# Transport Studies and Modeling in PEM Fuel Cells

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Project ID: FC054
June 8, 2010

# Transport in PEMFC Stacks

## Timeline
- Begin 10/5/2009
- Review 10/4/2012

## Budget
- Total Project Funding
  - $2.66M DOE Funding
    - FY09 $0
    - FY10 $915,499
  - $676K Recipient
  - 20% Cost Share

## Barriers Addressed
- Performance
- Water Transport with 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
- Engineered Fiber Technologies

# Objectives and Approach

**Project Goal: Develop fuel cell materials with specific water transport/thermal management properties along with a mathematical model to predict performance as a function of component properties**

**Virginia Tech**

- Synthesis of block copolymers
- Determination of polymer structure and water state

**University of South Carolina**

- Transient, 3-D modeling of fuel cell operation
- Design of gas diffusion layer, cell flow fields
- Fuel cell testing

**Tech Etch**

- Fabrication of fuel cell flow fields, current collectors and segmented cell

**Engineered Fibers Technology**

- Fabrication of specified gas diffusion layers

**Giner Electrochemical Systems**

- Determination of bulk membrane properties
  - Water uptake and diffusivity
  - Gas permeability
  - Electro-osmotic drag
- Fuel cell testing

# Objectives and Approach (cont.)

## Objectives

Utilize group expertise in the design and synthesis of polymer electrolyte membranes, manufacturing, mathematical modeling of dynamic systems and testing and characterization of fuel cells and fuel cell components (i.e., PEM, bipolar plates) to design parts with specific water transport/thermal management properties. The project will culminate in the development of components with tailored properties, as well as a mathematical model describing the water transport/thermal management of those components. The model will then be used to identify those components which are most limiting performance and direct future efforts.

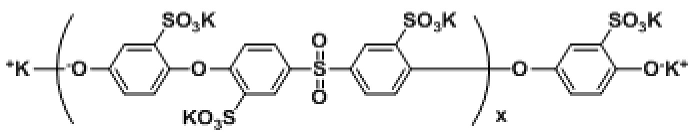
## Approach

The group has extensive experience in the design of electrochemical systems, particularly PEM fuel cells. Our approach seeks to utilize this experience to not only design a novel PEM with specific transport properties for the fuel cell system, but to approach characterization of these membranes in a new way. In particular, GES will develop novel testing methods to minimize many errors associated with the characterization of membrane transport properties. These data should better represent membrane properties, and will be used to develop a mathematical model capable of predicting dynamic fuel cell performance. Our approach will allow us to better design system components possessed of specific properties, to evaluate those components in fuel cell testing and develop a mathematical model, and to predict system performance as a function of varying component properties.

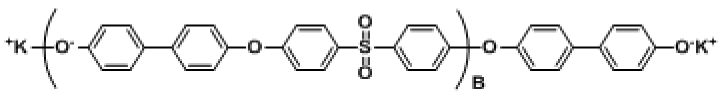
# Technical Target: Polymer Synthesis

## Synthesis of Multi-block copolymers (SQS-BPS0)

✓ Hydrophilic block (SQS)



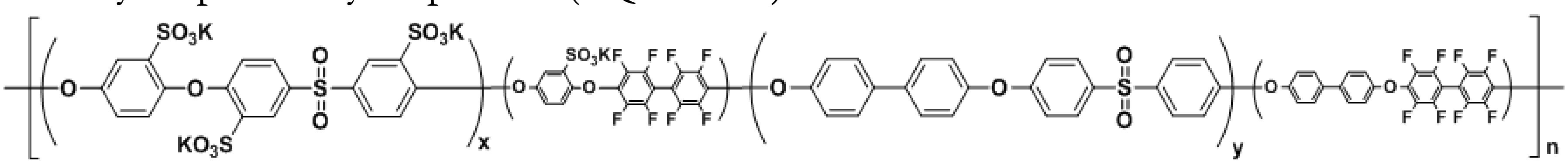

✓ Hydrophobic block (BPS0)



