Transport in PEMFCs

Giner, Inc.
Hui Xu
Junqing Ma
Shelly Brawn
Cortney Mittelsteadt (PI)

University of South Carolina
Sirivatch Shimpalee
Visarn Lilavivat

AvCarb
(Formerly Ballard Materials)
Don Connors
Guy Ebbrell
Jason Morgan

University of Alabama
John VanZee

Virginia Tech
James McGrath
Yu Chen
Jarrett Rowlett
Andy Shaver
Chang Hyun Lee

Tech Etch
Kevin Russell

Project ID #
FC054

Transport in PEMFCs

Timeline

- Project Start Date: 10/5/2009
- Project End Date: 10/31/2013
- Percent Complete: 80%

Budget

- Total Project Funding
  - DOE Share $2.66M
  - Cost Share $678K (20%)
- Funding Received in FY10: $915K
- Funding Received in FY11: $786K
- Funding Received in FY12: $400K
- Planned Funding in FY13: $560K

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 South Carolina
- Virginia Tech
- Tech Etch
- AvCarb

Approach: Team and Tasks

Objective: Improve Understanding/Correlation Between Material Properties and Model Equations

- Generate model
- Supply model relevant transport numbers
- Stress the model by developing different materials with different transport properties
- Determine sensitivity of fuel cell performance to different factors
- Guide research

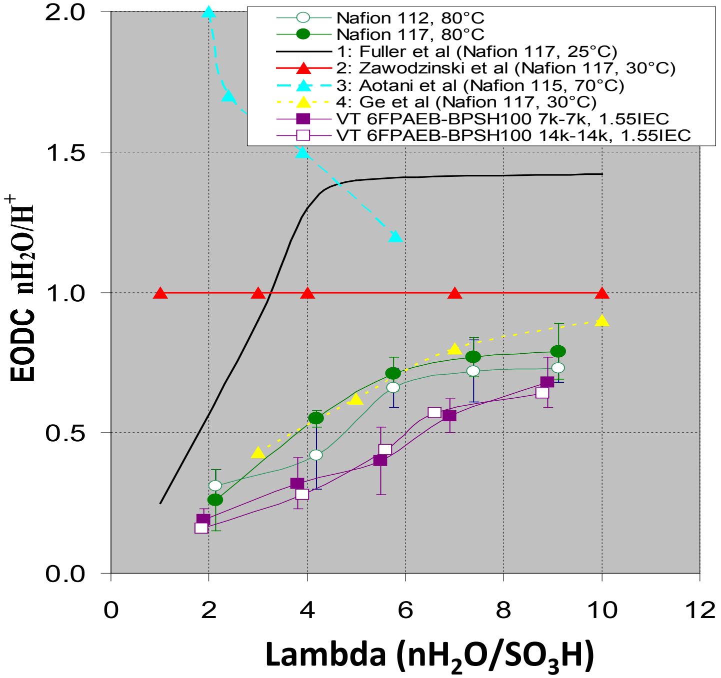
Milestone	Plan Complete	Actual Complete
Baseline PFSA model, with overall results correlating within +-20% of each other. Design the new apparatus for extending the range of electroosmotic drag and diffusivity.	4/15/2011	4/1/2011
Extend Model to a variety of membranes, catalyst content, GDM's, and flow fields. The model should be able demonstrate prediction of the actual data within +-20% of the experimental results.	8/15/2012	90%

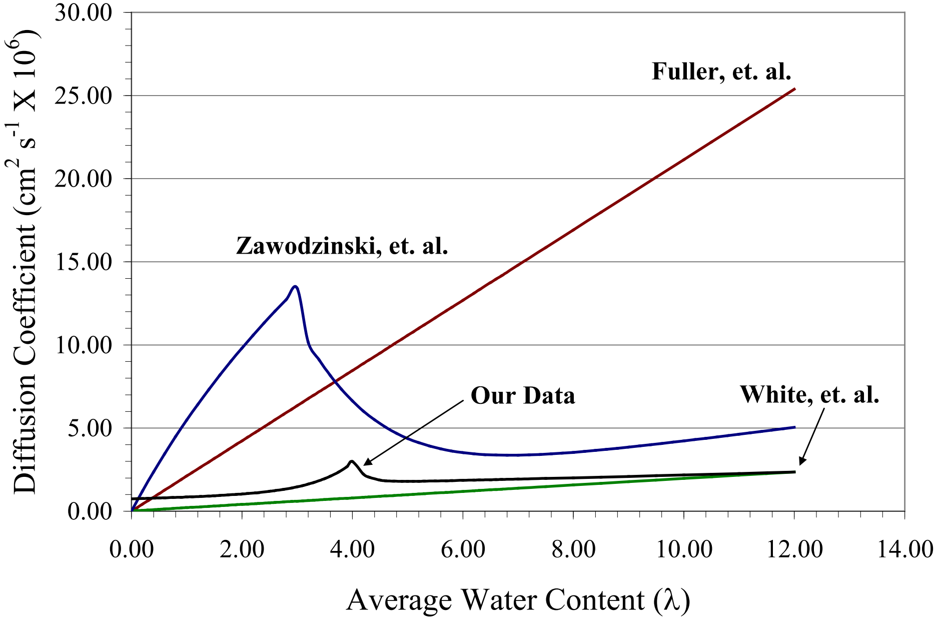
Approach & Milestones

	Techniques	Materials	Modeling
Year 1	New technique generation for static and dynamic diffusion, EODC, through plane conductivity confirmation with Baseline materials. Current Distribution Board Demonstration	Baseline hydrocarbon PEM generated and down selected Baseline Gas diffusion Media Delivered First Etched Plates	Set-Up of Model Use of Baseline materials for Testing Model Sensitivity Testing
Year 2	Techniques applied to alternative materials. Diffusivity apparatus used to characterize alternative diffusion media (33%).	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. (50%) Alternative diffusion media tested.
Year 3 (Period 2)	Low Temperature Studies	~~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.

Work on larger cells abandoned in favor of using GM "open source" hardware

Relevance: Use of Modeling in Fuel Cell Development is Widespread. Agreement on Fundamentals *is not*





- *NOTHING EVEN RESEMBLING CONSENSUS ON THESE FUNDAMENTALS*
- Systematic approach of generating and developing various materials with better characterization methods is needed

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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Relevance:

PEM Development

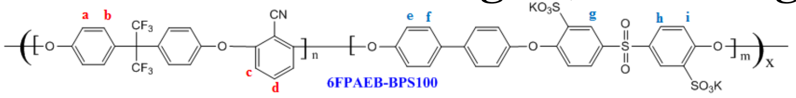
- Hundreds of PEMs developed for fuel cells
  - Would like to come up with design rules for PEMs
  - How does size/degree of Phase separation affect
    - Conductivity
    - EODC
    - Water Diffusivity
    - Gas Permeability
  - Similar Study done by *Gross et al* for side-chain polymers

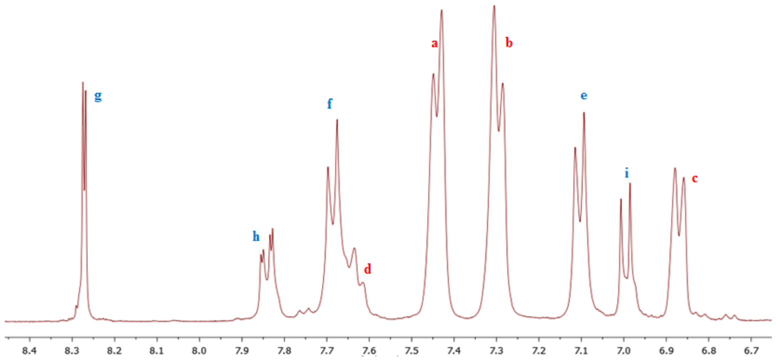
Modeling

- Need to make sure we know how changes in transport numbers effect fuel cell performance
- Transport numbers and model are used to confirm each other
- How sensitive is fuel cell performance to these different parameters?
- What should we be working on?

Achievements: Copolymer Membrane Design

- Matrix 1: Varied Block Lengths, Annealing Temperature and IEC

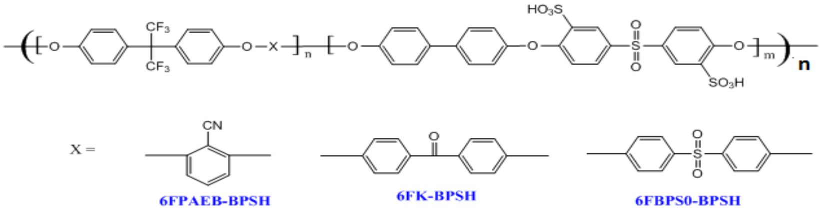


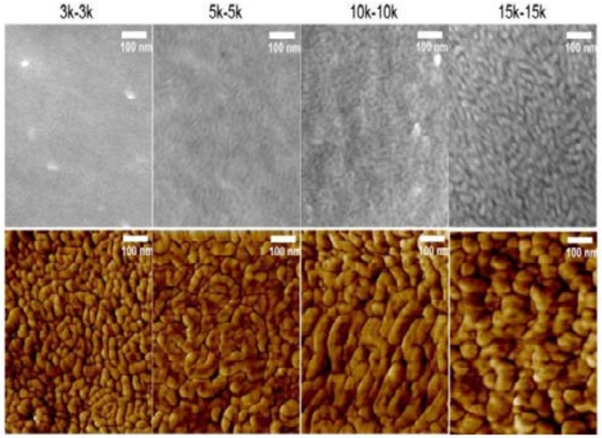


	Polymer	Thermal Treatment Temperature (°C)	IEC (meq/g)
1	6FPAEB-BPSH100 7k-7k	110	1.55
2	6FPAEB-BPSH100 15k-15k	110	1.55
3	6FPAEB-BPSH100 10k-18k	110	2.01
4	6FPAEB-BPSH100 7k-7k	220	1.55
5	6FPAEB-BPSH100 15k-15k	220	1.55
6	6FPAEB-BPSH100 10k-18k	220	2.01

- Matrix 2: Varied Oligomer Categories/Properties

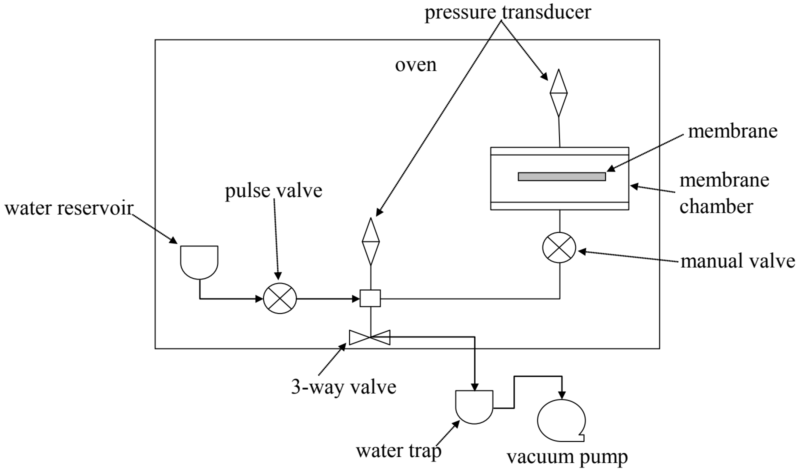
Sample	Block Copolymer	Block Length	IEC (meq/g)[a]	Water Uptake (%)[b]	Conductivity (S/cm)[c]
JR-143-2	6FK-BPSH	8K – 8K	1.45	21	0.10
JR-143-3	6FPAEB-BPSH	13K – 13K	1.63	37	0.14
JR-143-4	6FBPS0-BPSH	10K – 10K	1.47	35	0.10

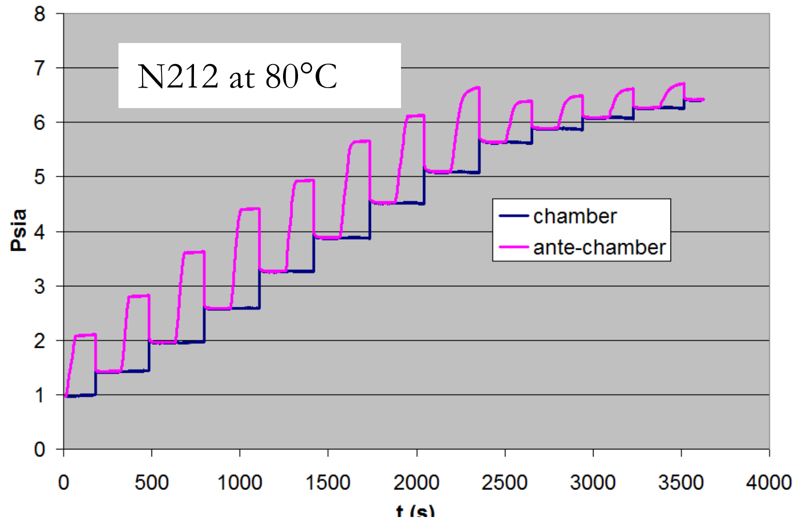


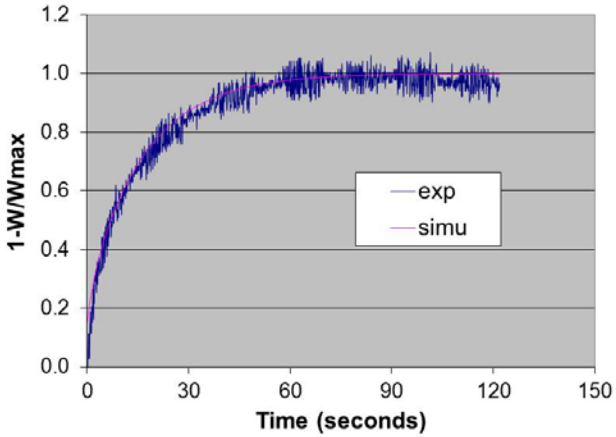


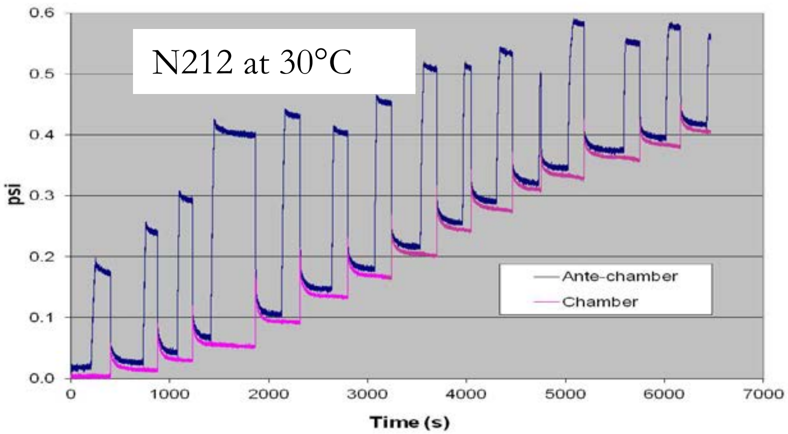
Achievements:

New Technique: Simultaneous Water Uptake and Diffusivity Extended to Sub-Ambient Conditions

