Plug Power, Ballard, IdaTech, Altergy, ReliOn
- Most manufacturers still below LRIP of 1000 units/year
- DOE/DoD supported demonstrations have resulted in design changes
  - For mature designs, MRLs up to 9, but product and processes not designed for LRIP
  - For new designs, lower MRLs (4-7) because systems not yet integrated

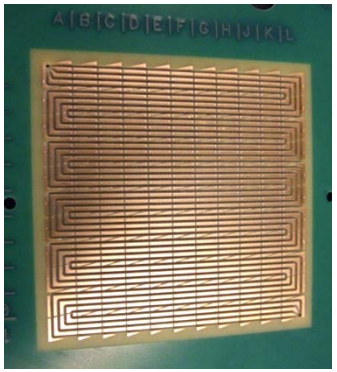
Baseline Automation Study: CHP fuel cells

- Assessed the current levels of adoption of automation in manufacturing processes and flow, as well as of continuous processes
- UTC Power, FCE, Acumentrics, Versa Power, ClearEdge Power, Altergy, Rolls Royce
- Findings for unit cells
  - Mix of continuous and batch processes
  - Demonstration of automated assembly
- Stack assembly is the best near-term application of automation

Future Work

- Utilize LBNL models to further understand and refine IR/DC diagnostic
  - Effect of aspect ratio and multiple defects on detectability
  - In-line configuration, e.g., minimum roller separation, optimization of data analysis, determining optimal statistical parameters for detection
- Implement diagnostics on research web-line
  - Membrane thickness imaging
  - IR/DC for catalyst layer uniformity
- Identify appropriate accelerated stress tests for electrode defects and begin growth rate testing
- Utilize NREL/3M segmented cell system to study the initial and long term effects of defects
- Complete specific partner studies and continue to support the industry
- Perform manufacturing assessments, as requested



