Transport in PEMFC Stacks

GES
Cortney Mittelsteadt
John Staser

University of South Carolina
John Van Zee
Sirivatch Shimpalee
Visarn Lilavivat

Ballard Material Products
Don Connors
Guy Ebbrell

Virginia Tech
James McGrath
Myoungbae Lee
Nobuo Hara
Kwan-Soo Lee
Chang Hyun

Tech Etch
Kevin Russel

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
    - FY10 $271,507
    - 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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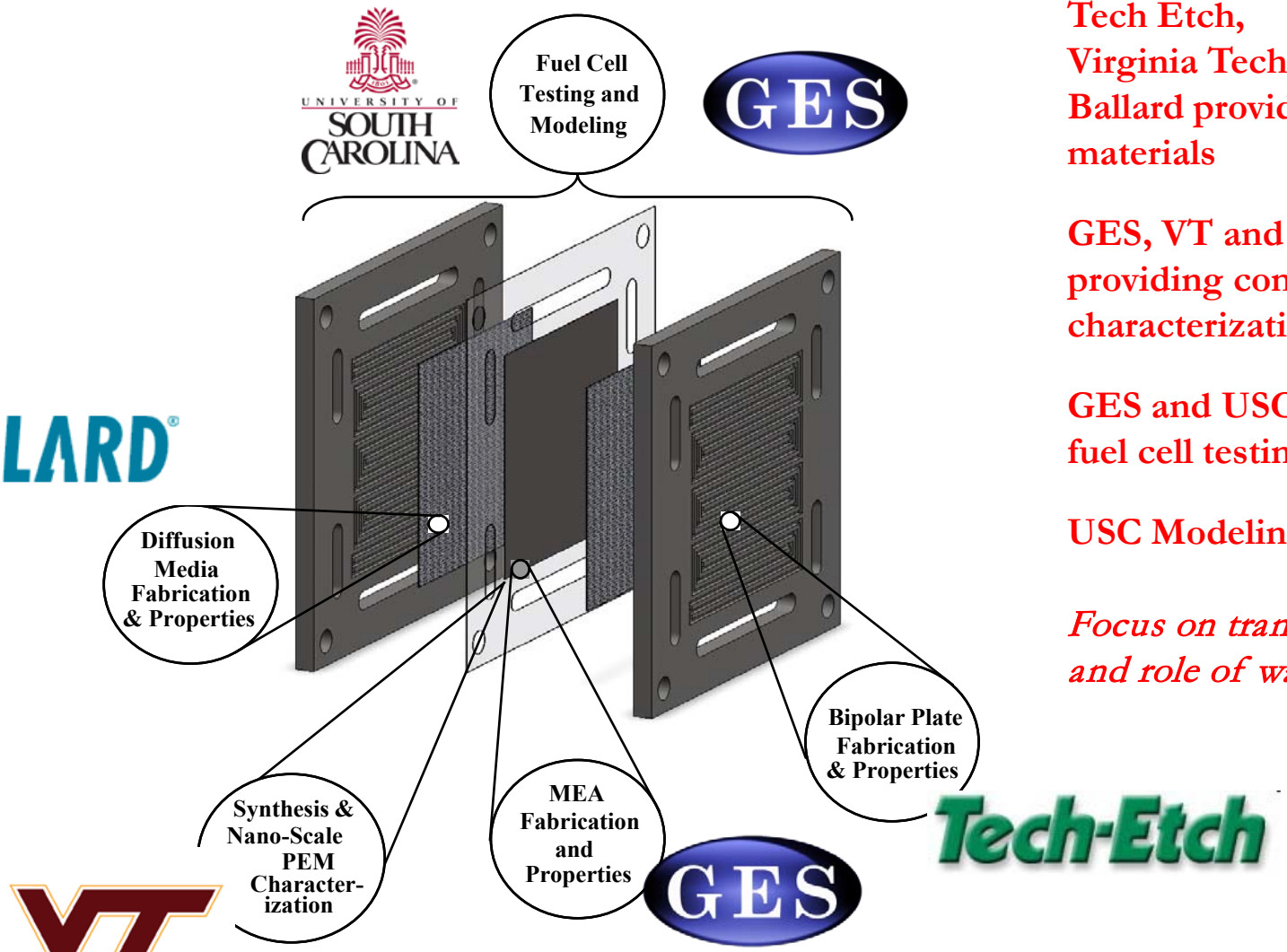
Approach: Team and Tasks



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

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

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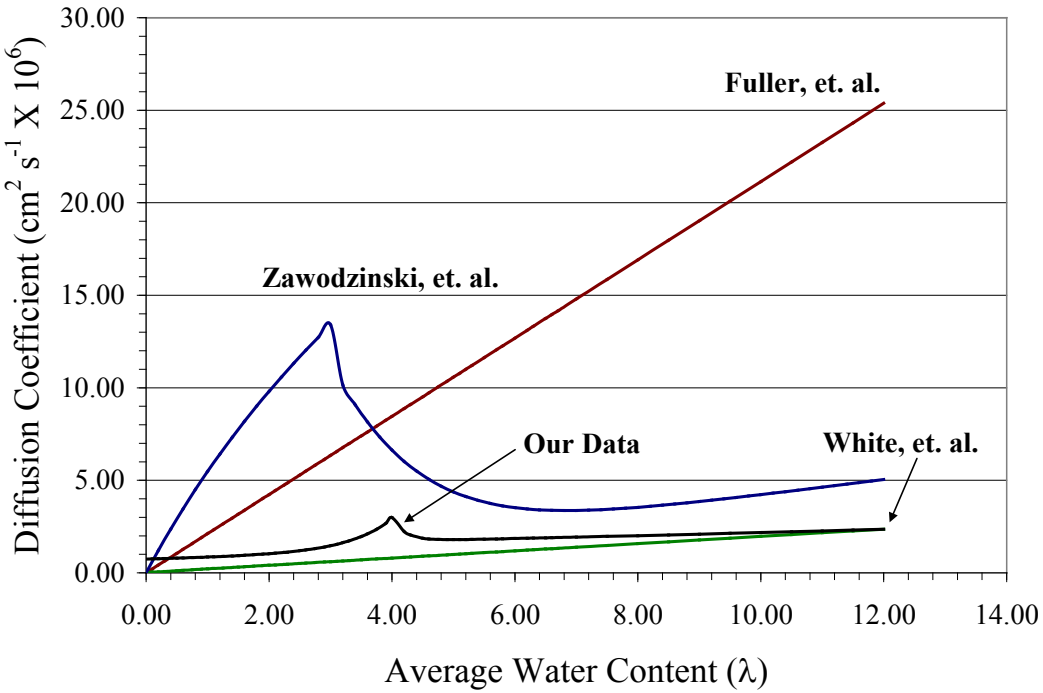
Develop New Techniques for Measurement of Key Parameters

- 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)

