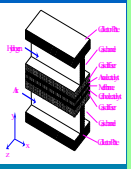
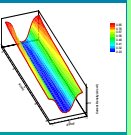
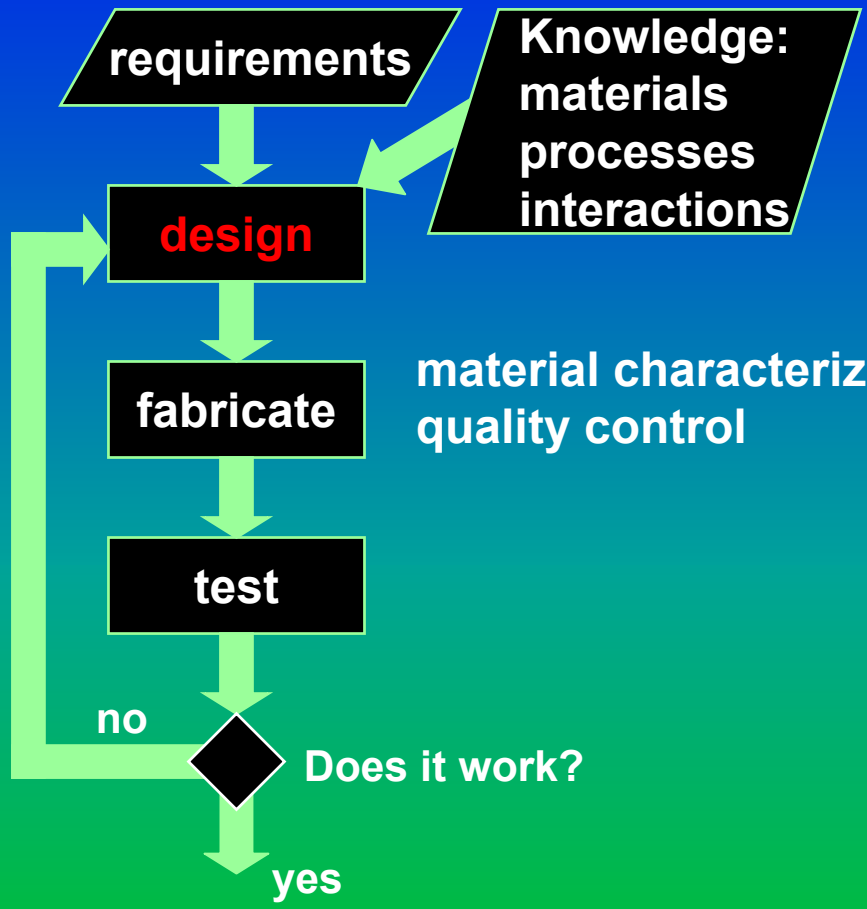




PEM Fuel Cell Design, Engineering, Modeling and Diagnostic Issues

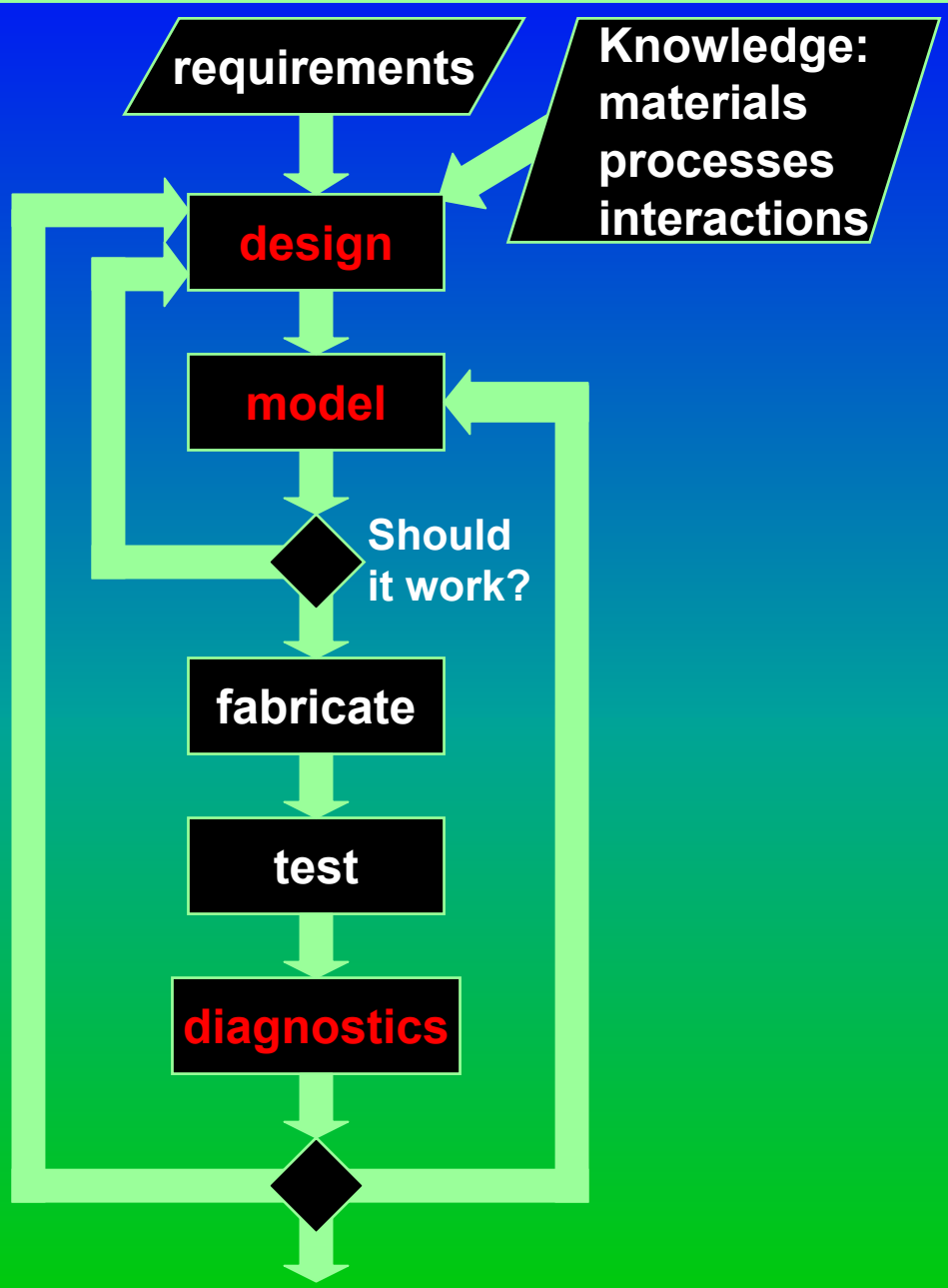
Frano Barbir
Director of Fuel Cell Technology and Chief Scientist
Proton Energy Systems
50 Inwood Road, Rocky Hill, CT 06067
e-mail: fbarbir@protonenergy.com
www.protonenergy.com