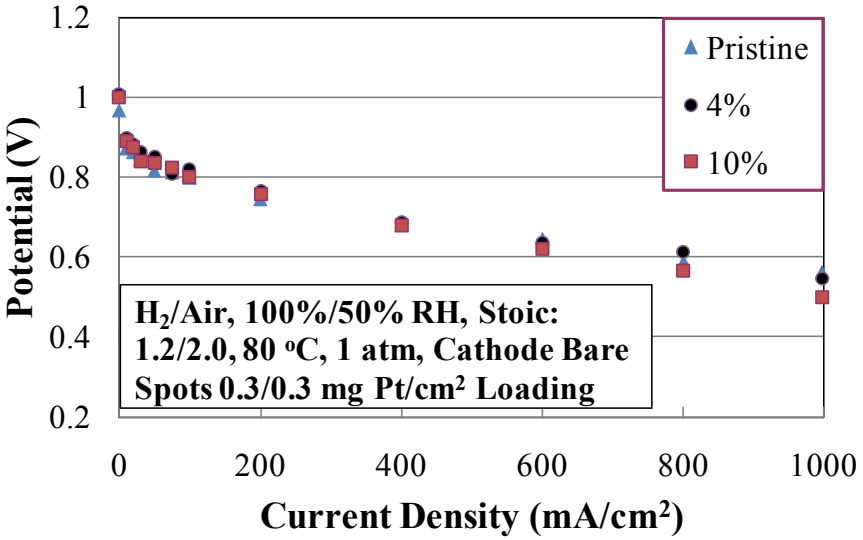


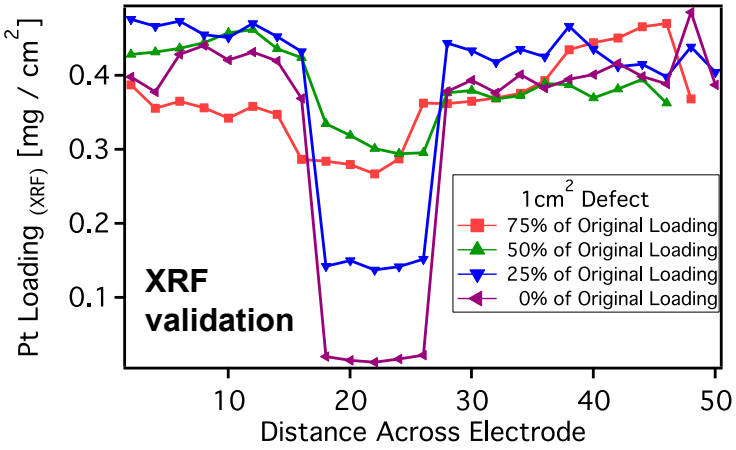
Summary

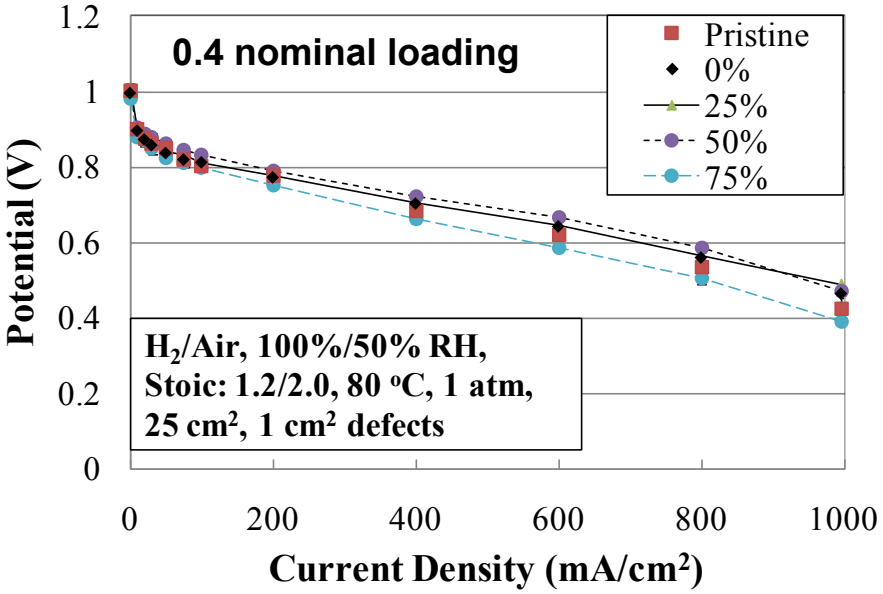
- Optical diagnostic
  - Demonstrated membrane thickness imaging with moving substrate
  - *Demonstrated feasibility of composite membrane/casting liner imaging*
  - *Demonstrated feasibility of SOFC tape cast electrode measurement*
- IR-based diagnostics
  - Demonstrated feasibility of IR/DC technique to measure catalyst layer uniformity (CCMs)
  - Utilized LBNL modeling as a predictive tool to understand IR/DC technique and feed back to development and implementation effort
  - Demonstrated IR/DC measurement with moving substrate
  - Demonstrated feasibility of IR/Reactive Flow Through technique to measure catalyst layer uniformity on gas diffusion electrodes
- Assessed effects of variability in PTFE content of gas diffusion media
- Completed the commissioning of a 121 segment test station
- Completed assessments of LT-PEM, HT-PEM, and high temperature fuel cell stack and system manufacturing
- *Studied the formation, detection, and effect on performance of electrode mudcracks*
- *Completed assessment of externally developed corona gun technique to detect membrane tears and holes in ½ MEAs*