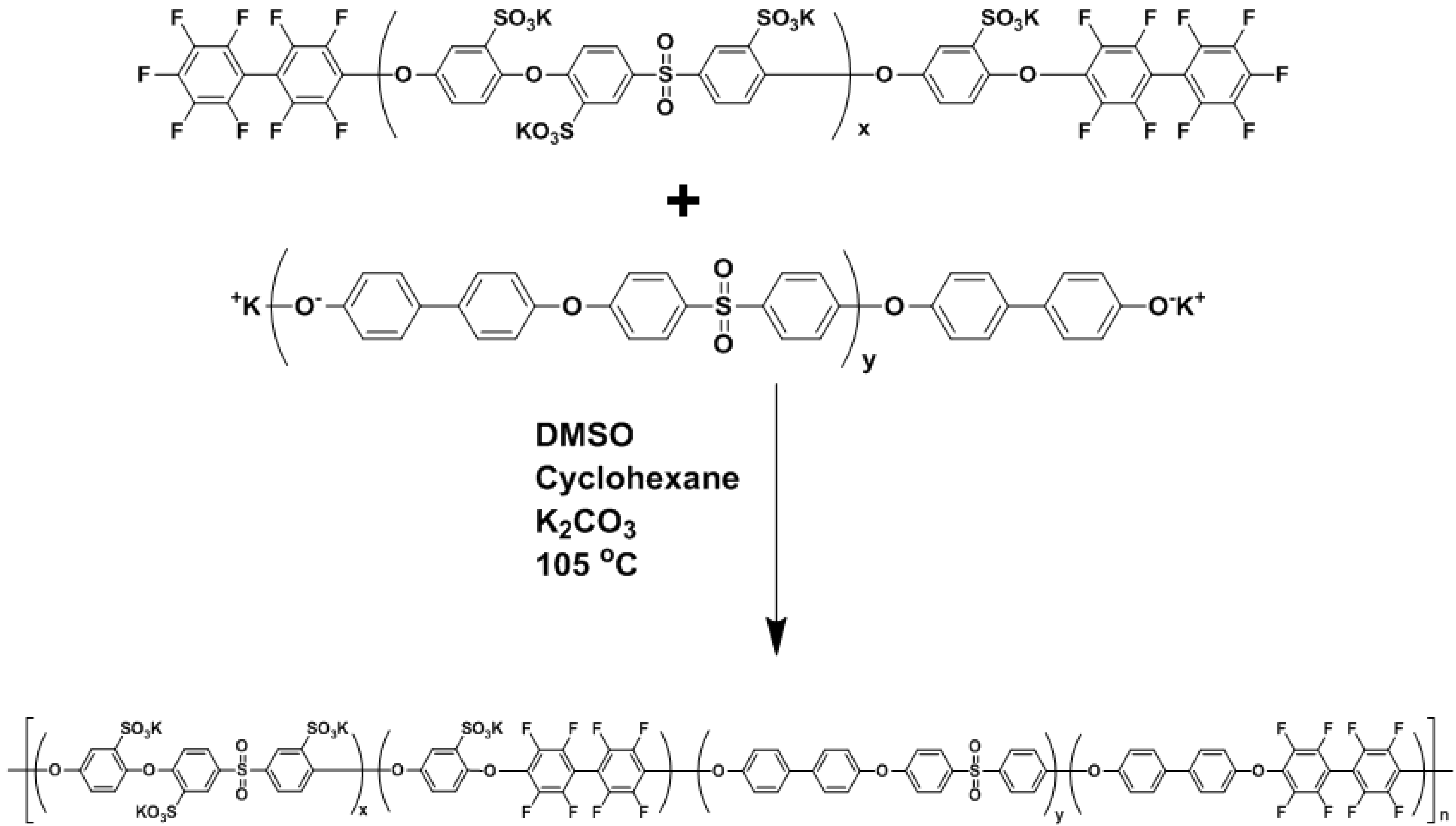

### Development of Novel PEM

- Utilization of hydrophobic (structure and support) block and hydrophilic (water transport, conductivity) block
- Goal to address performance and water transport technical barrier
- Designed for specific transport properties
- PEM designed in collaboration with VA Tech

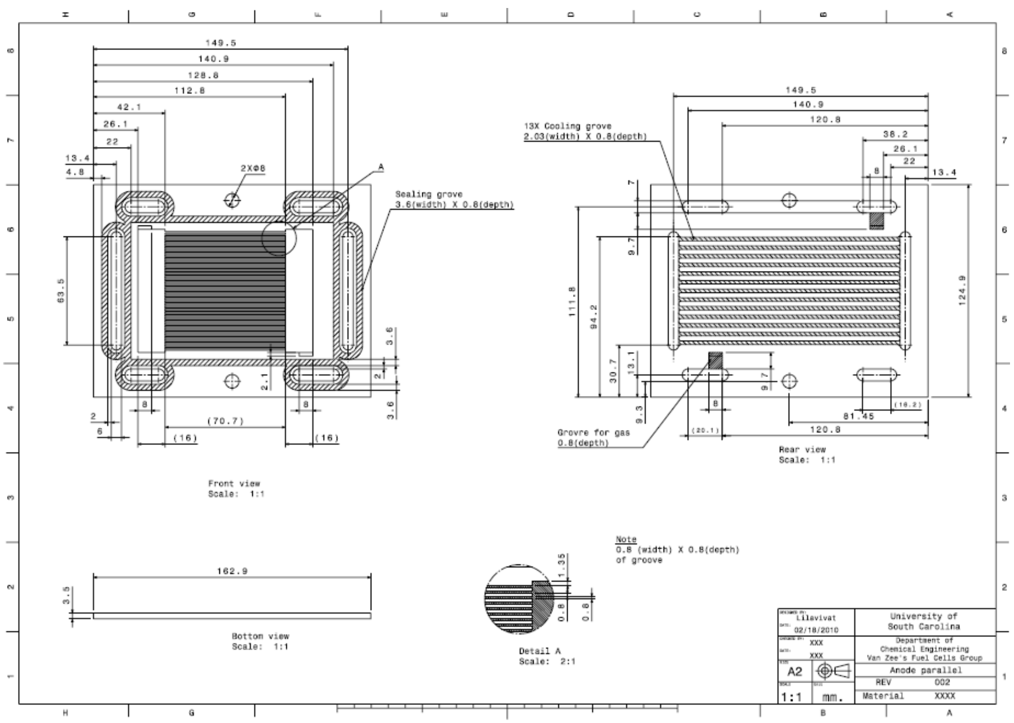
✓ Hydrophilic-Hydrophobic (SQS-BPS0)