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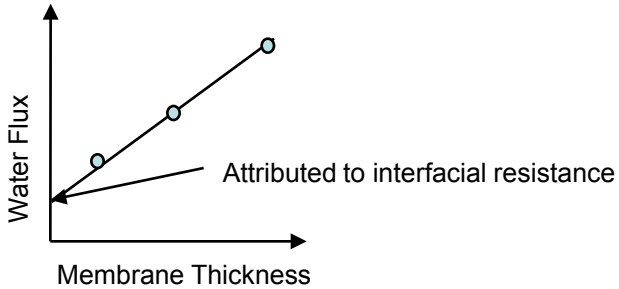
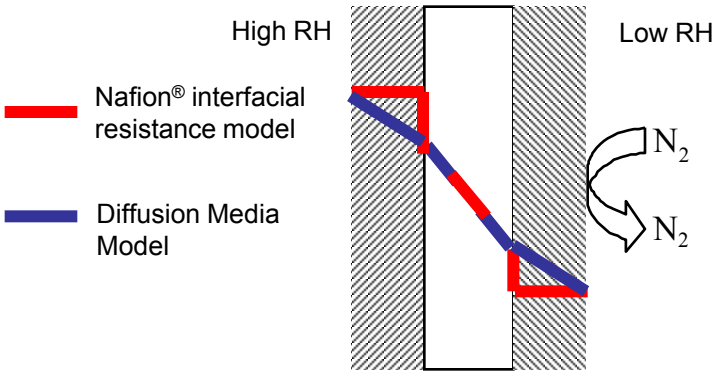
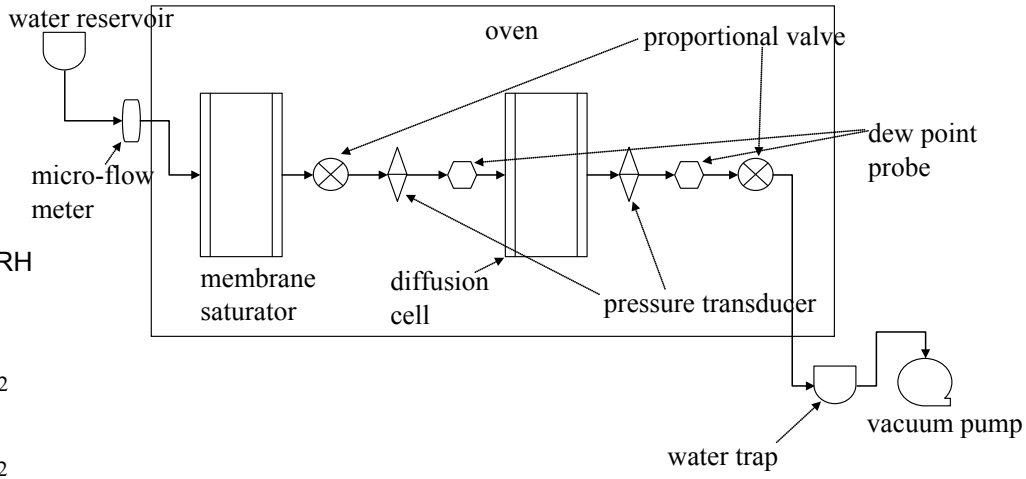
Achievements: New Techniques: Diffusivity

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



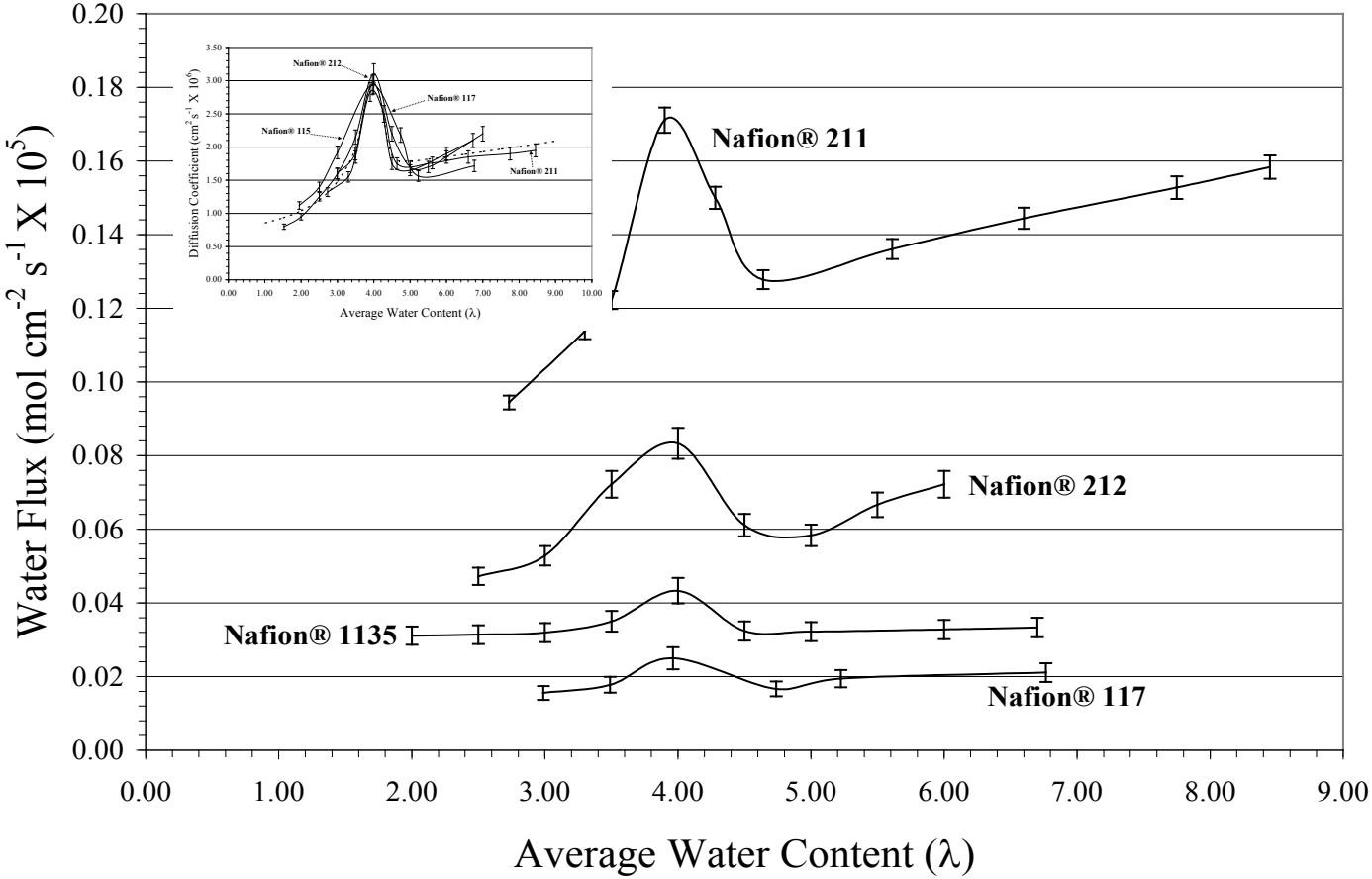
By eliminating inert gases we can eliminate non-membrane diffusion