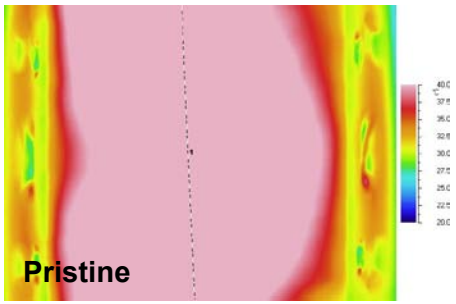
TECHNICAL BACK-UP SLIDES

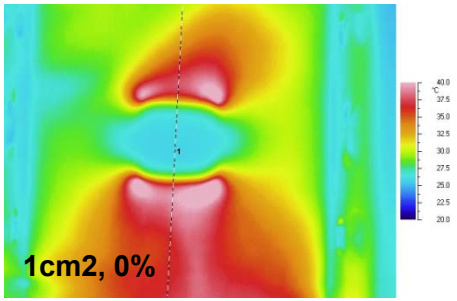
Technical back-up slides: IR/DC



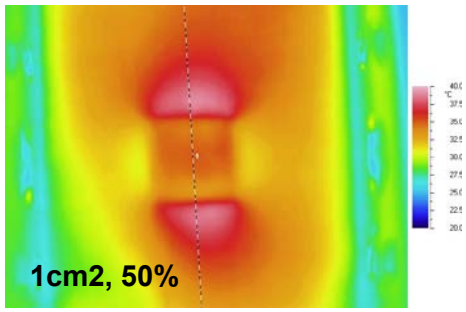


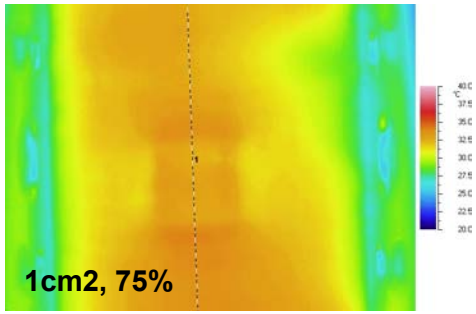




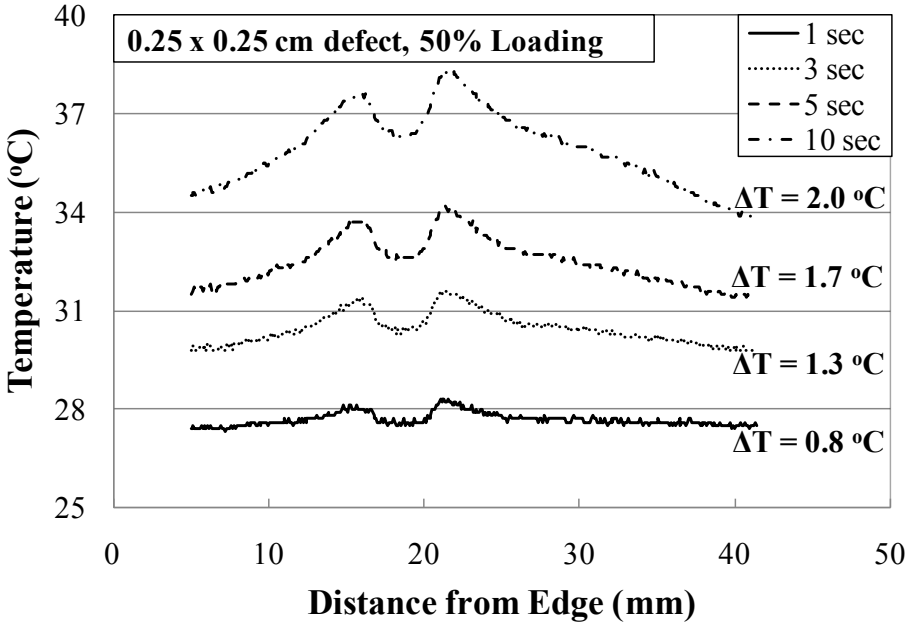


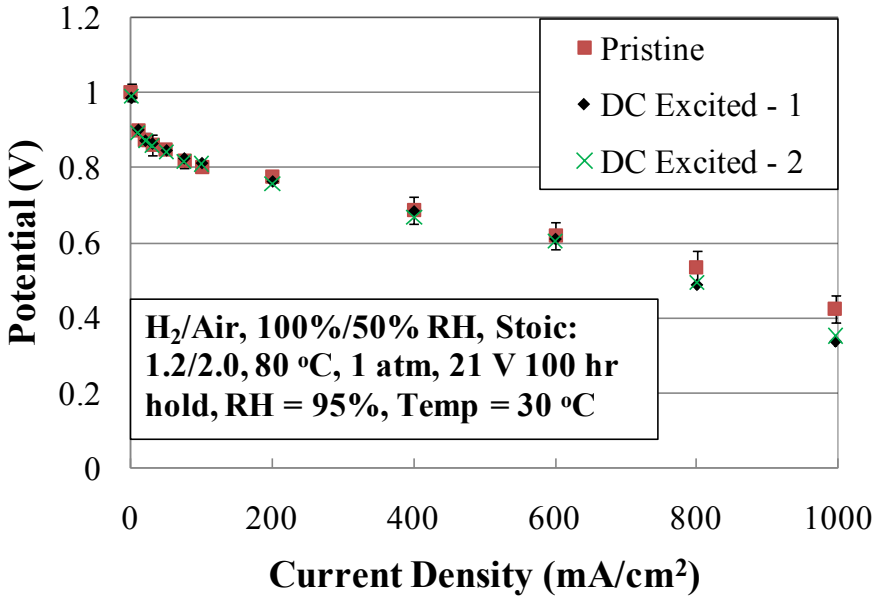