# Synthesis of SQS-BPS0 Multi-block Copolymer



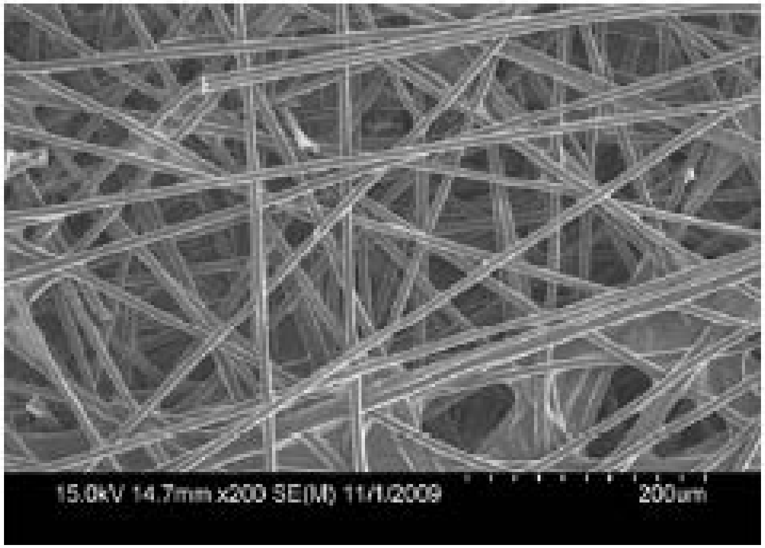
# Design of Anode Bipolar Plate



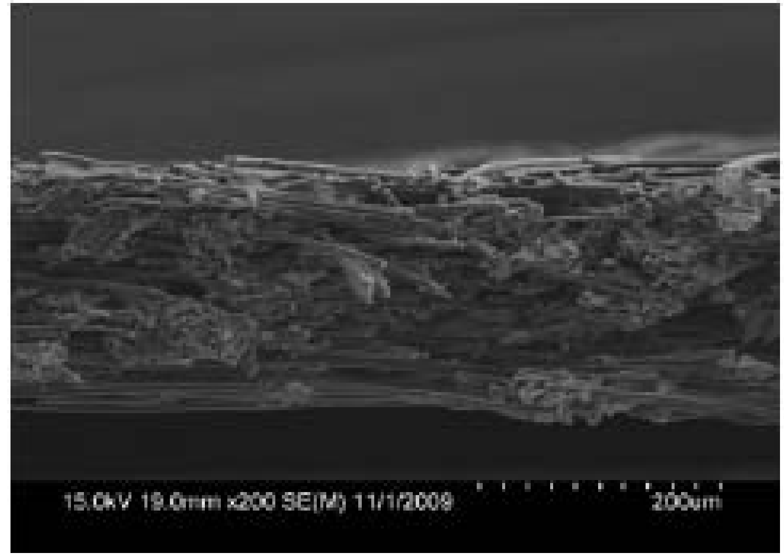

## Anode Bipolar Plate

- Designed in collaboration with USC
- Addresses performance and stack water transport technical barriers
- Design will be incorporated into model developed by USC
- Bipolar plate manufactured in collaboration with Tech-Etch

# Design of Gas Diffusion Layer




Top view




Cross section view

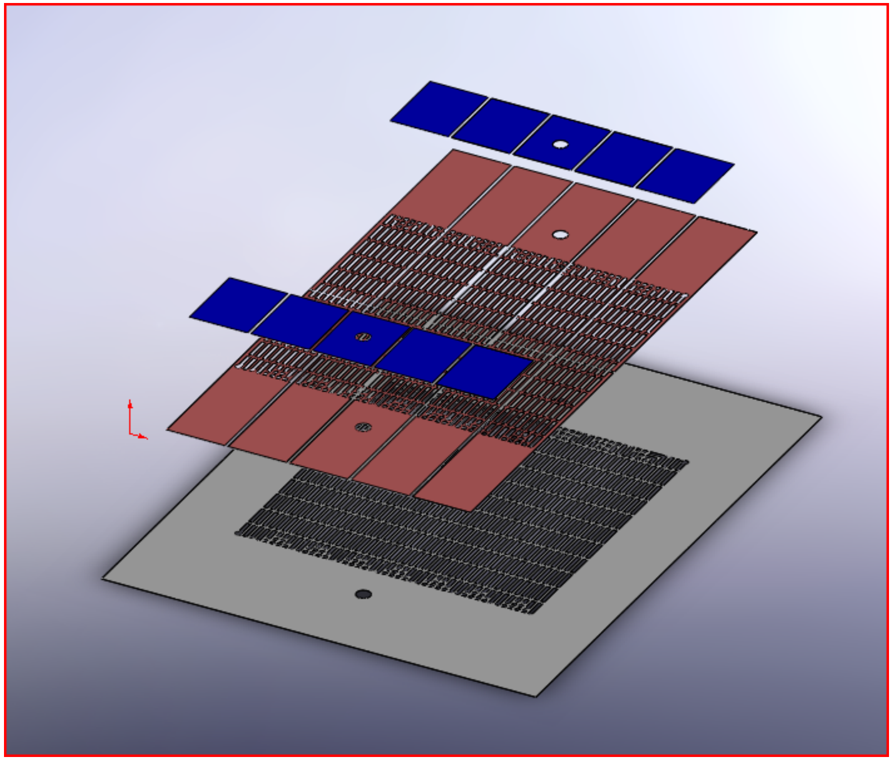
Gas Diffusion Layer

- Connects bipolar plate to MEA
- Responsible for fuel cell water and reactant transport between MEA and bipolar plate
- Addresses all technical barriers
- Design led by USC in collaboration with GES and Engineered Fibers Technology

# Segmented Cell

## Segmented Cell Design

- Breaks cell active area into component parts
- Allows for position-dependent evaluation of water and thermal management characteristics
- Essential for successful completion of computational fluid dynamics model being developed by USC
- Addresses all technical barriers



