# Transport in PEMFC Stacks

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Project ID # FC054

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# Transport in PEMFC Stacks

## Timeline
- Begin 11/1/2009
- End 10/31/2012
- 43% Complete

## Budget
- Total Project Funding
  - $2.66M DOE Funding
    - o FY10 $271,507
    - o FY11 $860,774
  - $678K Recipient
  - 20% Cost Share

## Barriers Addressed
- Performance
- Water Transport within Stack
- System Thermal and Water Management
- Start-Up and Shut Down

## Technical Targets
- *Cold Start-up Times*
- *Specific Power Density*
- *Stack Power Density*
- *Stack Efficiency*

## Partners
- University of S. Carolina
- Virginia Tech
- Tech Etch
- Ballard Materials

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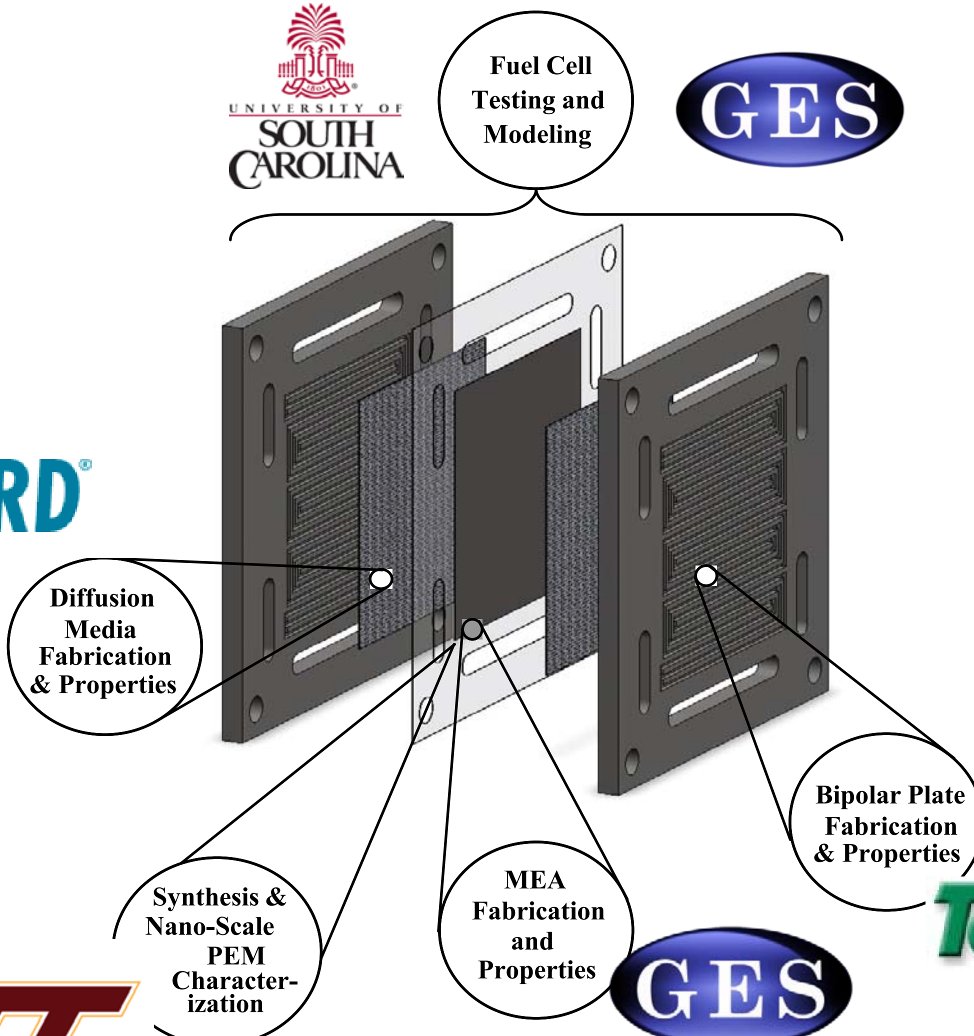
# Approach: Team and Tasks




Tech Etch, Virginia Tech and Ballard providing materials

GES, VT and Ballard providing component characterization

GES and USC doing fuel cell testing

USC Modeling

*Focus on transport and role of water*

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# Approach & Milestones

| Year | Techniques | Materials | Modeling |
|---|---|---|---|
| Year 1 | New technique generation for static and dynamic diffusion, EODC, through plane conductivity confirmation with Baseline materials. (90%)<br>Current Distribution Board Demonstration (100%) | Baseline hydrocarbon PEM generated and down selected (80%)<br>Baseline Gas Diffusion Media Delivered (100%)<br>First Etched Plates (100%) | Set-Up of Model (100%)<br>Use of Baseline materials for Testing (80%)<br>Model Sensitivity Testing (50%) |
| Year 2 | Techniques applied to alternative materials.<br>Diffusivity apparatus used to characterize alternative diffusion media. | Scale-up of Baseline PEM<br>Integration of catalysts<br>Modification of diffusion media<br>Alternative Plates & Design of larger plates. | Performance and water balance modeled and confirmed with baseline materials and hydrocarbon PEM.<br>Alternative diffusion media tested. |
| Year 3 | | Delivery of Large PEMs<br>Current Distribution board for larger plate<br>Fabrication of larger plate and current distribution board | Modeling extended to larger cells.<br>Effect of coolant/heat transfer.<br>Model confirmation with current distribution and water balance. |

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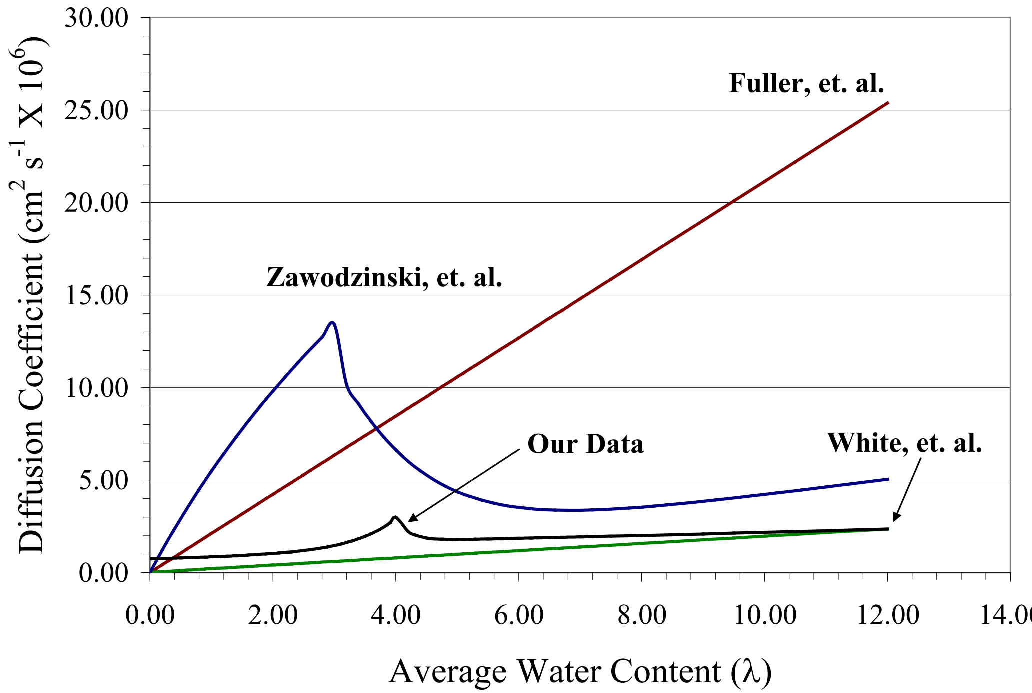
# Develop New Techniques for Measurement of Key Parameters