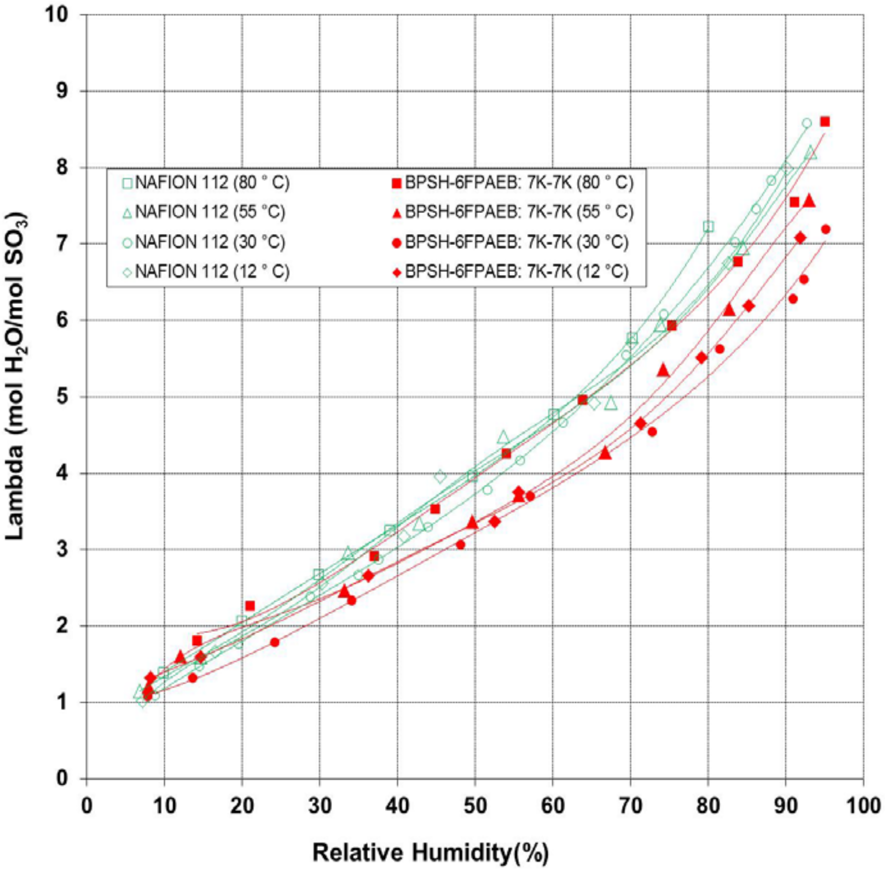


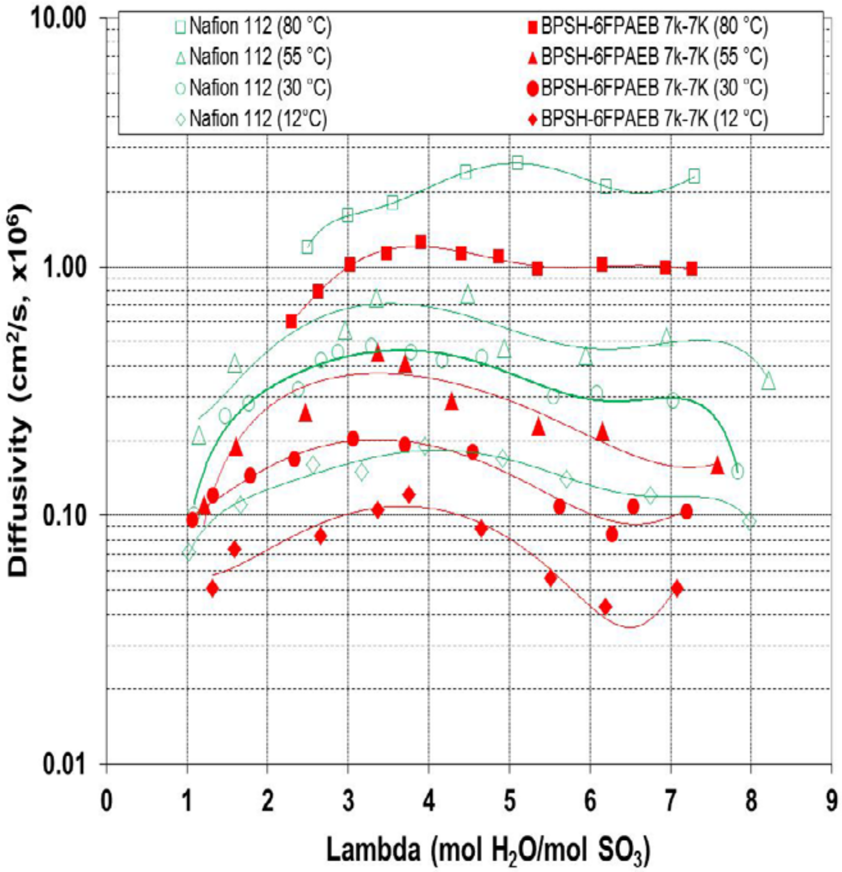






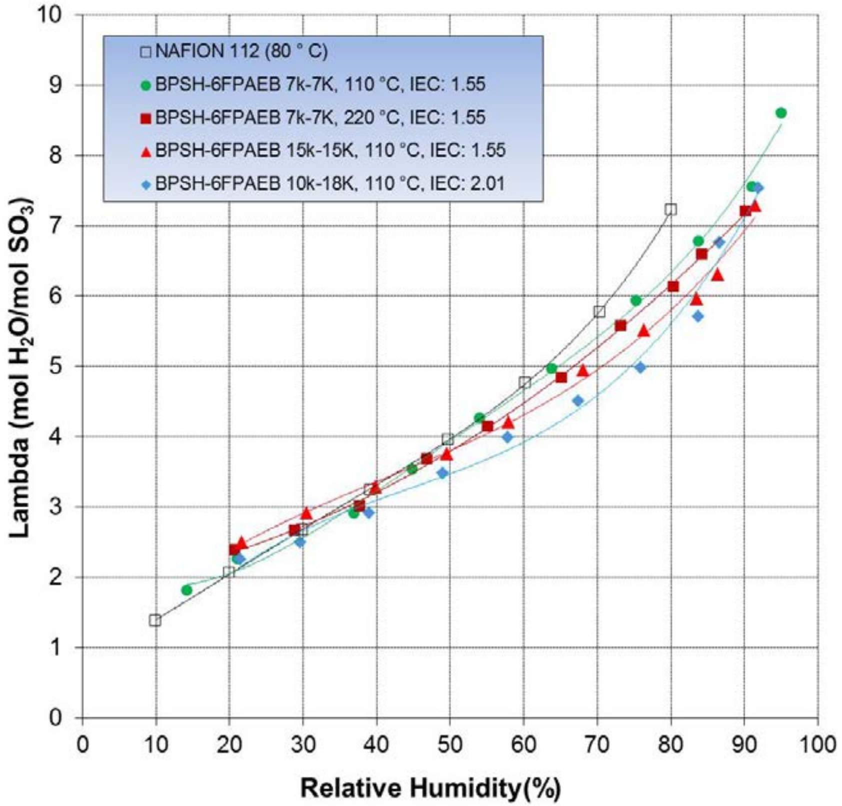
Achievements:
New Technique: Simultaneous Water Uptake and Diffusivity

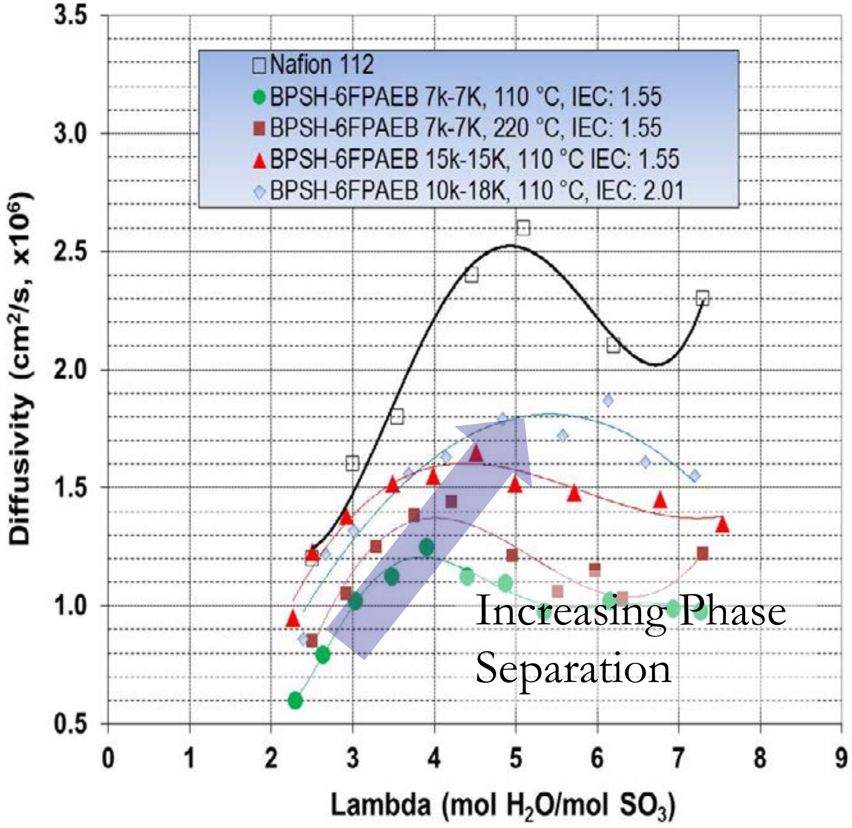




BPSH-6FPAEB Membranes show nearly identical water uptake with little temperature dependence
Water Diffusivity is ~ ½ that of Nafion® regardless of temperature.

Achievements: Water Diffusivity of Various Membranes

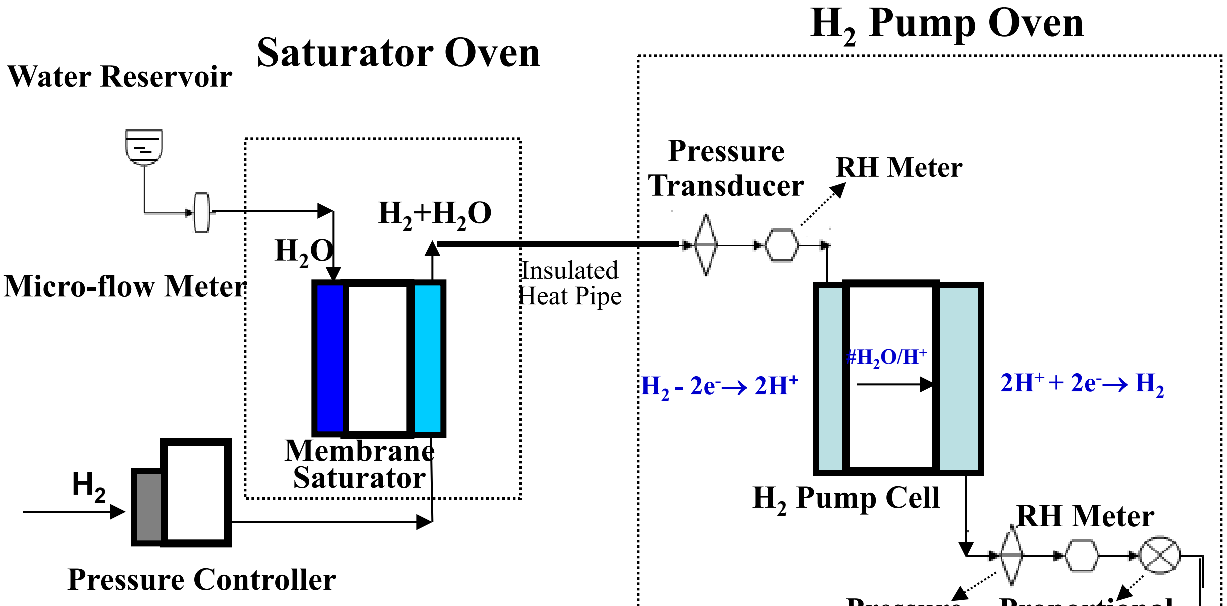


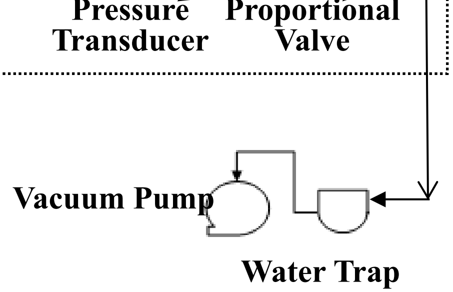


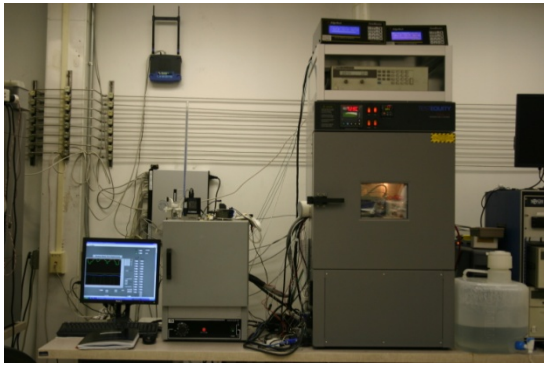
Increasing Phase Separation

- Morphology does not affect water uptake at low RH
- Phase separation on a smaller scale results in lower diffusivity. Annealing increases phase separation and diffusivity

Achievements: New Technique: EODC



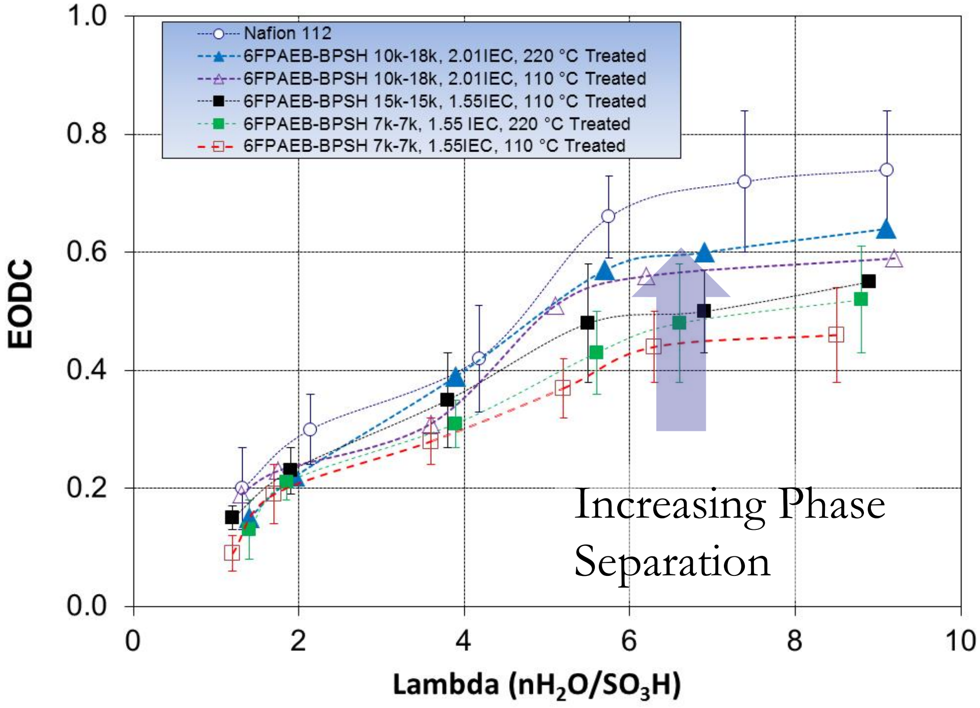




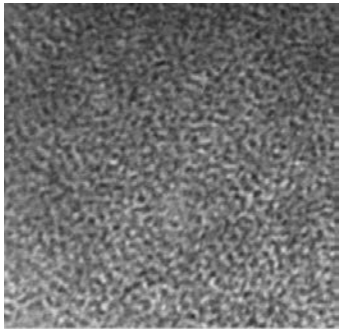
- Water/H_2 inlet ratio controlled by controlling saturator temperature and H_2 pressure
- If ratio is too high, not enough water is dragged across and cell floods and fails
- If ratio is too low, membrane dries out and cell fails
- At Water/H_2 = 2*EODC Cell operates in quasi-stable state

All gas/gas diffusion is eliminated

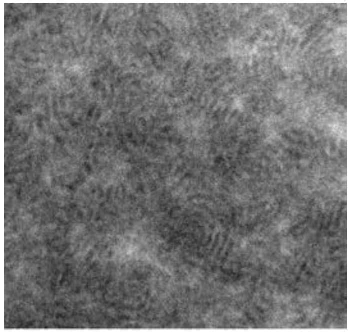
Correlation EODC to Copolymer Structure

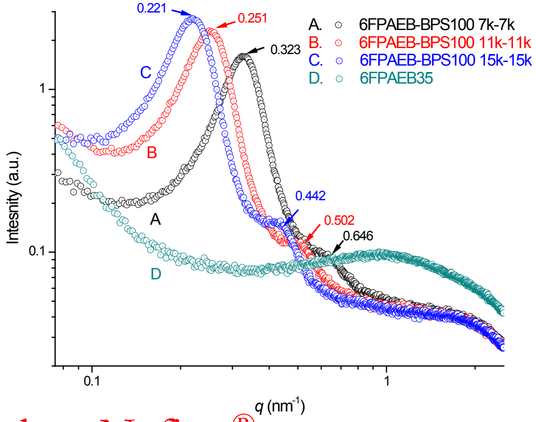


7K-7K



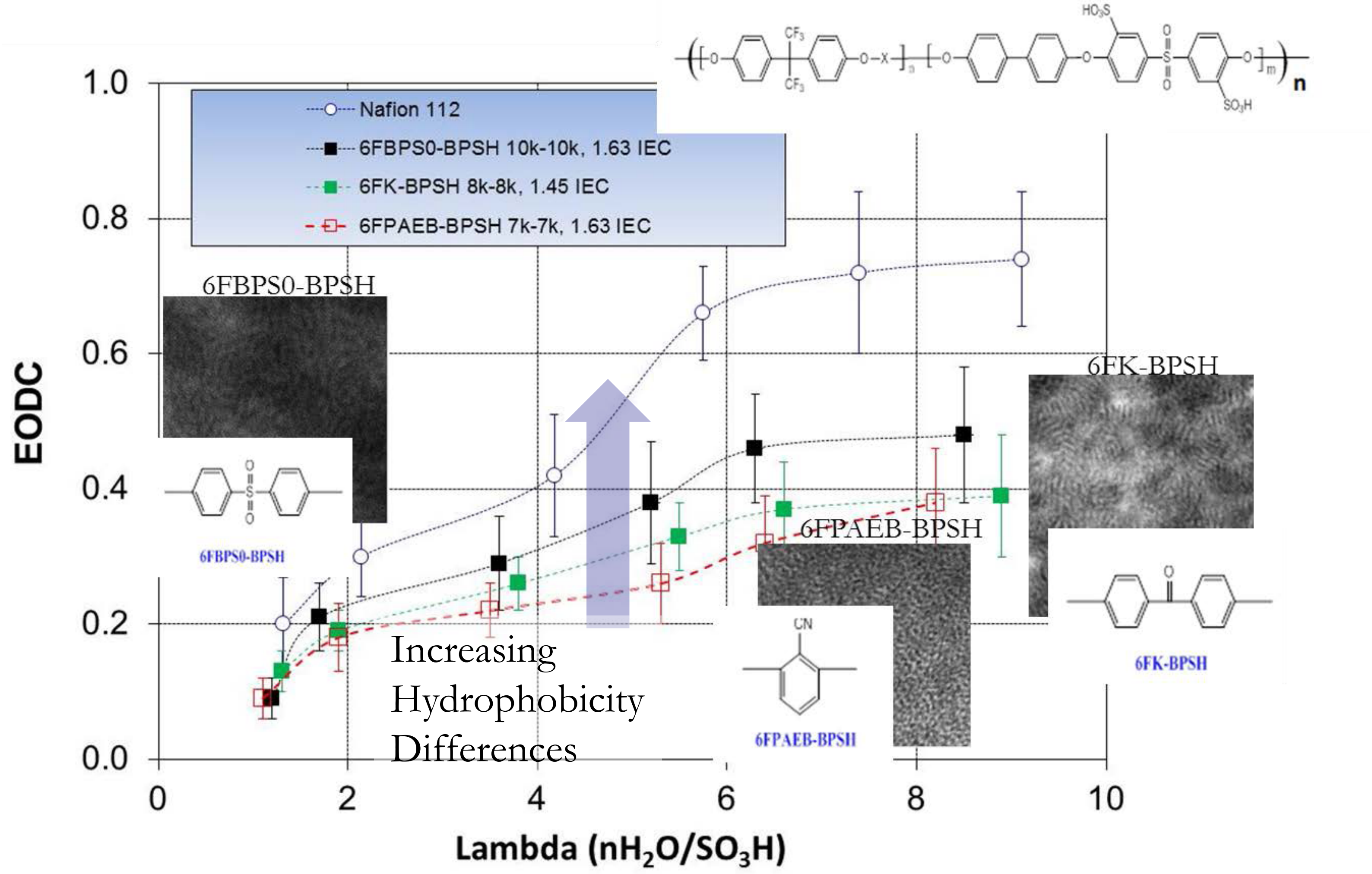
15K-15K





- All hydrocarbon membranes exhibit lower EODC than Nafion®
- Higher thermal annealing, block lengths and IEC seem to increase EODC