NSF Workshop on Engineering Fundamentals of Low-Temperature PEM Fuel Cells, Arlington, VA, November 14-15, 2001

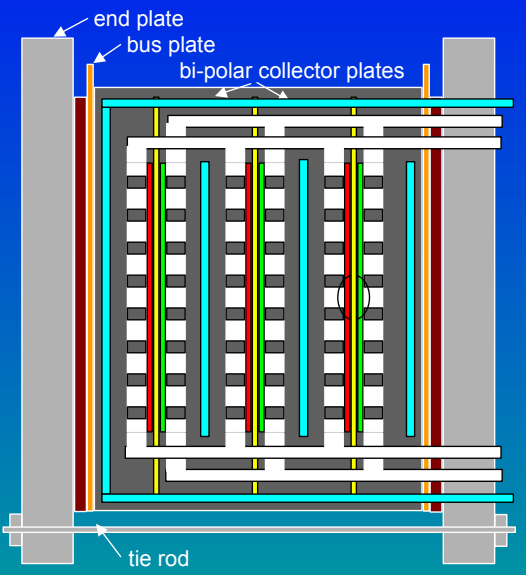
Fuel cell development process



Role of modeling and diagnostics in fuel cell development process



Major components



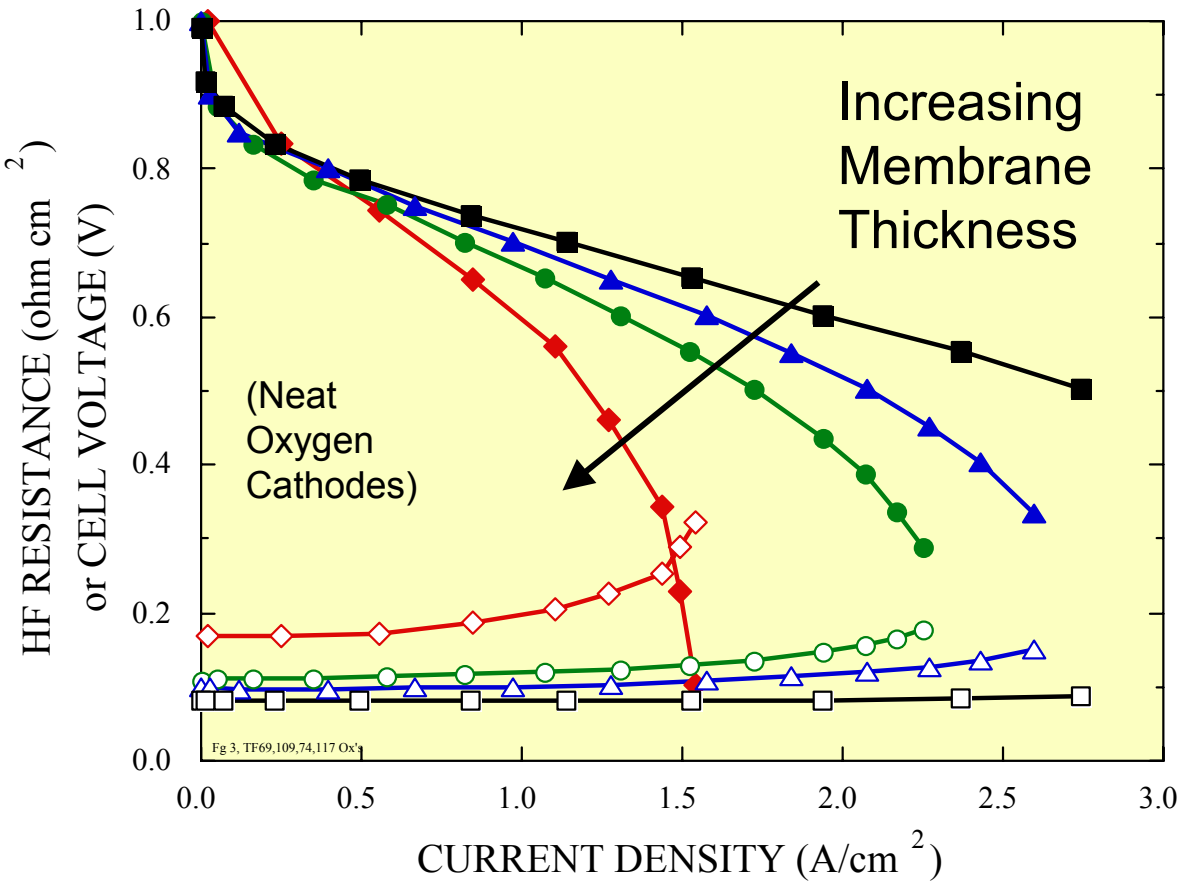
MEA
- Membrane
- Catalyst
- Catalyst support
- Catalyst layer
- Gas diffusion layer
- Gaskets/frames

