Neutron Imaging Study of the Water Transport in Operating Fuel Cells

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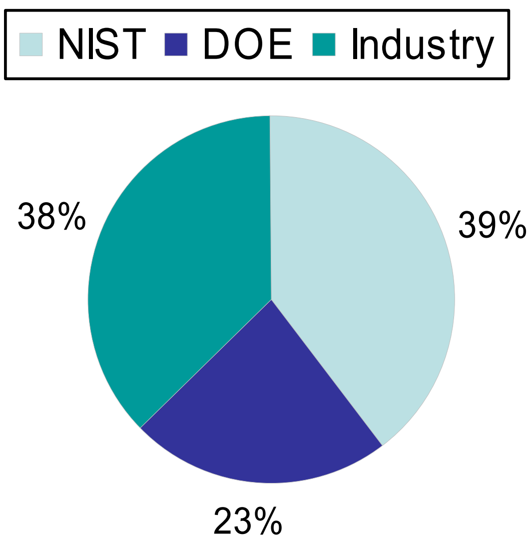
Gaithersburg, Maryland 20899-8461

Overview

Timeline

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

Budget



Total: $1.4M, DOE: $0.3M

Barriers Addressed

Thermal and Water Management.
Water management techniques to address humidification requirements and maintain water balance.

Users/Collaborators

- General Motors
- DiamlerChrysler
- Plug Power
- Sandia National Laboratory
- Los Alamos National Laboratory
- University of Kansas
- Rensselaer Polytechnic Institute (RPI)
- University of Michigan
- University of Waterloo
- University of Delaware
- Rochester Institute of Technology
- Wayne State University
- University of Connecticut
- Illinois Institute of Technology
- University of Tennesse
- Case Western University
- University of Mississippi
- University of California, Berkeley

Objectives of Fuel Cell Imaging at NIST

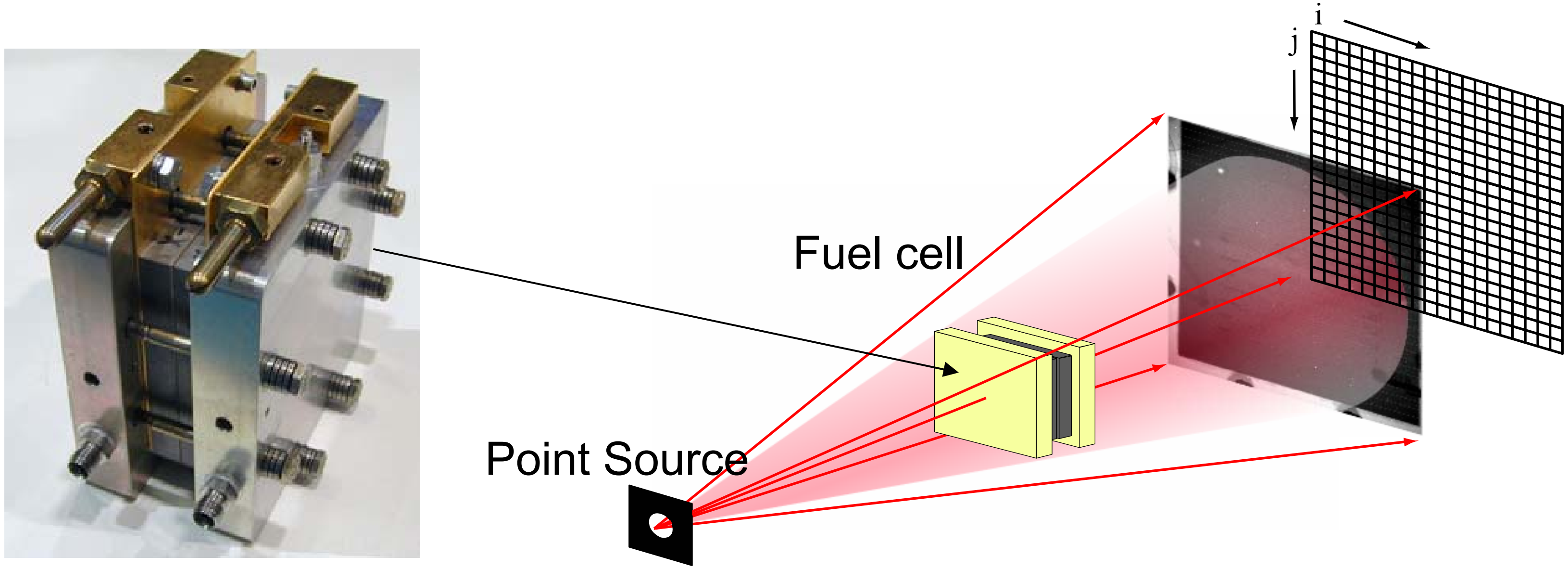
This National Institute of standards and Technology project aims to develop and employ an effective neutron imaging based, non-destructive diagnostics tool to characterize water transport in PEM fuel cells. Objectives include:

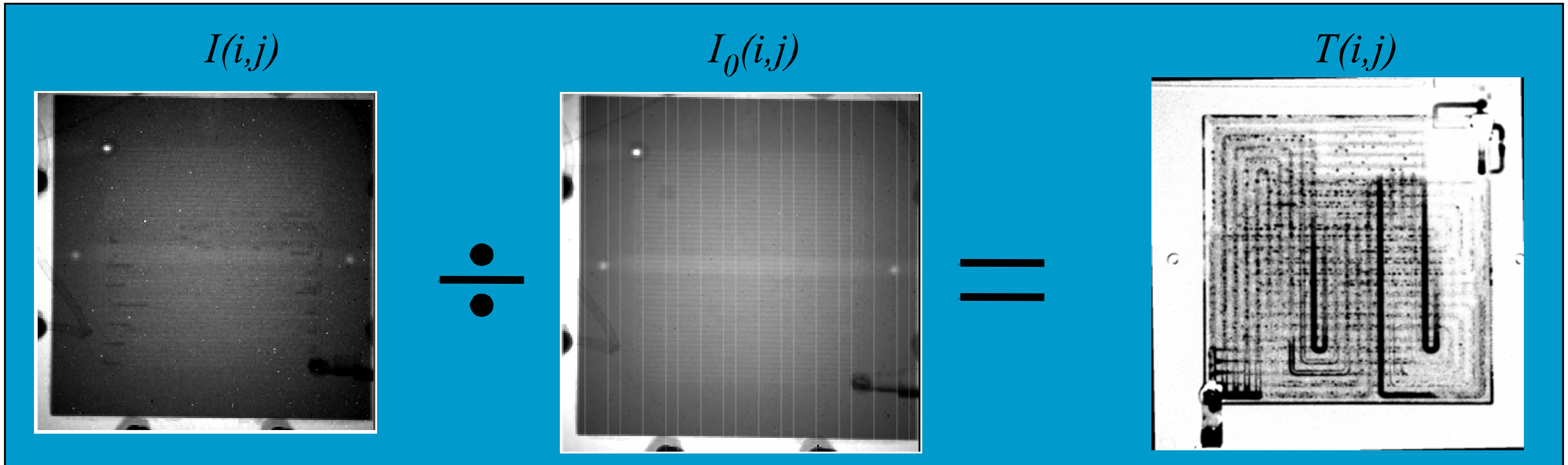
- **F**orm collaborations with industry, national lab, and academic researchers
-
- **P**rovide research and testing infrastructure to enable the fuel cell / hydrogen storage industry to design, test and optimize prototype to commercial grade fuel cells and hydrogen storage devices.
- **M**ake research data available for beneficial use by the fuel cell community
- **P**rovide secure facility for proprietary research by Industry
- **T**ransfer data interpretation and analysis algorithms techniques to industry to enable them to use research information more effectively and independently.
- **C**ontinually develop methods and technology to accommodate rapidly changing industry/academia need

Facility Uses

- We have nearly **doubled** the number of **non-proprietary** research users of the facility in the last year
- ***NO COST*** for open literature research
- Facility is fully subscribed (about 50% proprietary use)
- Typically beam time request exceed available time by 50%
- Proposals are externally peer reviewed for scientific merit.
- Technically reviewed for feasibility.
- Beam time is then awarded by a Program Advisory Committee (PAC) based on the reviews and available beam time.
- Potential users submit proposals through NCNR Proposal system (see links from: www.ncnr.nist.gov)
- Contact David Jacobson or Daniel Hussey with any questions
- Freely available data analysis software written by NIST

Brief Review of Method





Methods Developed

- **High Resolution** Imaging
  - Resolve Water distribution in GDL
  - Unambiguous discrimination of anode from cathode
  - Preliminary Experiments on thick membranes

- **Tomographic Imaging** has been adapted for fuel cells

- **Radiography** is still the bread and butter
  - Only way to measure transient processes
  - One-dimensional cells can be made to validate simple edge on radiography

- **Measurement focus**
  - Through-plane water distribution to understand water transport in the GDL
  - Capillary properties of GDL and Catalyst materials
  - In-Plane Water transport in MEA/Flow channels
  - Simulate real world stack conditions

NIST Neutron Imaging Facility: The world's premier Fuel Cell Neutron Imaging Facility

Freeze Chamber: Air Handler and Sample Environment

Major FY06 Technical Achievements

- High resolution detector in routine use
  - 10x improvement in spatial resolution enables through-plane water measurement
- Freeze Chamber installed in April 2007
  - study environmental impacts in real time with neutrons
- Factor of 2 increase in neutron intensity
  - 40% reduction in time for similar laminar water resolution
- Low flow MFCs in test stand
  - increased flexibility in controlling small active area fuel cells
- Many additions and improvements to data analysis software

High resolution detectors for better imaging

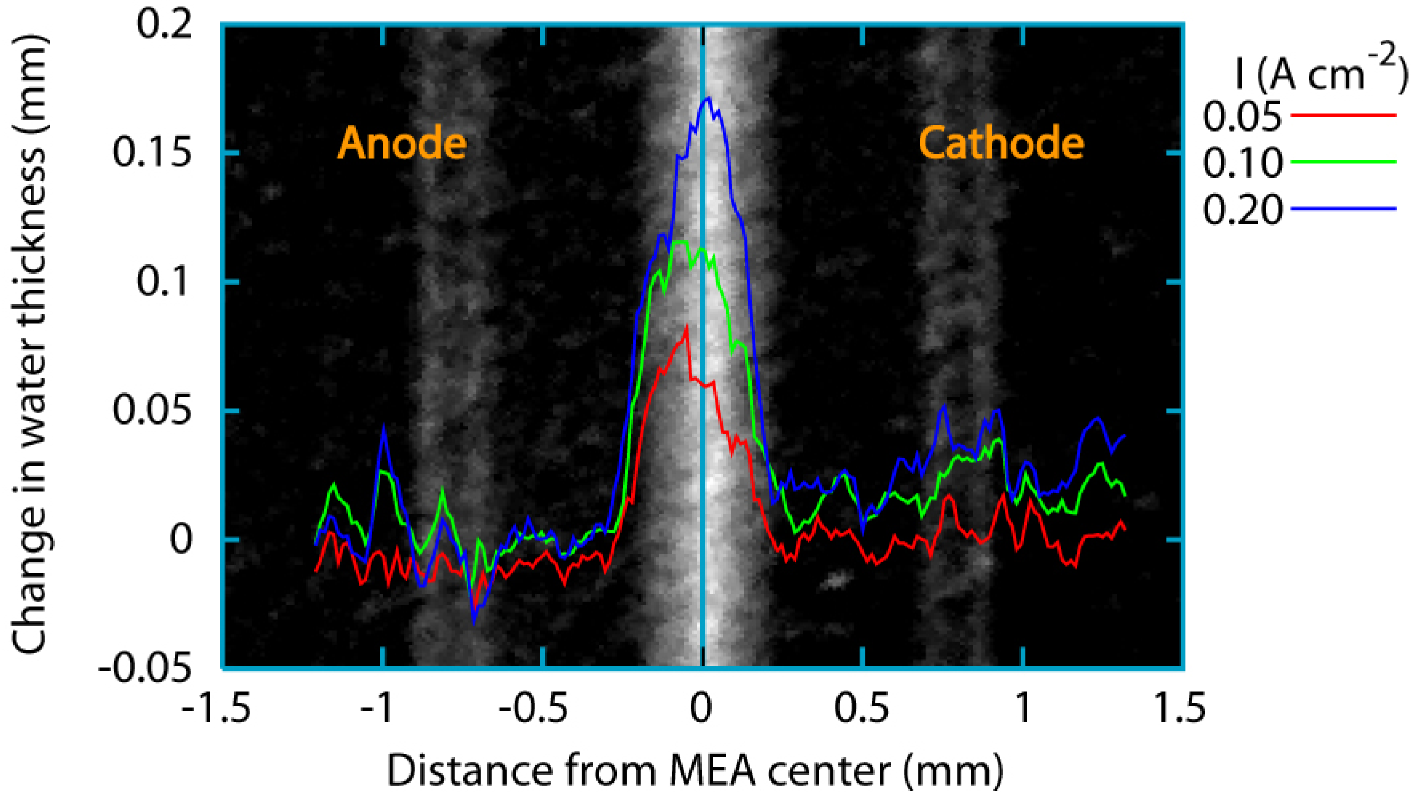
- Spatial resolution improved to **25 micron or better**
- Expect another factor of 2 better by fall of 2007
- Will begin proof of principle testing of **10 micron** spatial resolution by end of 2007