All samples: 25 cm2 active area, 5 second excitation at 21V DC





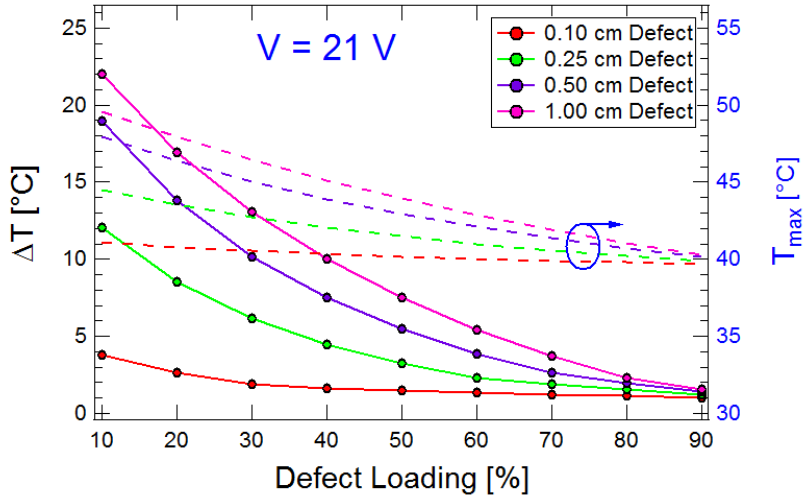
Technical back-up slides: IR/DC



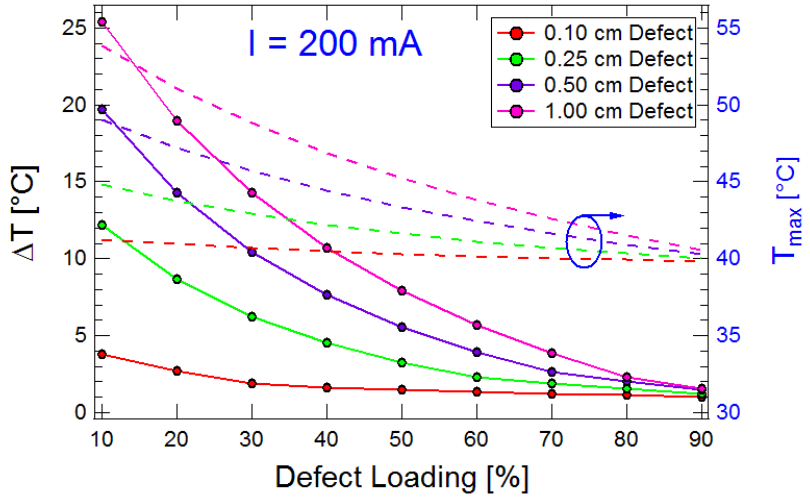


Sample	Average ECSA (m^2/g Pt)
Pristine	63.2
DC Excited (dry)	70.8
DC Excited (wet)	67.9