Bi-polar plate
- Flow field
- Separator/connector
- Bus plates/terminals
- End plates
- Clamping mechanism
- Fluid connections
- Manifolds
- Cooling plates/arrangements
- Humidification section (optional)

Stack design/engineering issues

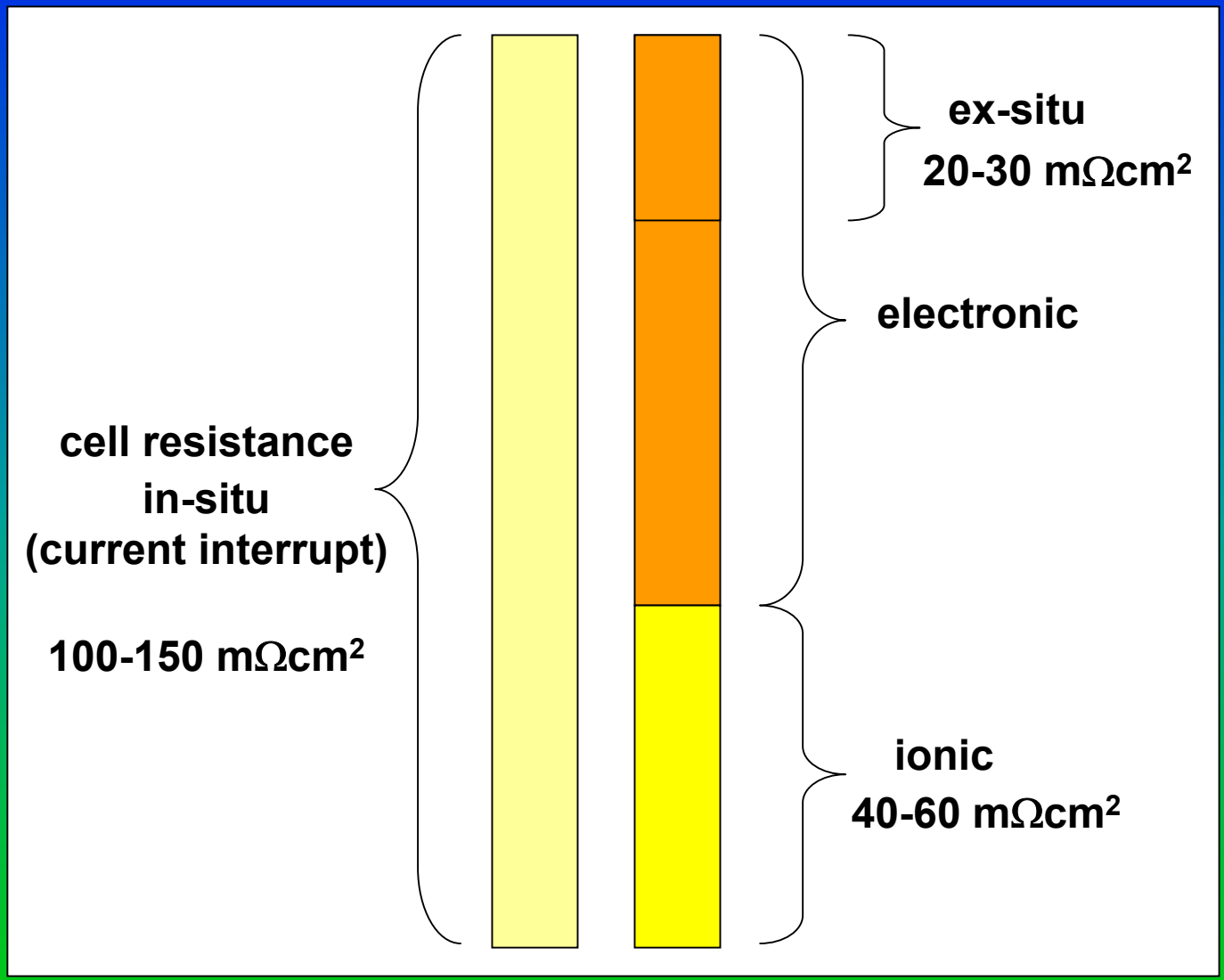
- Uniform distribution of reactants to each cell
- Uniform distribution of reactants inside each cell
- Uniform temperature distribution in each cell
- Minimal resistive losses
  - good electrical contacts
  - selection of materials