Collaboration:

- Berkley Space Sciences Laboratory
- Sensor Sciences, LLC.
- NOVA Scientific

Enhanced Resolution is Critical for MEA Studies

First Data with 25 micron resolution



- Resolving the membrane swelling complicates data analysis
- Use 0.02 A cm^{-2} as the reference state to analyze change in water content
- Improved mounting scheme will eliminate the issue
- ***Detector is in routine use, available to all users!***

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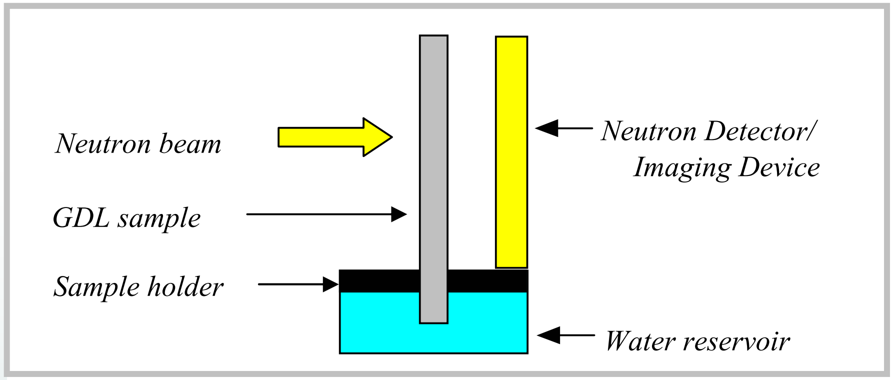
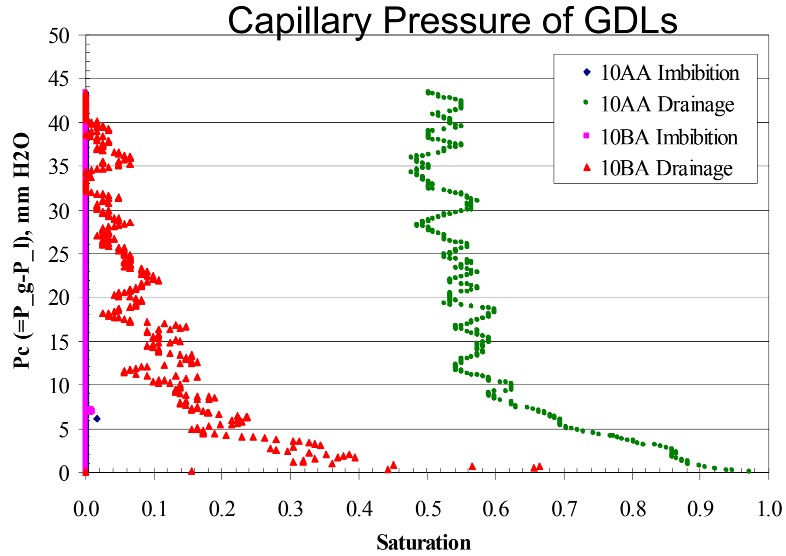
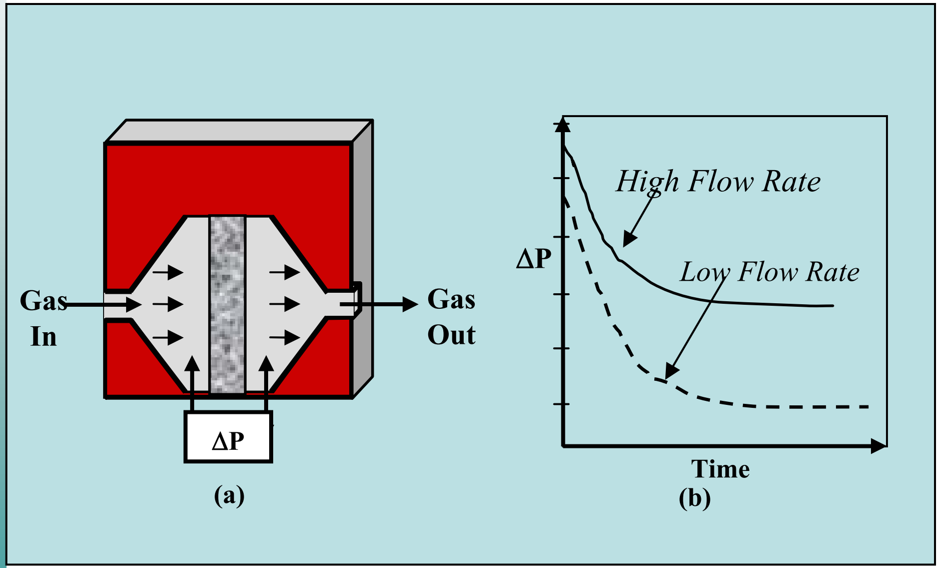
General Motors Fuel Cell Activities