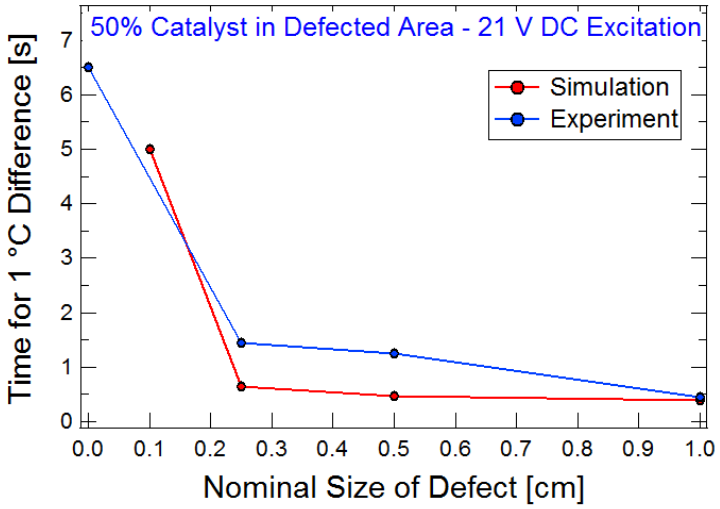
Technical back-up slides: IR/DC



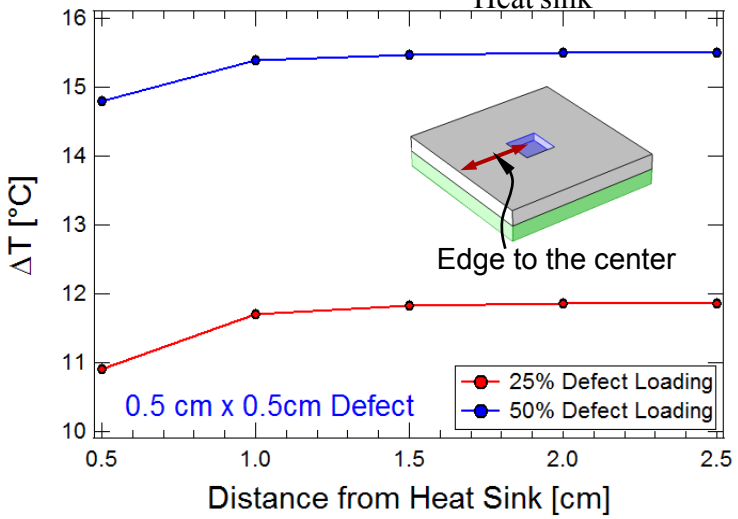
IR/DC performance with potentiostatic control