Cell Resistance and Performance: PEM Thickness Effects

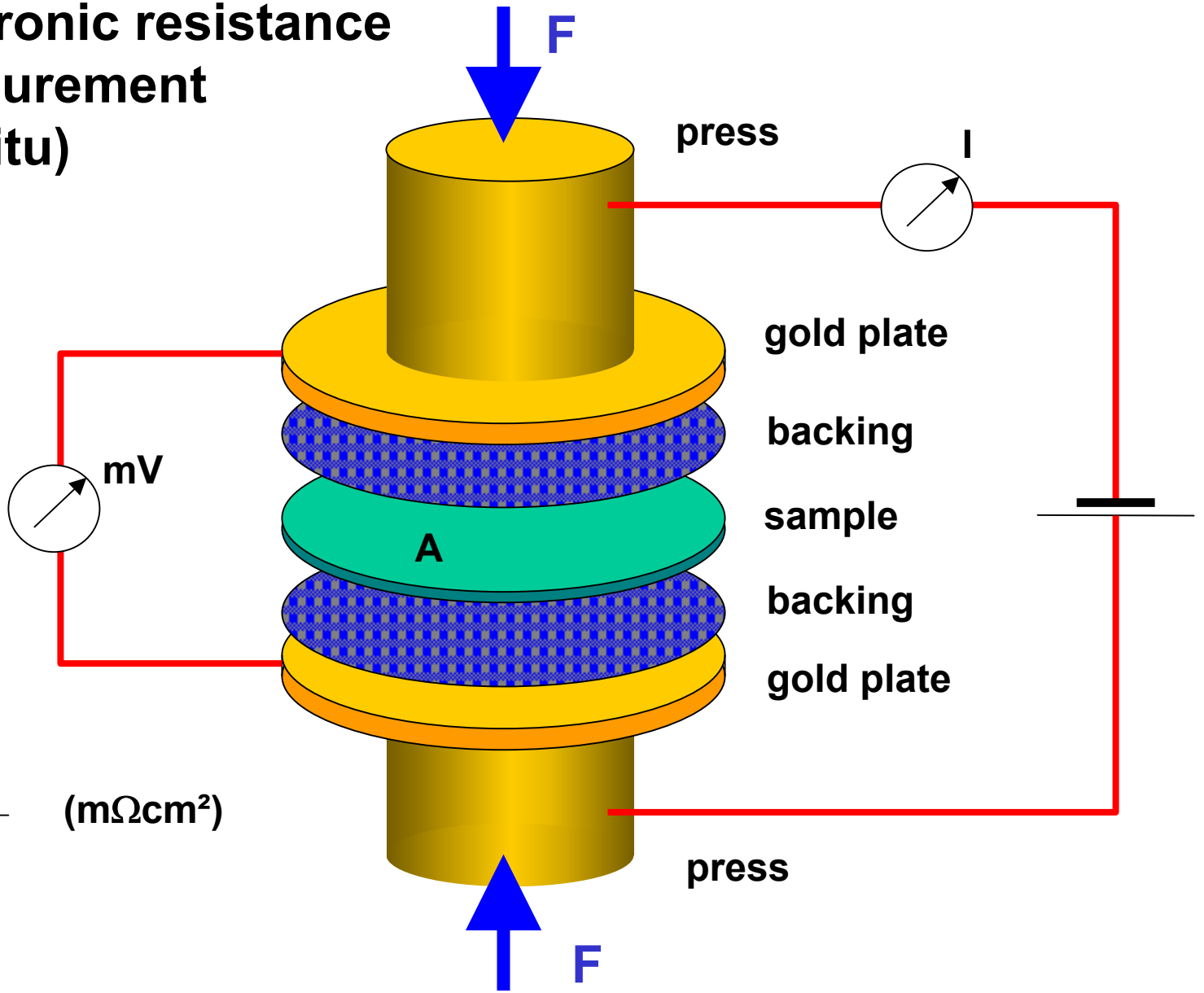


Electro-osmotic drag removes water from the anode side. With thicker membranes, back diffusion of water is difficult - the anode side loses water content.

Cell resistance

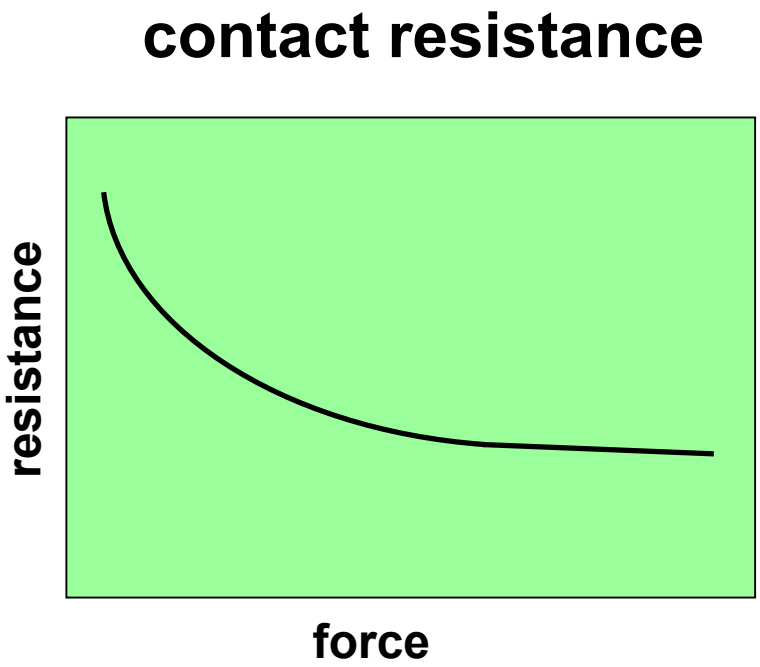


Electronic resistance measurement (ex-situ)

