Neutron Imaging Study of the Water Transport in Operating Fuel Cells

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Gaithersburg, Maryland 20899-8461

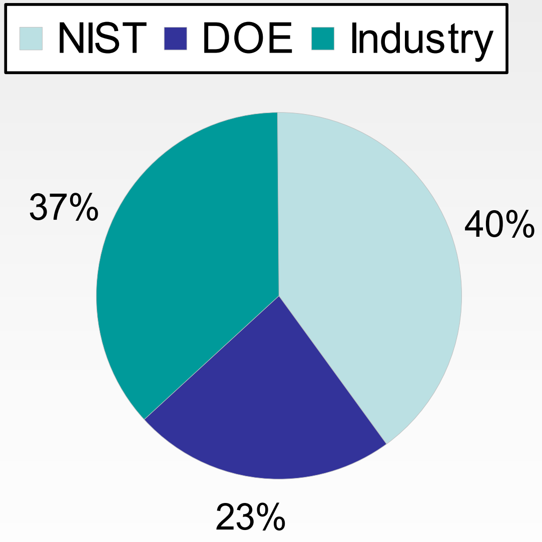
This presentation does not contain any proprietary or confidential information

Overview

Timeline

Project Start : 2001, continuing
Percent Complete:100% for each year

Budget



Total: $1.3M, DOE: $0.3M

Barriers Addressed

Barrier D. Thermal, Air, and Water Management
Water management techniques to address humidification requirements and maintain water balance.

Major Users/Collaborators

- University of Kansas
- University of Michigan
- Rensselaer Polytechnic Institute
- Sandia National Laboratory
- General Motors
- Daimler Chrysler
- Plug Power

Objectives

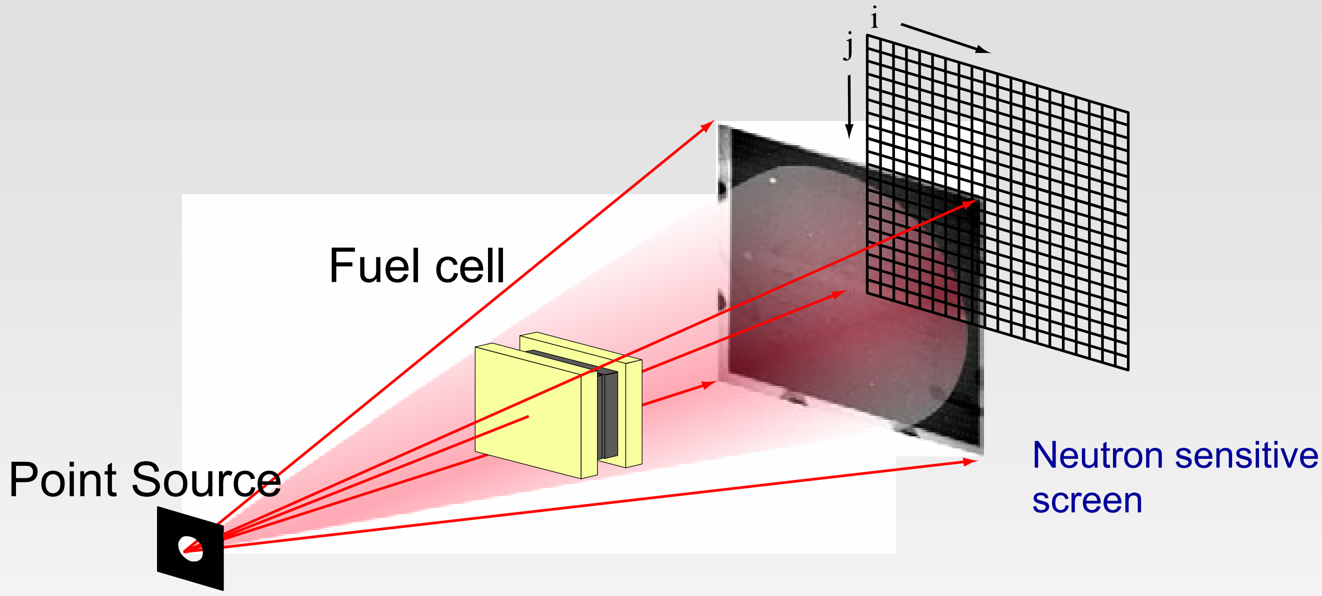
This National Institute of Standards and Technology project aims to develop and employ an effective neutron imaging based, non-destructive diagnostics tool to characterize water transport in PEM fuel cells. Objectives include:

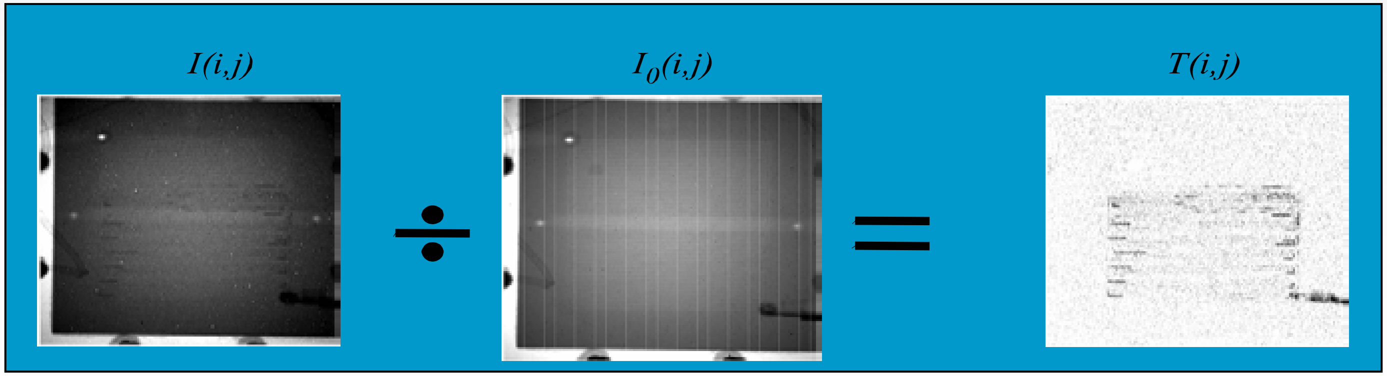
- Provide research and testing infrastructure to enable the fuel cell / hydrogen storage industry to design, test and optimize prototype to commercial grade fuel cells and hydrogen storage devices.
- Make research data available for beneficial use by the fuel cell community
- Provide secure facility for proprietary research by Industry
- Transfer data interpretation and analysis algorithms techniques to industry to enable them to use research information more effectively and independently.
- Continually develop methods and technology to accommodate rapidly changing industry/academia need