- Only water vapor no convection

Water Flux Data, T = 80 C



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

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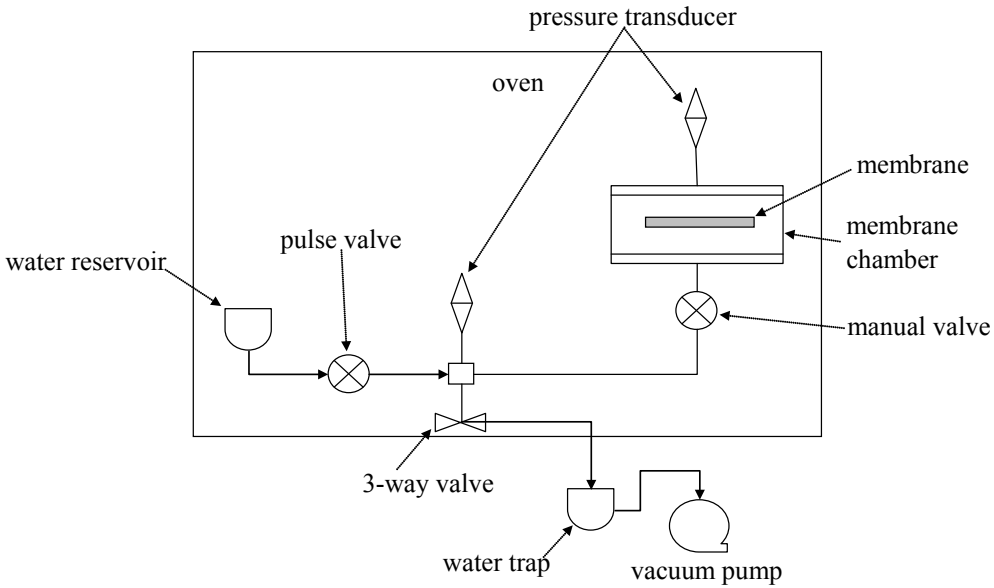
Achievements: New Techniques:
Diffusivity Static *vs.* Dynamic Gradients

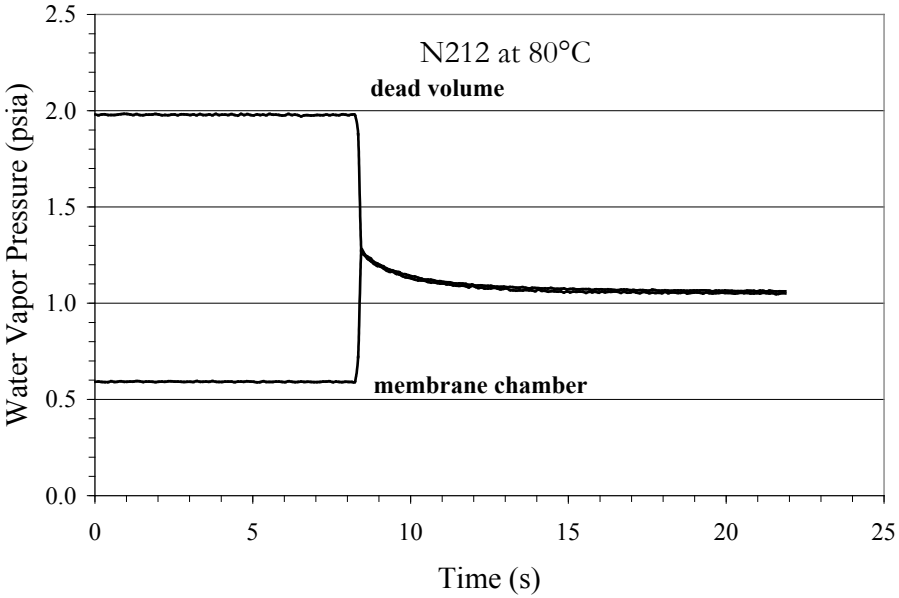
- In previous example water transport takes place across a static gradient; water content through thickness of the membrane does not change

- 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.

Dynamic Water Uptake/Transport: Dynamic Diffusivity





Again by eliminating inerts we eliminate non-membrane diffusion

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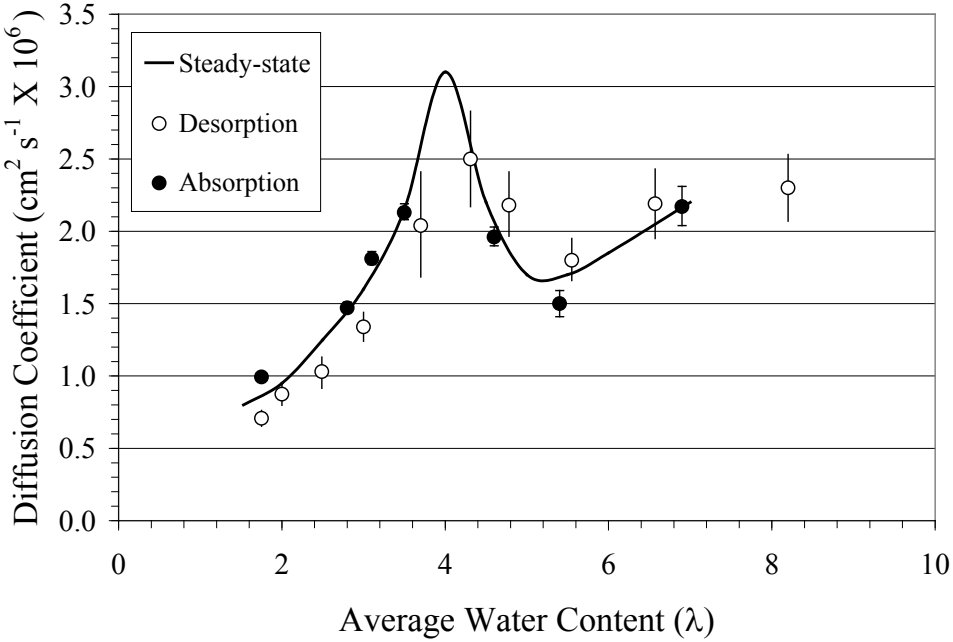
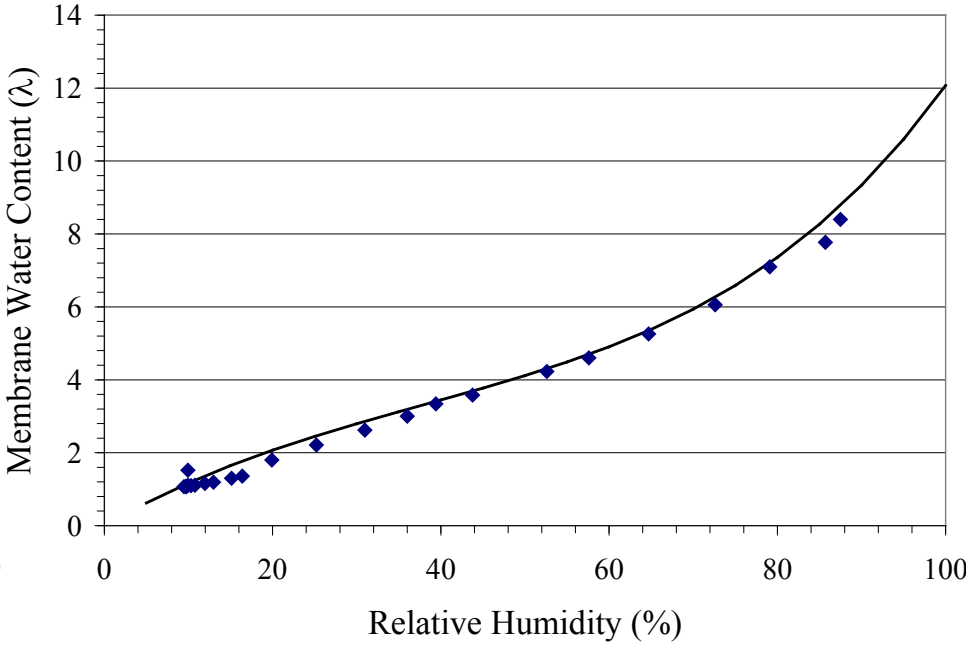
Water isotherms are also obtained!