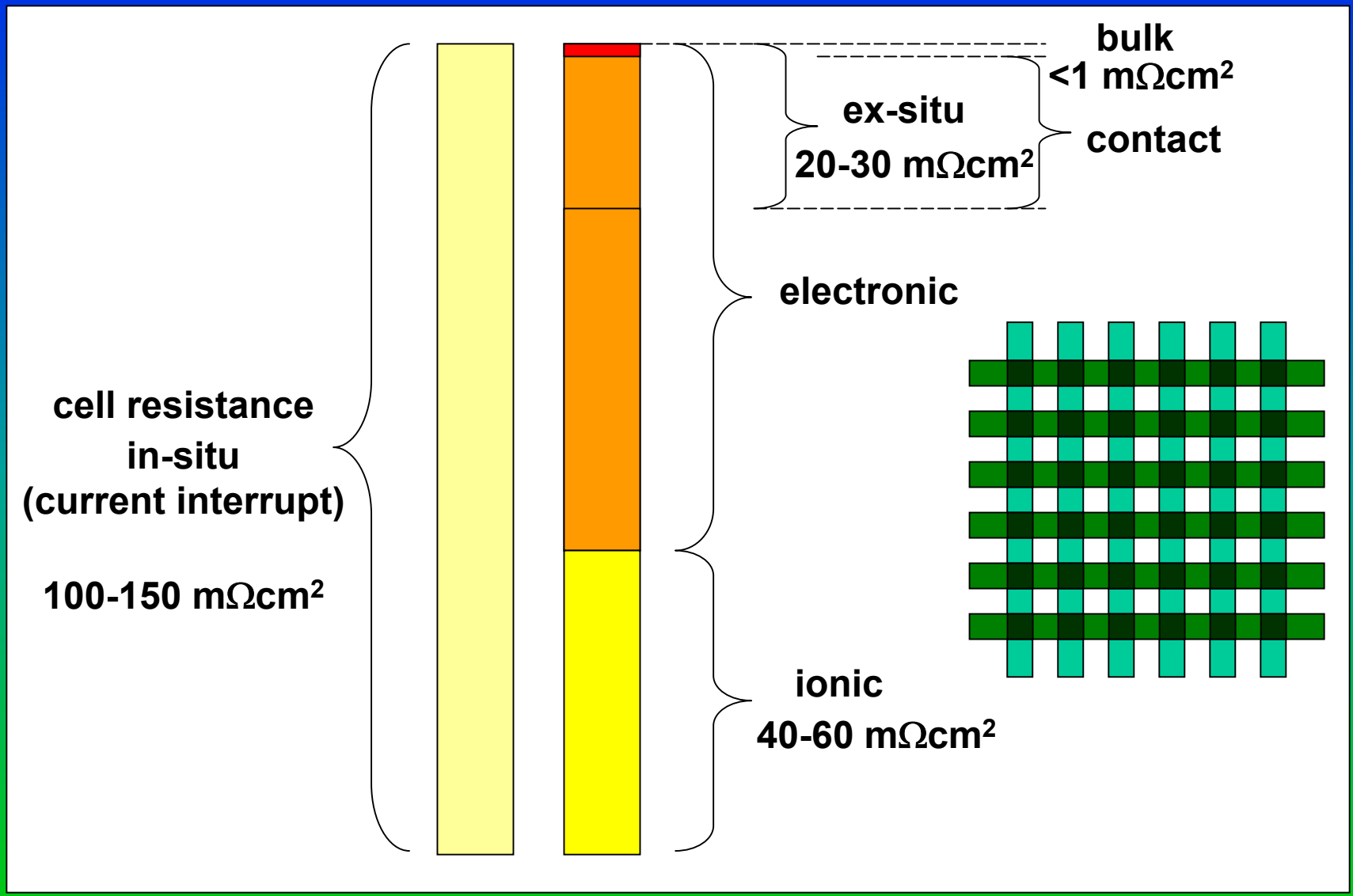


$$R = A\frac{V}{I} \quad (m\Omega cm^2)$$

Resistance is a function of clamping force

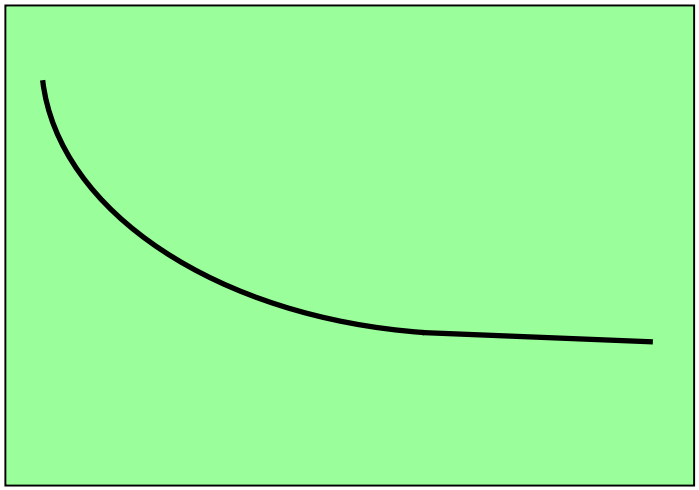


Cell resistance

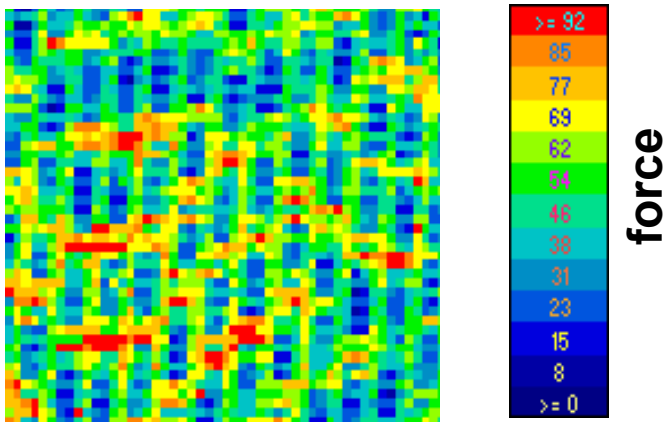


Resistance is a function of clamping force

contact resistance



example of pressure distribution



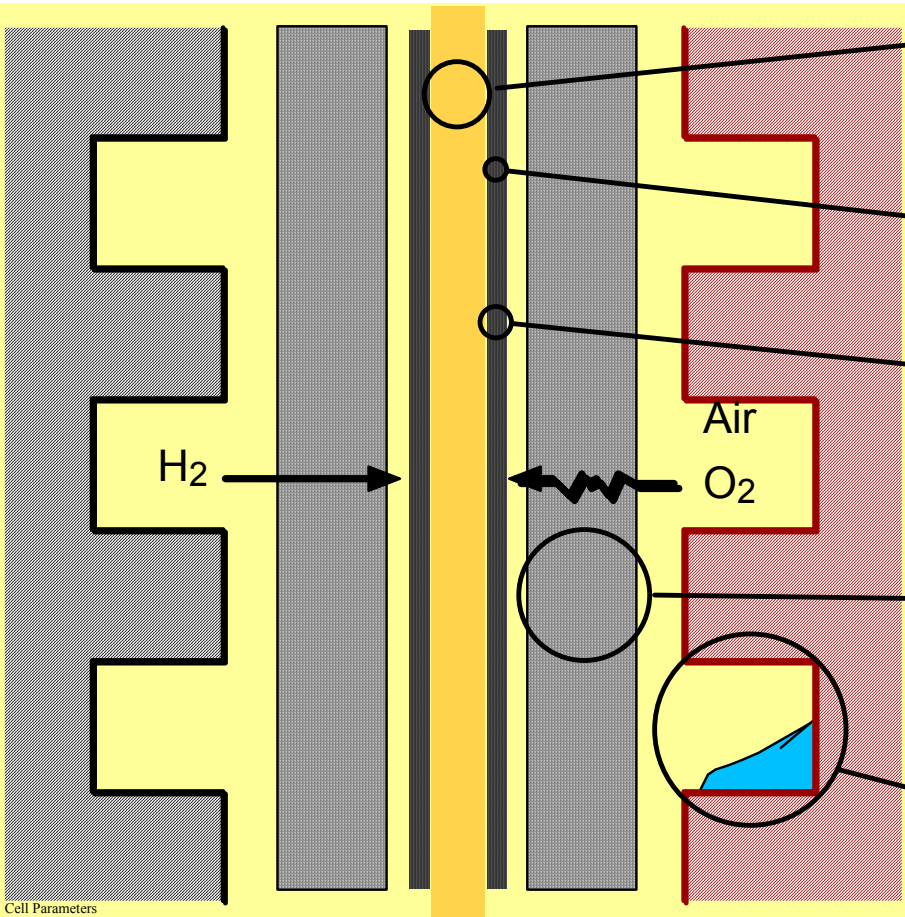
Stack design/engineering issues

- Uniform distribution of reactants to each cell
- Uniform distribution of reactants inside each cell
- Uniform temperature distribution in each cell
- Minimal resistive losses
  - good electrical contacts
  - selection of materials
- Account for thermal expansion
- No crossover or overboard leaks
- Minimum pressure drop (reactant gases and coolant)
- No water accumulation pockets
- Design for manufacture/design for assembly

Difference between single cell and stack

- Flow distribution
- Active area
- Temperature control (heating/cooling)
- Temperature distribution
- Compression/electrical contacts
- Leak paths
- Adjacent cell interference

Modeling:
Parameters and Processes (partial list)



Membrane
- Water Content
- Ionic Conductivity
- Water Diffusivity
- Electro-osmotic Drag
- Hydraulic Permeability

Electro-catalyst
- Exchange Current Density
- Tafel Slope
- Roughness Factor

Catalyst Layer
- Ionic Conductivity
- Electronic Conductivity
- Gas Permeability
- Reactant Solubility
- Capacitance

Gas Diffusion Layer
- Gas Diffusivity
- Porosity
- Tortuosity
- Electronic Conductivy
- Gas Composition