Approach

- Develop high resolution neutron imaging capability/facility for *in-situ nondestructive study of water/hydrogen transport in PEM fuel cells while in operation* and hydrogen transport/distribution in hydrogen storage media
- Develop capability for accurate data interpretation and quantitative image processing
- Develop/ provide infrastructure/facility for testing fuel cells
- Test fuel cells through partnership with industry and academia. Evaluate impact of research
- Transfer technology to industry as it matures
- Get feed back from users and seek opportunities for future technical breakthroughs

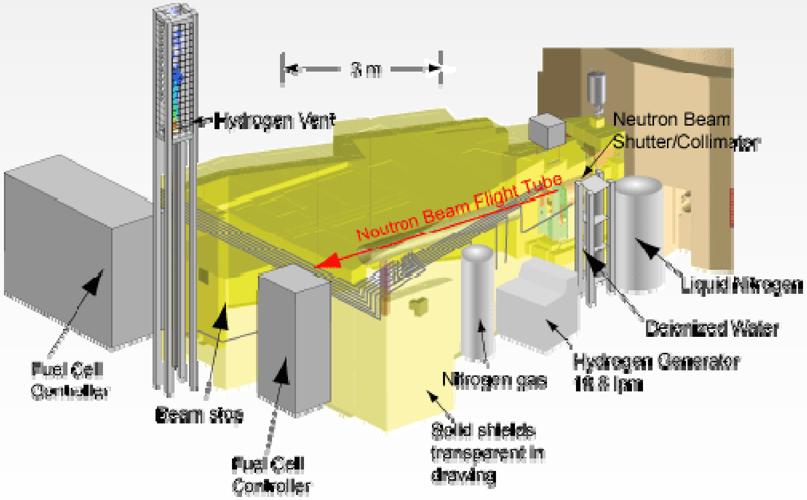
Neutron Imaging: How it works





Advanced Fuel Cell Imaging Facility

1. State of the art PEMFC test stand
2. Flow control over H2, Air, N2, He, O2 with accuracy of 1% full scale:
   - H2: 0-500 and 0-3000 sccm
   - N2: 0-2000 sccm
   - Air: 0-100, 0-500, 0-2000, 0-8000 sccm
   - O2: 0-500, 0-5000 sccm
   - He: 0-600, 0-6000 sccm
3. Custom gas mixtures for anode and cathode
4. Measurement of limiting current densities with boost power supply allowing voltage control of the cell to a minimum of 0.01 V
5. Heated Inlet gas lines
6. Built-in humidification of anode and cathode gas streams for all flow rates
7. -40 C freeze chamber with 1 kW cooling capacity (Fall 2006).
8. Sample preparation Lab
9. Advanced data acquisition system
10. Advance data analysis/reduction system
11. Extensive visualization capability



Facility use

- Facility Operates nearly 260 days a year (24 hours per day). **Facility is Open to ALL**
- 2005 **CONSTRUCTION** plus operating budget nearly $1.3 m
- Access requires beam allocation request and approval
- Users go through extensive radiation and laboratory safety training
- Typical time for a single visit is about 3-7 days
- Useful data can be obtained within a few hours

Both proprietary and non-proprietary research

- Non-proprietary research is free of cost (currently about 60% of total beam use)

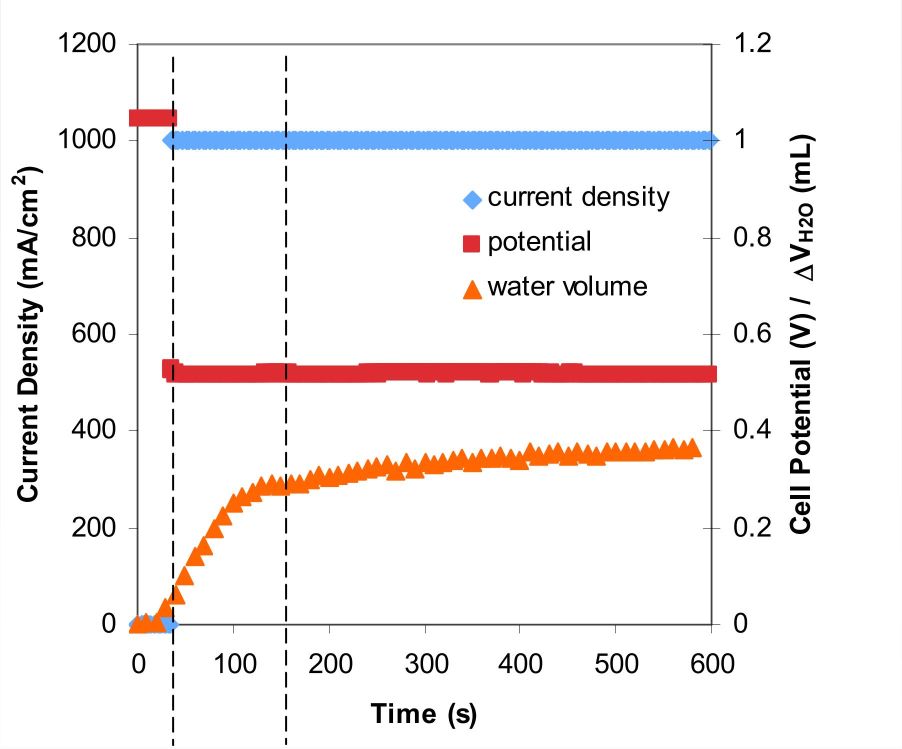
  - Requires results be made available through peer reviewed publications

- Proprietary use requires amortized daily reactor and personnel cost recovery (about 40% of current beam use)

  - Preferred by most industry
  - Results are confidential

Slow response of water content during a step change in current load

Current Step: 0 mA/cm² to 1000mA/cm²
40°C cell 100% RH



Current step occurs at time = 30 s.