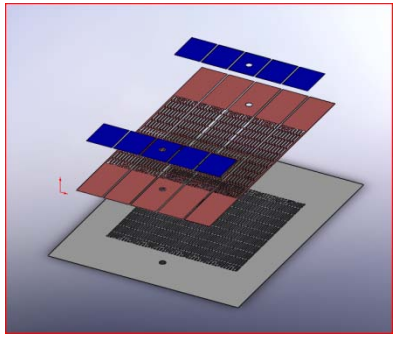




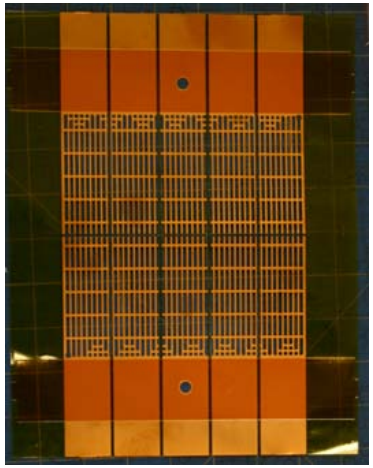
- Diffusivity is the same for absorption, desorption and steady-state measurements
- Isotherms are also obtained
- *Simultaneous isotherm; permeability & diffusivity*

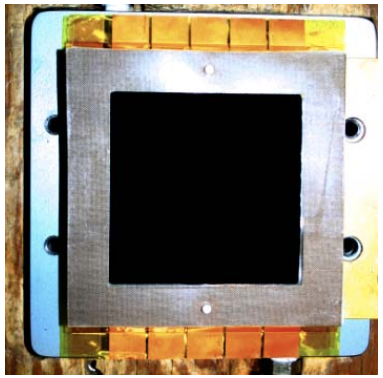
Achievements: New Techniques: Current Distribution

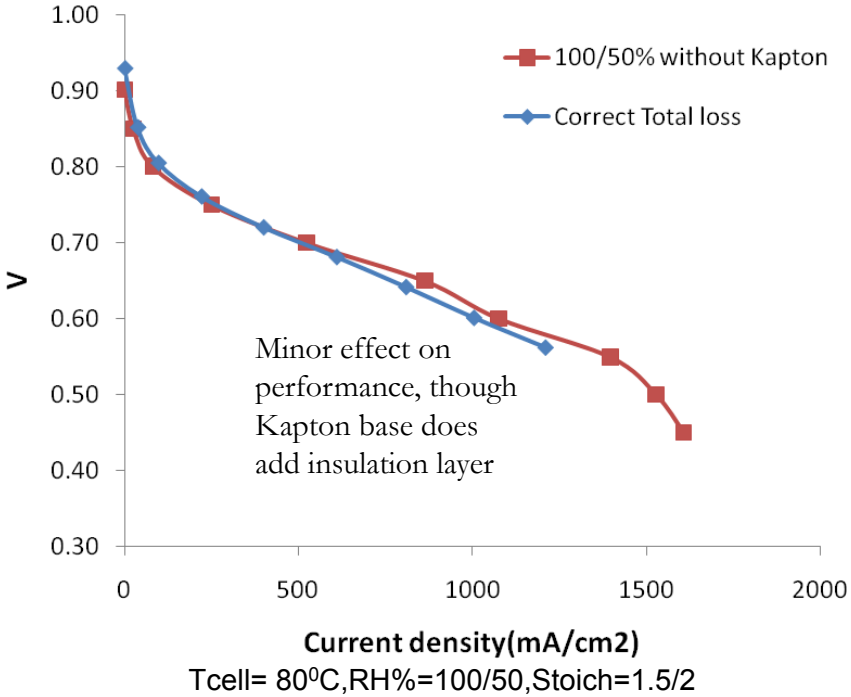
Many methods for current distribution significantly affect flow path and break up diffusion media. Others are very expensive. Needed a cheap way without disrupting flow.



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







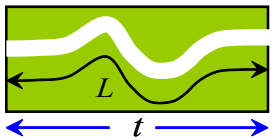
More work needed on the data acquisition end, but concept is shown

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

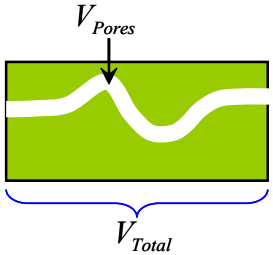
– Ratio of the actual path length through the pores to the shortest linear distance between two points.



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

•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.