Relating EODC to Block Chemistry

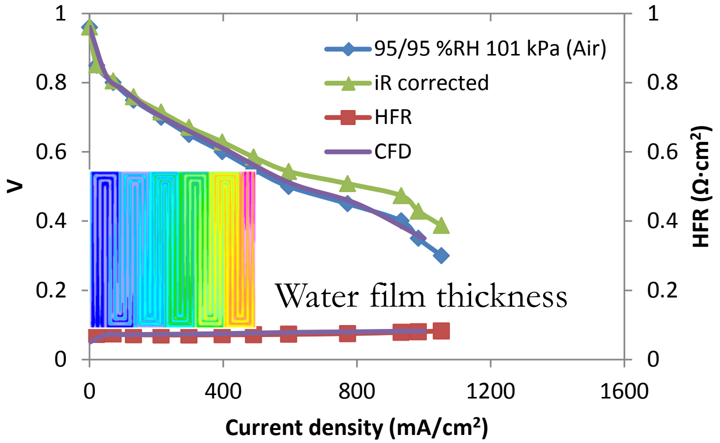


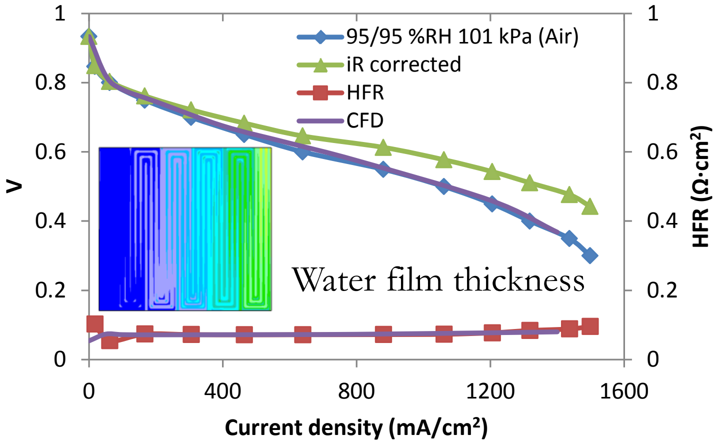
Increasing Hydrophobicity Differences

Polarization Curves: *(co-current flow: $80^{o}C$, 1.5/2.0 stoich, H_2/Air: GDL - EP40T)*

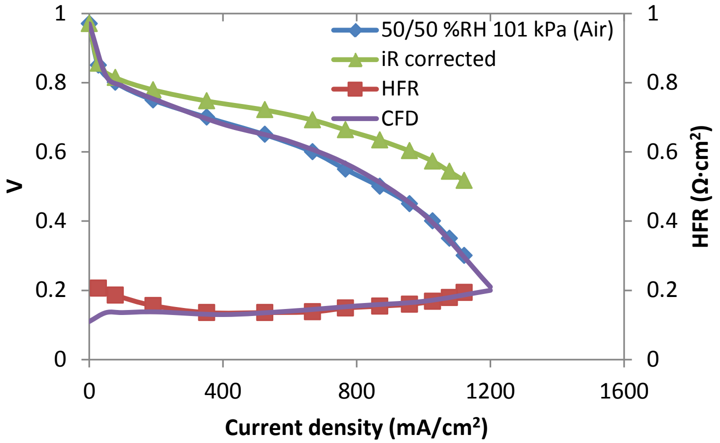
Nafion®

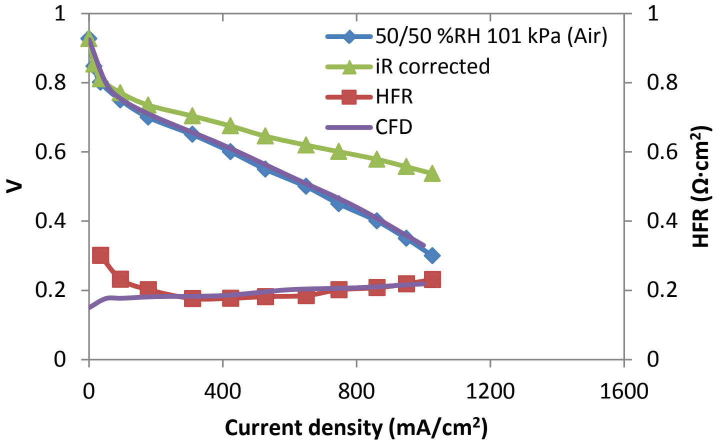
Hydrocarbon (VT) membrane





High RH



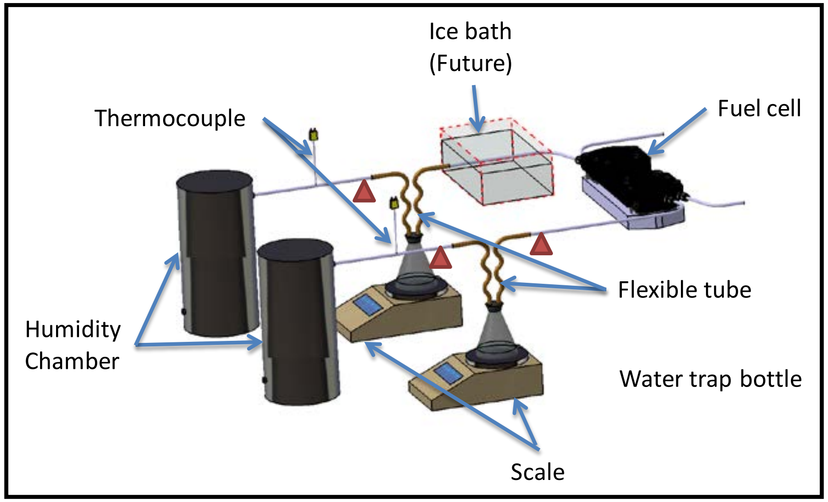


Low RH

HC's Lower EODC leads to less flooding **80% more H_2O** delivered to cathode (model and experimental validation)

Water Balance Measurement Under Different Conditions

Experimental vs. CFD (VT membrane)



Water Balance experiment and numerical result of new MEA
(80°C, 1.5/2.0 stoich H_2/O_2*)*

Water balance shows the transport of water inside fuel cell. For different operating conditions and membranes, the water transport inside fuel cell will also be different.

	i A/cm^2	RH	Anode Water Balance (mg/sec)			Cathode Water Balance (mg/sec)				Cross error (%)
			Water in	Water out	Cross to Cathode	Water in	Gen.	Water out	Cross from Anode	
EXP	**1.2**	80/80	1.40	0.071	1.32	0.95	2.80	4.82	1.25	5
CFD	**1.2**	80/80	1.40	0.055	1.34	0.95	2.80	5.10	1.36	1.5
EXP	**0.8**	100/100	1.27	1.42	-0.15	0.85	1.86	2.44	-0.17	11
CFD	**0.8**	100/100	1.28	1.44	-0.16	0.85	1.86	2.54	-0.17	6

Water Balance Measurement Under Different Conditions

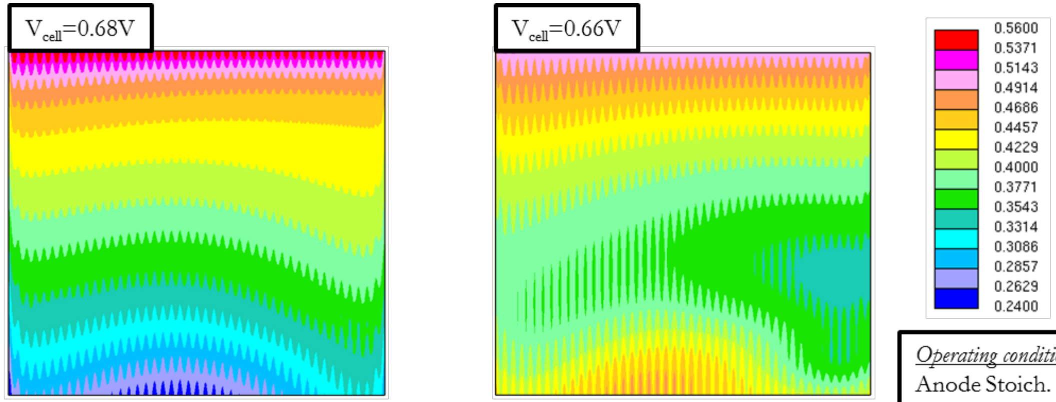
Water Balance experiment of VT MEA **6FPAEB-BPSH**

(80^{o}C, 1.5/2.0 stoich H_2/Air)

		i A/cm^2	RH	Anode Water Balance (mg/sec)			Cathode Water Balance (mg/sec)				error (%)
				Water in	Water out	Cross to Cathode	Water in	Gen.	Water out	Cross from Anode	
Low current density	EXP	**0.4**	75/25	0.75	0.22	0.53	0.59	0.93	2.01	0.49	7.5
	CFD	**0.4**	75/25	0.75	0.23	0.52	0.59	0.93	2.03	0.51	2.0
	EXP	**0.4**	50/50	0.42	0.29	0.13	1.35	0.93	2.42	0.14	7.1
	CFD	**0.4**	50/50	0.42	0.29	0.13	1.35	0.93	2.40	0.12	8.3
	EXP	**0.4**	95/95	1.10	0.86	0.25	3.51	0.93	4.73	0.29	13.7
	CFD	**0.4**	95/95	1.10	0.90	0.20	3.51	0.93	4.66	0.22	9.0
	EXP	**0.6**	75/25	1.12	0.33	0.79	0.88	1.40	3.09	0.81	2.5
	CFD	**0.6**	75/25	1.12	0.31	0.81	0.88	1.40	3.13	0.85	4.7
High current density	EXP	**0.8**	50/50	0.85	0.55	0.30	2.70	1.87	4.88	0.31	3.2
	CFD	**0.8**	50/50	0.85	0.58	0.27	2.70	1.87	4.85	0.28	3.5
	EXP	**0.8**	95/95	2.21	1.68	0.53	7.03	1.87	9.44	0.54	1.8
	CFD	**0.8**	95/95	2.21	1.66	0.55	7.03	1.87	9.45	0.55	0.0
	EXP	**1.2**	95/95	3.32	1.99	1.34	10.55	2.80	14.60	1.25	7.5
	CFD	**1.2**	95/95	3.32	2.01	1.31	10.55	2.80	14.72	1.37	4.4

WIDE AGREEMENT BETWEEN CFD MODEL AND EXP RESULTS

Local Distributions of Current Density & Water Transport on the Membrane Surface at low inlet RH at 0.4 A/cm^2



V_{cell}=0.68V

V_{cell}=0.66V

Current density (A/cm^2)

Operating condition:

Anode Stoich. = 1.5 Cathode Stoich. = 2.0

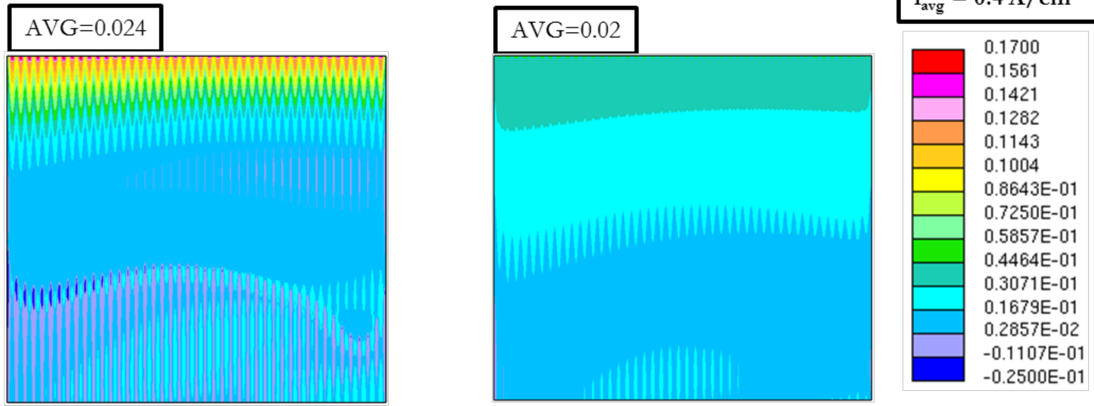
Anode RH = 75% **Cathode RH = 25%**

Tcell = 80°C System pressure = 101kPa

i_{avg} = 0.4 A/cm^2

NRE212

Hydrocarbon (VT)



AVG=0.024

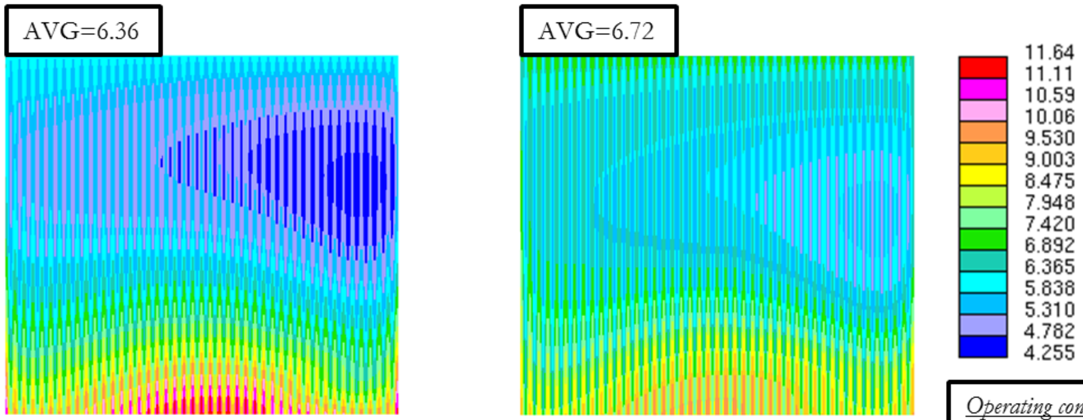
AVG=0.02

Water flux across membrane (mg/cm^2-s)

VT membrane shows slightly lower performance but more uniformity in distributions of both current density and water transport across membrane.

At dry condition: no liquid water is presented in fuel cell

Local Distributions of Water Content in Membrane & Liquid Water on Cathode MEA/GDL Interface at high inlet RH at 0.6 A/cm^2



λ (mol H_2O/mol SO_3)

VT membrane sustains more water than Nafion® membrane.

NRE212

Hydrocarbon (VT)

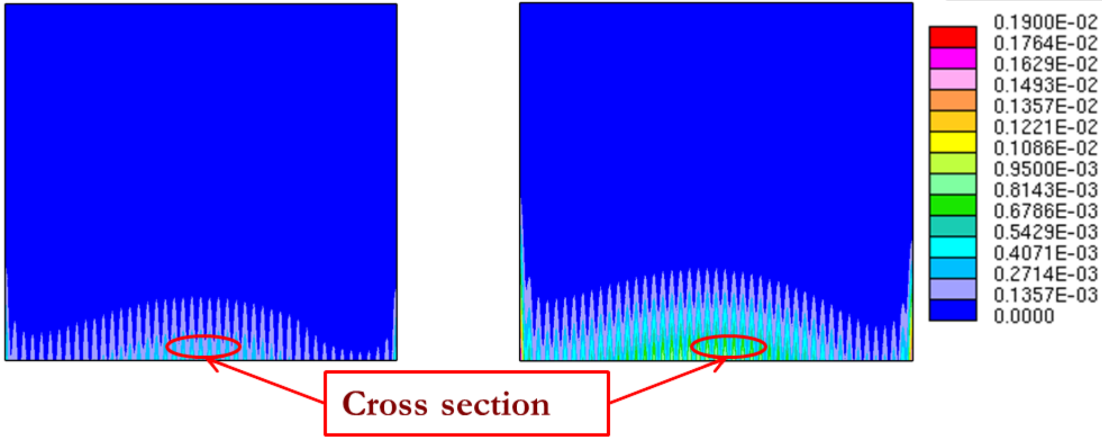
Operating condition:

Anode Stoich. = 1.5 Cathode Stoich. = 2.0

Anode RH = 100% **Cathode RH = 50%**

Tcell = 80°C System pressure = 101kPa

i_{avg} = 0.6 A/cm^2



Liquid water(kg/kg)

Liquid water is presented in both Nafion® and VT membranes but not significant.