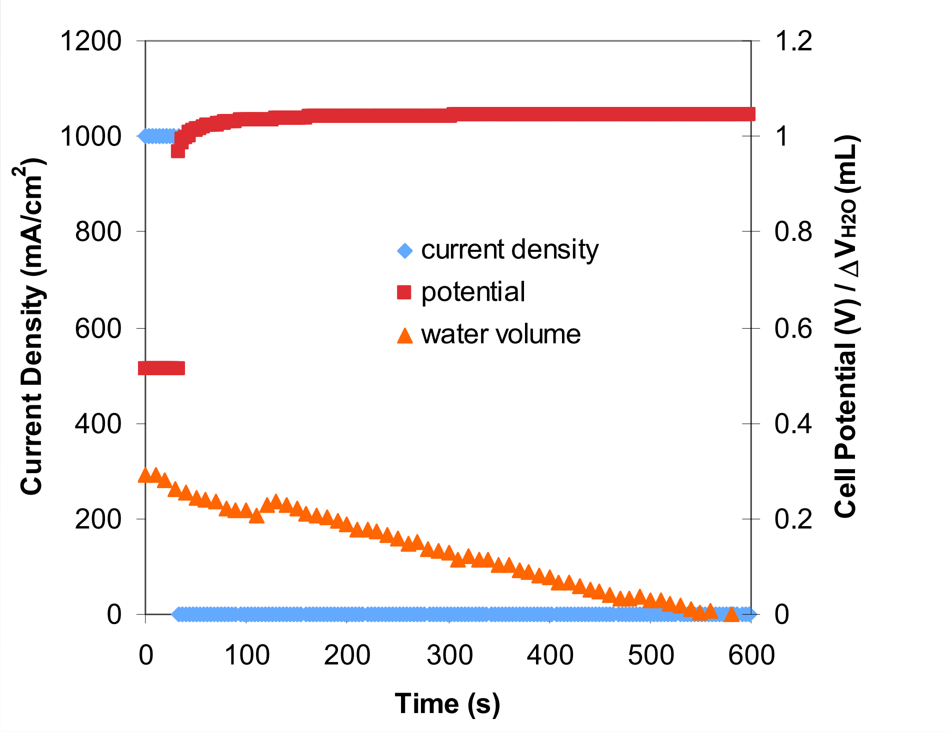
Voltage decreases from OCV to 0.52V when the current is increased from 0 mA/cm^2 to 1000 mA/cm^2.

A significant amount of time after the current step is required for the water content of the cell to increase.

Collaborator: Sandia National Lab

Slow response of water content during a step change in current load

Current Step: 1000 mA/cm² to 0 mA/cm²
40°C cell 100% RH



Current step occurs at time = 30 s.

Cell potential increases from 0.52V to OCV when the current is decreased from 1000 mA/cm² to 0 mA/cm².

The GDL fills slowly with water, but drains even more slowly without the help of evaporation.