IR/DC performance with galvanostatic control

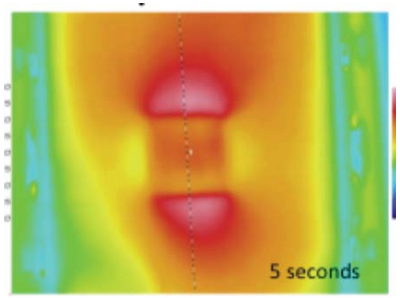


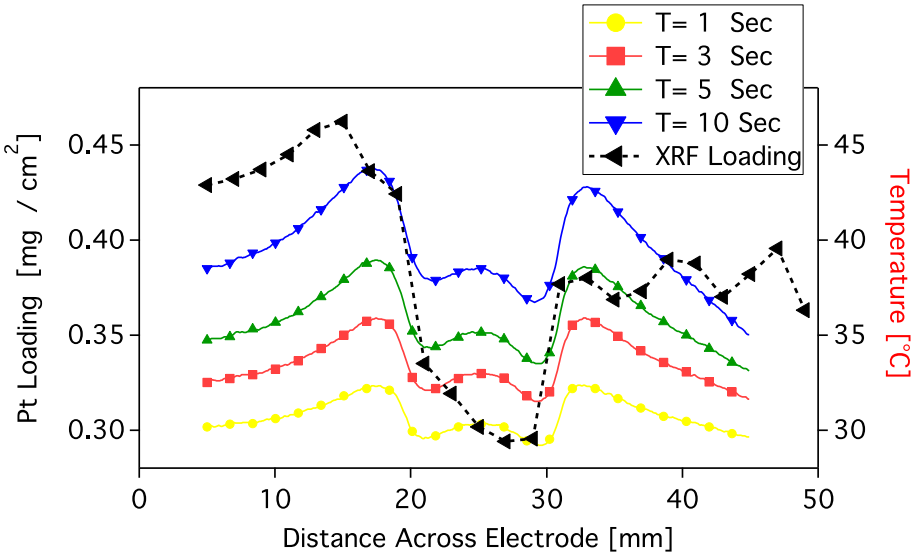
$$\Delta T = T - T_{\text{Heat sink}}$$



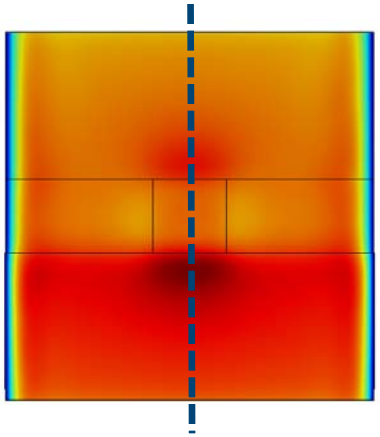
Technical back-up slides: Model validation

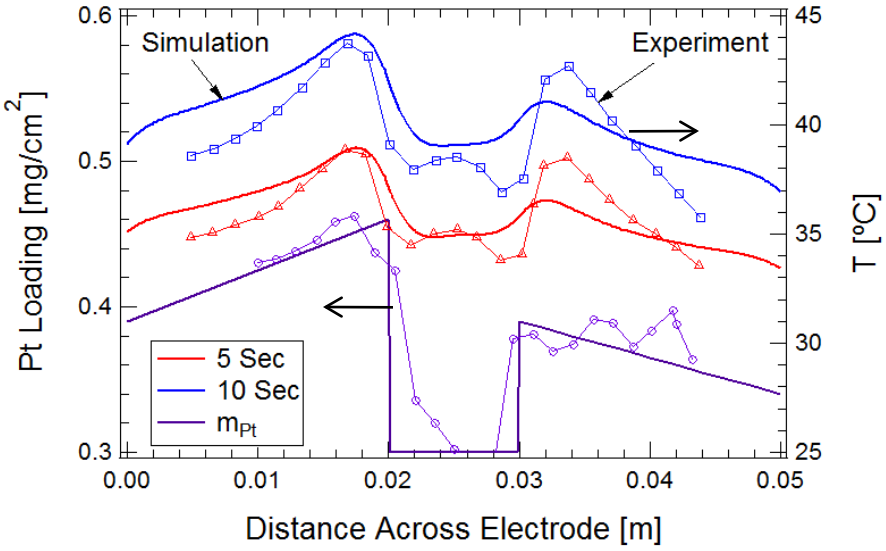
Experimental





Modeling





Technical back-up slides: Manufacturing Assessment

- Data from 2010 MRA update report, comparing MRLs between 2008 and 2010
- 2008 report documents development of DOE fuel cell MRL scale and the MRA methodology, which was repeated for the 2010 report