# Membrane Characteristics

## Water Uptake and Diffusivity

- Determine dynamic water uptake as a function of initial membrane water content and %RH
- Measure diffusivity as a function of membrane water content and %RH
- Essential knowledge for development of mathematical model (USC)

## Gas Permeability

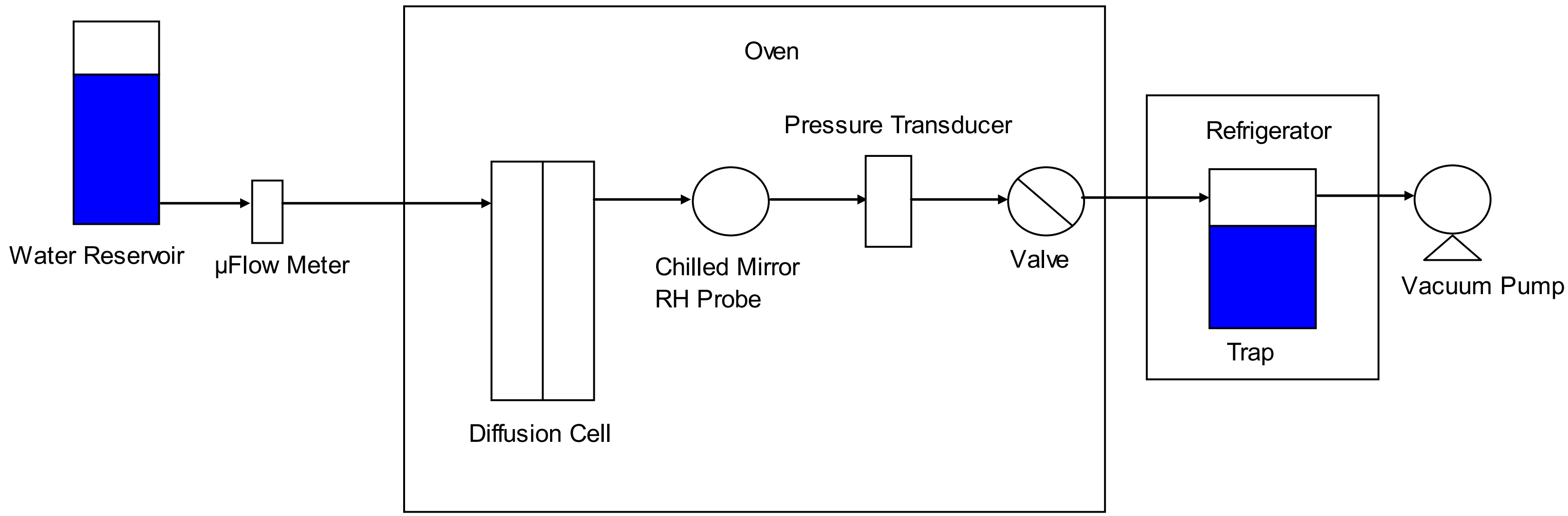
- Membrane synthesis goal of minimizing $H_2$ crossover
- Novel membrane gas permeability measured to evaluate membrane advances

## Electro-osmotic Drag

- Little agreement about electro-osmotic drag dependency on membrane water content
- Will measure electro-osmotic drag over a range of membrane water content by controlling %RH
- Novel test method should mitigate errors in measurement due to diffusion

Addresses performance and transport technical barriers, with collaboration among all group members. Membranes will be tailored to achieve specific water transport/thermal management goals.