Flow-Fields
- Convection
-Two-Phase Flow

Fluid flow
Heat transfer

Overall: Mass Balance - Heat Balance

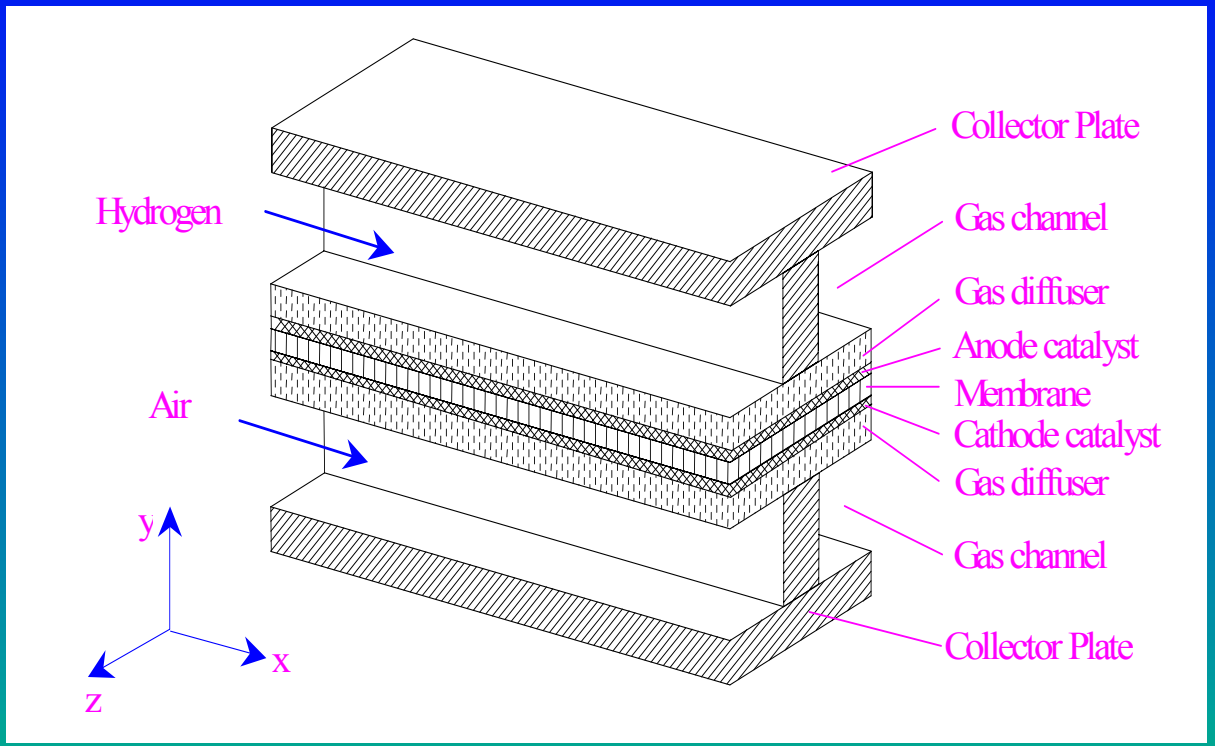
Modeling as a design tool

- A model is approximation of the real world.
- Every model is wrong!
- Any model is as good as the assumptions it is built upon are valid!

Assumptions used in fuel cell modeling

- Concentration at the boundary is known
- Local current density is known
- Isothermal conditions
- Heat transfer by conduction in the gas phase in negligible
- Pressure is constant

Modeling domain



Different models

- 1-D (y)
- 2-D (x-y or z-y)
- 2 2-D (x-y and z-y)
- 3-D models (x-y-z)

- One phase
- Two phase models

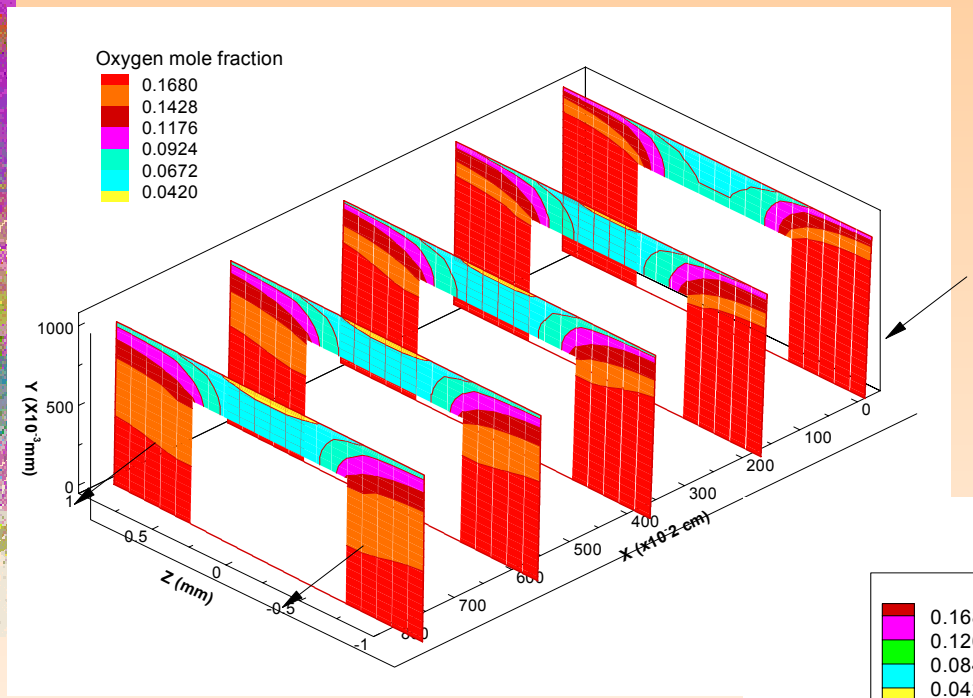
Truths and myths about experimental and modeling work