Capillary properties of GDLs and Catalyst layers

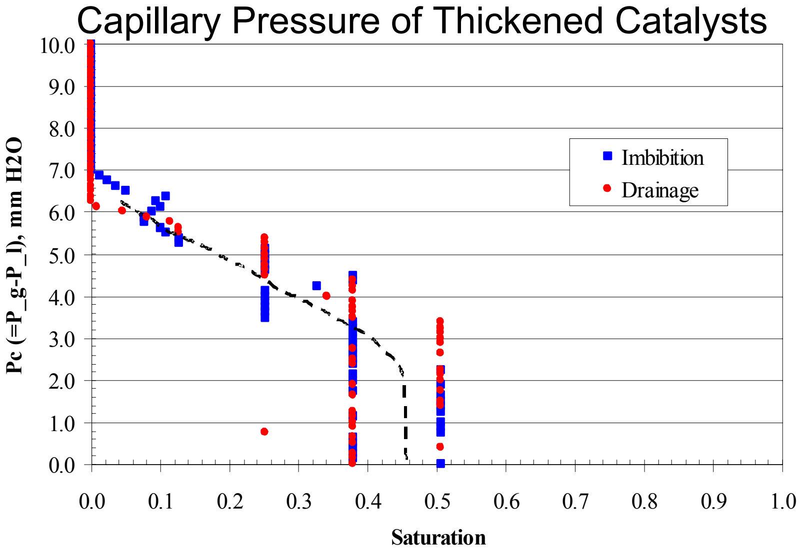


Sketch of Capillary Pressure Experiment





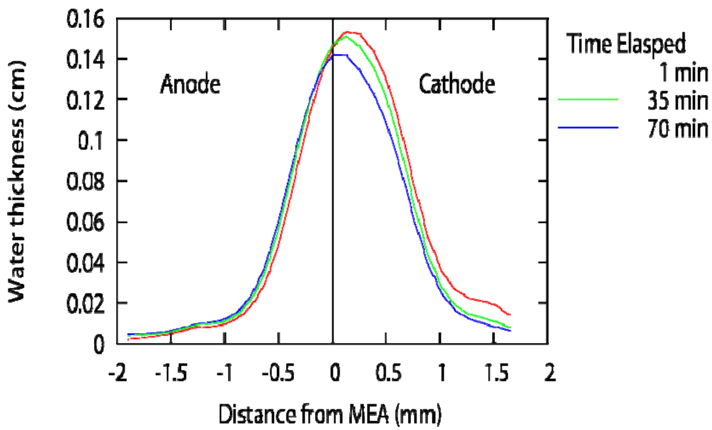
Gas Permeability versus saturation



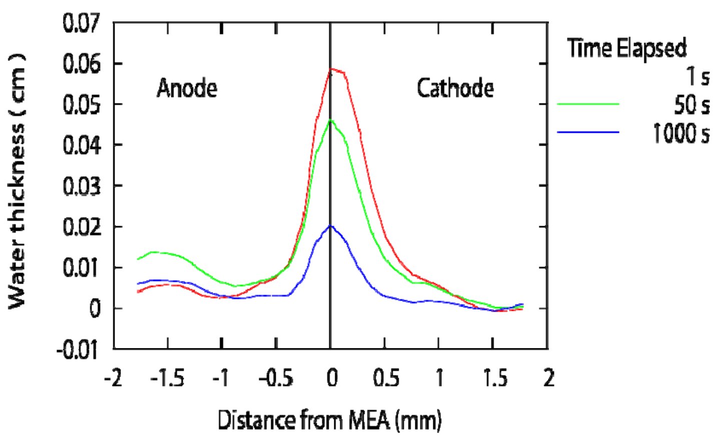
In collaboration with T.V. Nguyen, et al

GDL Water Transport

- Previous tomography experiments suggested “edge-on” imaging would yield transient water profile in the GDL
- Ran small (4 cm^2) cell for 2 h to establish steady state conditions
- Water concentration is max in the Cathode GDL
- Two types of experiment:
  - Cease current load and gas flows – changes due to capillary forces
  - Cease current load, maintain gas flow – changes due to capillary and evaporation
- Capillary forces seem to be insignificant compared to evaporation



Capillary Forces Only



Evaporation and Capillary

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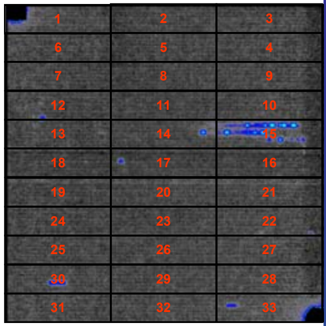
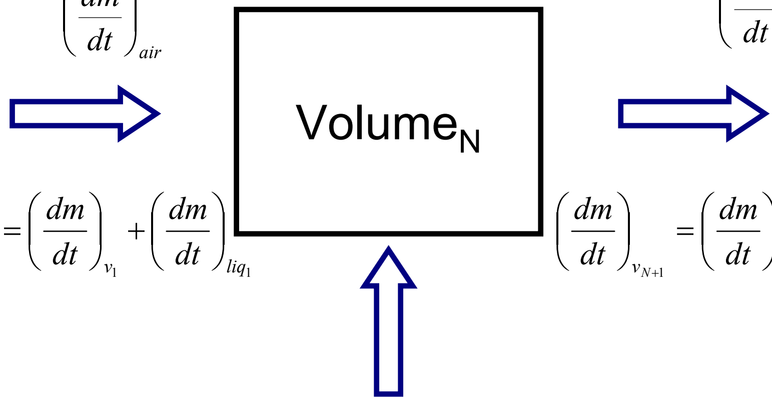
Moving Outwards: Down-Channel Condensation Model