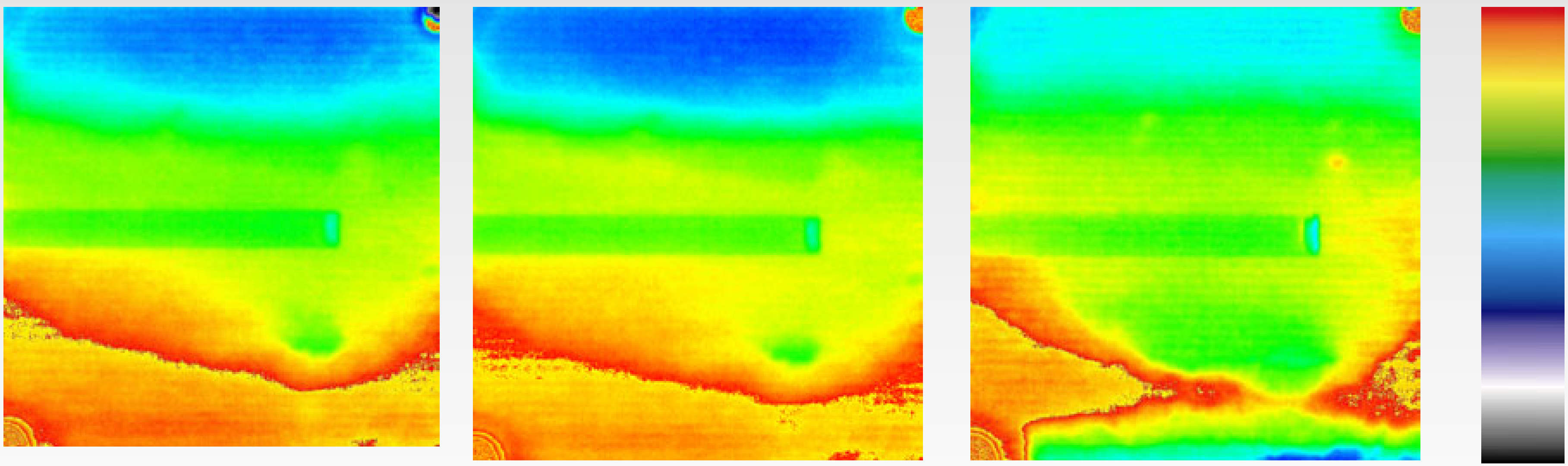
Collaborator: Sandia National Lab

Effect of temperature on liquid water content

100% RH, 1250 mA/cm²

40° C **60° C** **80° C**

More

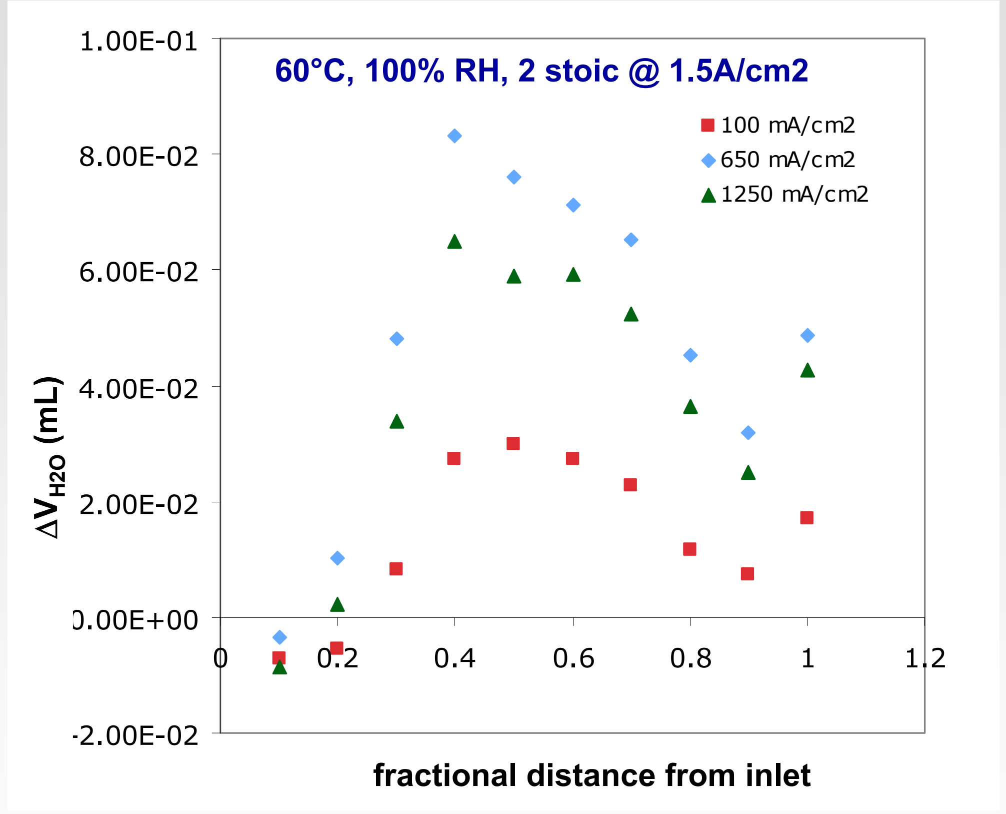


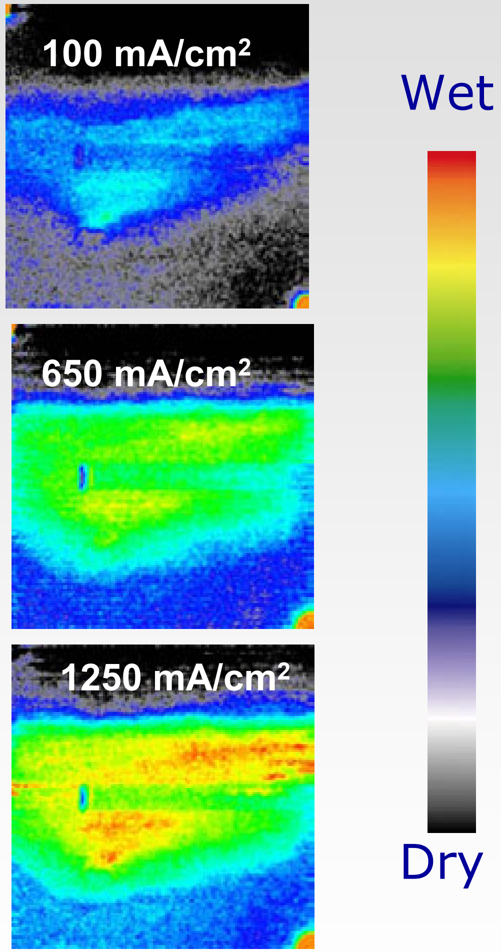
Less

Less water in the cell at higher temperatures can cause increased performance over what could be expected due to catalytic and transport temperature dependence.

Collaborator: Sandia National Lab

Additional Water Content Due to Current

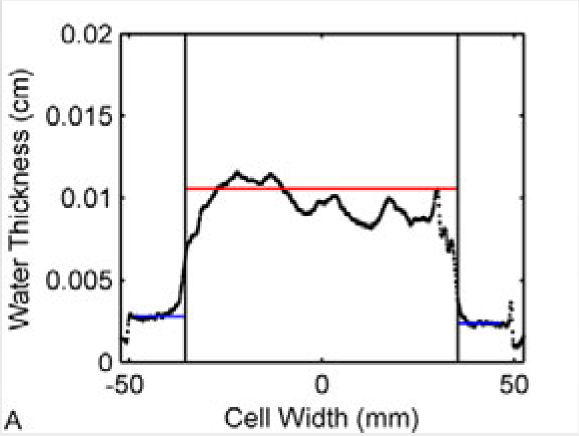




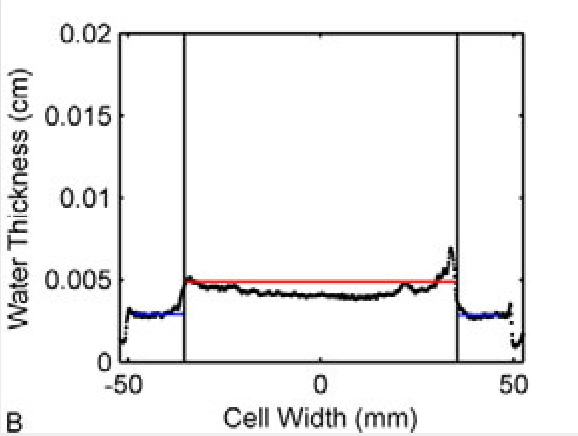
The highest water content is not always observed at the greatest current density. There is a competition between water generation and local heating.