- In developing a model for transport in fuel cell systems, the first thing that is needed is the key transport numbers
  - Diffusivity
  - Water Uptake
  - Electro-osmotic Drag
  - Through Plane Conductivity
- *NOTHING EVEN RESEMBLING CONSENSUS ON THESE FUNDAMENTALS*

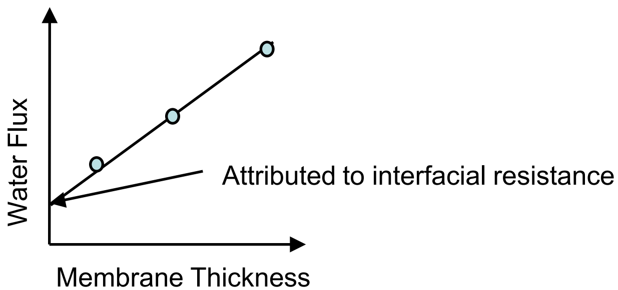




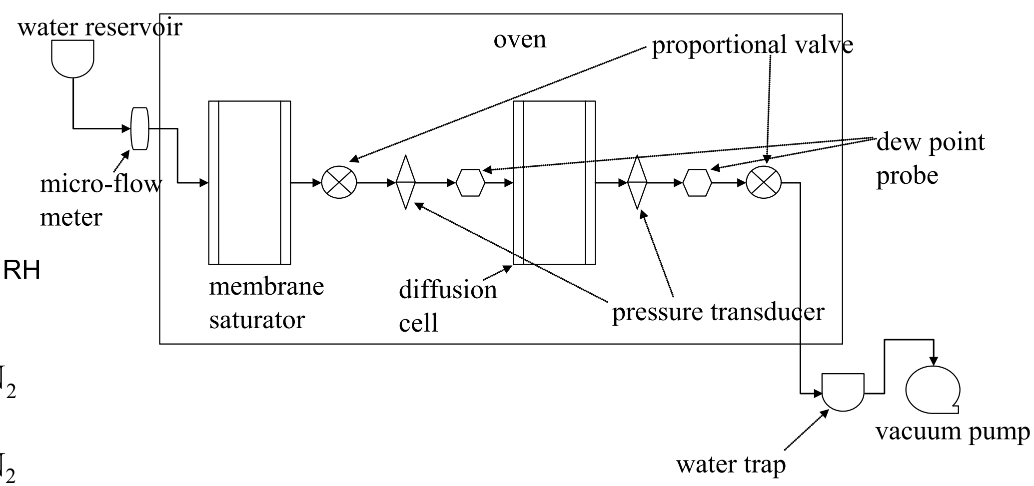
T.A. Zawodzinski, M. Neeman, L.O. Sillerud and S. Gottesfeld, *J. Phys. Chem.*, **95**, 6040 (1990)
T.F. Fuller, Ph.D. Thesis, University of California, Berkeley, CA (1992)
T.V. Nguyen and R.E. White, *J. Electrochem. Soc.*, **140**, 2178 (1993)
Equations of the form of: S. Motupally, A.J. Becker and J.W. Weidner, *J. Electrochem. Soc.*, **147**, 3171 (2000)

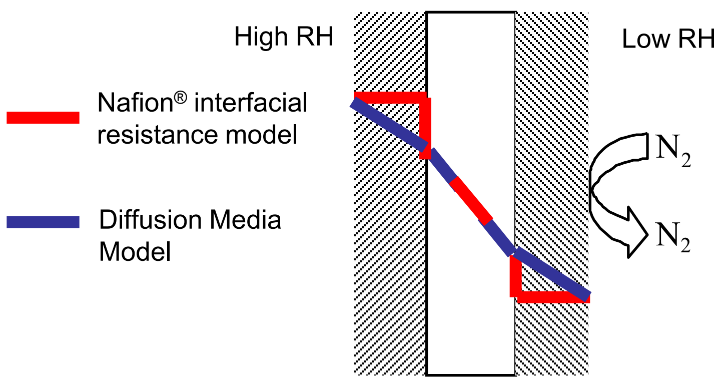
# Achievements: New Techniques: Diffusivity

- Disagreement in literature as to whether an “interfacial resistance” exists with Nafion®




**By eliminating inert gases we can eliminate non-membrane diffusion**




- Only water vapor no convection

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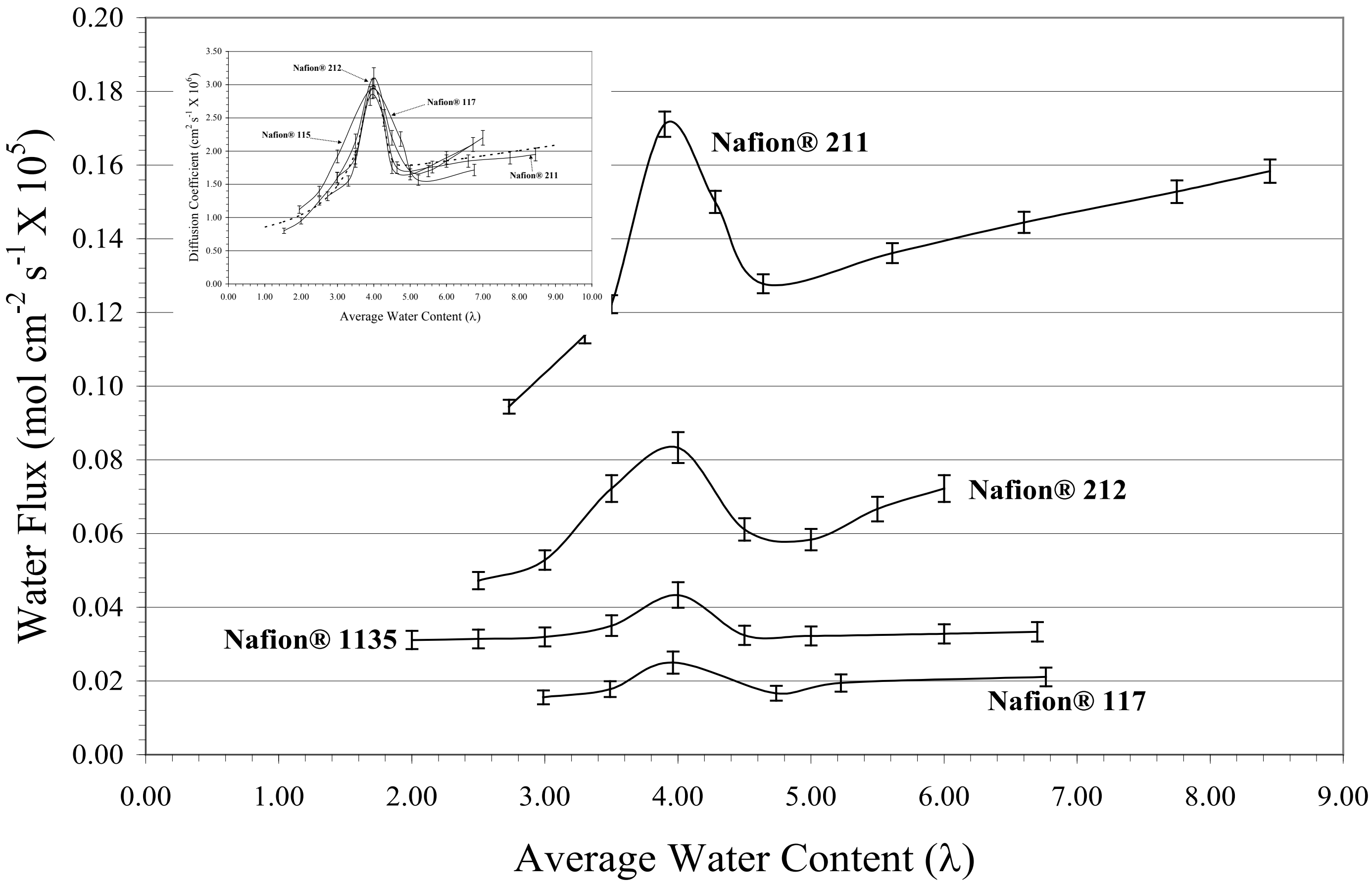
# Water Flux Data, T = 80 C