- Models should be able to develop a basic understanding and predictive power of a single cell.
- Important Predictions
  - Onset of water condensation
  - Overall water content
- Data analysis is tailored to analyze segments of the image in order to follow serpentine pattern.
- Measuring water content allows one to determine onset of condensation, which should be predicted by the model.
- Current model does predict onset of condensation to within one segment at different operation conditions.

$$\omega_2 = \frac{\left(\frac{dm}{dt}\right)_{v_1} + \left(\frac{dm}{dt}\right)_{liq_1}}{\left(\frac{dm}{dt}\right)_{air}}$$

$$\omega_{N+1} = \frac{\left(\frac{dm}{dt}\right)_{v_N} + \left(\frac{dm}{dt}\right)_{liq_N}}{\left(\frac{dm}{dt}\right)_{air}}$$



$$\left(\frac{dm}{dt}\right)_{v_2} = \left(\frac{dm}{dt}\right)_{v_1} + \left(\frac{dm}{dt}\right)_{liq_1}$$

$$\left(\frac{dm}{dt}\right)_{v_{N+1}} = \left(\frac{dm}{dt}\right)_{v_N} + \left(\frac{dm}{dt}\right)_{liq_N}$$

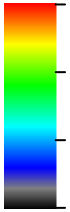
$$\left(\frac{dm}{dt}\right)_{liq_N} = \frac{I \cdot A_{DV}}{2F}$$

Logical test applied at the exit of each volume:

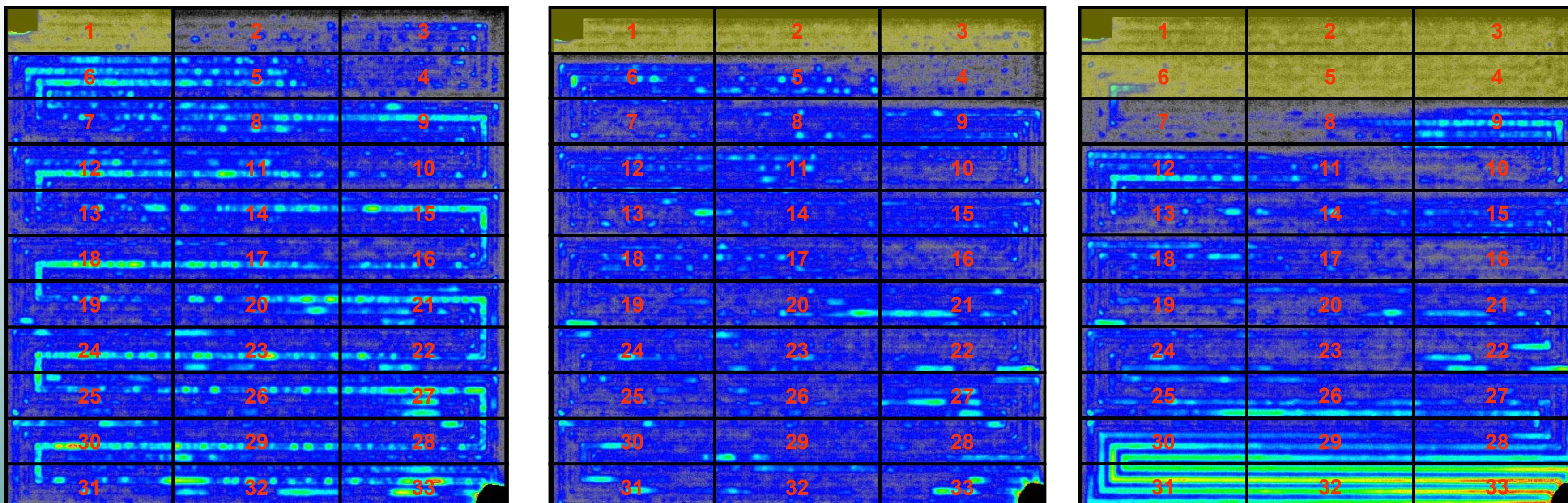
If ($\omega_{N+1} > \omega_{\max_{N+1}}$) ***Then*** Volume$_N$ = Saturated

$$\omega_{\max_2} = \frac{MW_{H_2O}}{MW_{Air}} \cdot \frac{P_{sat}(T_{exit})}{P_{tot_2} - P_{sat}(T_{exit})}$$

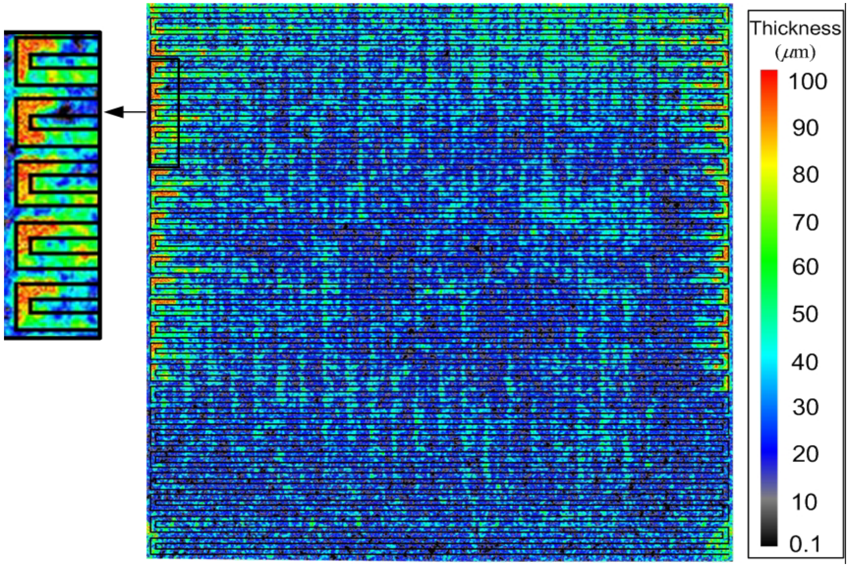
Down-channel condensation – Bulk Cell Temperature of 60°C