Collaborator: Sandia National Lab

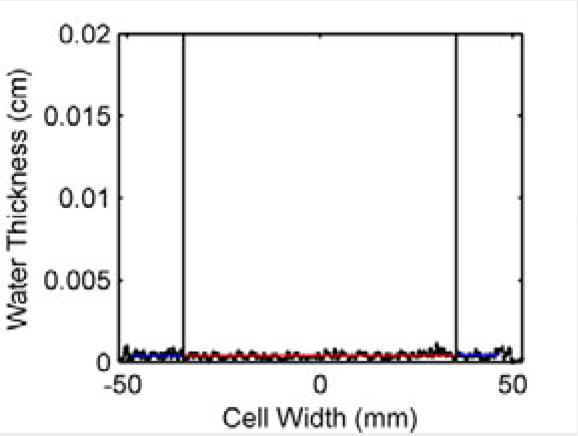
MEA Hydration Characterization



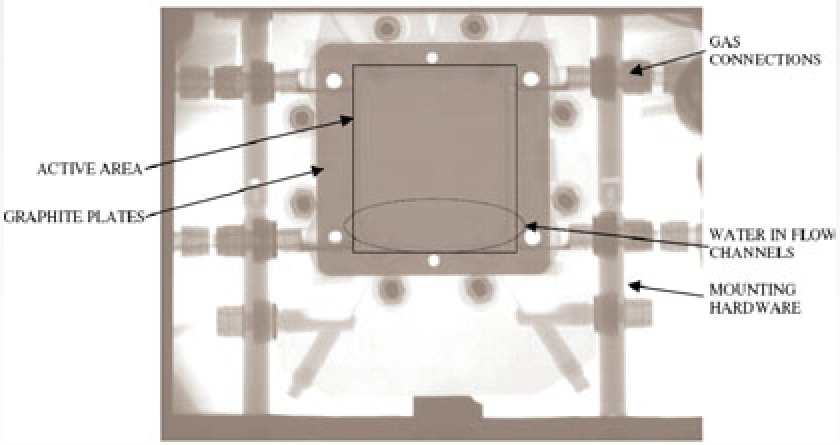
Initial Water Content



Water after 20 min purge with Dry Nitrogen



Water after 40 min purge with Dry Nitrogen

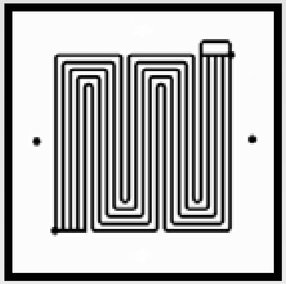


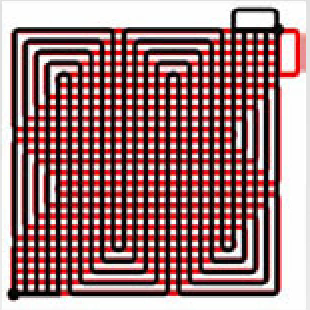
- Assume the water content underneath the gaskets is due solely to MEA water
- Can evaluate membrane hydration without interference from GDL or channel water
- Red is average active area water content, Blue is average water content under gasket
- Future studies planned to assess the method
- Accepted in Journal of Power Sources

Collaborator: Rensselaer Polytechnic Institute, Plug Power

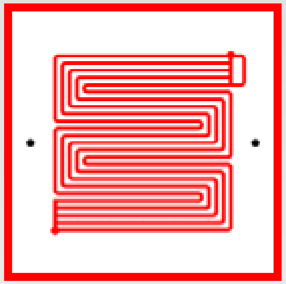
Geometry Comparison 0.5 A/cm²

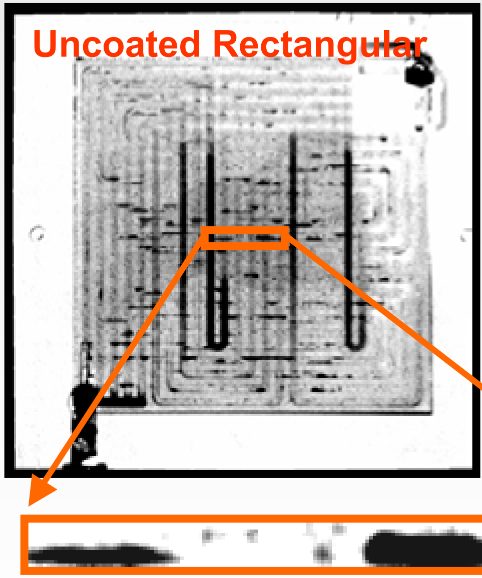
Anode black/vertical

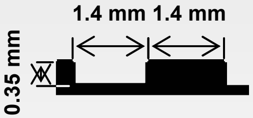


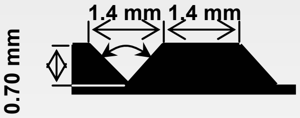


Cathode red/horizontal

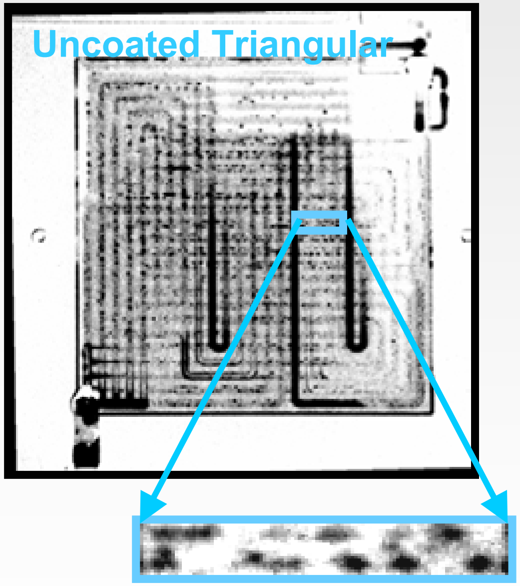








Vertical channels are anode (ignore water trapped here) and focus on horizontal cathode flow fields.