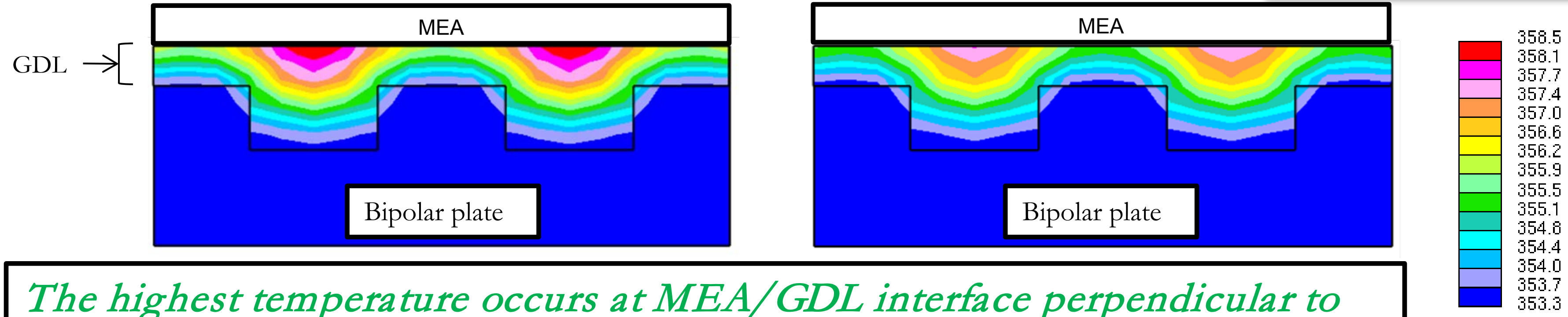
Local Distributions of Temperature and Liquid Water at High RH

Cathode Cross Section

T_{avg} = 358K

T_{avg} = 357.4K

Temperature (K)

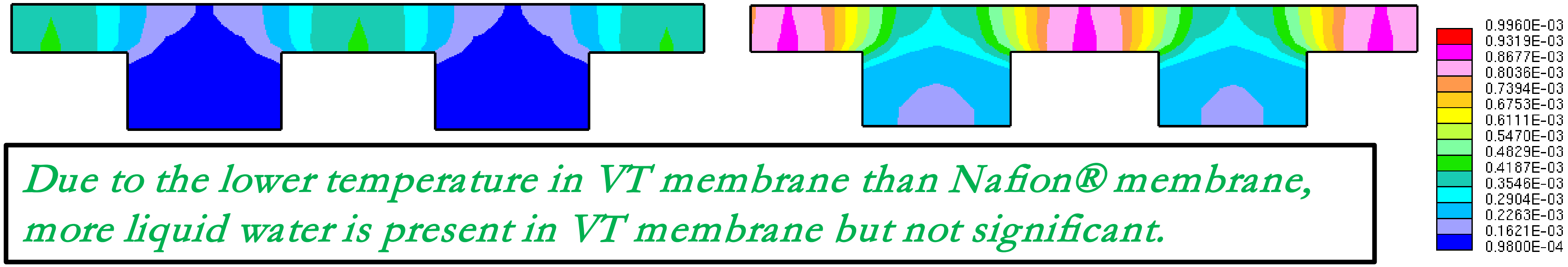


The highest temperature occurs at MEA/GDL interface perpendicular to the flow channel. The temperature gradient across GDL ~ 3°C

NRE212

Hydrocarbon (VT)

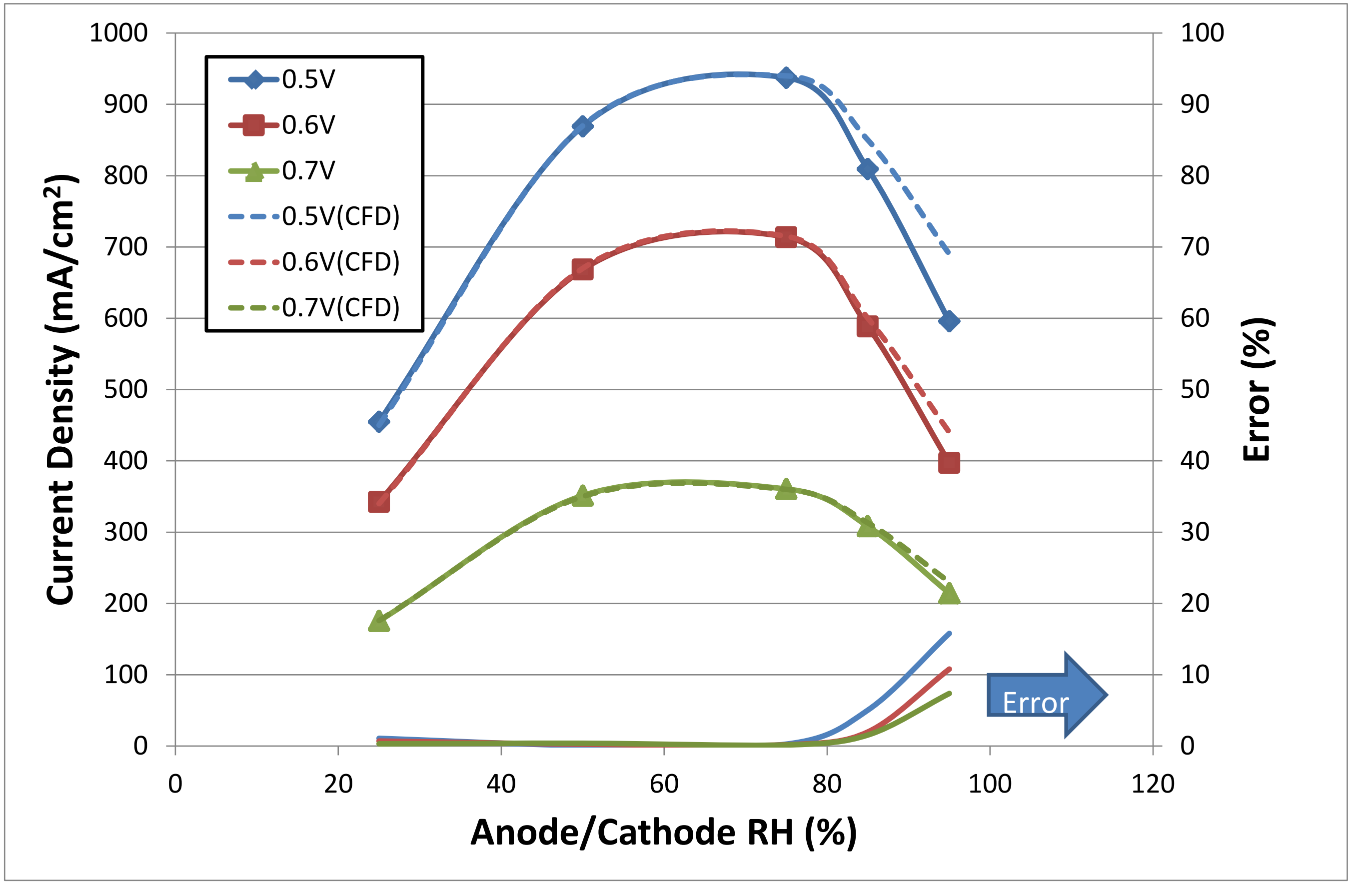
Liquid Water (kg/kg)



Due to the lower temperature in VT membrane than Nafion® membrane, more liquid water is present in VT membrane but not significant.

Effect of Inlet Humidity on Current Density at Different Potentials

(80 ^{o}C, 1.5/2.0 stoich H_2/Air : Memrbrane – NRE212: GDL – EP40T)

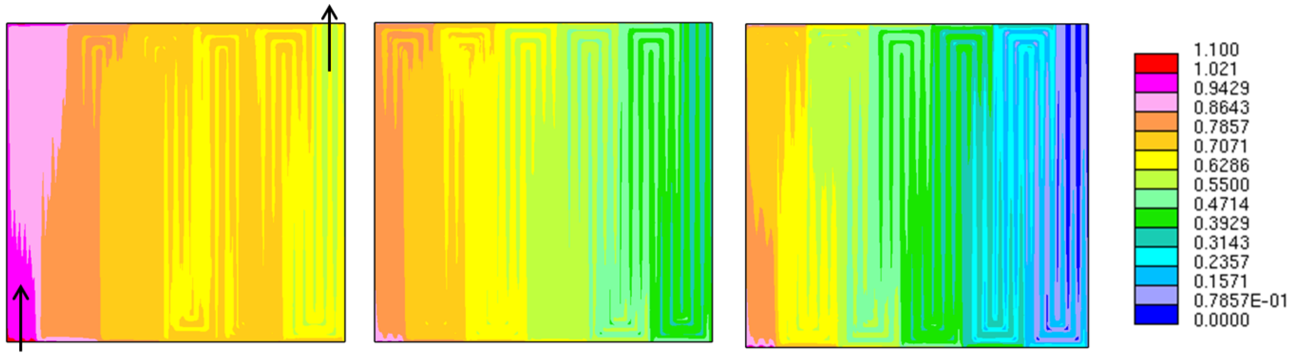


Using to probe/characterize efficiency of diffusion media to remove liquid water

Will try to relate to porosity, hydrophobicity McMullin Number

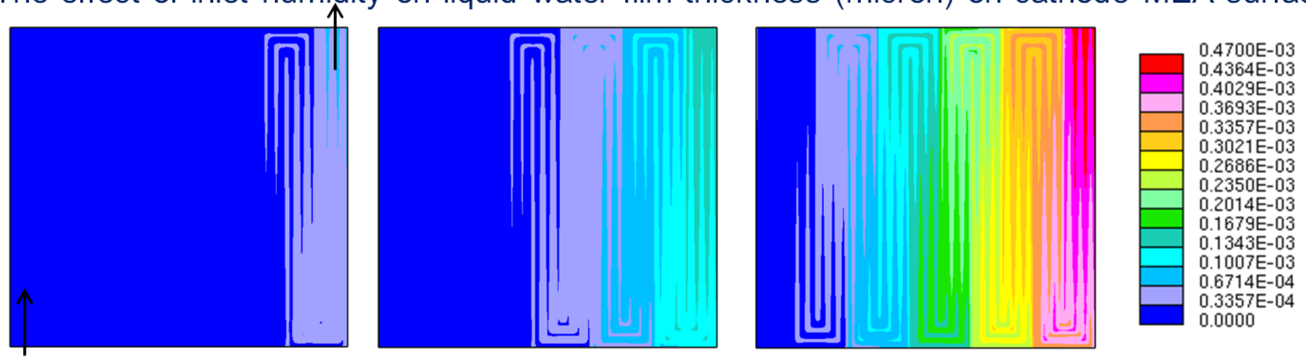
Effect of Inlet RH on CDD (A/cm^2) on MEA Surface

at Vcell = 0.6V (80°C, 1.5/2.0 stoich H_2/Air : Membrane – NRE212: GDL – EP40T)



75%/75% RH   85%/85% RH   95%/95% RH

The effect of inlet humidity on liquid water film thickness (micron) on cathode MEA surface



75%/75% RH   85%/85% RH   95%/95% RH

Model does a good job of handling flooding by assuming accumulation of water film.

Summary

- Membrane design and development (VA Tech) & Characterization (Giner):
  - Membranes with similar *charge densities* but different
    - Chemistries (different hydrophobicity of the non-functional block)
    - Morphologies
      - Block length
      - Annealing
  - Increased hydrophobicity of the non-functional group, longer block lengths and annealing all lead to a more distinct separation of phases, on a larger length scale
    - Increases conductivity at low RH
    - Increases diffusivity
    - Increases EODC

- Transport Modeling, GDL & Current Distribution Board Characterization (USC & Giner):
  - Model successfully predicts:
    - *Dry, Wet Conditions. Hydrocarbon and PFSA membranes*
    - *Performance and Water Balance*
    - *Increased flooding for PFSA membranes compared to hydrocarbon membranes*

Future Work

- Emphasis on Saturated Conditions
    - Diffusion Media
    - Membrane Transport Properties

- Electrode Effects
    - High Current Density at Low Catalyst Loading
    - Flooding of NSTF layers

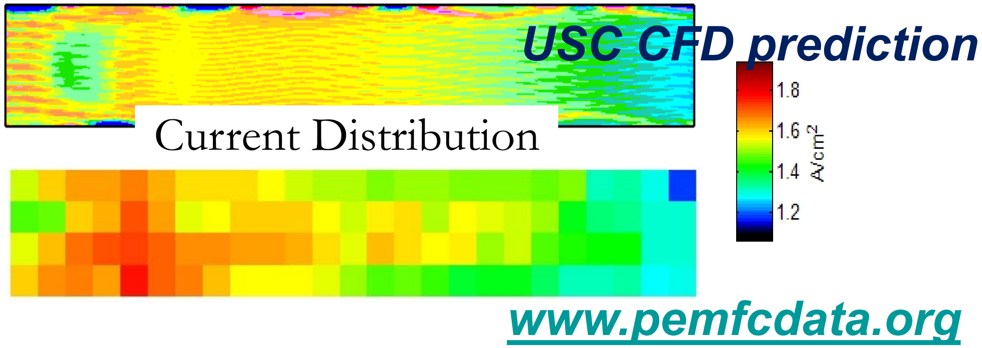
Technical Back Up Slides

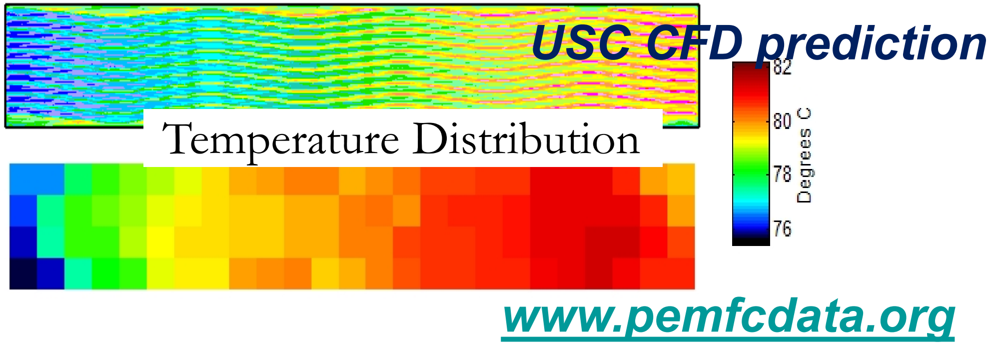
- Not Discussed:
  - Current Distribution Boards
  - Verification of Model with GM Open Data
  - Diffusion Media

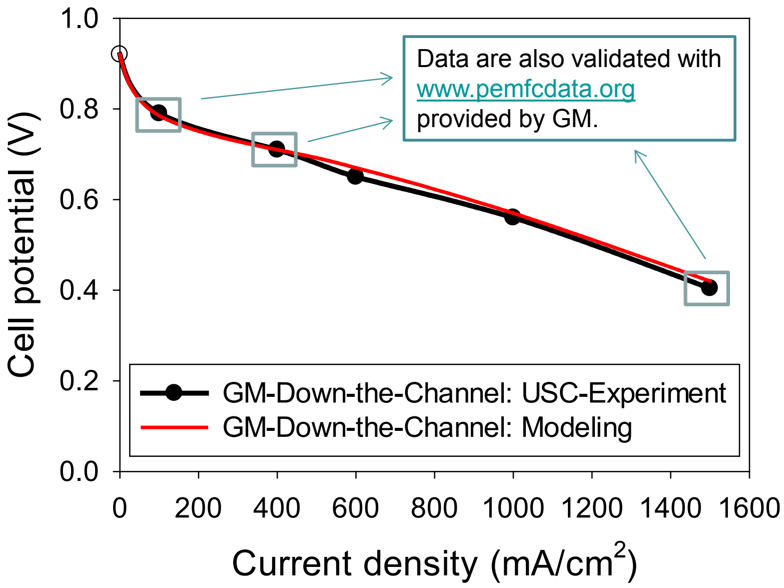
Achievement: Model Verification:

Distributions of current density and temperature of 50-cm^2 GM-Down-the-Channel flow-field compared with www.pemfcdata.prg

(I_{avg} = 1.5 A/cm^2, counter-current flow: 50/50%RH, 150/150kPa, 80°C, 1.5/2.0 stoich)

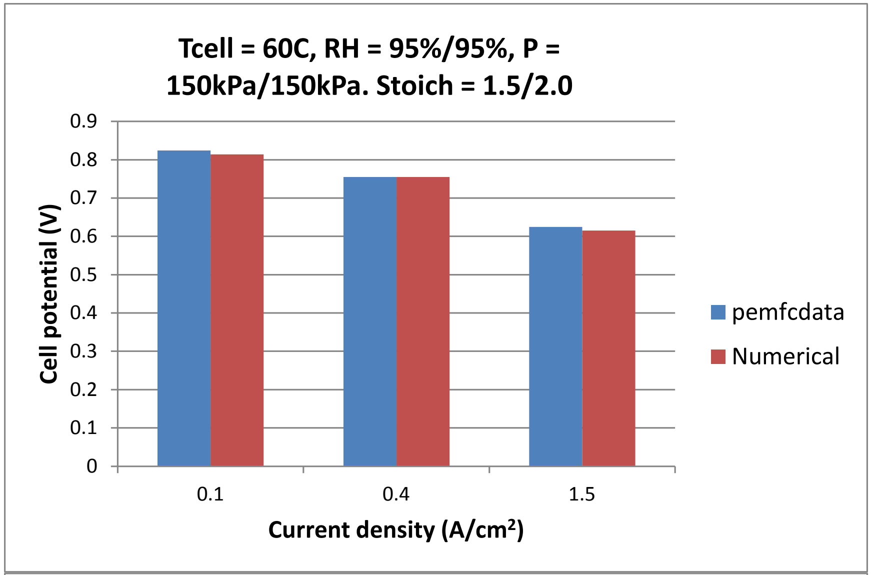


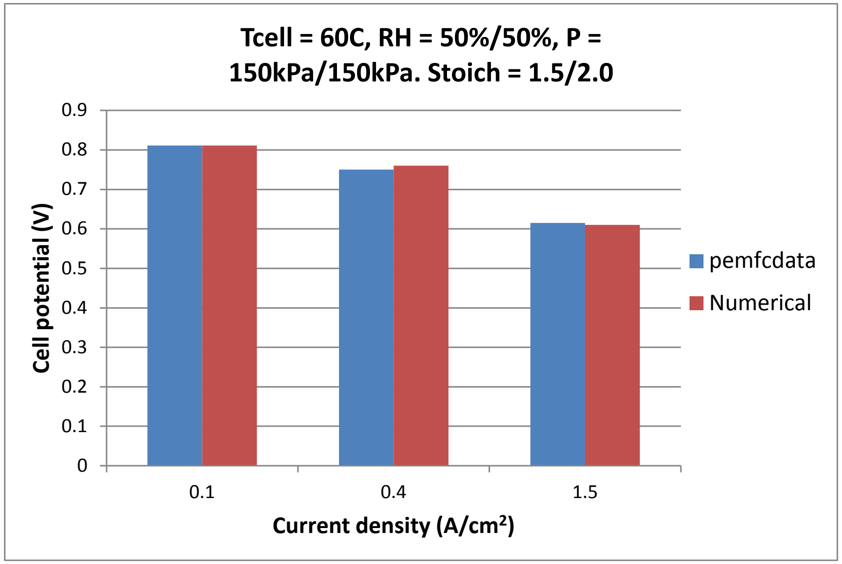


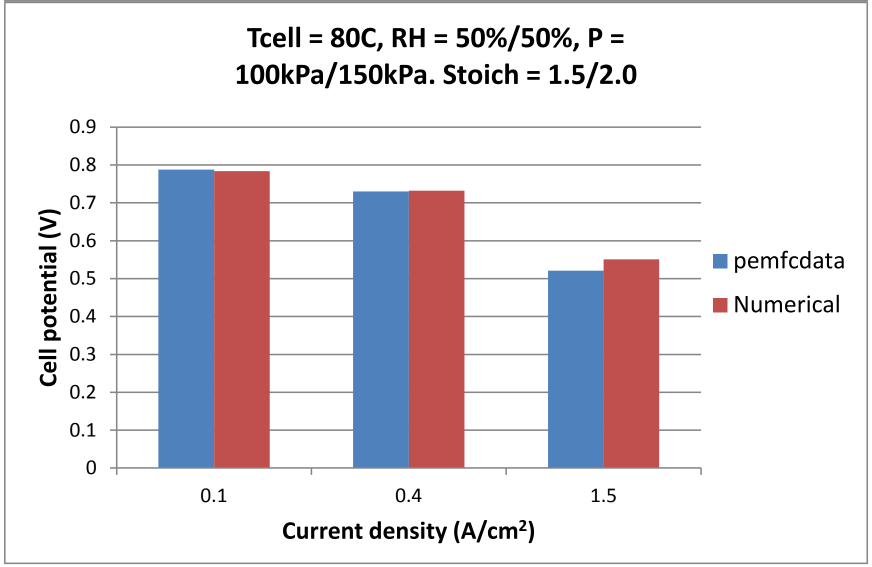

Data are also validated with www.pemfcdata.org provided by GM.