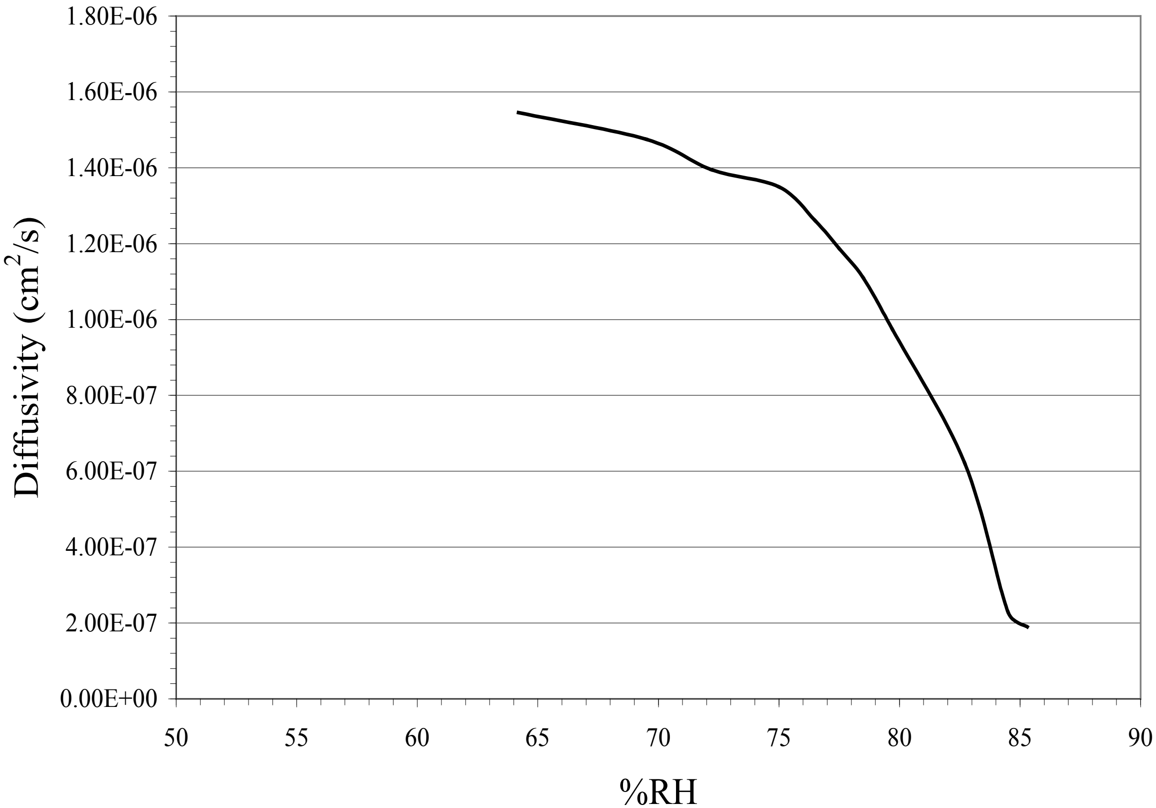
# Measurement of Diffusivity




- Isolate diffusional flux
  - Liquid water on one side of diffusion cell, atmospheric pressure
  - Control RH on vapor side by valve and pressure transducer
  - Measure net water flux through membrane by μFlow meter
  - Small differential pressure shouldn't significantly affect transport
  - Calculate diffusivity as a function of membrane water content (via measured RH)

Addresses all technical barriers; led by GES with collaboration from VA Tech and USC

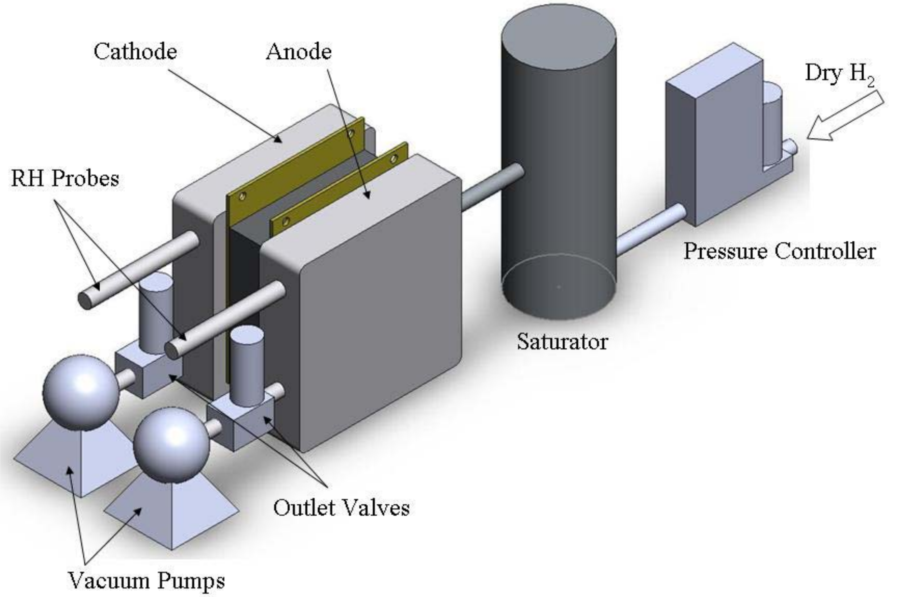
# Preliminary Diffusivity Data



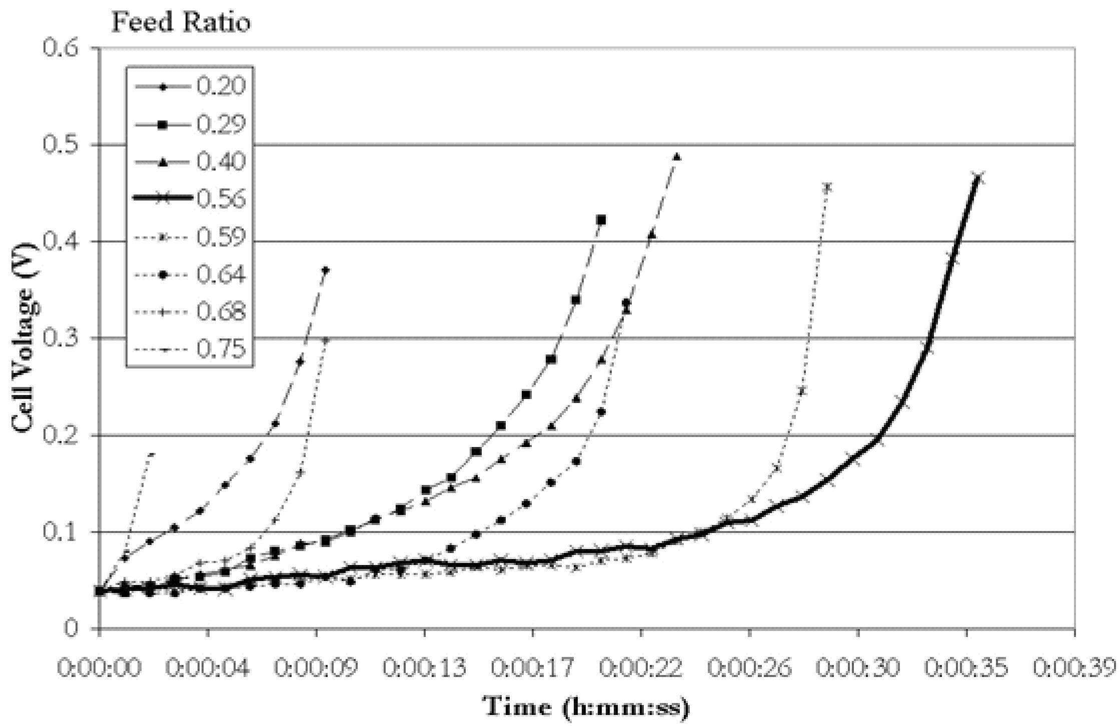

- Data show decrease in diffusivity with increase in %RH
- Test matrix will be expanded to other %RH and membrane types
- Addresses performance and transport technical barriers
- Testing led by GES with collaboration from VA Tech and USC