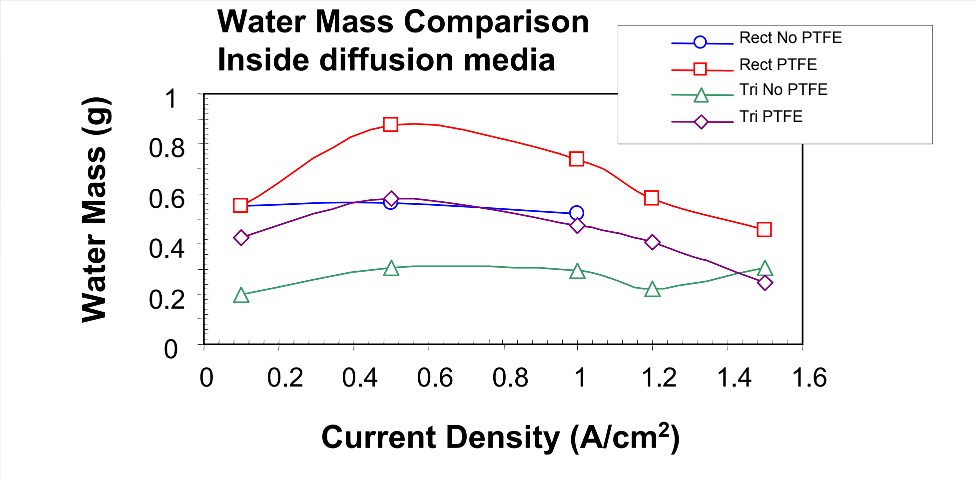


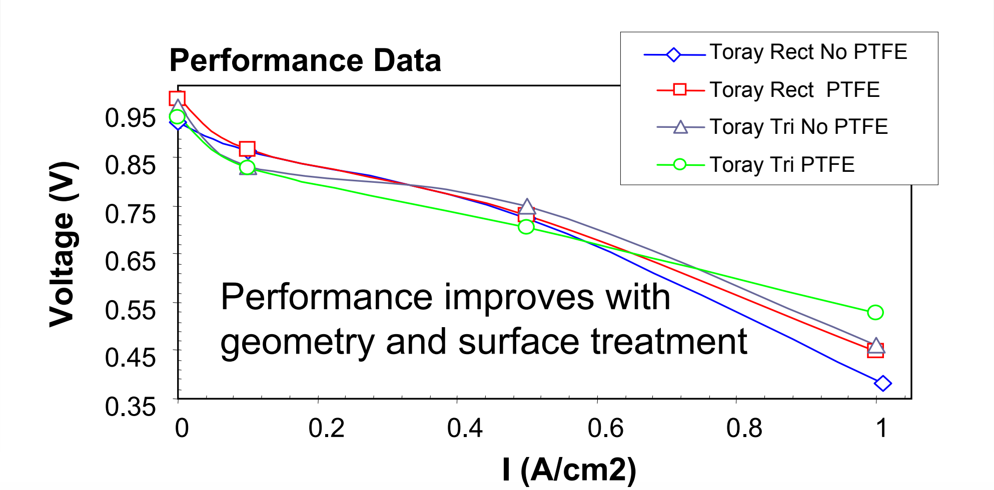
Laminar slugs trapped and plugging flow channel