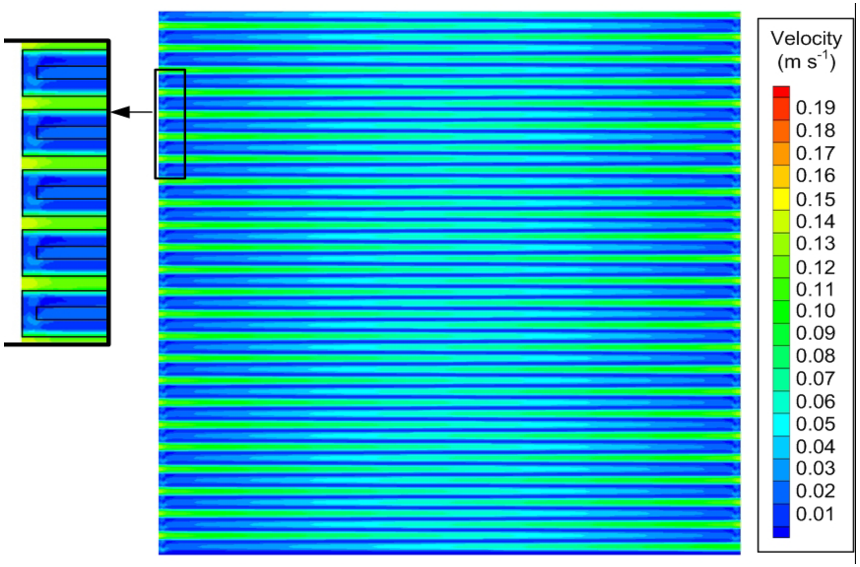
0.5 A/cm²	1.0 A/cm²	1.5 A/cm²
cell 2 – predicted	cell 4 – predicted	cell 7 – predicted
cell 2 – actual	cell 5 – actual	cell 8 – actual