- Water flux scales with thickness
- *NO INTERFACIAL RESISTANCE*

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# Achievements: New Techniques:

## Diffusivity Static *vs.* Dynamic Gradients

- In previous example water transport takes place across a static gradient; water content through thickness of the membrane does not change
- When there is a change in RH the membrane must "grow" or "shrink" to accommodate water or fill in void.
- There are internal viscoelastic forces restraining this process so transport in a dynamic gradient may be slower, especially for water uptake as water has to perform work.

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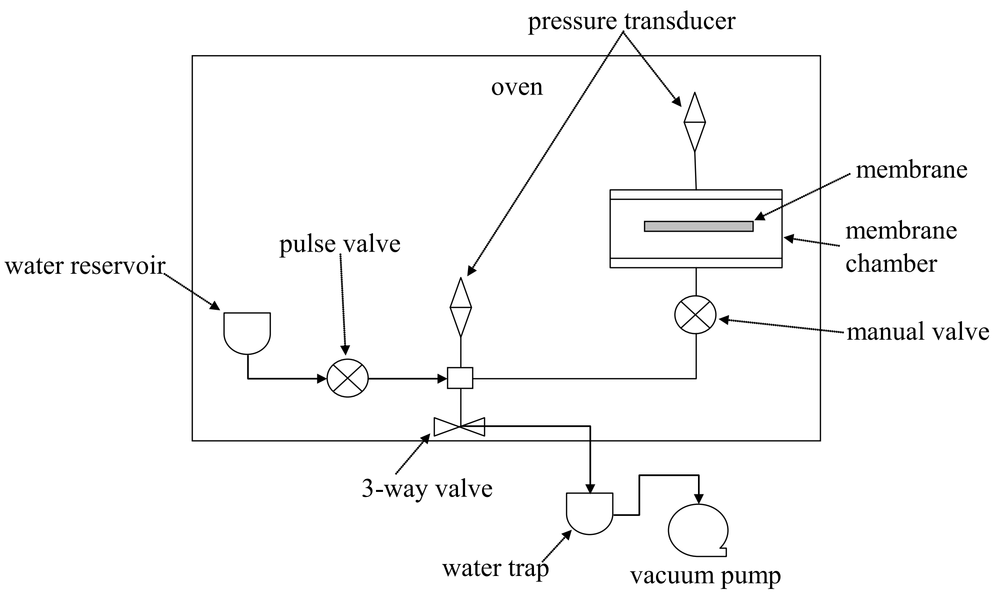
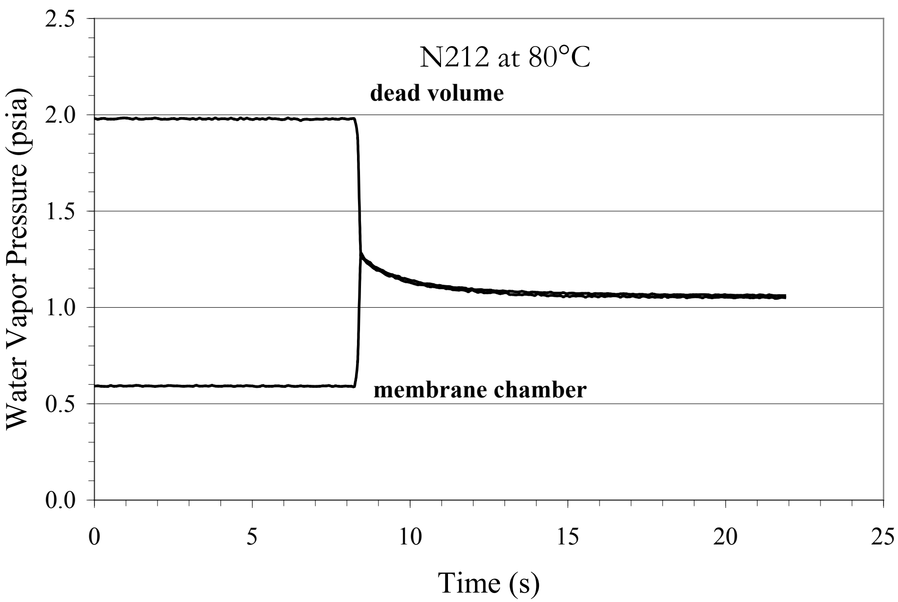
# Dynamic Water Uptake/Transport: Dynamic Diffusivity




Again by eliminating inerts we eliminate non-membrane diffusion

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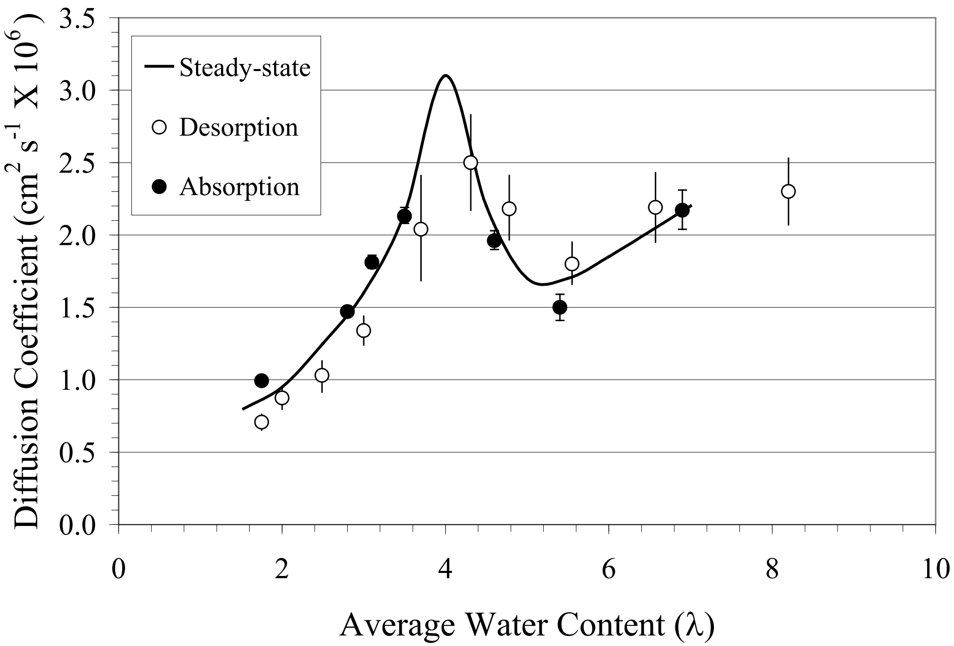
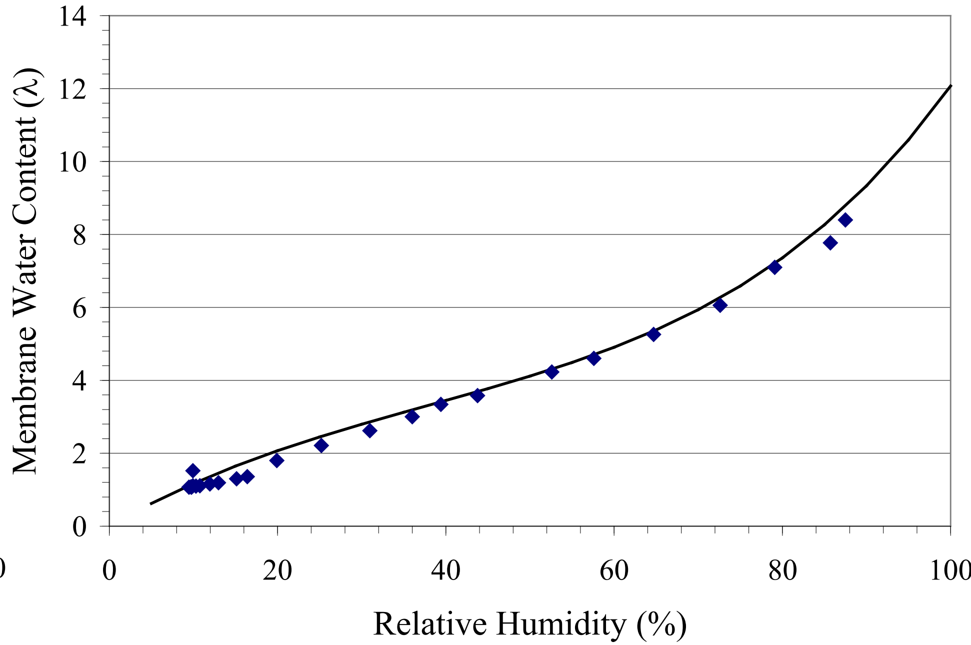
# Water isotherms are also obtained!