# Electro-osmotic Drag

- Isolate electro-osmotic drag
  - Control RH on both sides
  - Apply constant current
  - Guess EODC, feed water/$H_2$ in that ratio
  - If EODC is higher than water/$H_2$, water is transported across membrane faster than fed to anode, cell dries out, resistance (and potential) increases
  - If EODC is less than water/$H_2$, cell becomes flooded, potential increases

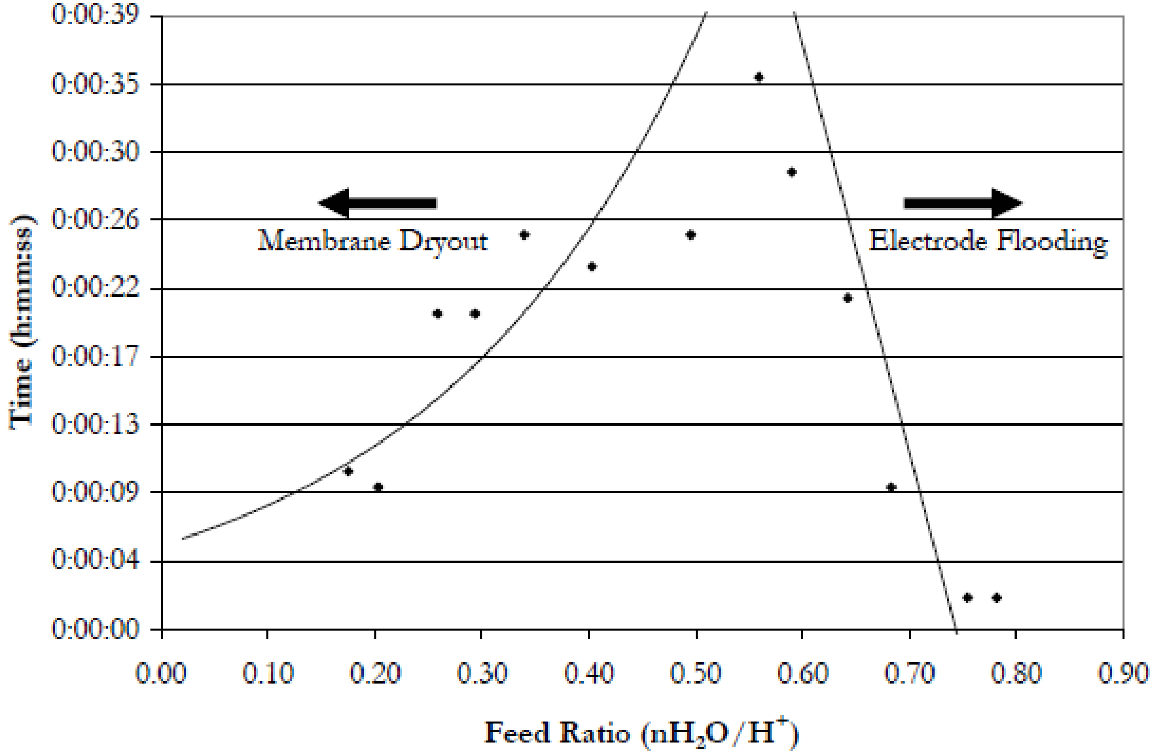


# Typical EODC Measurement Results




- Potential as a function of time for EODC experiment
- Longer operating times indicate better guess of EODC