USC data matches published data very well, both with performance and model results

CFD comparison with pemfcdata.org at different operating conditions

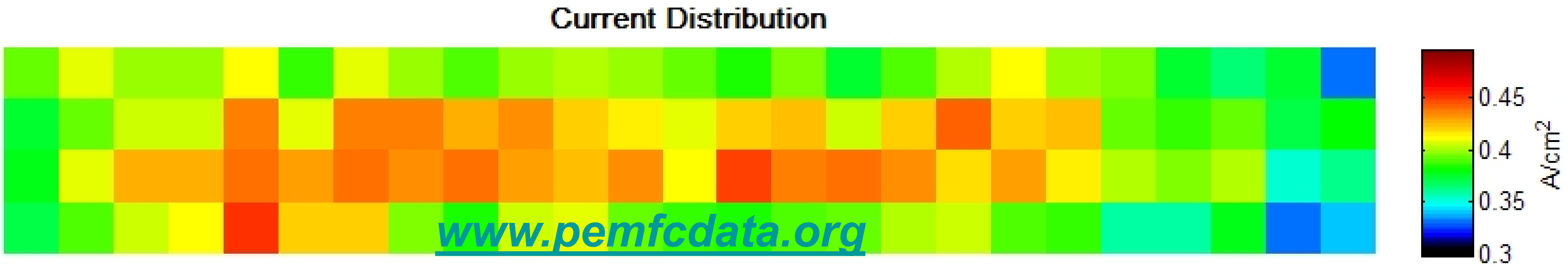


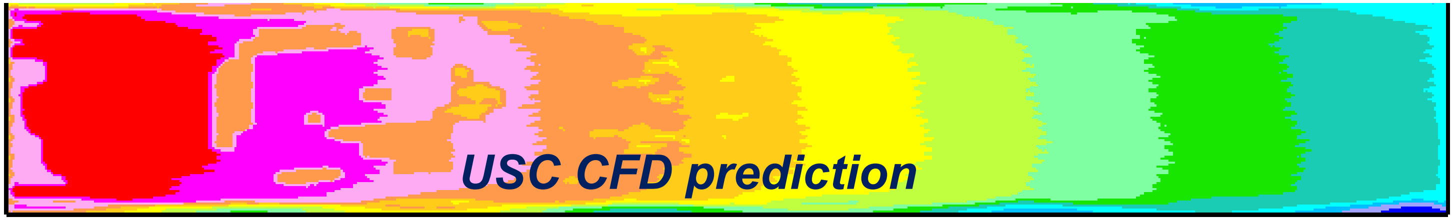


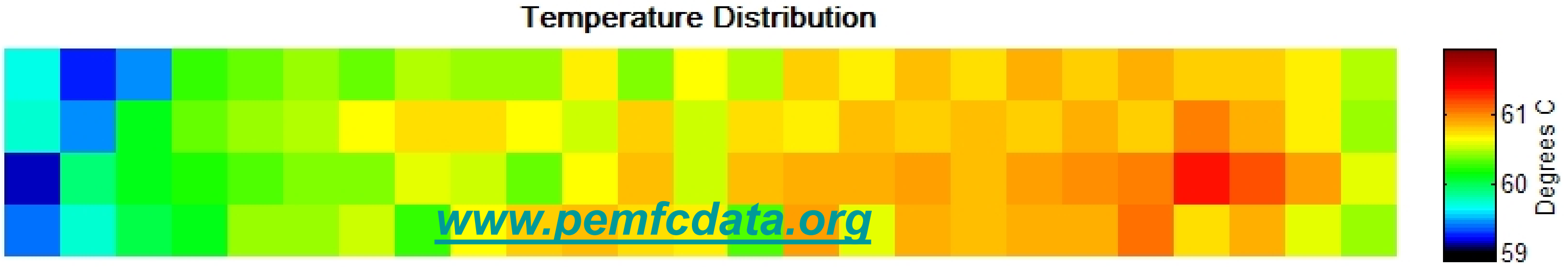


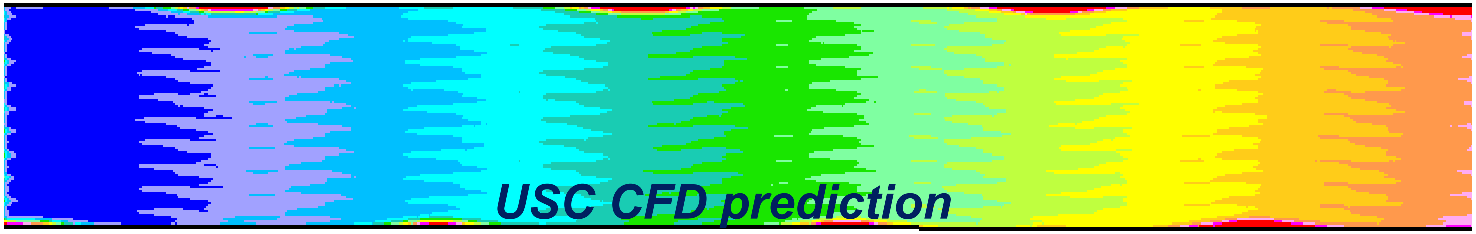
USC's CFD predictions compare well with published data from pemfcdata.org

Local distributions of current density and temperature on membrane surface at I_{avg} = 0.4 A/cm^2 T_{cell} = 60C, RH = 95%/95%, P = 150kPa/150kPa. Stoich = 1.5/2.0

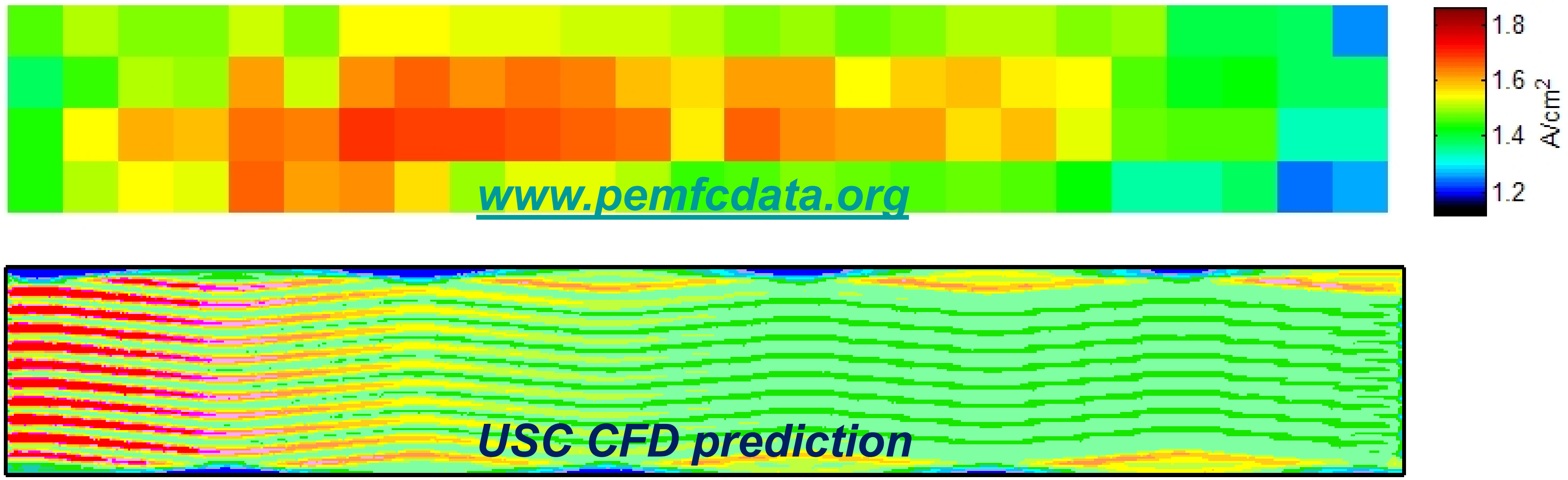








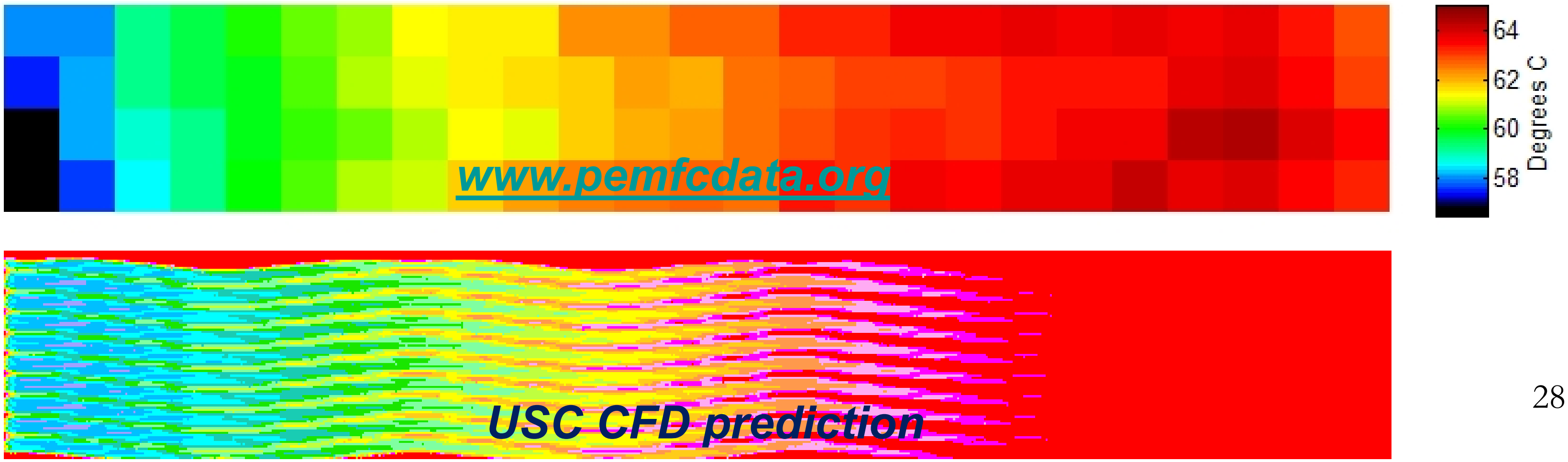
Local distributions of current density and temperature on membrane surface at $I_{avg} = 1.5$ A/cm^2 T_{cell} = 60C, RH = 95%/95%, P = 150kPa/150kPa. Stoich = 1.5/2.0



Current Distribution

www.pemfcdata.org

USC CFD prediction



Temperature Distribution

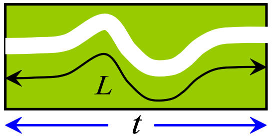
www.pemfcdata.org

USC CFD prediction

Achievements: New Materials: Diffusion Media

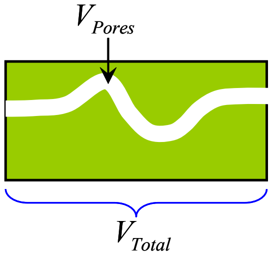
- AvCarb added to the program recently
- Started with Toray Materials
  - Variable Wet-Proofing
  - Microporous Layer
- AvCarb will provide more custom materials
- Want to generate differences in:
  - MacMullin Number
    - Porosity
    - Tortuosity
  - Hydrophobicity

- 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.

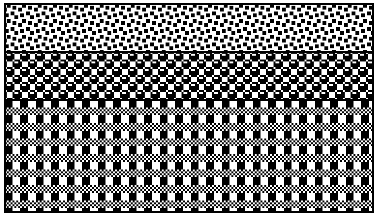


$$\varepsilon = \frac{V_{Pores}}{V_{Total}}$$

- MacMullin Number
  - Function of tortuosity and pososity.

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

Achievements: Design of Gas Diffusion Media



MPL 1

MPL 2

Carbon Substrate

Baseline Material at start of program was Toray H060

The new design of GDLs have been modified from standard AvCarb GDLs by adding two micro porous layers. Each set has been treated with two different methods in order to provide two different values of diffusivity.

Substrate	**Diffusivity Modification**	**MPL 1/MPL2 (carbon particle size)**
P50 EP40 P75	Low High	Small/Large Large/Small

Total of 12 new papers generated
5 characterized ex-situ to date

AvCarb GDLs Status

5 sets of 12 assigned new design of GDLs with two different micro porous layers

Substrate	Diffusivity	MPL 1	MPL 2	# of Samples	MacMullin No.
P50	low (<0.15)	Small	Large	5	
P50	low (<0.15)	Large	Small	2	2.63
P50	high (>0.25)	Small	Large	5	
P50	high (>0.25)	Large	Small	2	2.16
EP40	low (<0.25)	Small	Large	5	
EP40	low (<0.25)	Large	Small	5	
EP40	high (>0.35)	Small	Large	5	
EP40	high (>0.35)	Large	Small	2	2.34
P75	low (<0.20)	Small	Large	5	
P75	low (<0.20)	Large	Small	2	2.26
P75	high (<0.3)	Small	Large	5	
P75	high (<0.3)	Large	Small	2	1.88

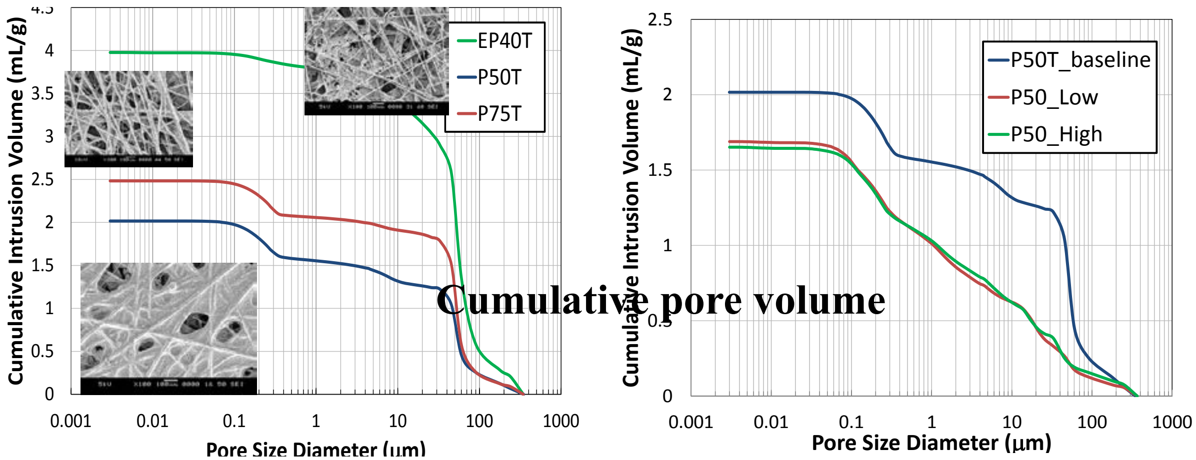
The new design of GDLs have been modified from standard Ballard GDLs by adding two micro porous layers. Each set has been treated with two different methods in order to provide two different values of diffusivity.

Achievements: Design of Gas Diffusion Media

Comparison of Mercury pore size distributions of new design GDLs

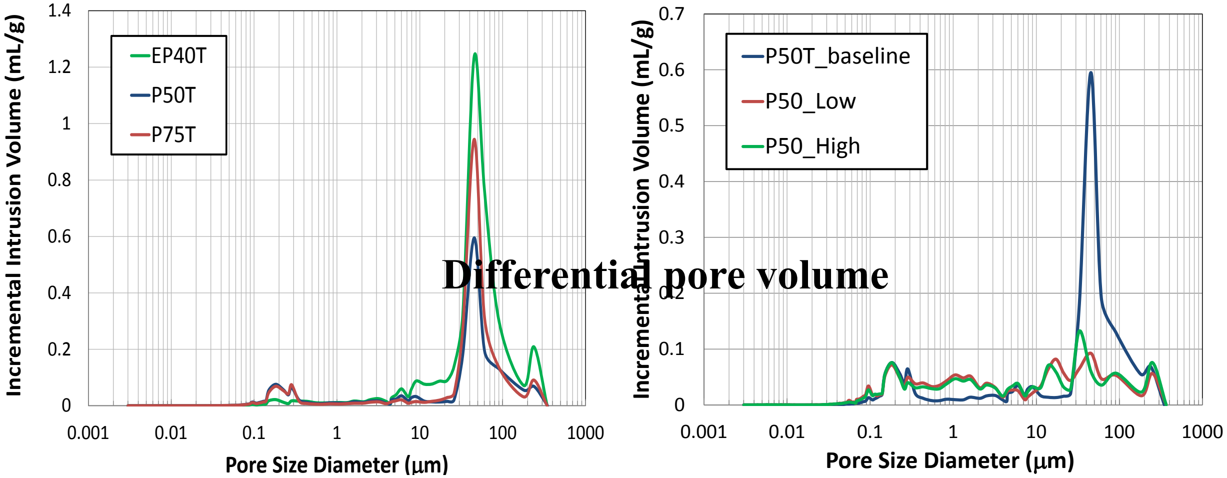
Baseline Substrates

Modified Substrates



Cumulative pore volume

EP40T has largest pore volume, concentrated at 50 μm



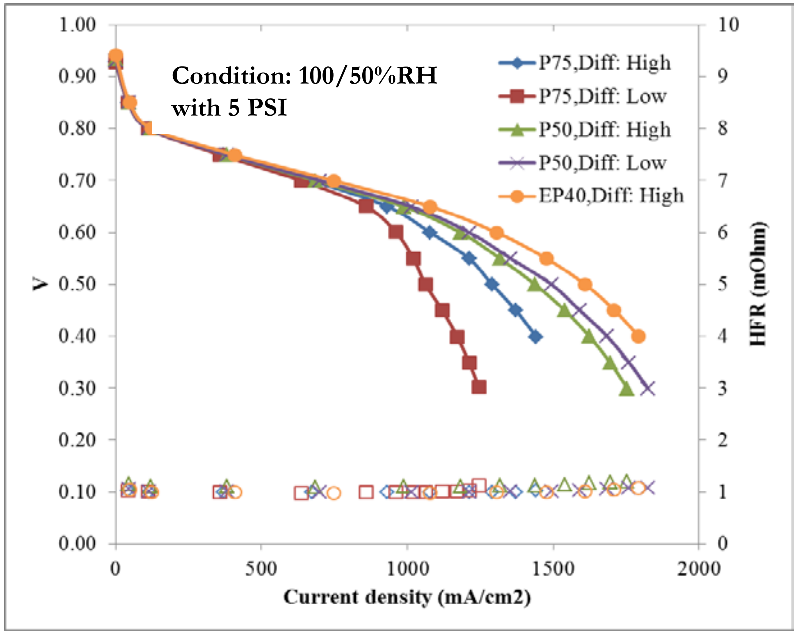
Differential pore volume

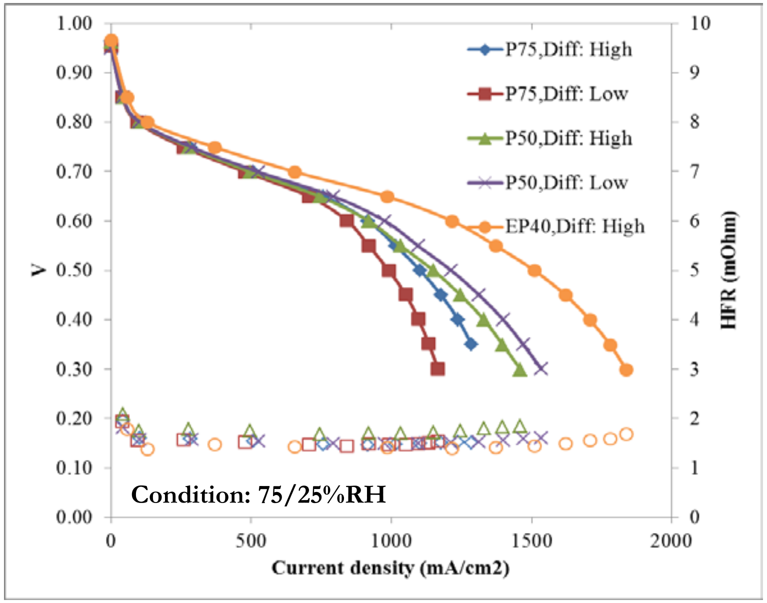
Modification greatly reduces volume of large pores