Collaborator: General Motors

Pinned water forms beads with large cross section to gas flow

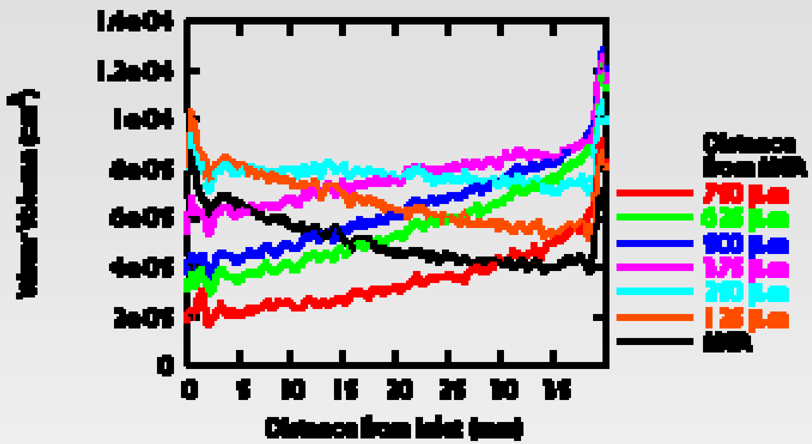
Geometry Comparison 0.5 A/cm^2

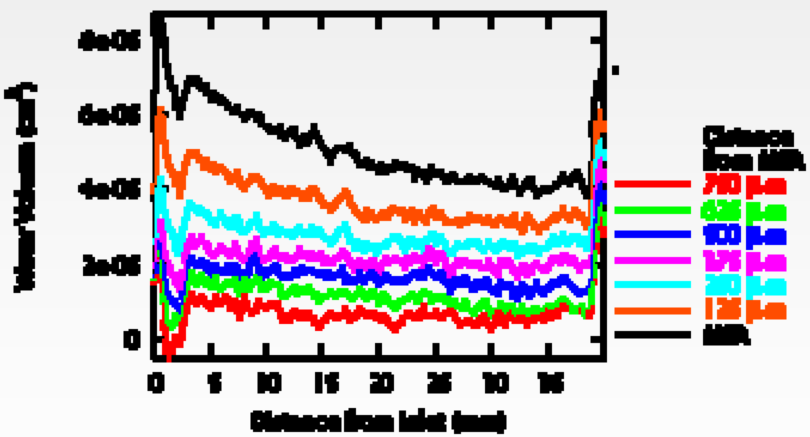


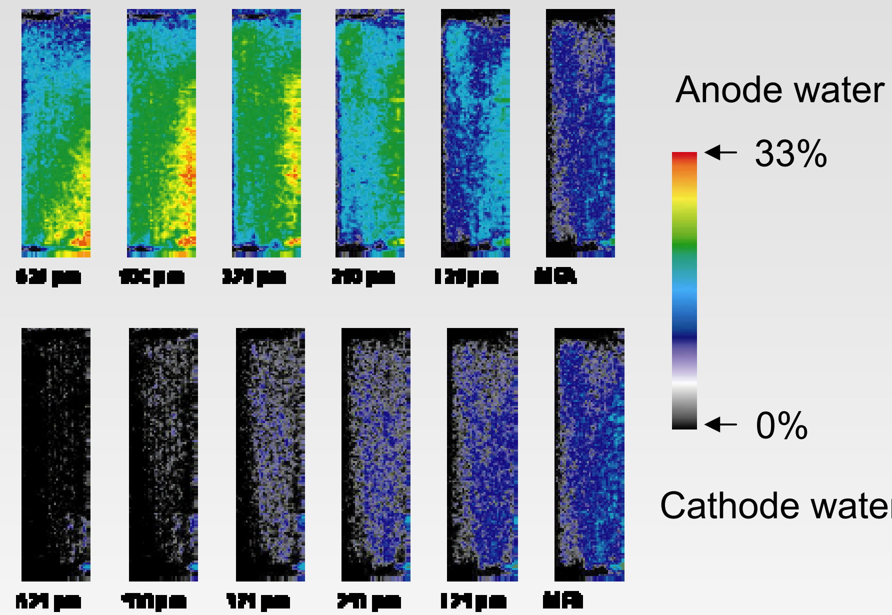


Collaborator: General Motors

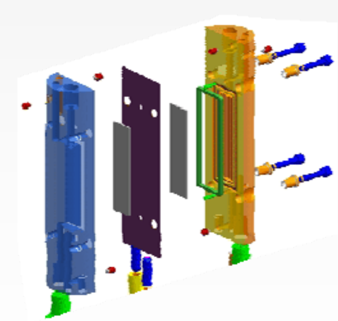
3-D water distribution in an operating PEMFC







Complete 3-D set collected in less than 20 min



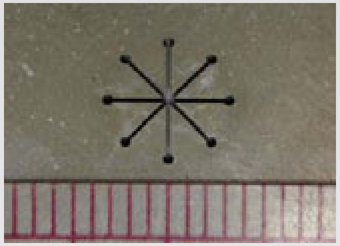
Collaborator: General Motors

Future plans

- Remainder of FY 2006:
  - Incorporate coded source methods into a neutron imaging system.
  - Incorporate 25 micrometer resolution detectors into facility
  - Incorporate Freeze/Thaw capability into facility
  - Incorporate deuterium gas electrolyzer as another contrast and calibration mechanism.
  - Incorporate pure oxygen capability for controlling oxygen to nitrogen ratios.
  - Experiments with collaborators

- FY 2007:
  - Push development of large area detectors with 25 micrometer resolution
  - Image fuel cell stacks with tomography
  - Provide continued neutron imaging support to fuel cell community
  - Experiments with collaborators

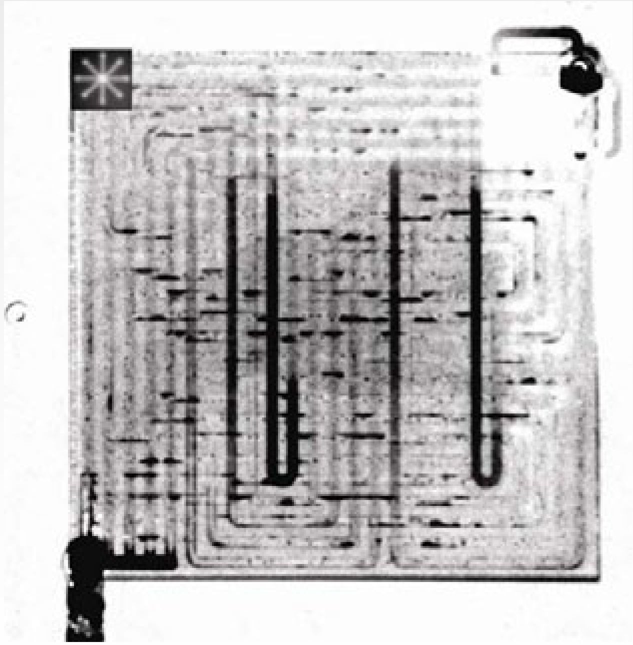
High Resolution Neutron Imaging Detector

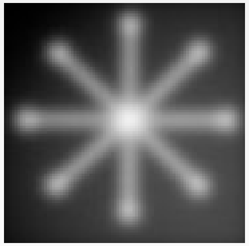


Target

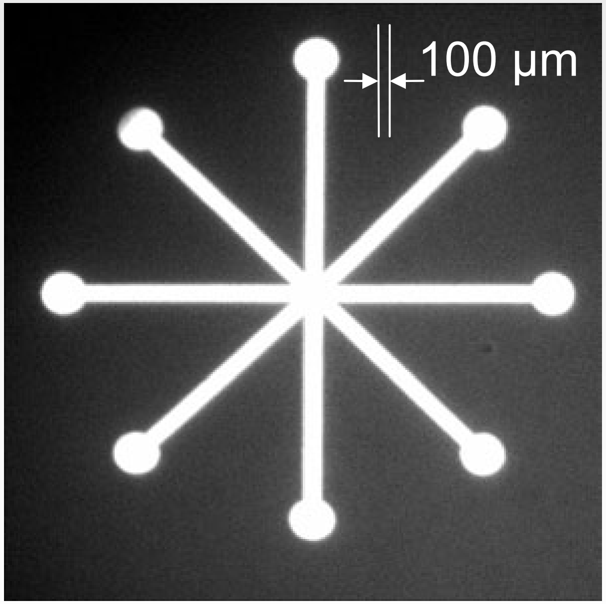
- Detector technology based on MCPs overcomes scintillator resolution limits
- Measured neutron resolution of < 25 microns
- Should be available early fall 2006