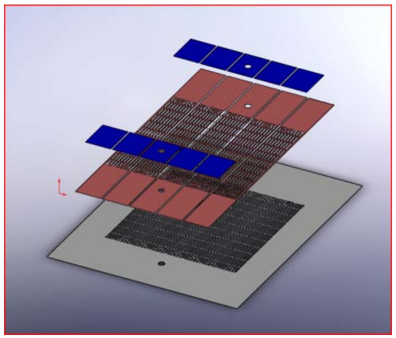


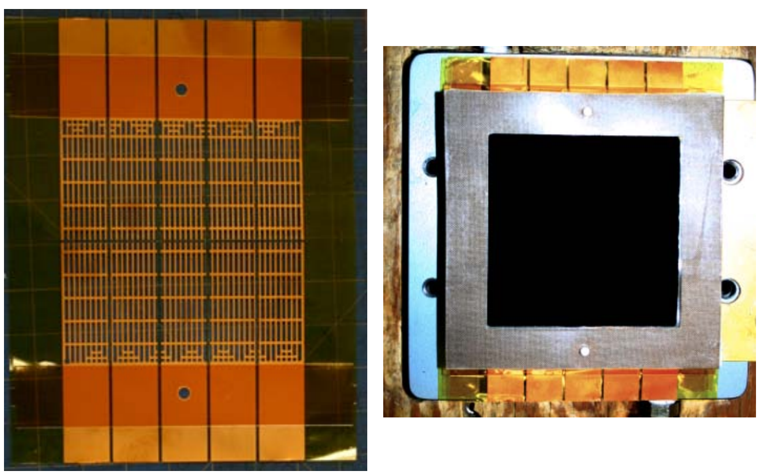

- Diffusivity is the same for absorption, desorption and steady-state measurements
- Isotherms are also obtained
- *Simultaneous isotherm; permeability & diffusivity*

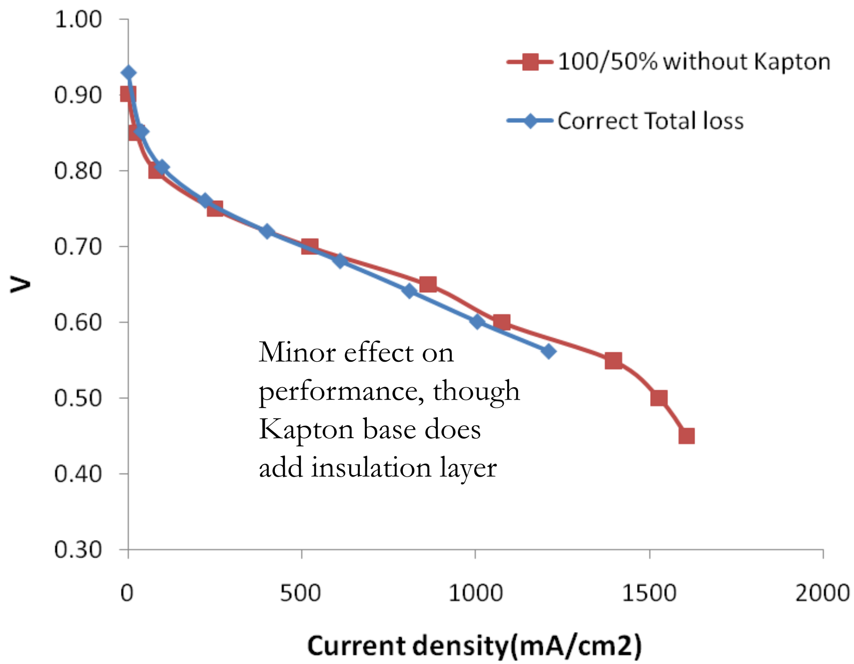
# Achievements: New Techniques: Current Distribution

**Many methods for current distribution significantly affect flow path and break up diffusion media. Others are very expensive. Needed a cheap way without disrupting flow.**



Concept tested in common 50 $cm^2$ hardware first; *Adds only 1.5 mΩ resistance for 50 $cm^2$ cell*
Will make available to other groups






Tcell= 80$^0$C,RH%=100/50,Stoich=1.5/2

More work needed on the data acquisition end, but concept is shown

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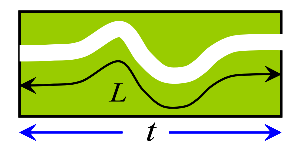
# Achievements: New Materials: Diffusion Media

- Ballard added to the program recently
- Started with Toray Materials
  - Variable Wet-Proofing
  - Microporous Layer
- Ballard will provide more custom materials
- Want to generate differences in:
  - MacMullin Number
    - Porosity
    - Tortuosity
  - Hydrophobicity

•Tortuosity

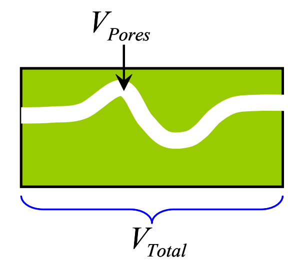
– Ratio of the actual path length through the pores to the shortest linear distance between two points.




$$\tau = \frac{L}{t}$$

•Porosity

– Ratio of void volume (volume of pores) to the total volume.




$$\varepsilon = \frac{V_{Pores}}{V_{Total}}$$

•MacMullin Number

– Function of tortuosity and pososity.