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

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Achievements: New Materials: Diffusion Media

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

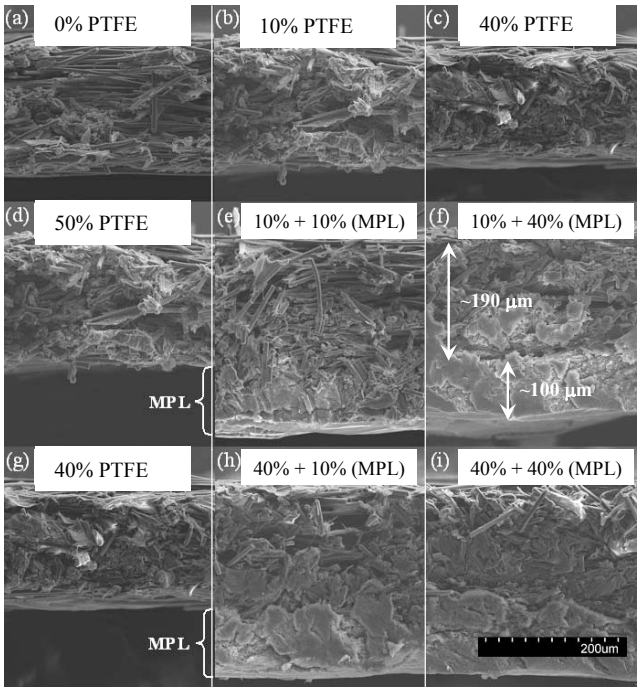
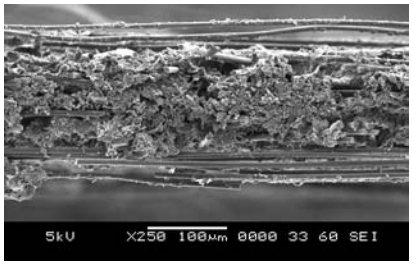
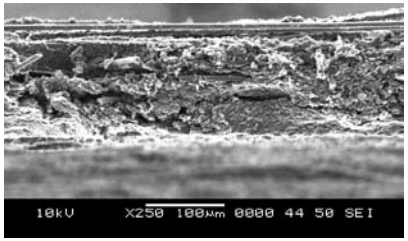


Photo micro-graphs of cross-section: Ballard GDLs



EP40



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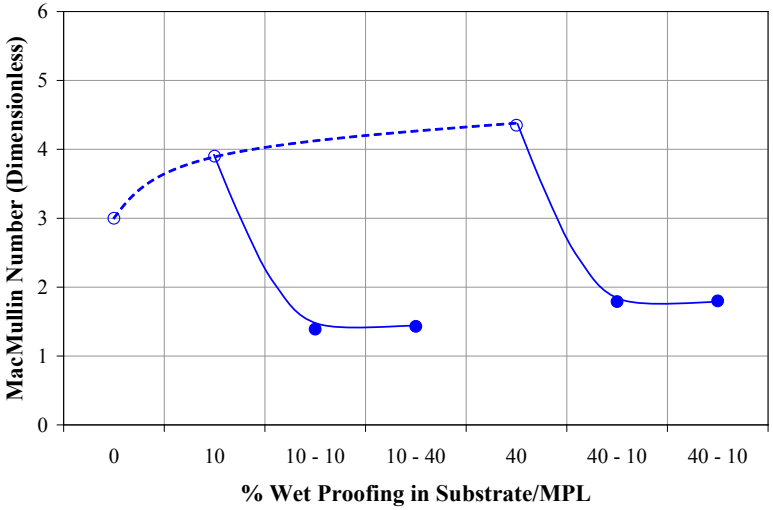

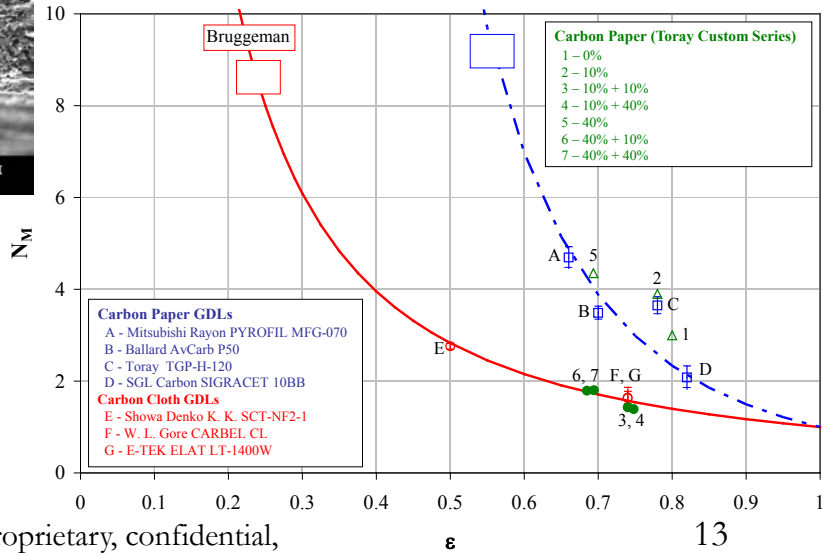

MPL: Microporous Layer

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

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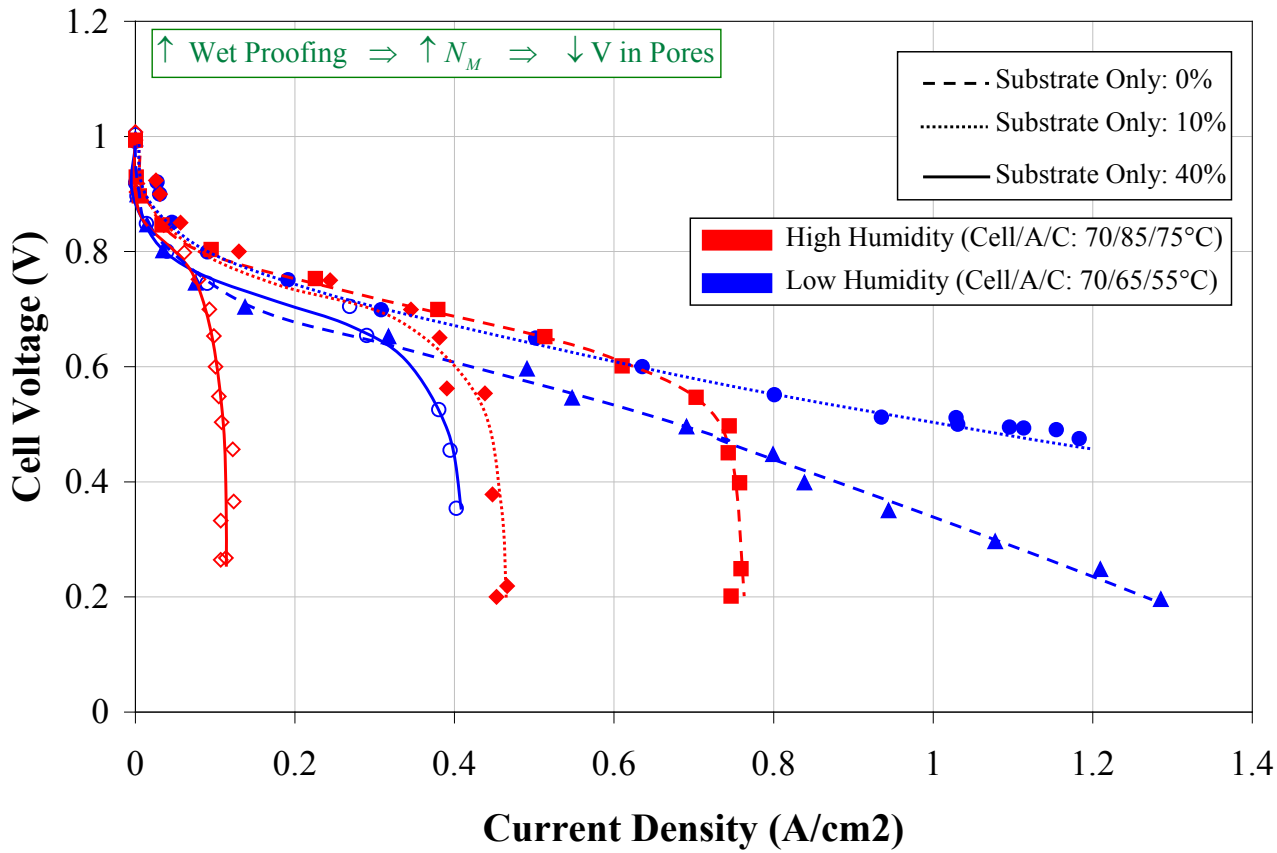
Achievements: New Materials: Diffusion Media