Resolution with standard system



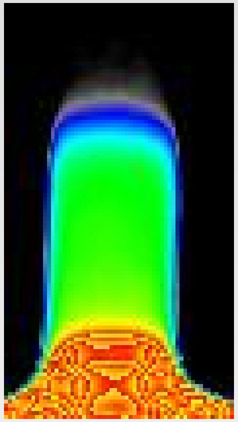


Blurring due to scintillator



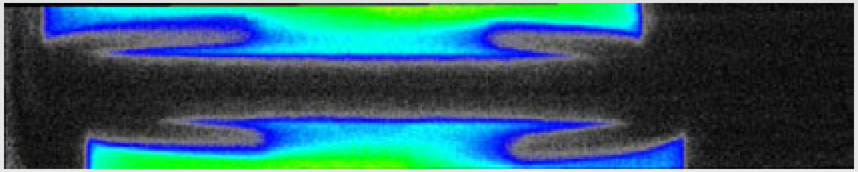
Collaborator: University of California-Berkeley

Properties of porous media

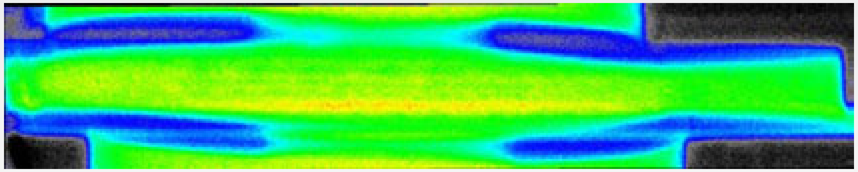


Water uptake of Vycor glass

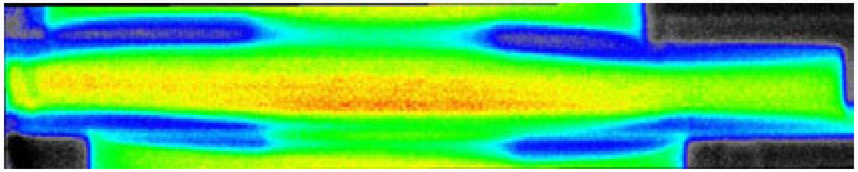
- Measure in-plane permeability and capillary properties of porous media by observing the water head height (article in preparation)
- We can measure the through-plane water permeability in GDL, and other materials



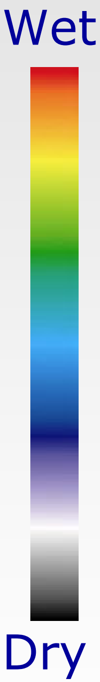
No applied pressure



5 psi applied pressure from top



10 psi applied pressure from top



Collaborator: University of Kansas, University of California-Berkeley

Publications/Talks

D.J. Ludlow, C.M. Calebrese, S. Yu, C. Dannehy, D.L. Jacobson, M.K. Jensen, G.A. Eisman, D. S. Hussey, and M. Arif, "PEM fuel cell membrane hydration measurement by neutron imaging", Journal of Power Sources (accepted).

T. Trabold, J. Owejan, D. Jacobson and M. Arif, "Experimental Method and Serpentine Flow Field Results", International Journal of Heat and Mass Transfer (in press).

J. P. Owejan,*, T. A. Trabold, D. L. Jacobson, D. R. Baker, D. S. Hussey, M. Arif, "Transient Water Accumulation in an Interdigitated Cathode Flow Field", International Journal of Heat and Mass Transfer (in press).

M.A. Hickner, N.P. Siegel, K.S. Chen, D.N. McBrayer, D.S. Hussey, D.L. Jacobson, M. Arif, "Real-time Imaging of Liquid Water in an Operating Proton Exchange Membrane Fuel Cell", Journal of the Electrochemical Society (accepted).

D.S. Hussey, J.P. Owejan, D.L. Jacobson, T. A. Trabold, J. Gagliardo, M. Arif, “Tomographic imaging of an operating proton exchange membrane fuel cell”, (in preparation).

November 17, 2005 in Palm Springs, CA. Gave a talk at the 2005 Fuel Cell Seminar entitled "Neutron Imaging at NIST: An in situ method for visualizing and quantifying water dynamics in low temperature PEM fuel cells.“

November 28, 2005 in Sydney, Australia. Gave a talk at the International Conference on Neutron Scattering entitled "NIST Neutron Imaging Facility for Fuel Cell Imaging.“

Reviewers' Comments

- FC researchers may not understand how best to utilize capabilities. NIST analytical experts may not understand what the real questions are.
  - *We are setting up an expert panel to evaluate merits of proposals*
- Need more exposure.
  - G*atherings like this help*
  - *Website will be available soon*
- Need to continue to make results of their work publicly available -- need to make steady progress towards 50% public research goal.
  - *We have made excellent progress towards that goal*

In Conclusion

- We are providing and will continue to provide a uniquely powerful, one of a kind diagnostic tool that is helping US industry and academia to solve real world problems in fuel cell research.
- A new state of the fuel cell imaging facility has been built and is now operational.
- A wide range of fuel cell related research is being carried out/planned. We can test prototype to commercial grade fuel cells.
- Open publishable research benefiting all users is being encourage. We have reached parity in proprietary and open research
- We are developing cutting edge technology to meet future need
- This program is recognized and featured in the President's **American Competitiveness Initiative** (ACI, 2007) as one of the important technological breakthrough in hydrogen economy related research