$$N_M = f(\tau, \varepsilon) = \frac{\tau^n}{\varepsilon^m}$$

# Achievements: New Materials: Diffusion Media

Photo micro-graphs of cross-section: Toray TGP-H-060 under different treatments

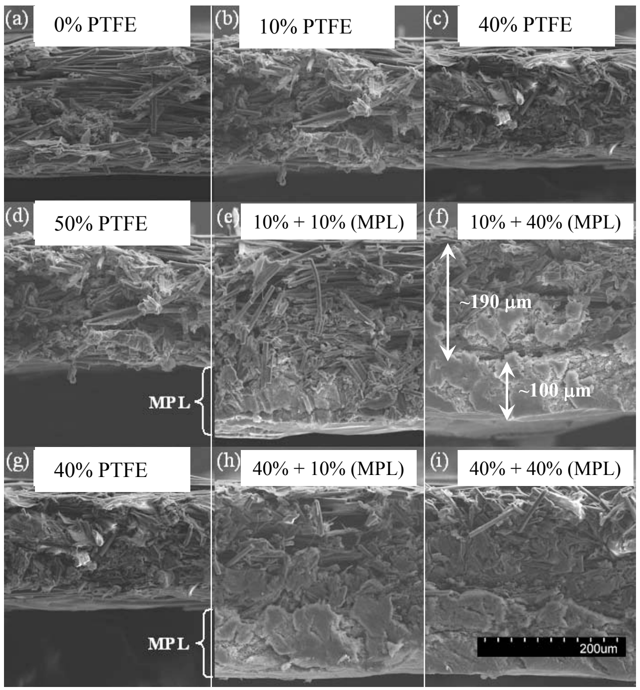
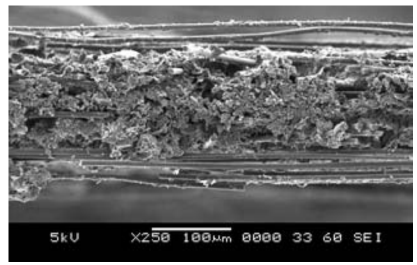
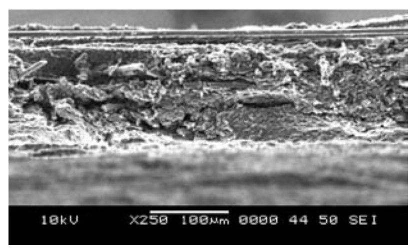


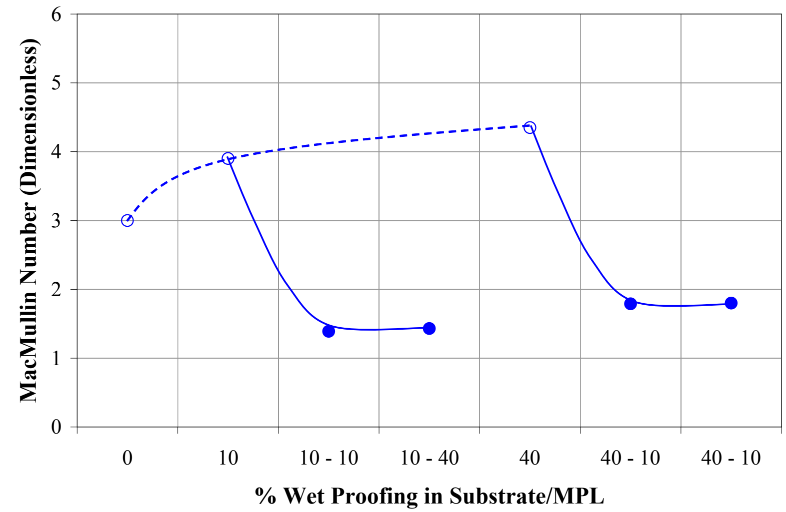

Photo micro-graphs of cross-section: Ballard GDLs

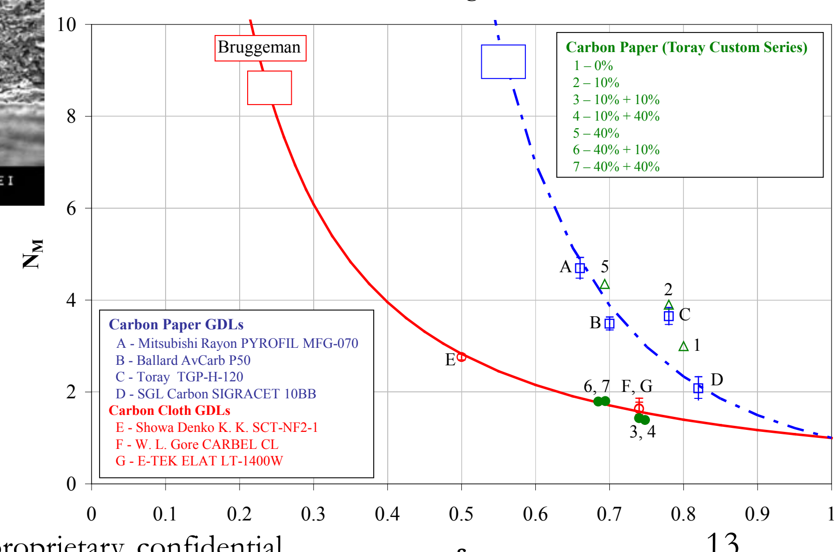



EP40




P50




MPL: Microporous Layer

*With current materials, we have a wide variation in MacMullin number, porosity, and hydrophobicity.*

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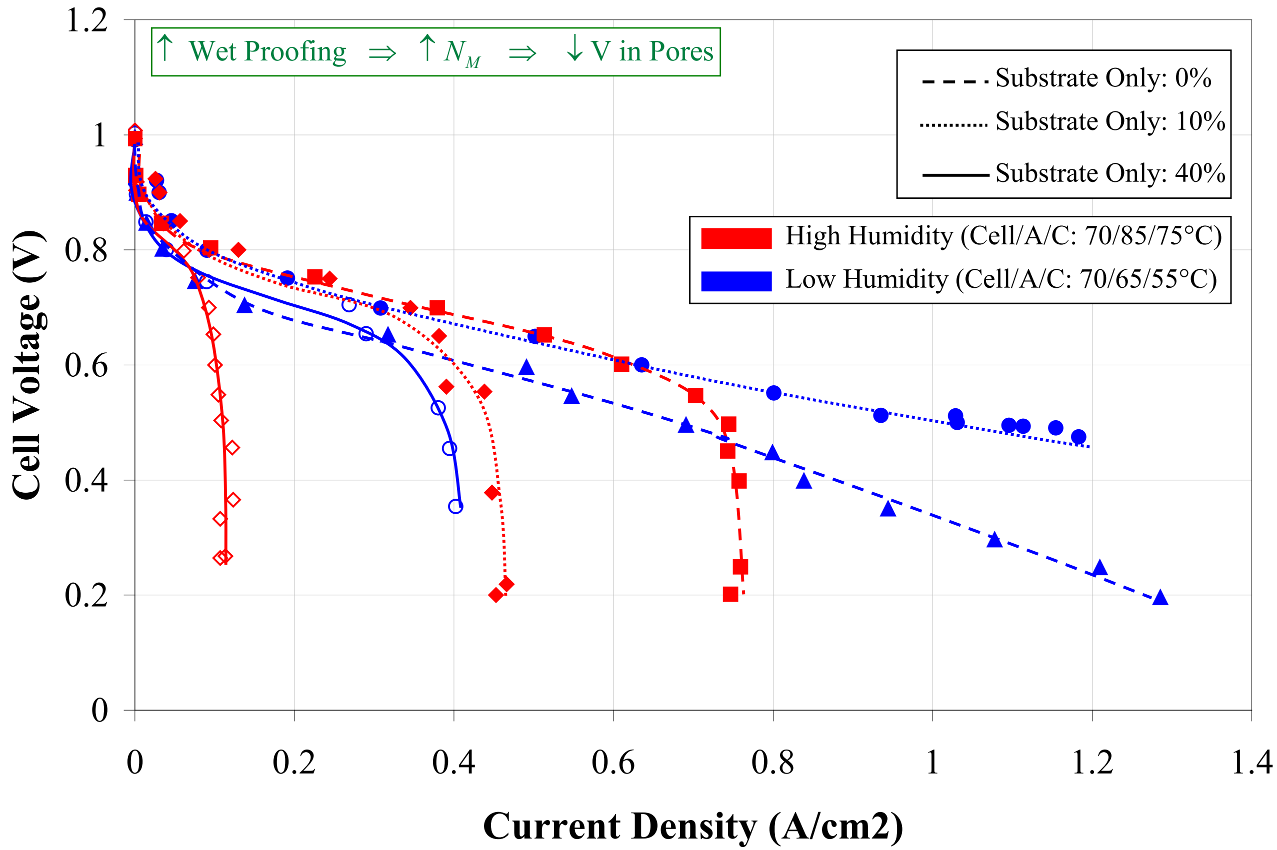
# Achievements: New Materials: Diffusion Media