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

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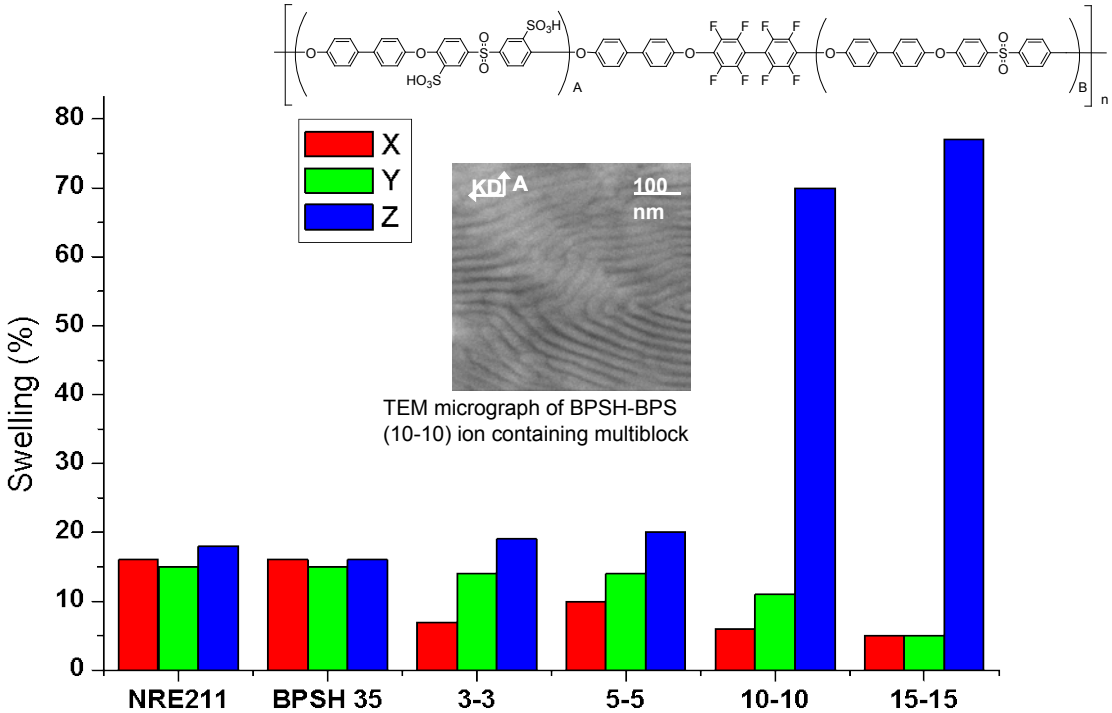
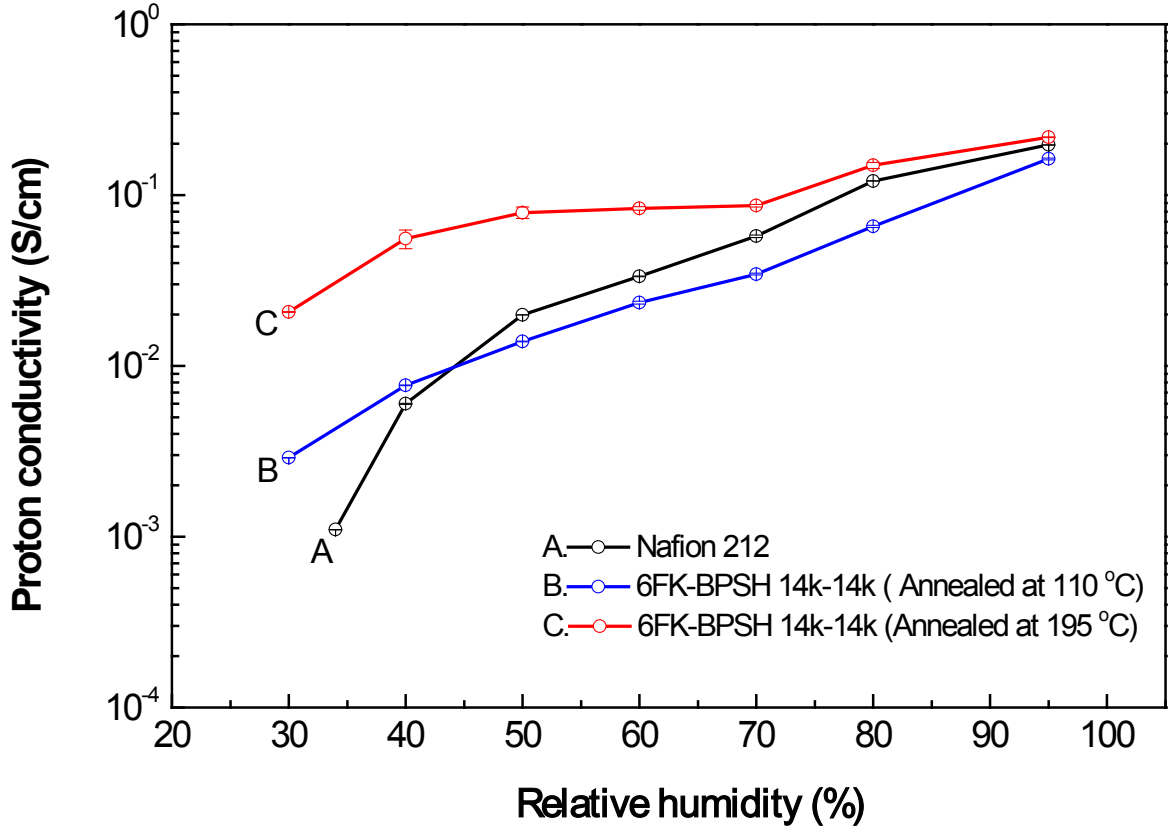
Achievements: New Materials: Polymers