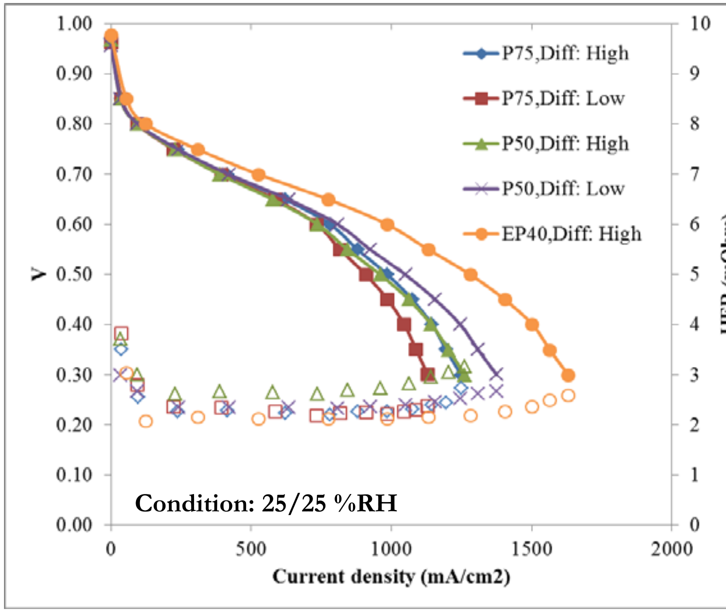
AvCarb GDLs Status

Baseline performance at Tcell = 80°C MEA = Gore™ 57; Serpentine

Substrate	Diffusivity	MPL1	MPL2	Macmullin#	Status
P50	Low (<0.15)	Large	Small	2.63	Done
P50	High (>0.25)	Large	Small	2.18	Done
EP40	High (>0.25)	Large	Small	2.34	Done
P75	Low (<0.20)	Large	Small	2.14	Done
P75	High (<0.30)	Large	Small	1.92	Done







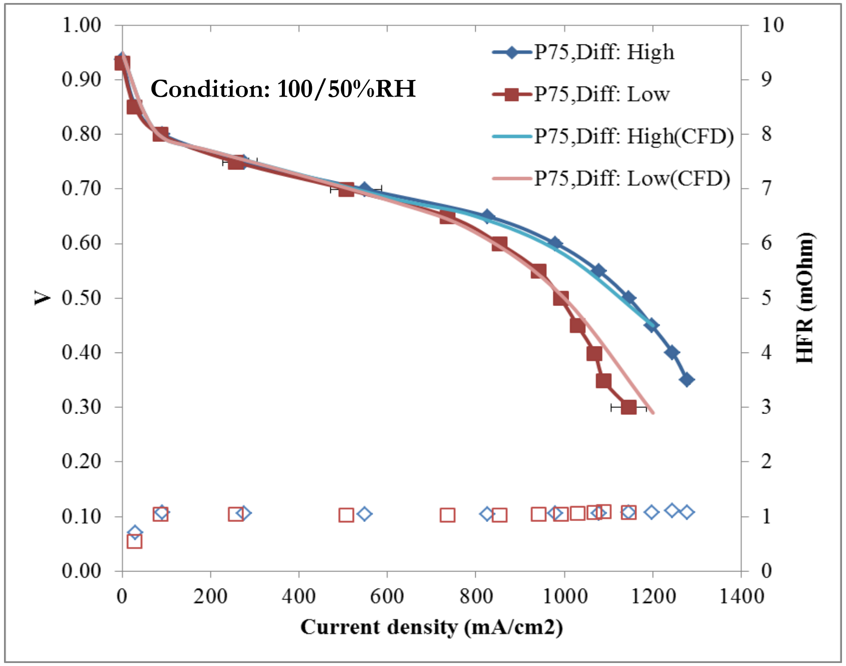
- *EP40,Diff: high shows the highest performance for all three cases*
- *P75, Diff: low shows the lowest performance for all three cases*
- *Both P50, Diff: high and Diff: low show similar performance*

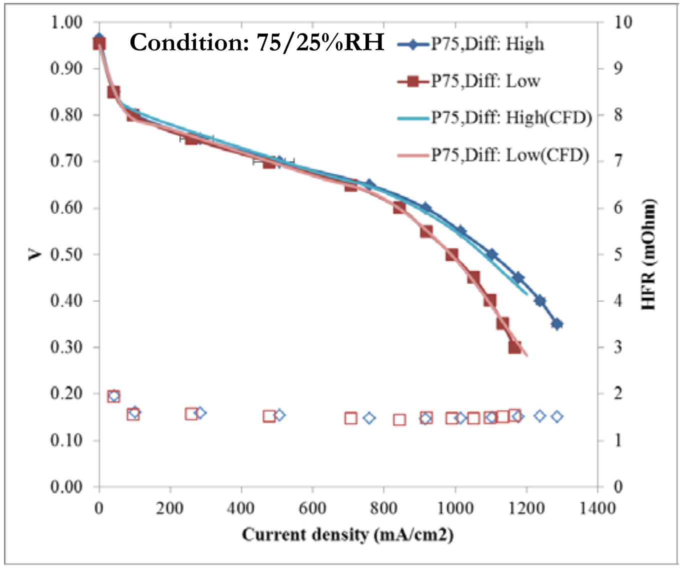
AvCarb GDLs Status

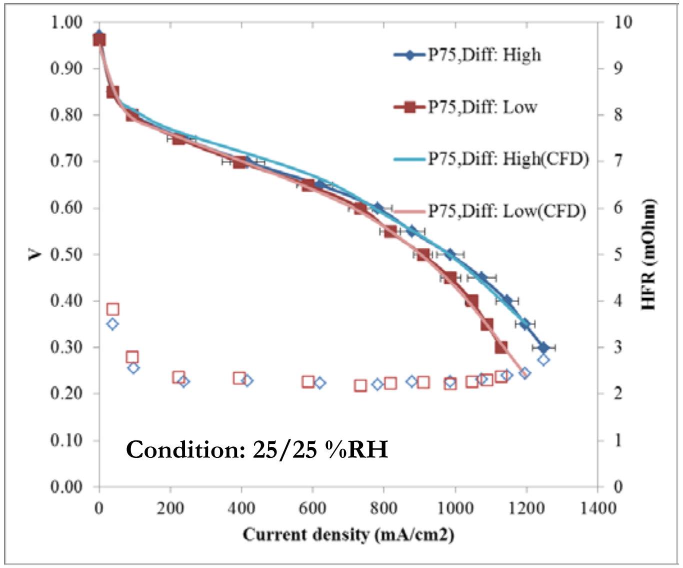
CFD comparison at $T_{cell} = 80^{o}C$

MEA = Gore^{TM} 57; Serpentine cell

GDL: P75 Diffusivity low and High







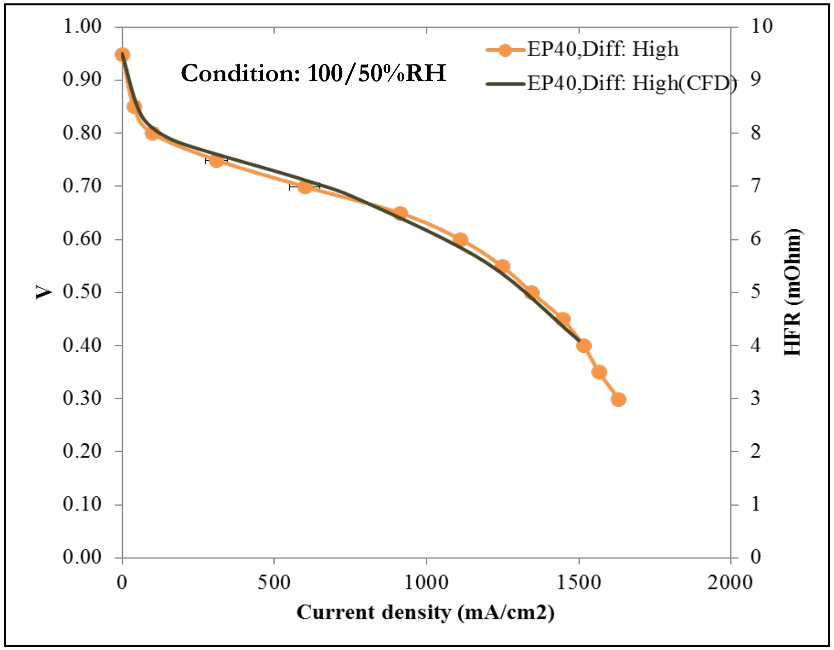
Using data of pore size distribution information and McMullin Number from GDL characterization, CFD predictions are able to compare well with experimental data.

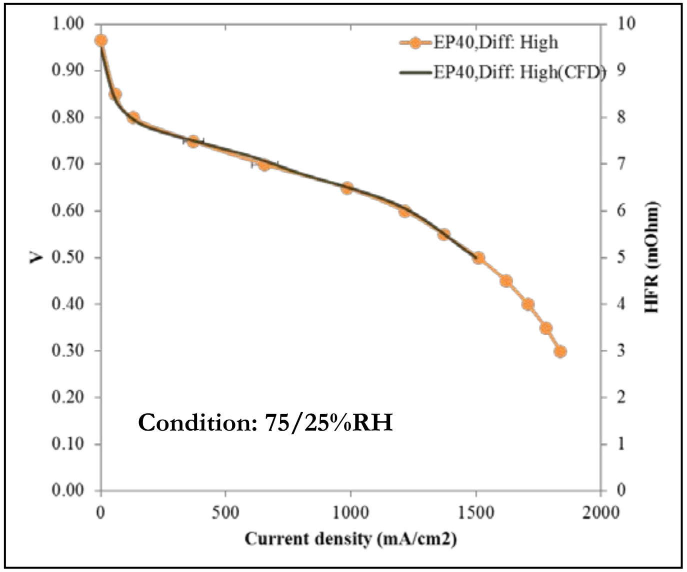
AvCarb GDLs Status

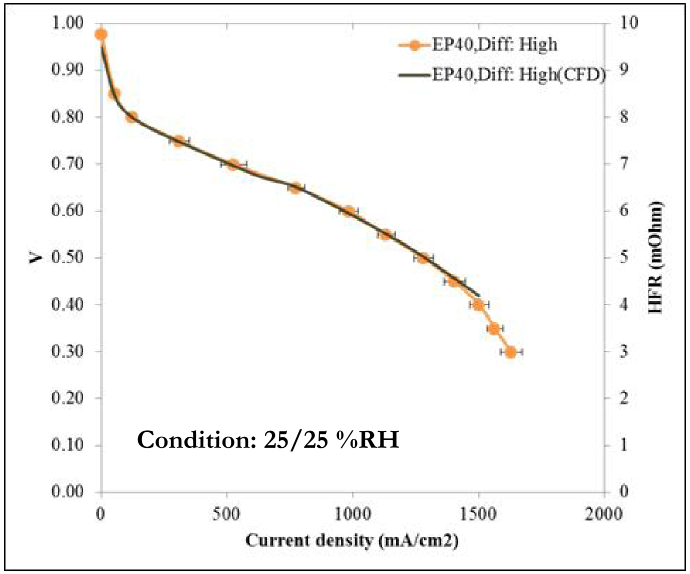
CFD comparison at Tcell = 80°C

MEA = Gore™ 57; Serpentine cell

GDL: EP40 Diffusivity High



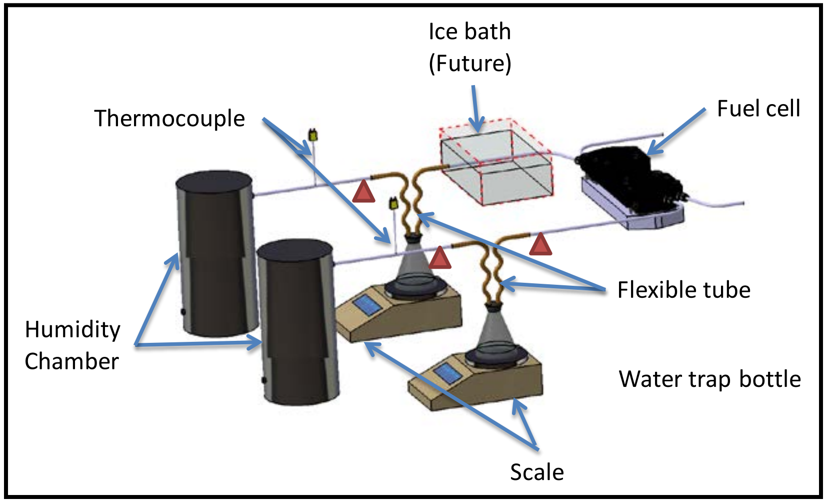




Using data of pore size distribution information and McMullin Number from GDL characterization, CFD predictions are able to compare well with experimental data.

Water balance measurement under different conditions

Experimental vs. CFD (Nafion® membrane)



Water Balance experiment and numerical result of the parallel Channel flow-field

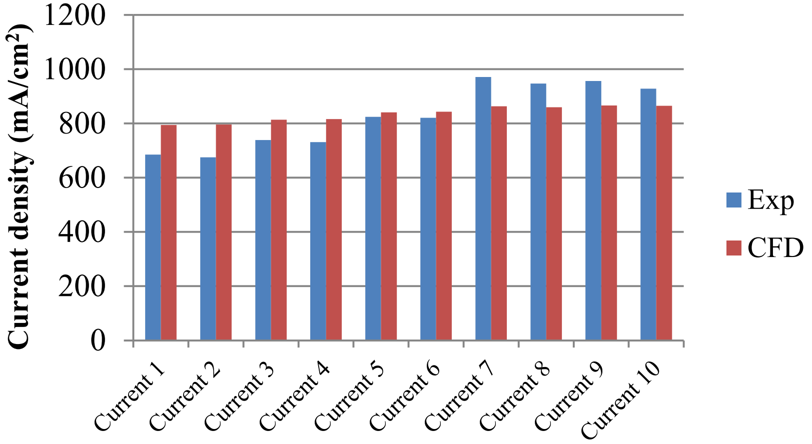
(80^oC, 1.5/2.0 stoich H_2/Air)

Water balance shows the transport of water inside fuel cell. For different operating condition the water transport inside fuel cell will be different.