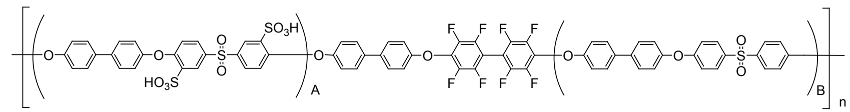


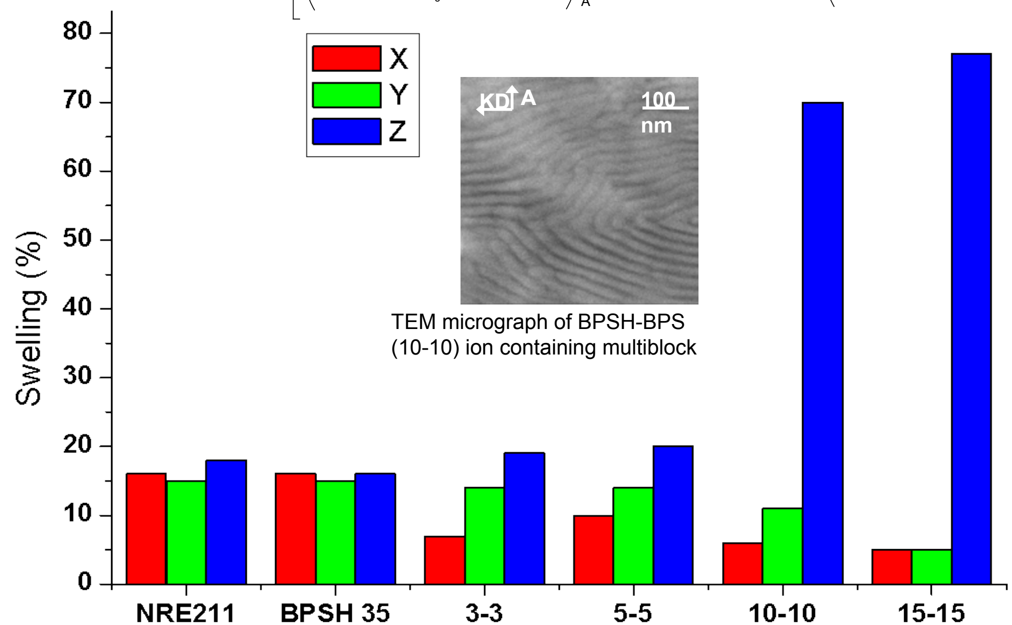

Using different diffusion media we obtain and can model radically different performances

# Achievements: New Materials: Polymers

- Recent hydrocarbon materials from McGrath (VT) have shown large differences in conductivity based on block length and processing
- Perfect system for designing guidelines for PEMs
  - Importance of structure, chemistry and phase separation
- Perfect for testing model

## BPSH-BPS Multiblock Copolymers with Higher Block Lengths Develop Self Assembled Nanostructures

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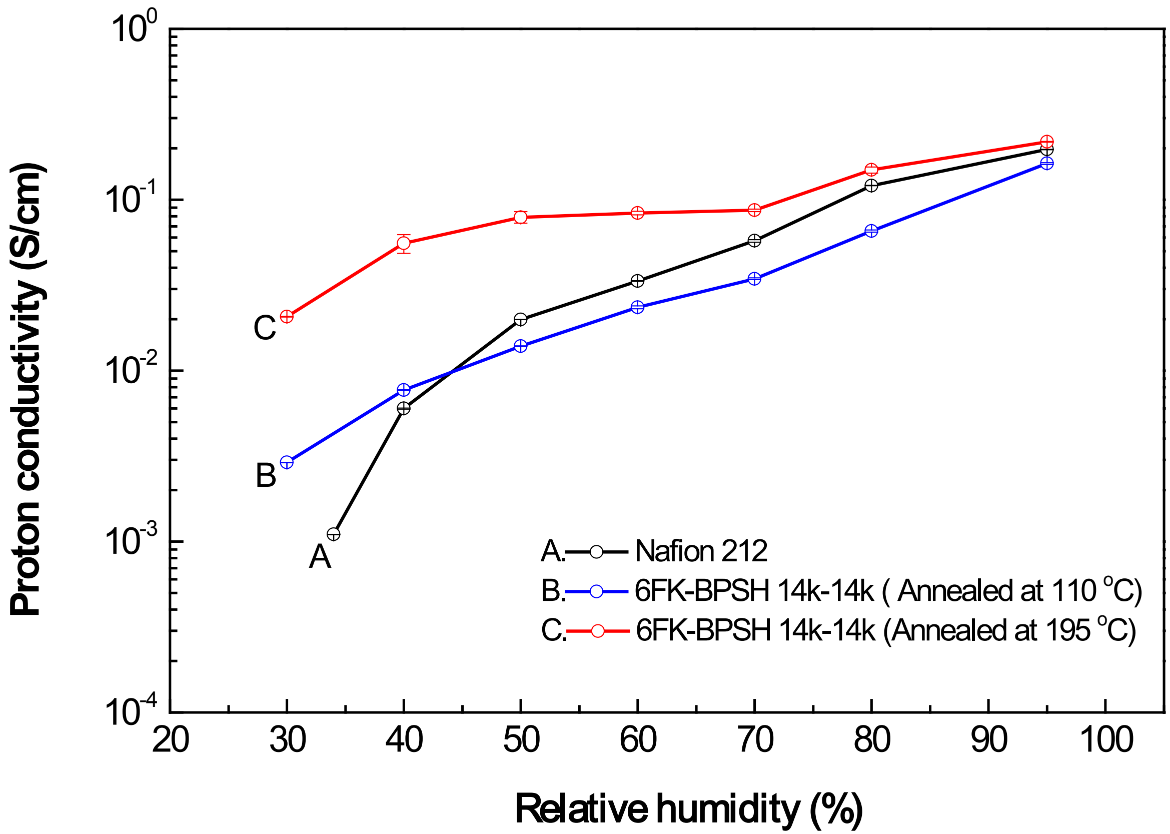
# Achievements: New Materials: Polymers Effect of Annealing