- 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

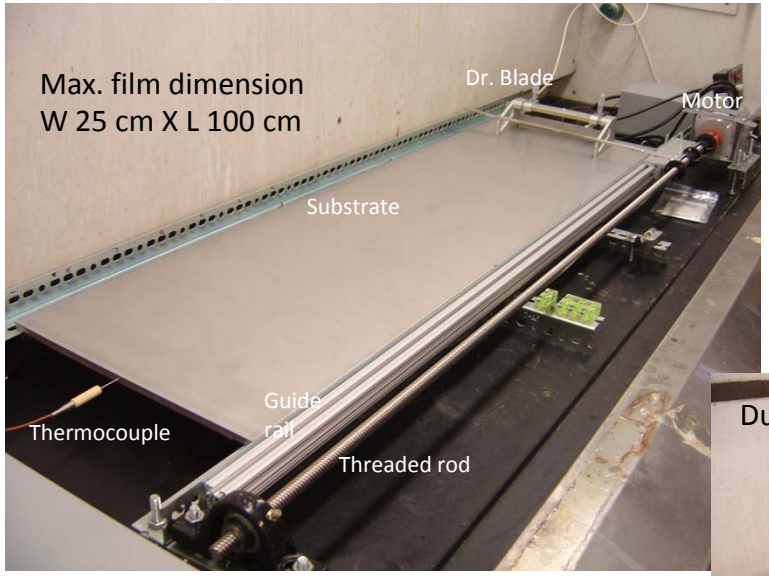


Achievements: New Materials: Polymers Effect of Annealing

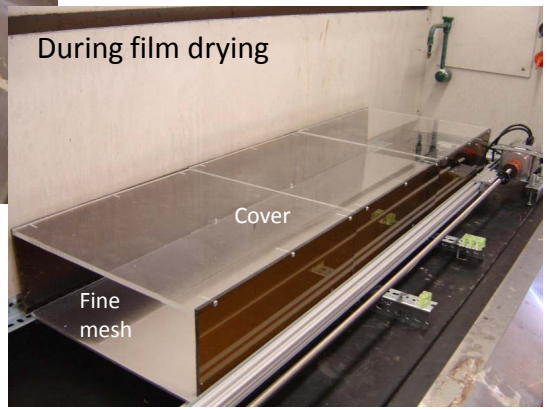


- Beyond Chemistry and Block Length, thermal history can greatly affect PEM properties

Achievements: New Materials: Polymers



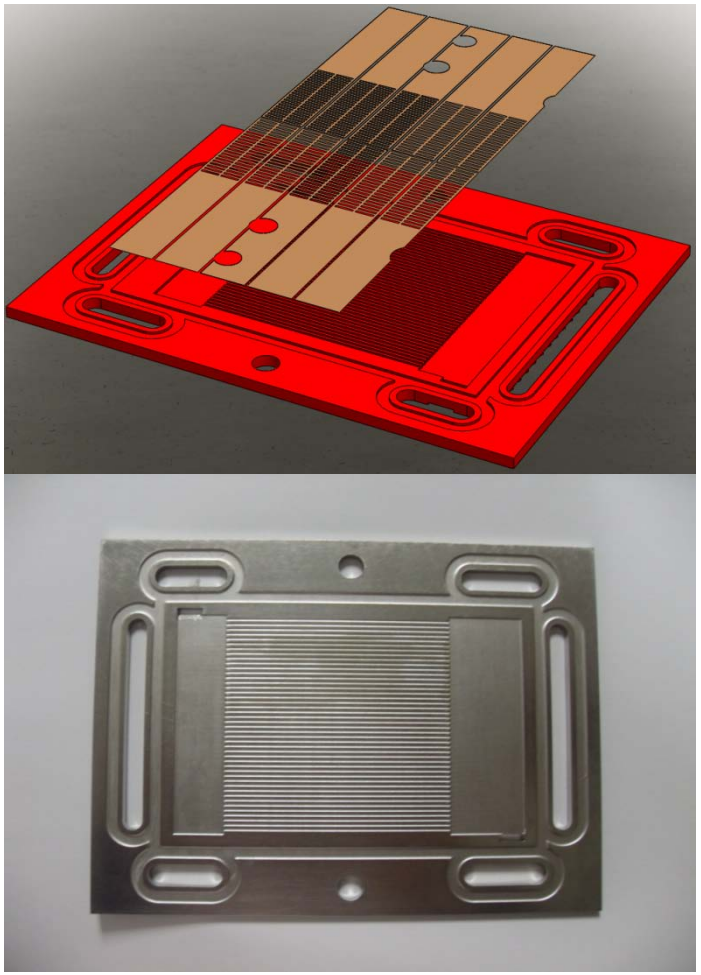
Film drying system
Heating blanket (2 pcs, 30 cm X 60 cm)
5 Watts / cm^2
Up to ~ 150°C



- Advanced film caster generated for large membrane task

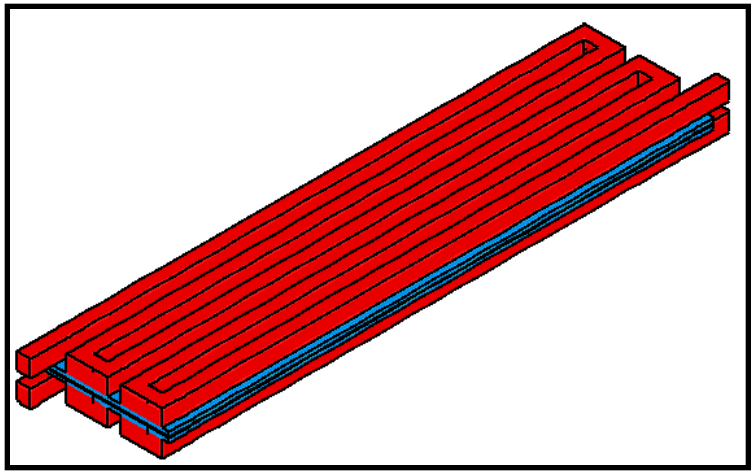
Achievements: New Materials: Flow Field and Current Distribution Board