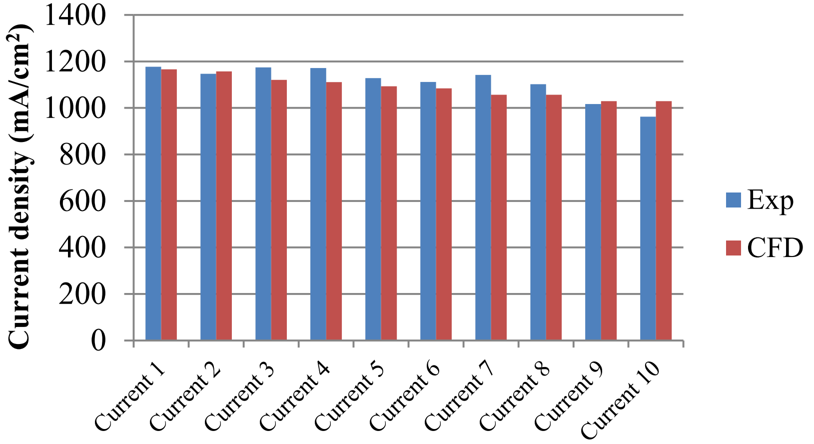
	i A/cm^2	RH	Anode Water Balance (mg/sec)			Cathode Water Balance (mg/sec)				error (%)
			Water in	Water out	Cross to Cathode	Water in	Gen.	Water out	Cross from Anode	
EXP	**0.4**	25/25	0.37	0.42	-0.20	1.15	1.87	2.81	-0.21	4.6
CFD	**0.4**	25/25	0.37	0.52	-0.15	1.15	1.87	2.85	-0.17	10
EXP	**0.4**	75/25	1.50	0.55	0.94	1.15	1.87	3.79	0.91	3.8
CFD	**0.4**	75/25	1.50	0.53	0.97	1.15	1.87	4.00	0.98	1
EXP	**0.6**	75/25	2.25	0.87	1.38	1.70	2.80	5.80	1.30	5.9
CFD	**0.6**	75/25	2.25	0.81	1.44	1.70	2.80	6.00	1.50	4

Achievement: Model Verification: Serpentine

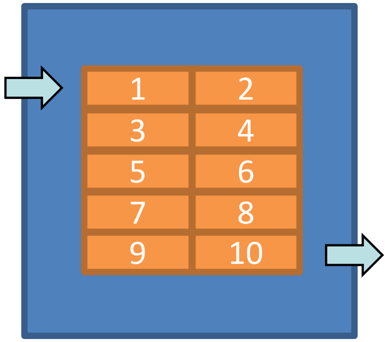
At potential=0.3V

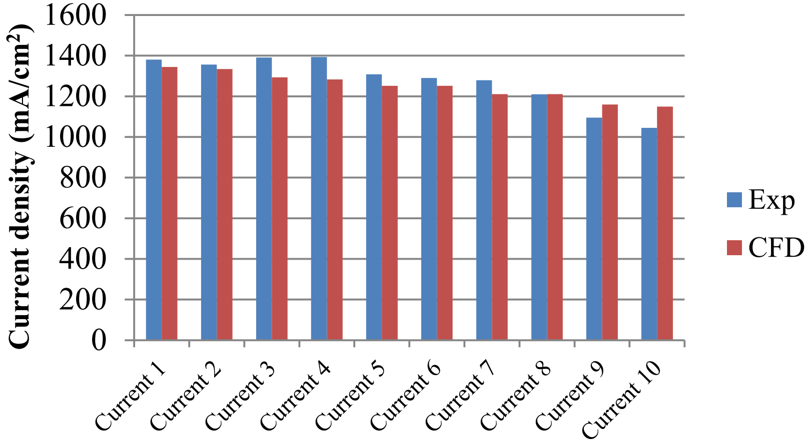


Anode 25%RH, Cathode 25%RH
Average current density = 809 mA/cm²



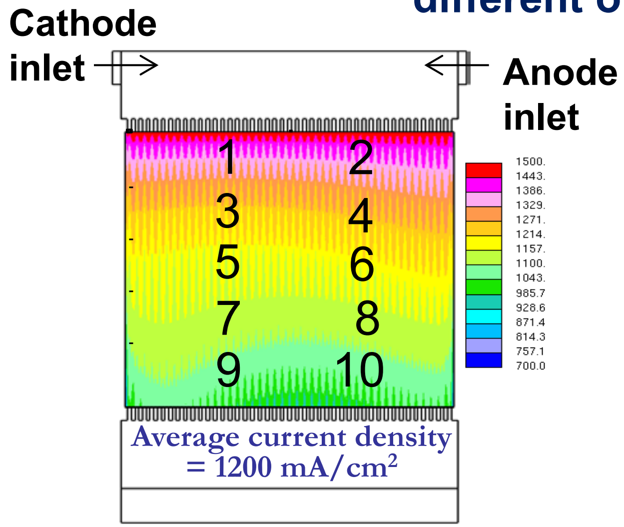
Anode 75%RH, Cathode 25%RH
Average current density = 1094 mA/cm²



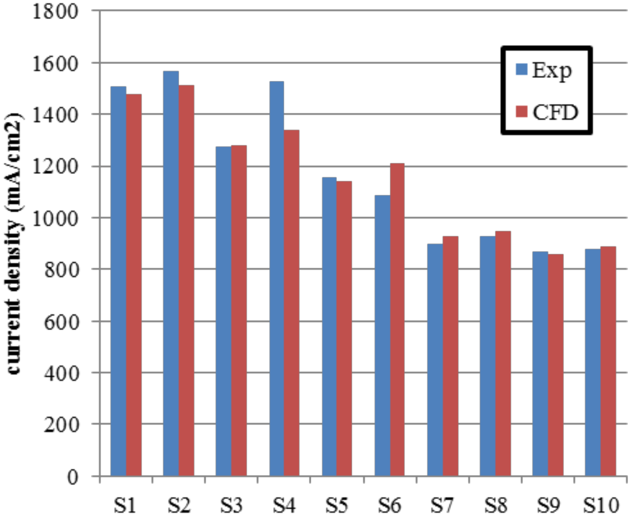


Anode 100%RH, Cathode 50%RH
Average current density = 1250 mA/cm²

Numerical prediction and Experimental result of current density distributions for different operating condition (Nafion® membrane)



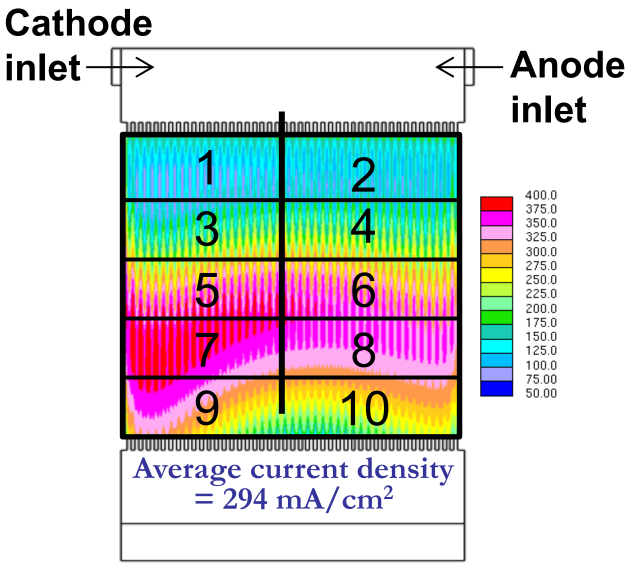
Average current density = 1200 mA/cm^2



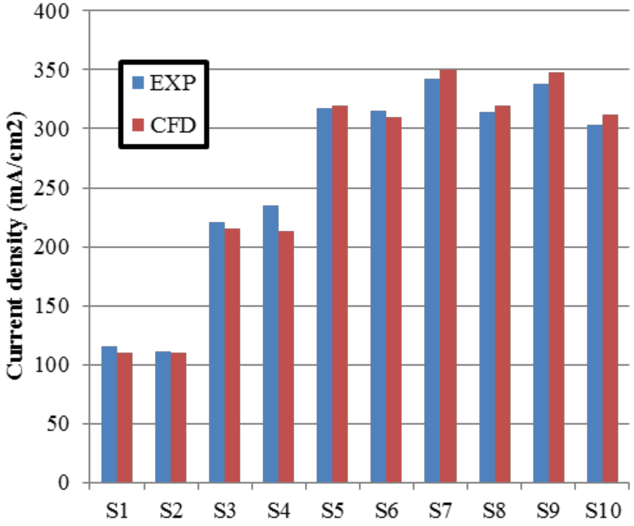
Operating condition:
Anode Stoich. = 1.5
Anode RH = 100%
Cathode Stoich. = 2.0
Cathode RH = 50%
Tcell = 80°C
System pressure = 136kPa

High Current Wet

Model Predicts Equally Well



Average current density = 294 mA/cm^2



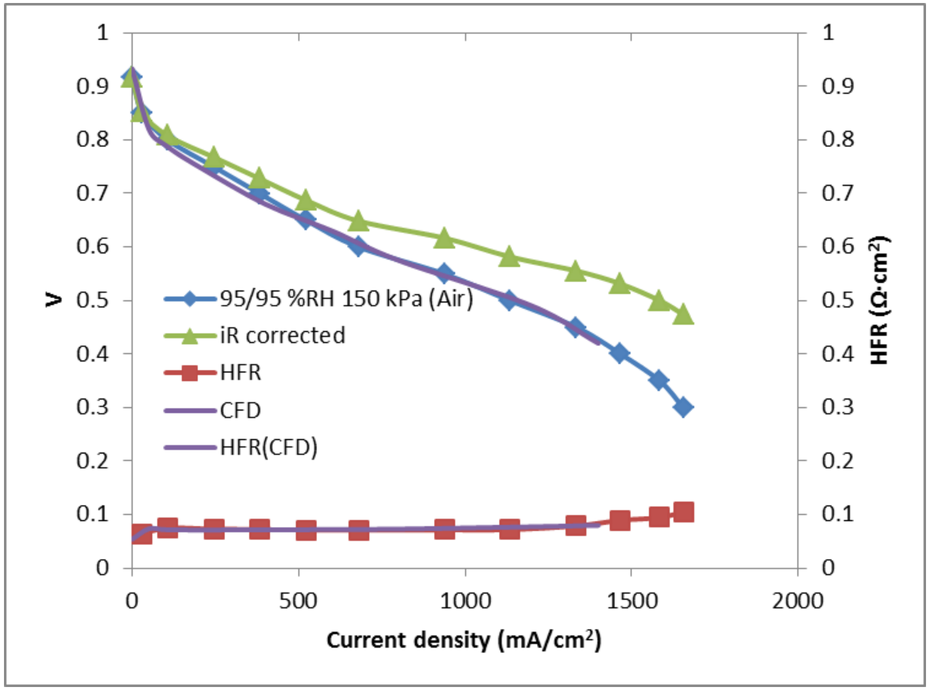
Low Current Dry

Operating condition:
Anode Stoich. = 1.5
Anode RH = 25%
Cathode Stoich. = 2.0
Cathode RH = 25%
Tcell = 80°C
System pressure = 101kPa

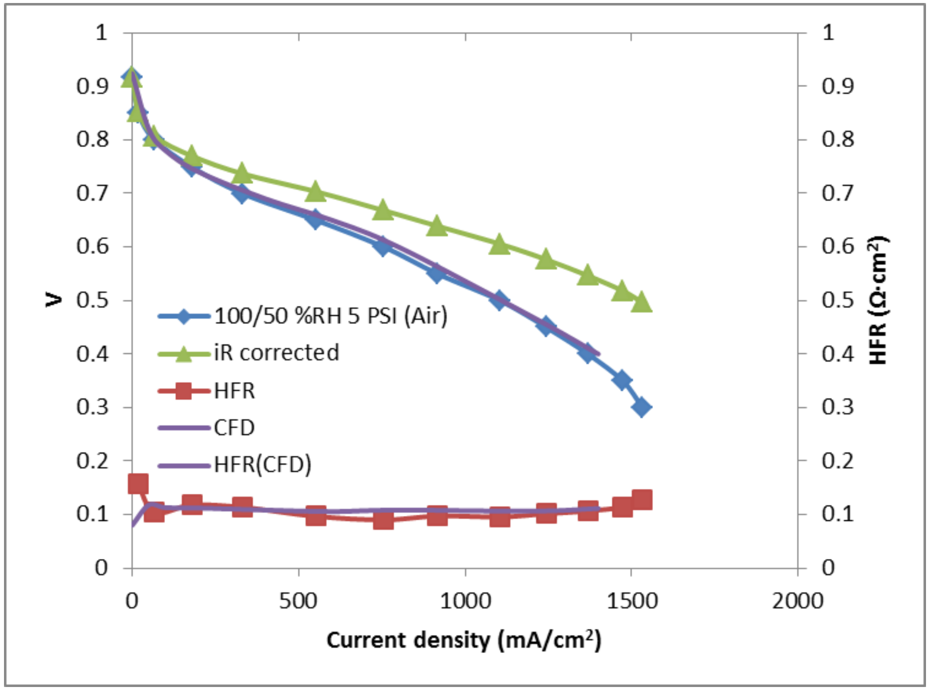
Polarization curves of VT MEA (update 01/14/2013)

6FPAEB-BPSH

(co-current flow: 80°C, 1.5/2.0 stoich, H_2/Air)



95/95 %RH 150 kPa (Air)

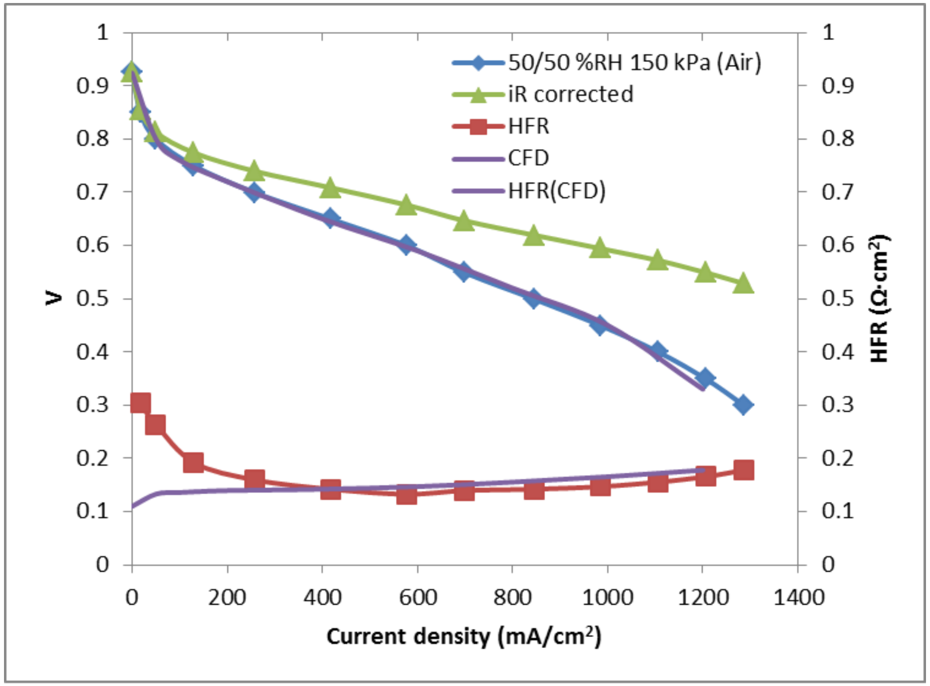


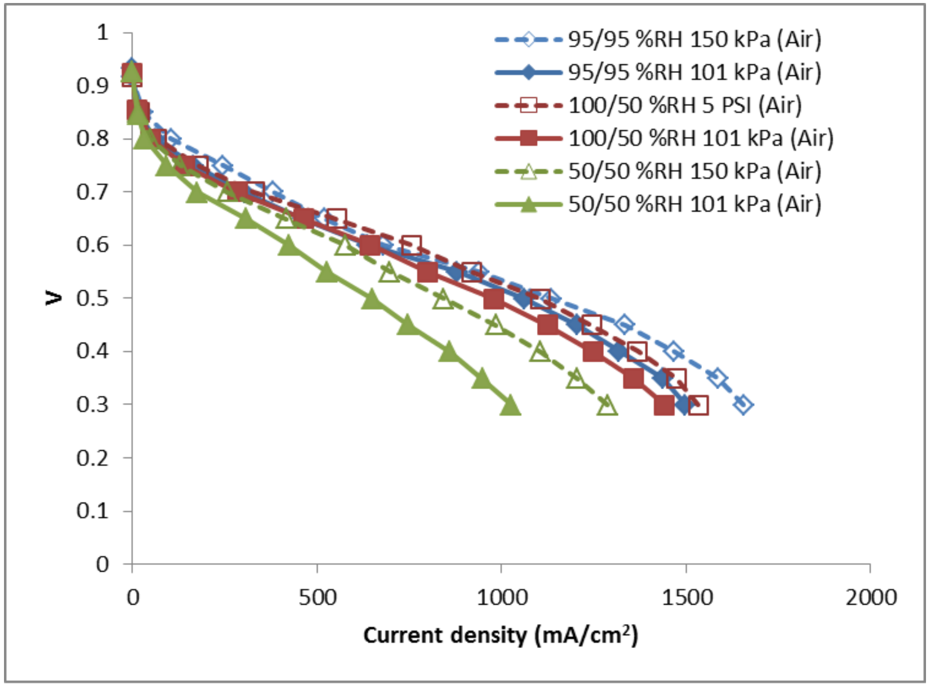
100/50 %RH 5 PSI (Air)

Polarization curves of VT MEA (update 01/14/2013)

6FPAEB-BPSH

(co-current flow: 80°C, 1.5/2.0 stoich, H_2/Air)



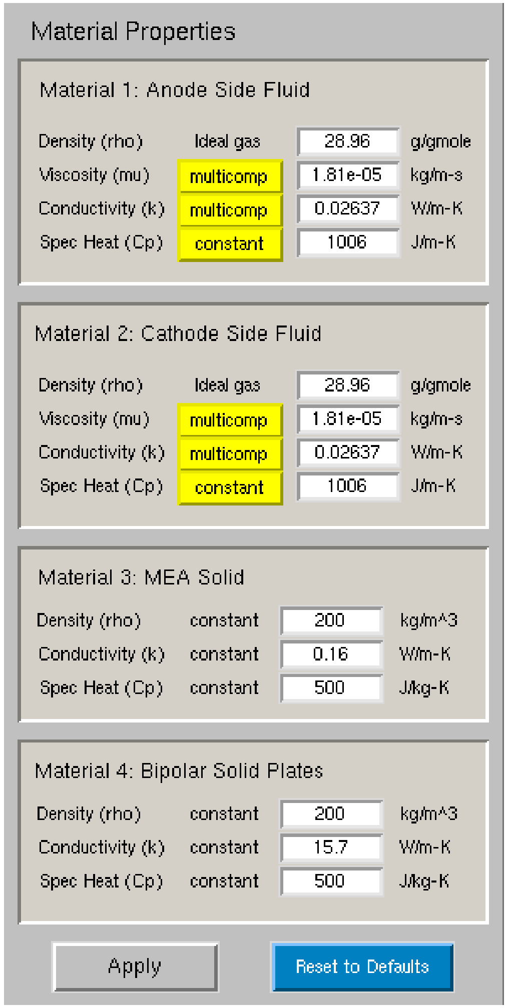


50/50 %RH 150 kPa (Air)

i-V polarization curve

Backup Slides for Model’s Input Parameters and Output Variables

Modeling Input Parameters



Material Properties

Material 1: Anode Side Fluid

Density (rho)	Ideal gas	28.96	g/gmole
Viscosity (mu)	multicomp	1.81e-05	kg/m-s
Conductivity (k)	multicomp	0.02637	W/m-K
Spec Heat (Cp)	constant	1006	J/m-K