- Beyond Chemistry and Block Length, thermal history can greatly affect PEM properties

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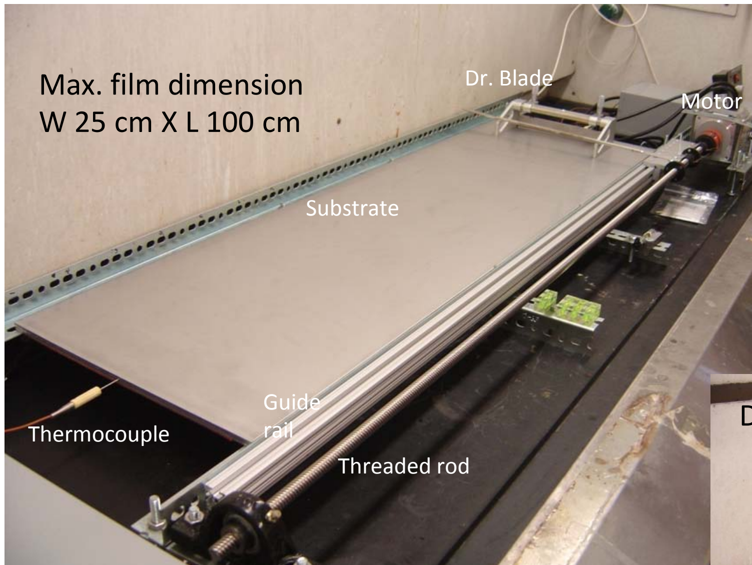
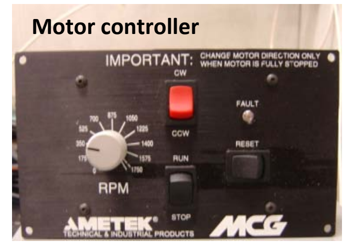
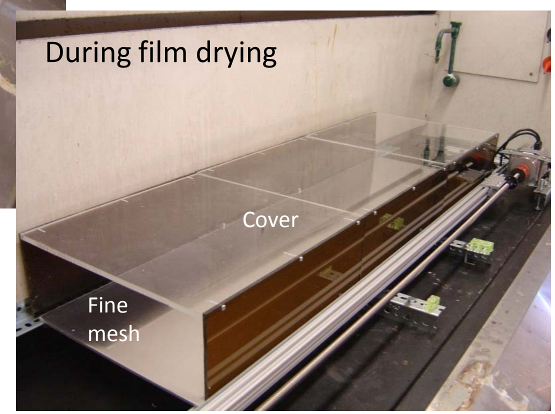
# Achievements: New Materials: Polymers





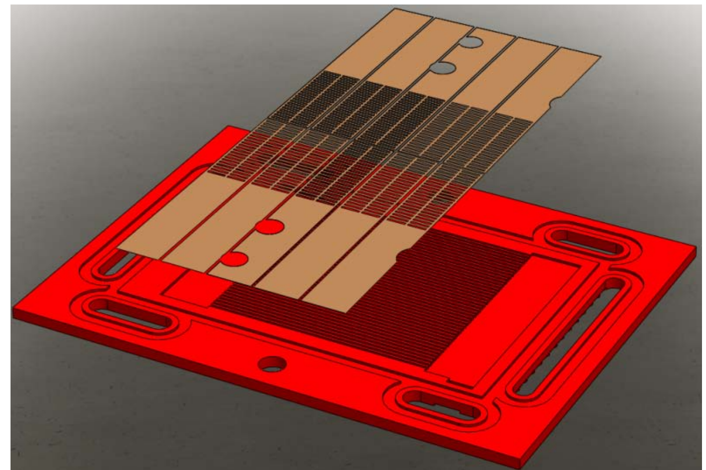
**Film drying system**
Heating blanket (2 pcs, 30 cm X 60 cm)
5 Watts / cm$^2$
Up to ~ 150°C




- Advanced film caster generated for large membrane task

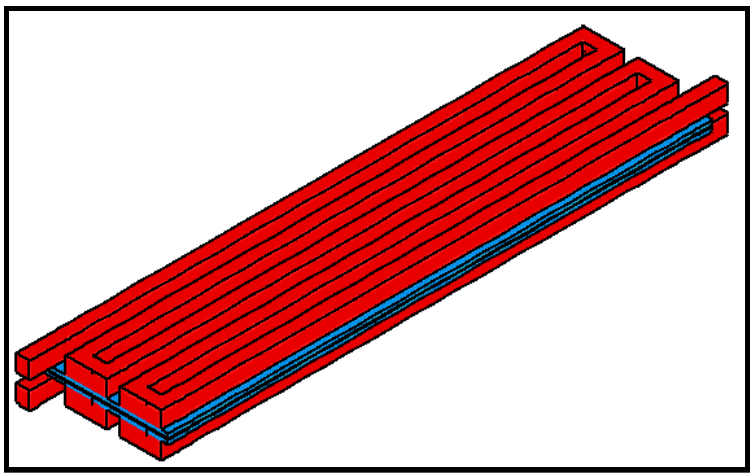
# Achievements: New Materials: Flow Field and Current Distribution Board

- Heat transport and fluid cooled plates can have large impact, therefore we need to simulate real hardware as closely as possible
- Flow field with thin metallic sheets designed
- New current distribution board designed as well



# Achievements: Modeling: Effect of Diffusivity

- First Alternative PEM is targeted to have similar conductivity but different diffusivity than the baseline PFSA
- **Model the effect of altering PEM diffusivity to 6x and 1/6x that of PFSA.**
  - Performance
  - Water Distribution
- Serpentine model initially, will extend to parallel flow fields



Base Case of 80°C H2/Air 1.3/2.0 Stoich 1 atm.