- 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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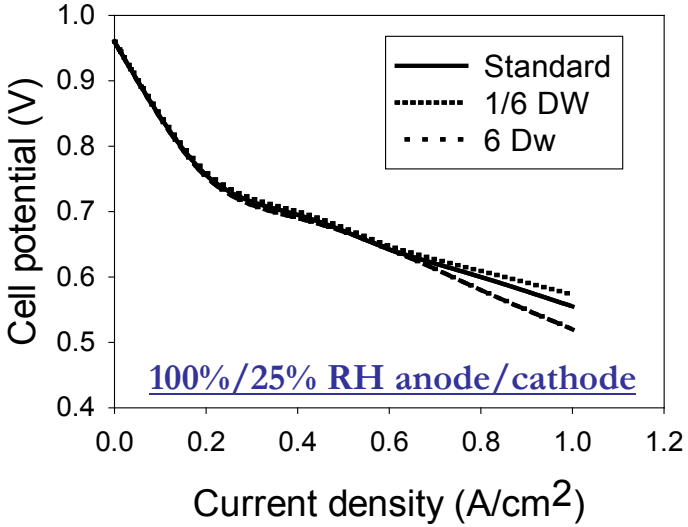
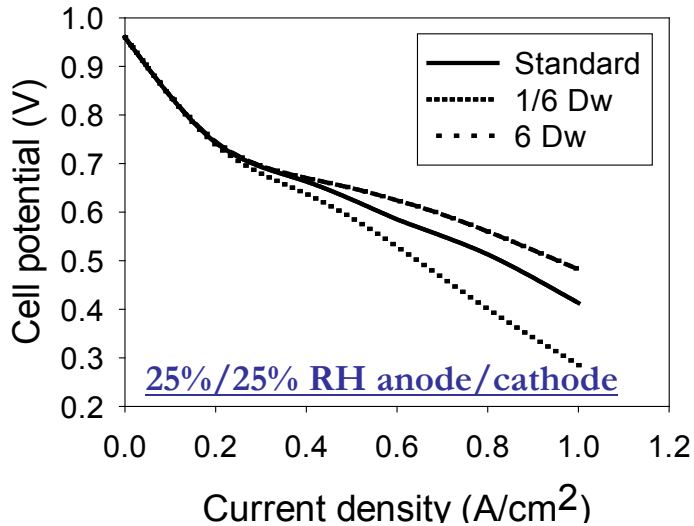
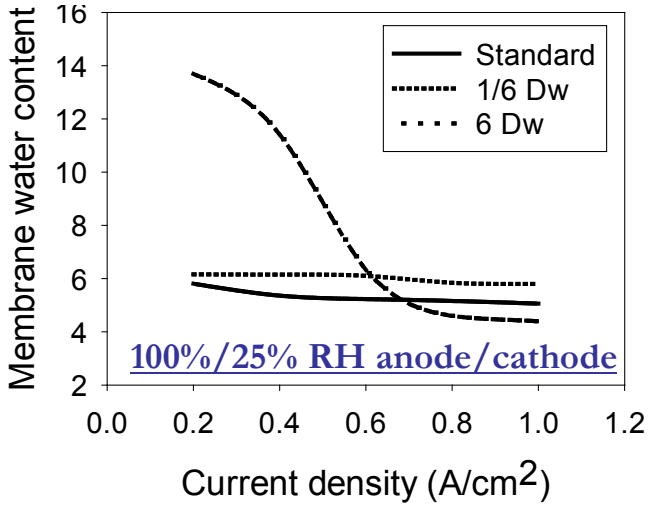
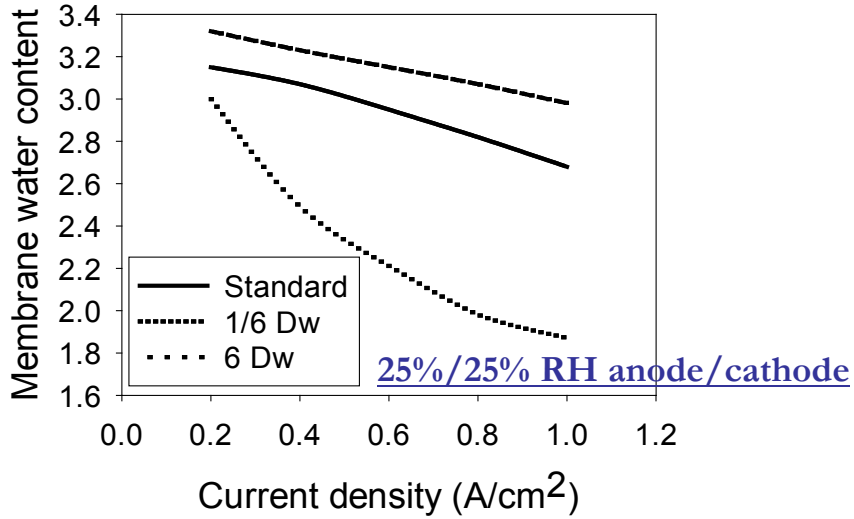
Effect of D_w More Pronounced for Dryer Anodes



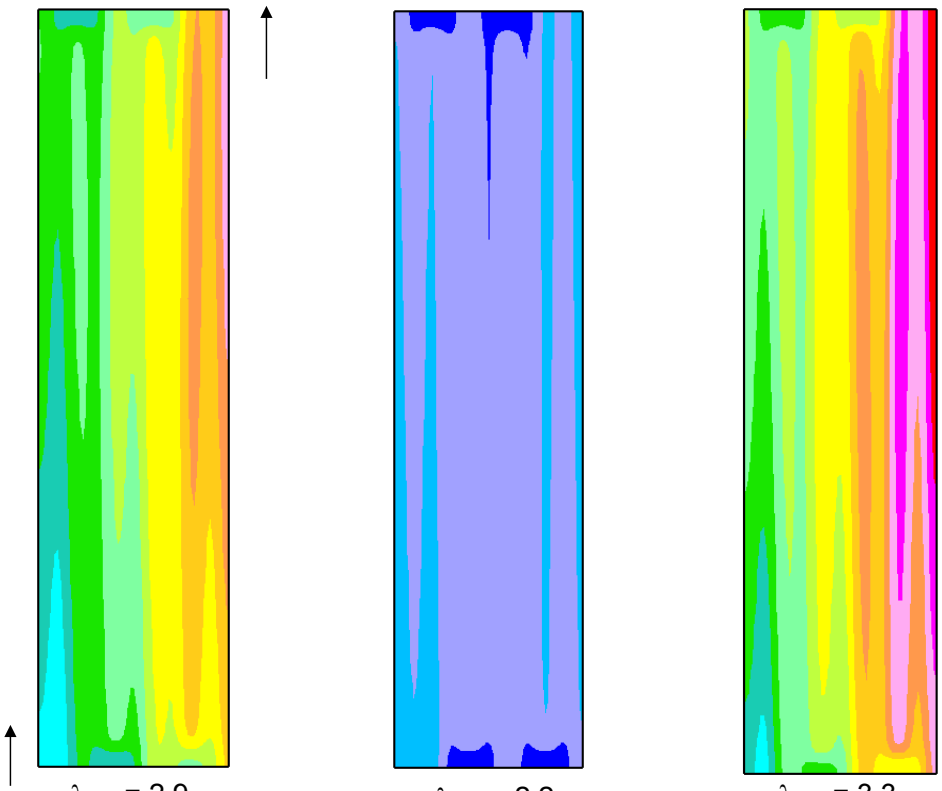






Achievements: Modeling: Effect of Diffusivity

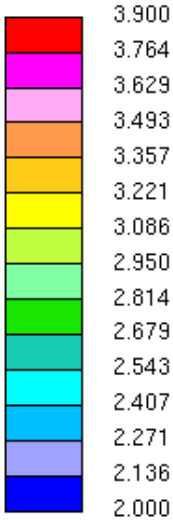
Effect of Diffusivity on Water Content



λ_{avg} = 2.9
Standard Dw

λ_{avg} = 2.2
1/6 D_w

λ_{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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