Modeling a single serpentine

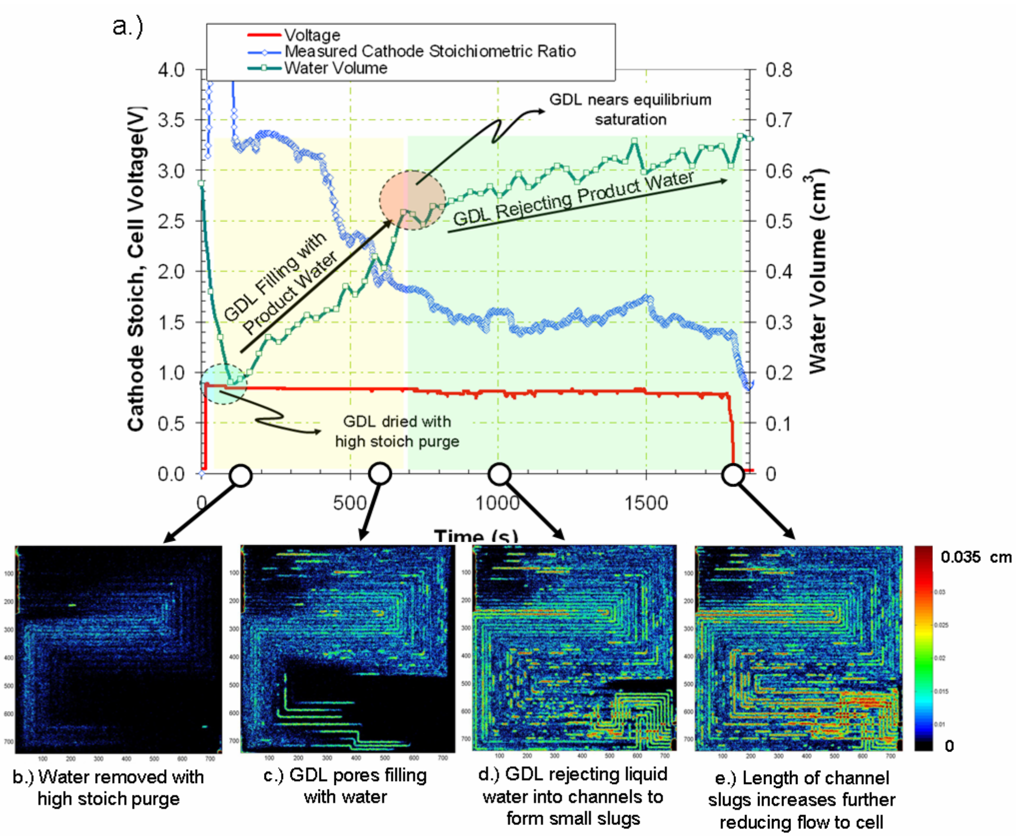


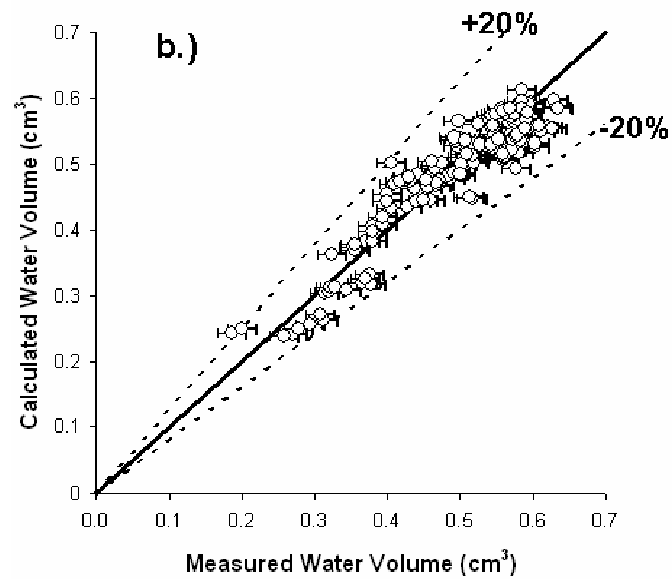
Neutron Imaging Data

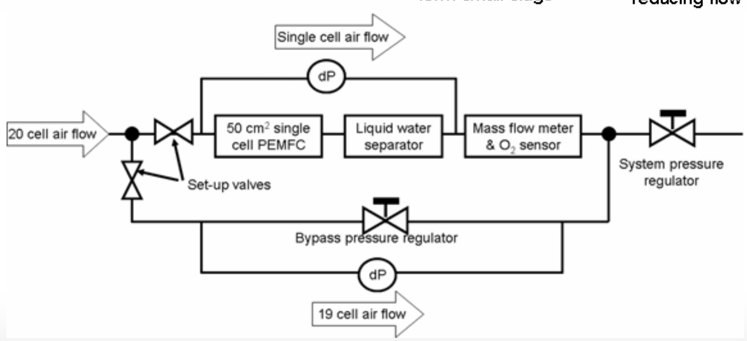


Fluent Model

Stack Simulation







- Separate anode and cathode purges determine cathode GDL water content
- Assume a functional form for the GDL water content and cathode stoichiometry below cathode GDL saturation
- Derive an empirical correlation that is time independent between cathode GDL water content and stoichiometry
- Above cathode GDL saturation, liquid water enters channels
- Cathode stoichiometry falls below one when about 90 % of the channels are flooded

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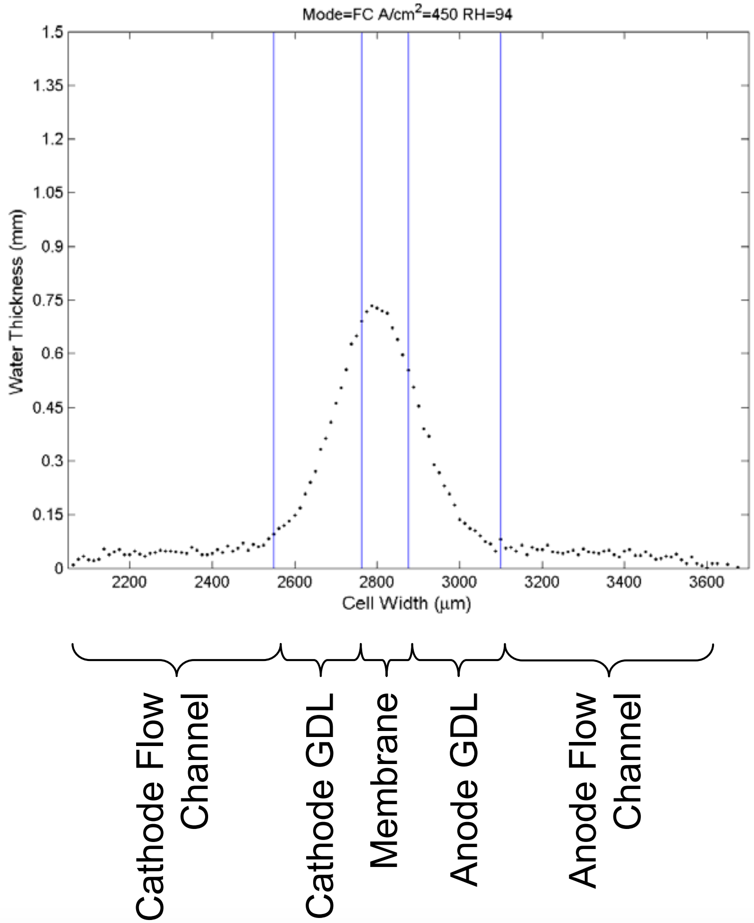
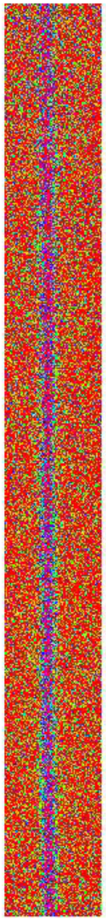
General Motors Fuel Cell Activities

Potential of High Resolution imaging beginning to be realized

Average water thickness across the center region of the fuel cell (flow channels, GDL, and membrane)





- Goal: Measure membrane water content vs conductivity
- Initial experiments are promising

Plans for future work:

- Improve experimental technique
  - More thorough cell dehydration
  - Perform dehydration experiments prior to neutron imaging experiments.
- Dedicated impedance instrumentation
  - AC Spectroscopy
  - Sweep through a range of frequencies
  - Allow for impedance measurement during open circuit condition and during dehydration