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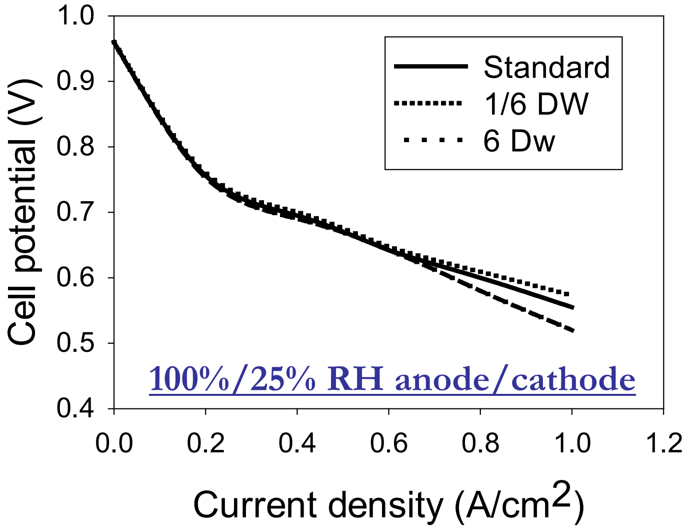
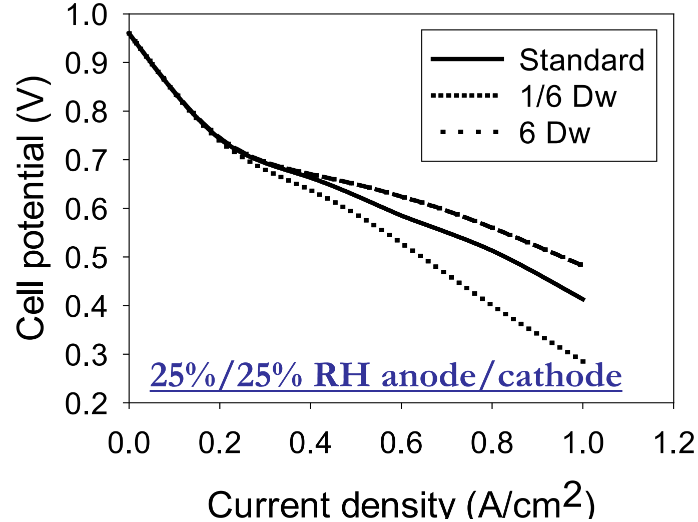
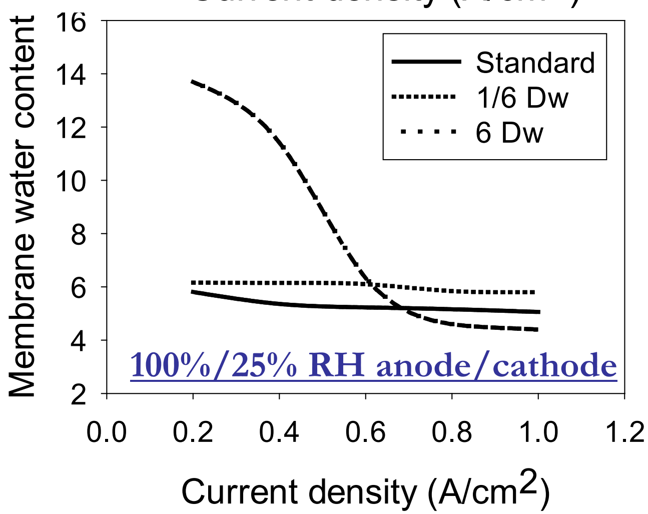
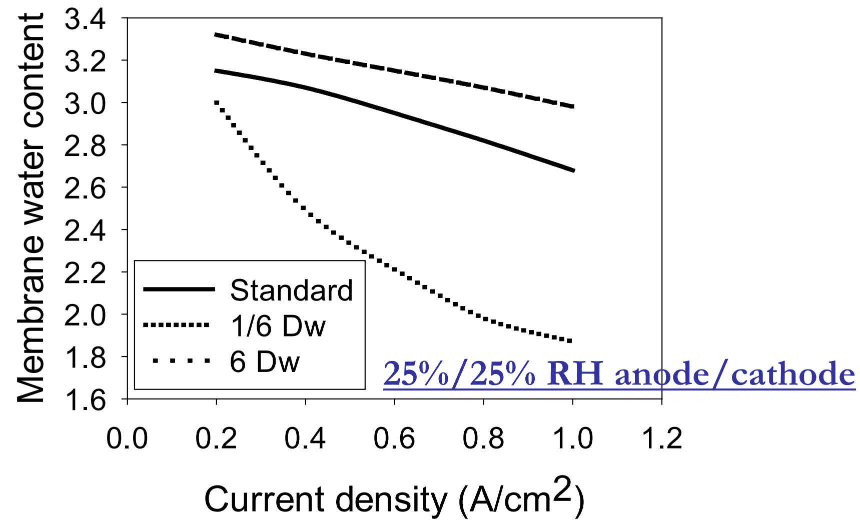
# Effect of $D_w$ More Pronounced for Dryer Anodes

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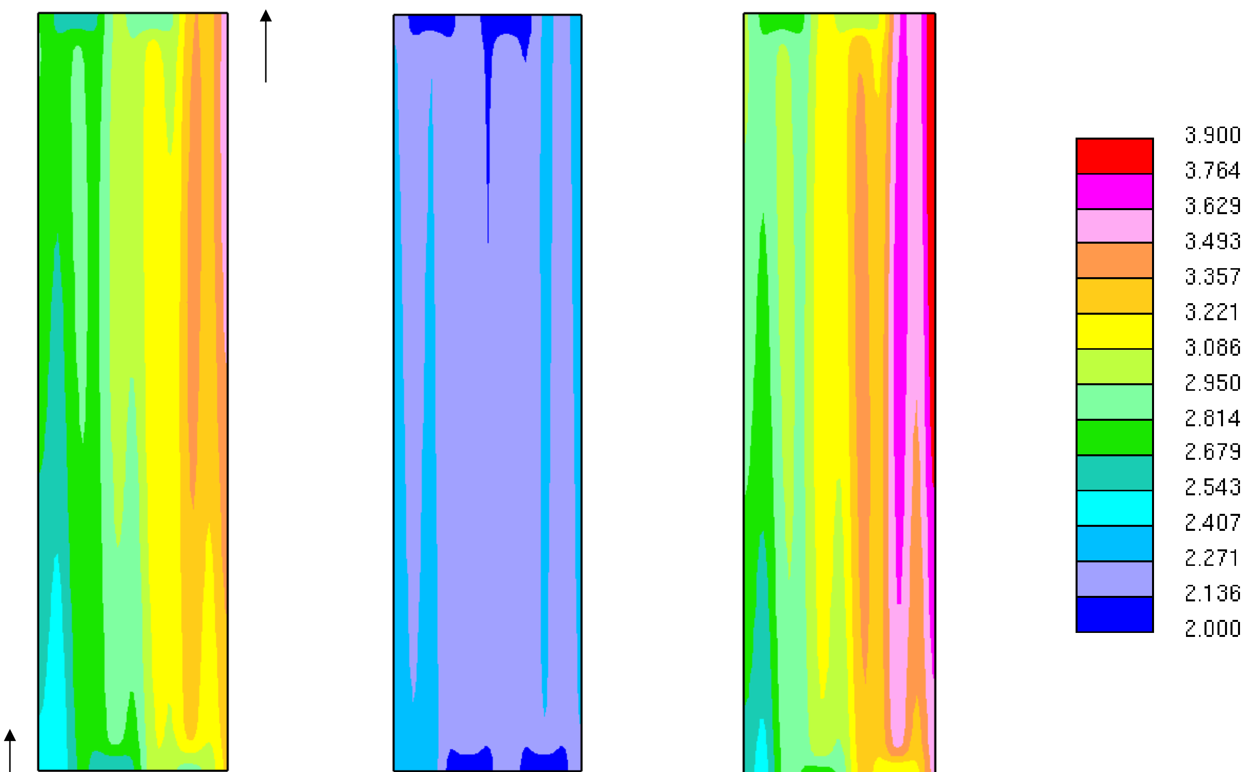
# Achievements: Modeling: Effect of Diffusivity

## Effect of Diffusivity on Water Content




$\lambda_{avg}$ = 2.9
Standard Dw

$\lambda_{avg}$ = 2.2
1/6 $D_w$

$\lambda_{avg}$ = 3.3
6 x $D_w$

Membrane water content (lambda) distribution on MEA surface at average current density of 0.6 A/cm$^2$ : **25%/25% RH anode/cathode**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# SUMMARY

- Many new analytical techniques developed for characterizing water transport
  - No interfacial resistance found for Nafion
  - *Static* and *Dynamic* Diffusivity found to be the same
  - Techniques widely available to community
- Widely Varied PEMs and Diffusion Media will allow us to model the important parameters of each
- Base Model developed and used to describe various performance results with different diffusion media

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# FUTURE WORK

- Extend Characterizations to Alternative Materials
- Extend testing to more realistic automotive platform
- Down-select alternative polymers and generate larger, consistent materials
- Confirm model with performance, current distribution and water collection results
- Use model to determine performance sensitivity to build materials, suggest focus areas

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