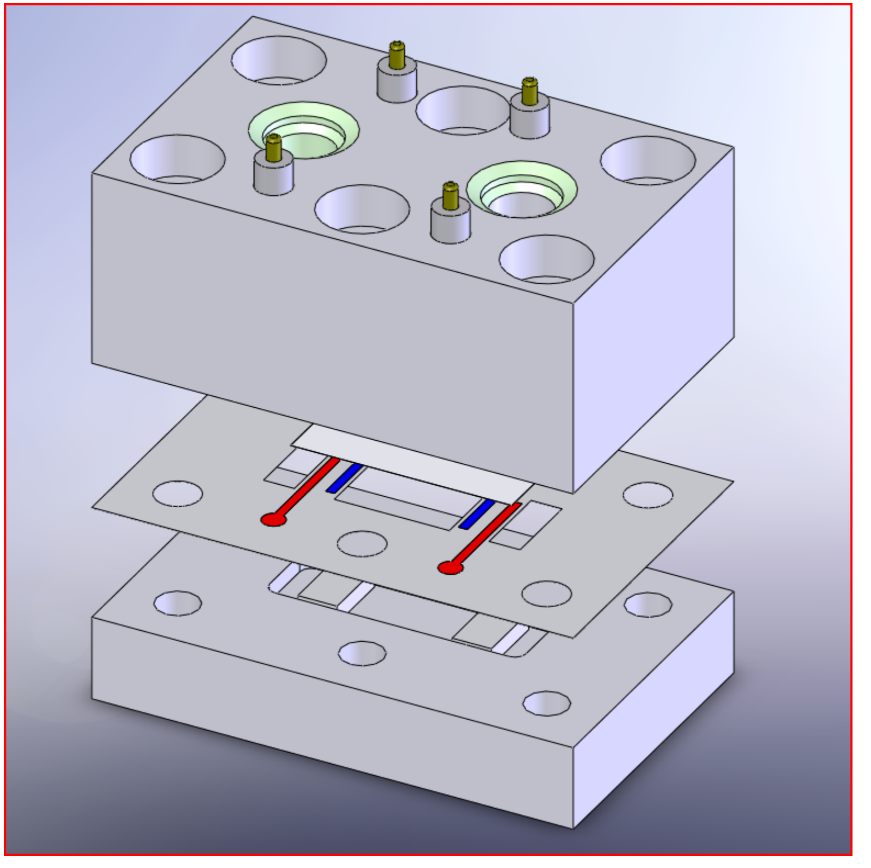
# Typical EODC Measurement Results




- "Zoom in" on EODC by changing feed ratio
- Longer times before dryout and flooding indicate good guess of EODC

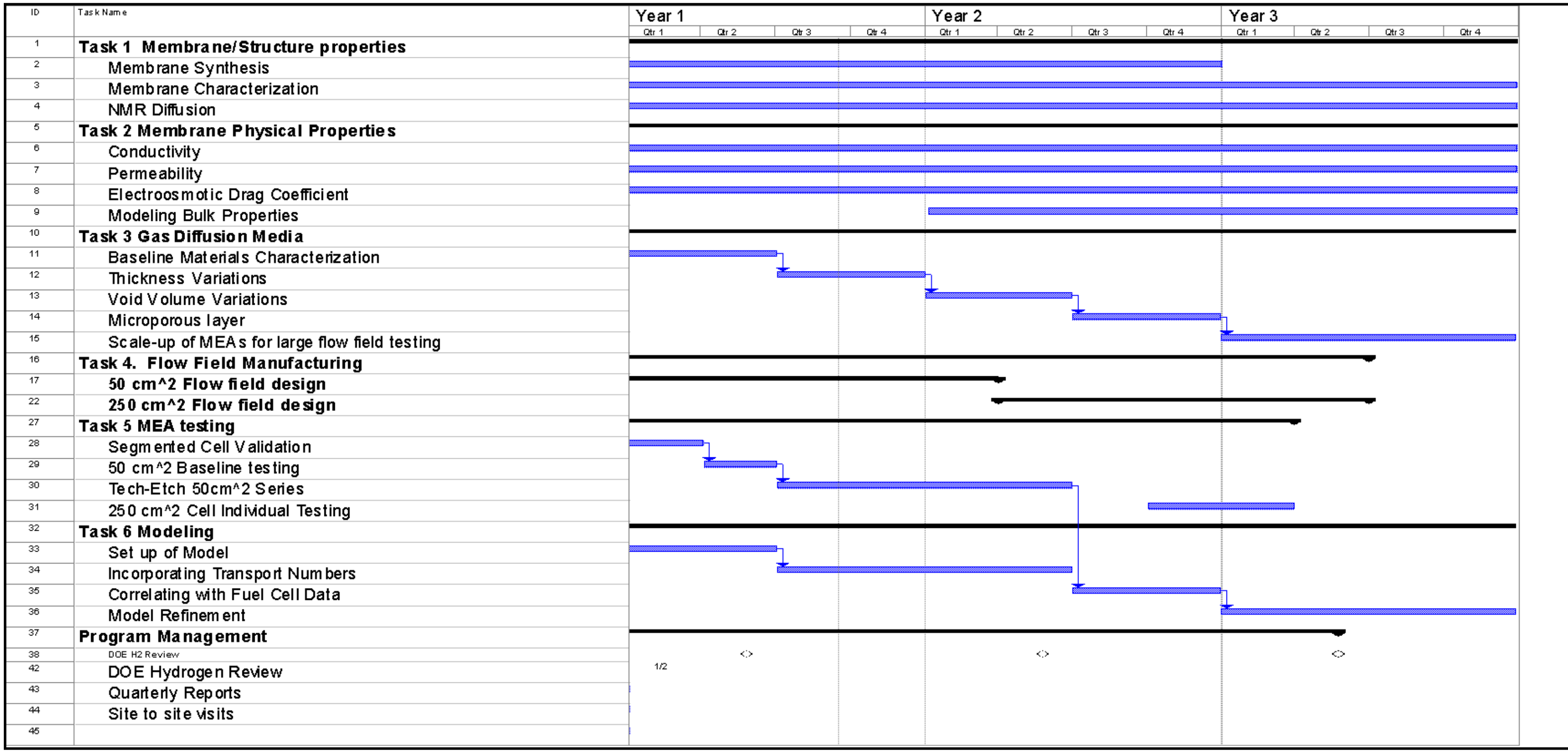
# Simultaneous Water Uptake/Conductivity

- Measures conductivity with four-point probe
- Held in oven for temperature control
- Cell Vacuumed out and known amount of water vapor is added
- RH monitored by pressure
- Water uptake measured by pressure change