Material 2: Cathode Side Fluid

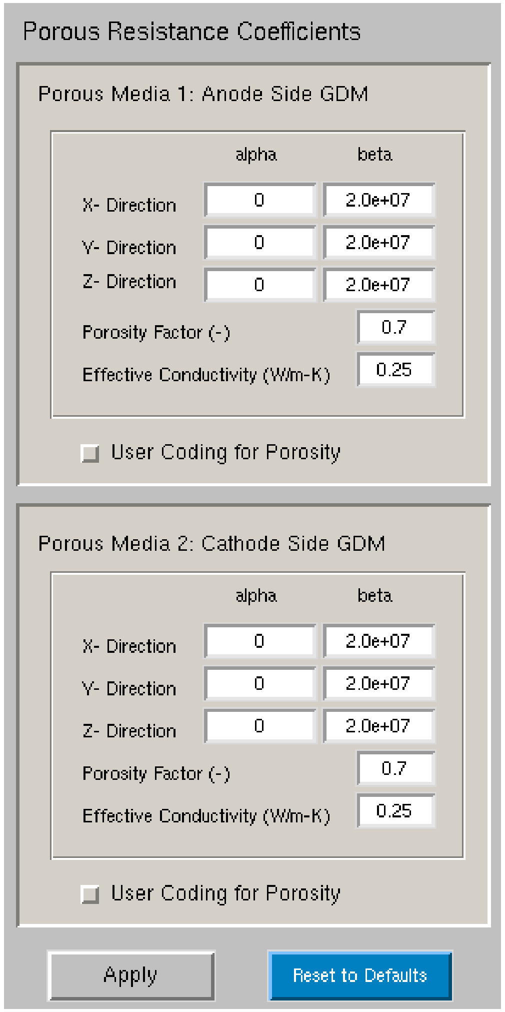
Density (rho)	Ideal gas	28.96	g/gmole
Viscosity (mu)	multicomp	1.81e-05	kg/m-s
Conductivity (k)	multicomp	0.02637	W/m-K
Spec Heat (Cp)	constant	1006	J/m-K

Material 3: MEA Solid

Density (rho)	constant	200	kg/m^3
Conductivity (k)	constant	0.16	W/m-K
Spec Heat (Cp)	constant	500	J/kg-K

Material 4: Bipolar Solid Plates

Density (rho)	constant	200	kg/m^3
Conductivity (k)	constant	15.7	W/m-K
Spec Heat (Cp)	constant	500	J/kg-K



Porous Resistance Coefficients

Porous Media 1: Anode Side GDM

	alpha	beta
X- Direction	0	2.0e+07
Y- Direction	0	2.0e+07
Z- Direction	0	2.0e+07

Porosity Factor (-)	0.7
Effective Conductivity (W/m-K)	0.25

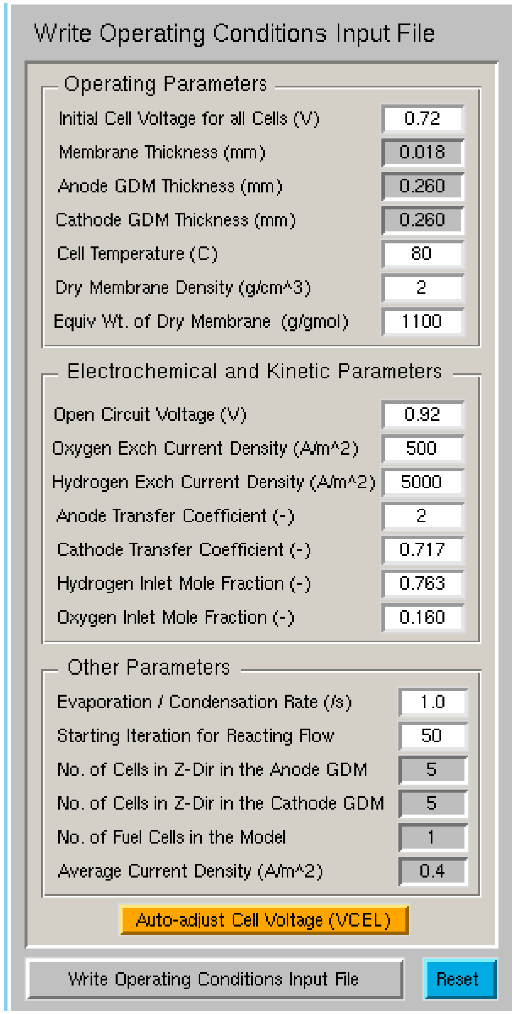
☐ User Coding for Porosity

Porous Media 2: Cathode Side GDM

	alpha	beta
X- Direction	0	2.0e+07
Y- Direction	0	2.0e+07
Z- Direction	0	2.0e+07

Porosity Factor (-)	0.7
Effective Conductivity (W/m-K)	0.25

☐ User Coding for Porosity



Write Operating Conditions Input File

Operating Parameters

Initial Cell Voltage for all Cells (V)	0.72
Membrane Thickness (mm)	0.018
Anode GDM Thickness (mm)	0.260
Cathode GDM Thickness (mm)	0.260
Cell Temperature (C)	80
Dry Membrane Density (g/cm^3)	2
Equiv Wt. of Dry Membrane (g/gmol)	1100

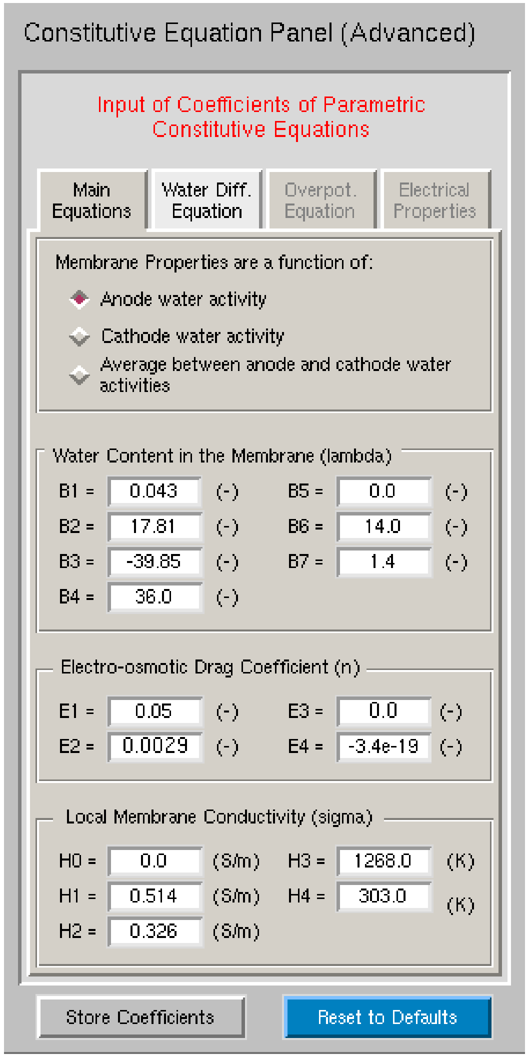
Electrochemical and Kinetic Parameters

Open Circuit Voltage (V)	0.92
Oxygen Exch Current Density (A/m^2)	500
Hydrogen Exch Current Density (A/m^2)	5000
Anode Transfer Coefficient (-)	2
Cathode Transfer Coefficient (-)	0.717
Hydrogen Inlet Mole Fraction (-)	0.763
Oxygen Inlet Mole Fraction (-)	0.160

Other Parameters

Evaporation / Condensation Rate (/s)	1.0
Starting Iteration for Reacting Flow	50
No. of Cells in Z-Dir in the Anode GDM	5
No. of Cells in Z-Dir in the Cathode GDM	5
No. of Fuel Cells in the Model	1
Average Current Density (A/m^2)	0.4

Modeling Input Parameters (Cont.)



Constitutive Equation Panel (Advanced)

Input of Coefficients of Parametric Constitutive Equations

Membrane Properties are a function of:

- ● Anode water activity
- ○ Cathode water activity
- ○ Average between anode and cathode water activities

Water Content in the Membrane (lambda)

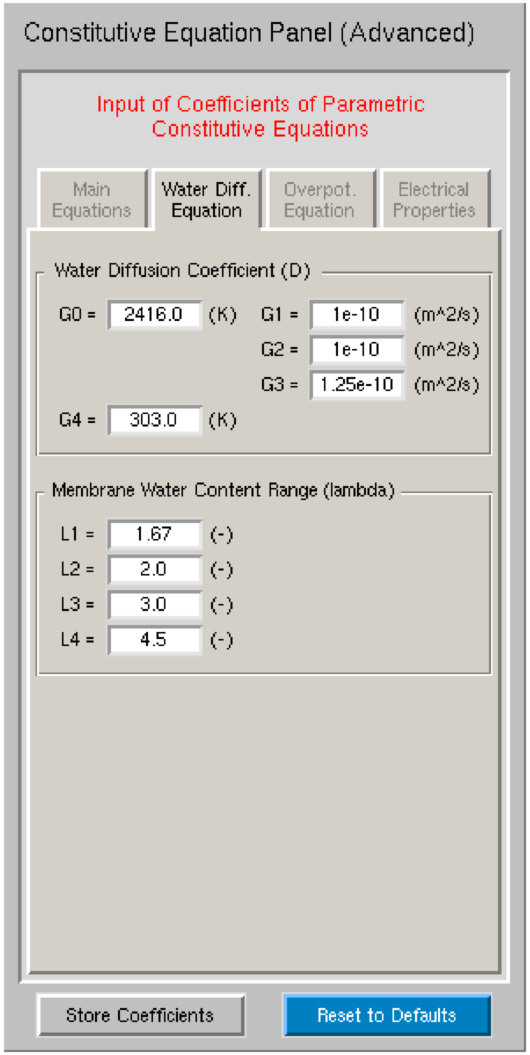
B1 = 0.043 (-)
B2 = 17.81 (-)
B3 = -39.85 (-)
B4 = 36.0 (-)
B5 = 0.0 (-)
B6 = 14.0 (-)
B7 = 1.4 (-)

Electro-osmotic Drag Coefficient (n)

E1 = 0.05 (-)
E2 = 0.0029 (-)
E3 = 0.0 (-)
E4 = -3.4e-19 (-)

Local Membrane Conductivity (sigma)

H0 = 0.0 (S/m)
H1 = 0.514 (S/m)
H2 = 0.326 (S/m)
H3 = 1268.0 (K)
H4 = 303.0 (K)



Constitutive Equation Panel (Advanced)

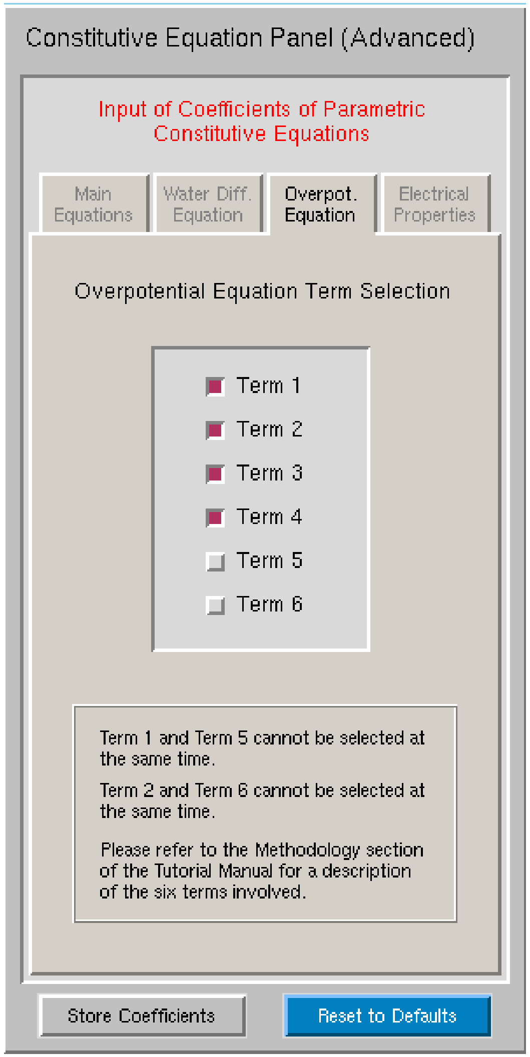
Input of Coefficients of Parametric Constitutive Equations

Water Diffusion Coefficient (D)

G0 = 2416.0 (K)
G1 = 1e-10 (m^2/s)
G2 = 1e-10 (m^2/s)
G3 = 1.25e-10 (m^2/s)
G4 = 303.0 (K)

Membrane Water Content Range (lambda)

L1 = 1.67 (-)
L2 = 2.0 (-)
L3 = 3.0 (-)
L4 = 4.5 (-)



Constitutive Equation Panel (Advanced)

Input of Coefficients of Parametric Constitutive Equations

Overpotential Equation Term Selection

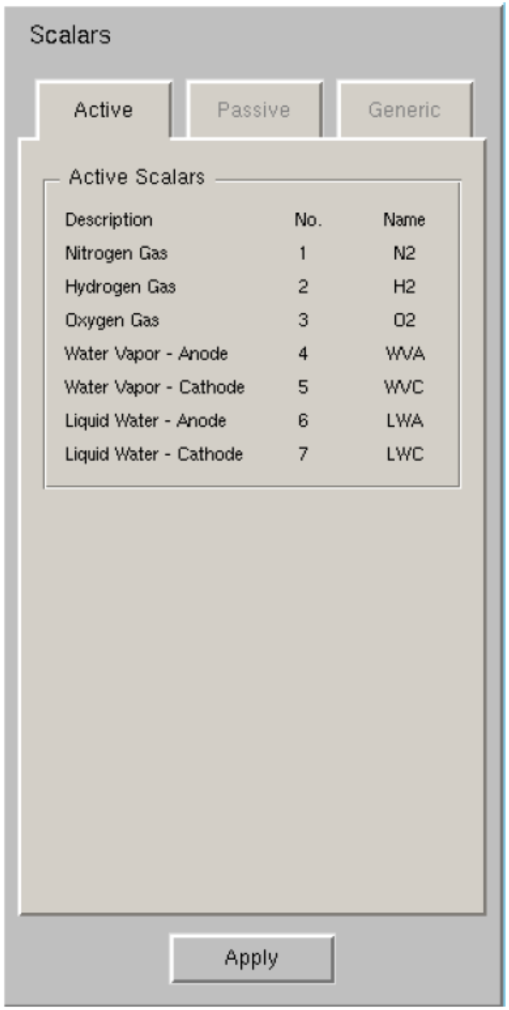
- ☑ Term 1
- ☑ Term 2
- ☑ Term 3
- ☑ Term 4
- ☐ Term 5
- ☐ Term 6

Term 1 and Term 5 cannot be selected at the same time.

Term 2 and Term 6 cannot be selected at the same time.

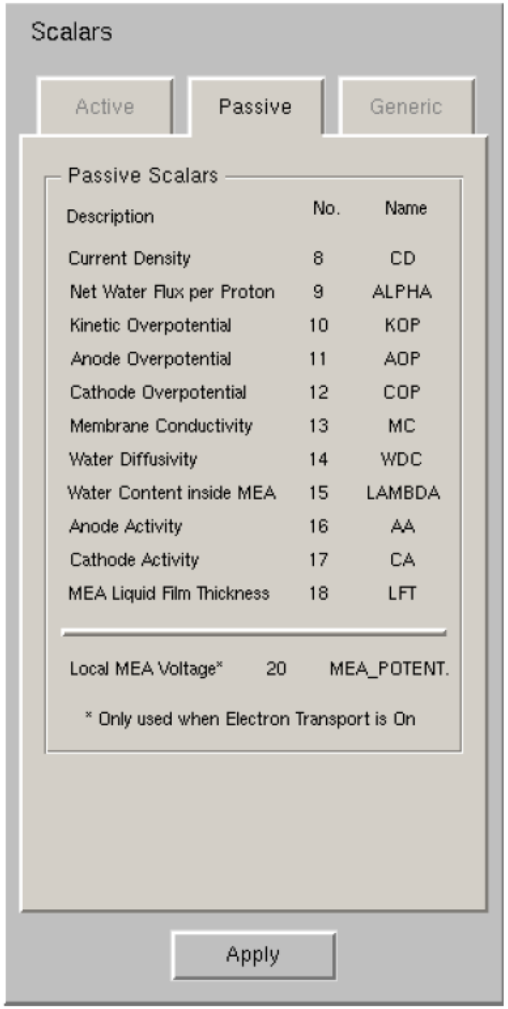
Please refer to the Methodology section of the Tutorial Manual for a description of the six terms involved.

Modeling Outputs



Active Scalars

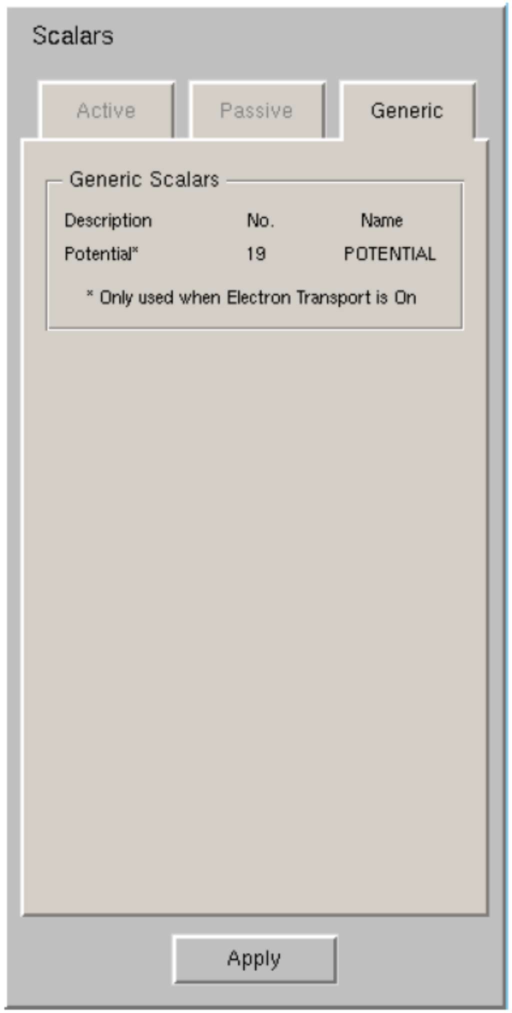
Description	No.	Name
Nitrogen Gas	1	N2
Hydrogen Gas	2	H2
Oxygen Gas	3	O2
Water Vapor - Anode	4	WVA
Water Vapor - Cathode	5	WVC
Liquid Water - Anode	6	LWA
Liquid Water - Cathode	7	LWC



Passive Scalars

Description	No.	Name
Current Density	8	CD
Net Water Flux per Proton	9	ALPHA
Kinetic Overpotential	10	KOP
Anode Overpotential	11	AOP
Cathode Overpotential	12	COP
Membrane Conductivity	13	MC
Water Diffusivity	14	WDC
Water Content inside MEA	15	LAMBDA
Anode Activity	16	AA
Cathode Activity	17	CA
MEA Liquid Film Thickness	18	LFT
Local MEA Voltage*	20	MEA_POTENT.

* Only used when Electron Transport is On



Generic Scalars

Description	No.	Name
Potential*	19	POTENTIAL

* Only used when Electron Transport is On