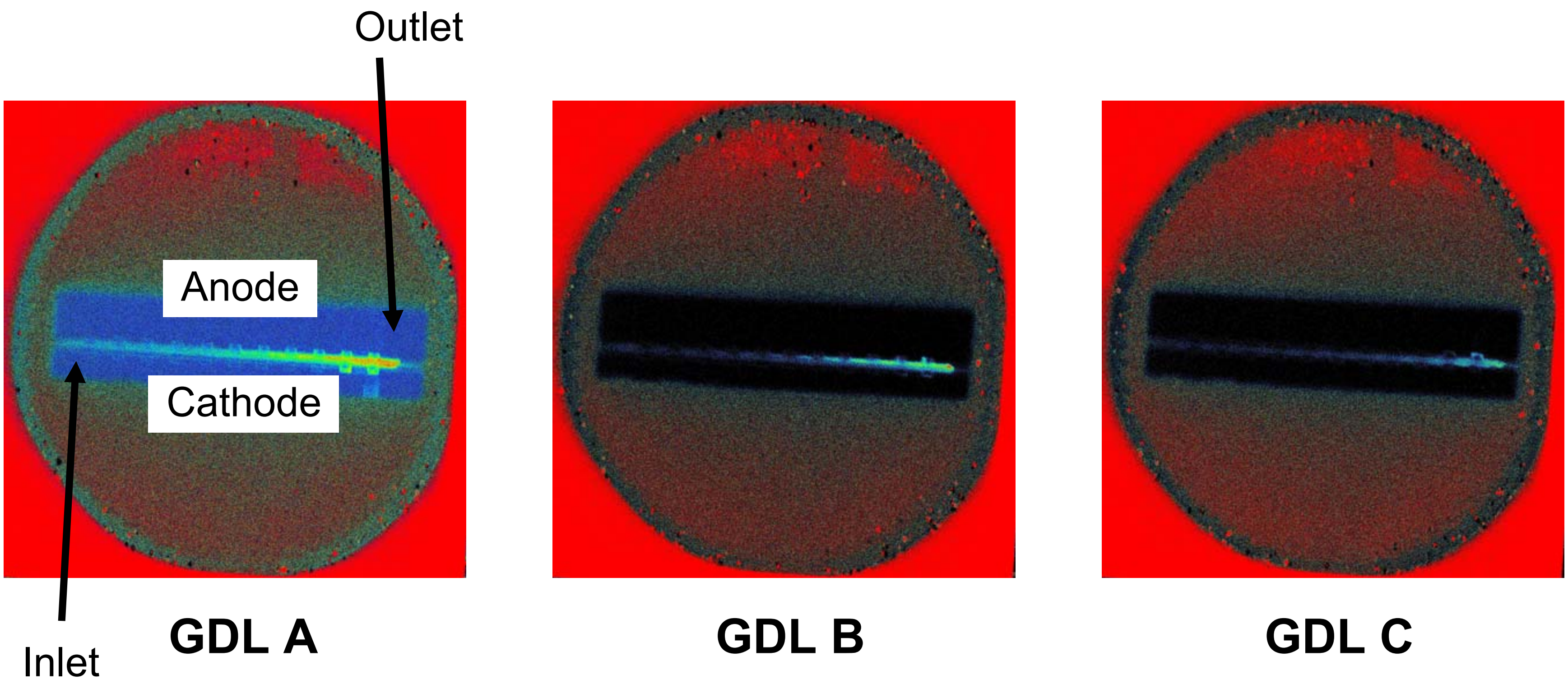
Image of water thickness

NIST Project ID #: FC2

Rensselaer

In collaboration with D.J. Ludlow, M. Silva, M.K. Jensen, G.A. Eisman

GDL Characterization with High Resolution Detector

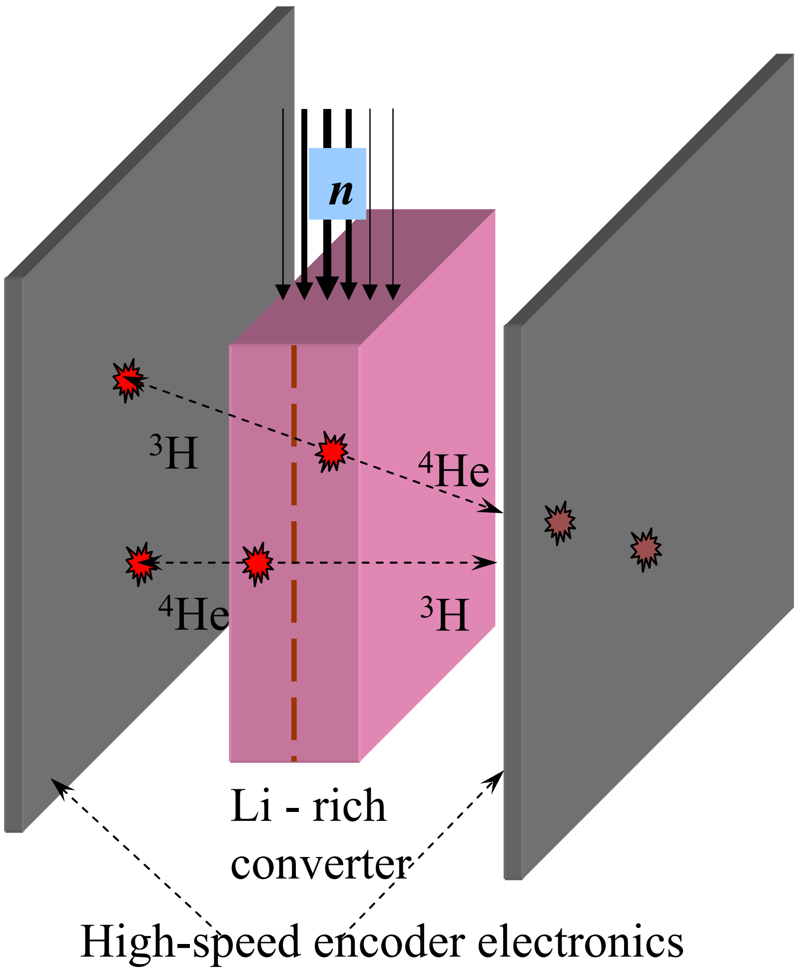


See Poster FCP24, Wed. May 16 for more details

Los Alamos
R. Mukundan, R. Borup, J. Davey, T. Rock

Future work: Sub-micron Resolution?

- Current technology resolution limit is 10 microns
- “Quantum Leap” in detector technology will resolve membrane water profile
- Neutron capture by ^{6}Li results in emission of two charged particles
- The initial energies are well known
- Using Time of Flight difference, the neutron capture event can be localized with an uncertainty of ***0.1 micron***
- ***With 0.1 micron resolution, neutron imaging could resolve water content of catalyst layers***
- Proof-of-concept experiment to happen this year
- ***NIST Internal Research***



Future Work

- Anticipate receipt of 10 micron resolution detector in Fall 07
  - Highly resolved measurement of through-plane GDL water content and coarse measurement of MEA water content
- First Freeze Chamber experiments starts late spring, 07
  - Study Environmental impacts on fuel cell performance and durability
- Possible new Cold Neutron Imaging Facility incorporated into the NIST Center for Neutron Research Expansion
  - Increased sensitivity to water and improved neutron detection efficiency
- Proof-of-Principle work on sub-micron resolution detector
  - Highly resolved measurement of through-plane MEA water content

Summary

- The NIST Neutron Imaging Facility is the world's premier facility for fuel cell neutron imaging
  - High resolution (25 microns) neutron imaging is routinely available
  - We continue to develop methods to improve image resolution
  - Neutron imaging during a freeze-thaw process is now available
  - Fuel cell infrastructure is added, updated, and maintained to meet user needs and suggestions

- The number of participating groups using the NIST Neutron Imaging Facility has nearly doubled, and many first time users are planning experiments for remainder of FY07

- A broad range of water management issues is being investigated and published

- Visit: http://physics.nist.gov/MajResFac/NIF/index.html
  for more details and facility access