# Work Plan

## Milestones to be worked out with Program Monitor

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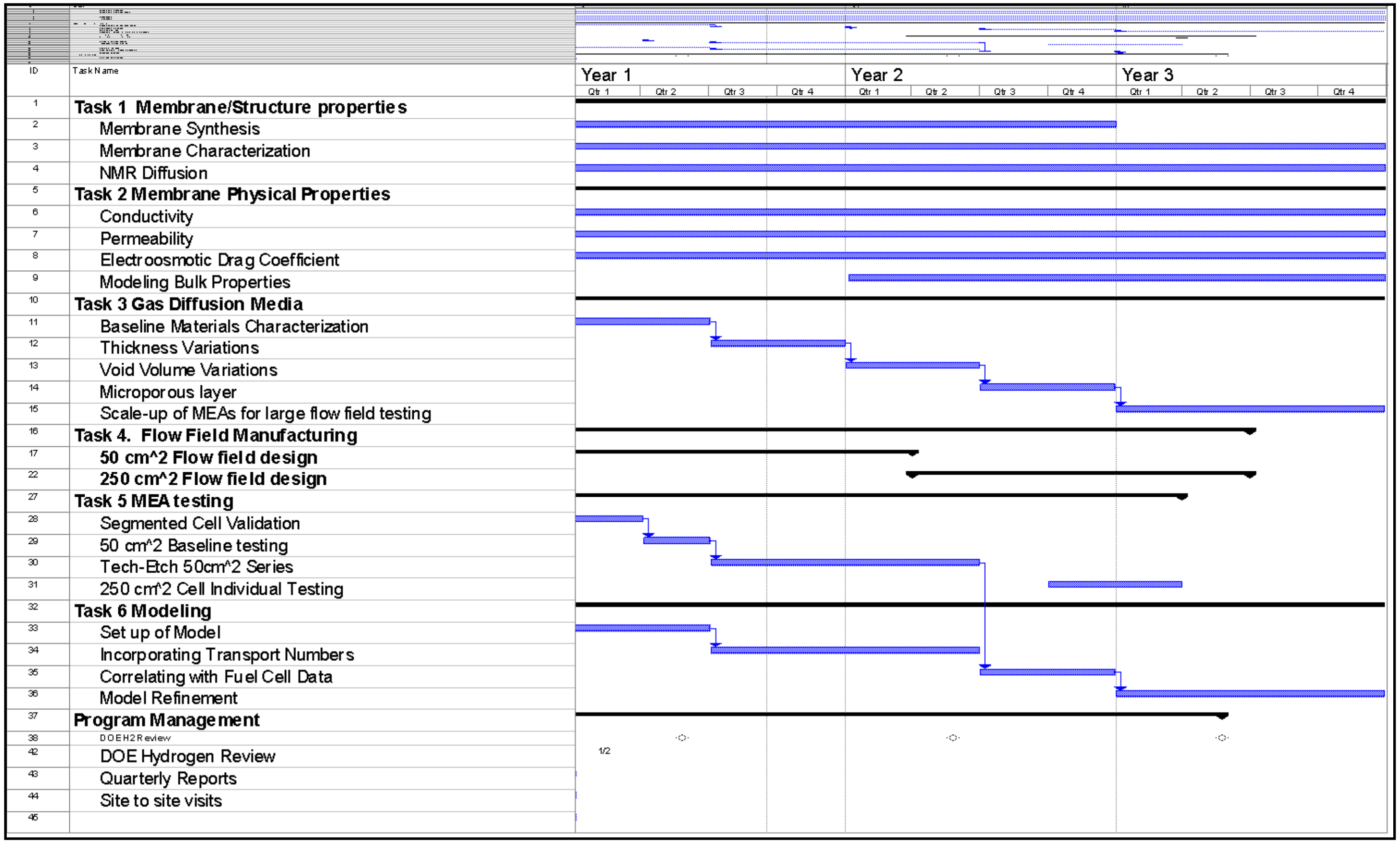
# Work Plan


ID
Task Name
Year 1
Year 2
Year 3
Qtr 1
Qtr 2
Qtr 3
Qtr 4
1 Task 1 Membrane/Structure properties
2 Membrane Synthesis
3 Membrane Characterization
4 NMR Diffusion
5 Task 2 Membrane Physical Properties
6 Conductivity
7 Permeability
8 Electroosmotic Drag Coefficient
9 Modeling Bulk Properties
10 Task 3 Gas Diffusion Media
11 Baseline Materials Characterization
12 Thickness Variations
13 Void Volume Variations
14 Microporous layer
15 Scale-up of MEAs for large flow field testing
16 Task 4. Flow Field Manufacturing
17 50 cm^2 Flow field design
22 250 cm^2 Flow field design
27 Task 5 MEA testing
28 Segmented Cell Validation
29 50 cm^2 Baseline testing
30 Tech-Etch 50cm^2 Series
31 250 cm^2 Cell Individual Testing
32 Task 6 Modeling
33 Set up of Model
34 Incorporating Transport Numbers
35 Correlating with Fuel Cell Data
36 Model Refinement
37 Program Management
38 DOEH2Review
42 DOE Hydrogen Review
43 Quarterly Reports
44 Site to site visits
45
1/2

# Summary

## Large multi-disciplinary project for fuel cell water transport

- Brings together several members from academia (VA Tech, USC) and industry (GES, EFT, Tech-Etch)
- Will utilize each member's expertise to design and evaluate fuel cell systems

## Technical Objectives

- Project will result in the design of a novel PEM tailored to specific transport properties
- PEM will be utilized in fuel cell hardware designed for this system and a mathematical model developed
- End of project:
  - Development of novel PEM
  - Newly designed bipolar plates/flow fields/GDL
  - Novel approach to testing membrane characteristics (i.e., diffusivity, EODC)
  - Mathematical model for water transport and performance
  - Model will be used to predict performance by changing component properties