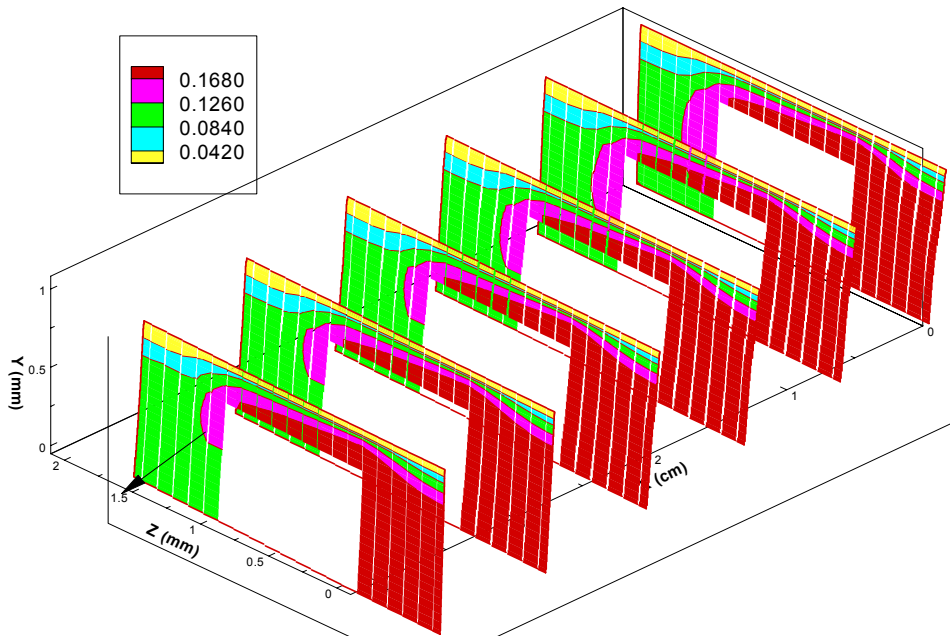
When someone presents the modeling results no one trusts those except the presenter/person who did the modeling.

When someone presents the experimental results everyone trusts those except the presenter/person who performed the experiment.

Oxygen molar fraction

conventional flow field vs. interdigitated flow field





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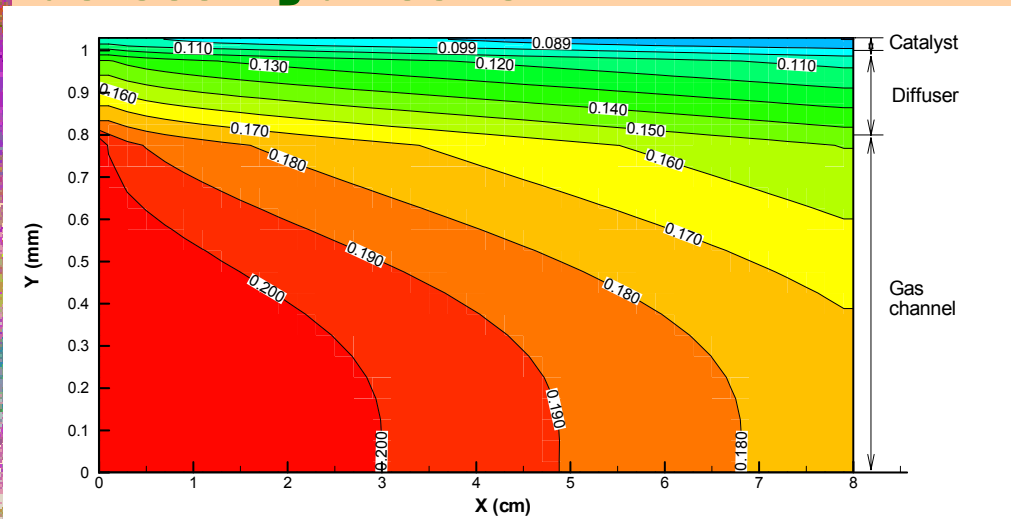
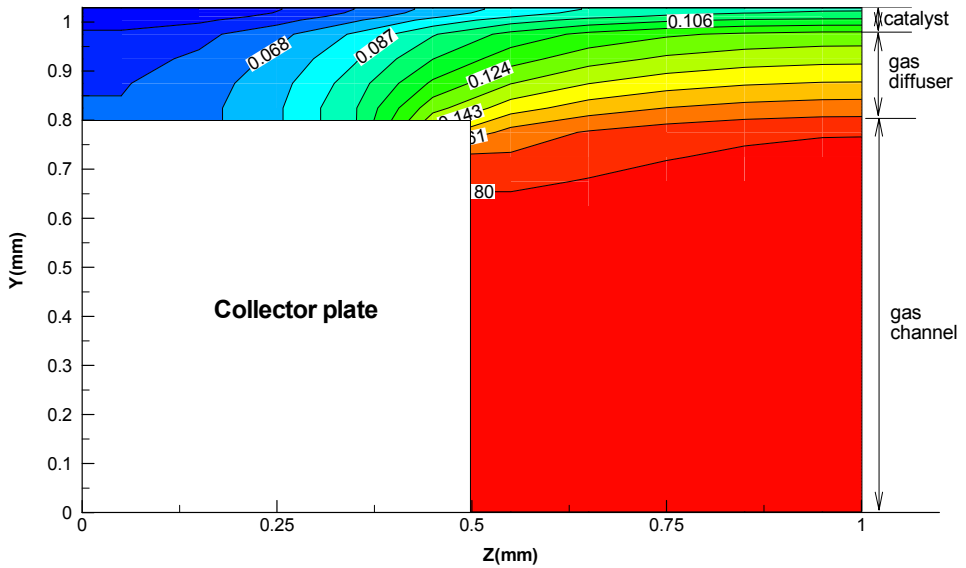
Oxygen molar fraction contours

across x-y direction



across y-z direction



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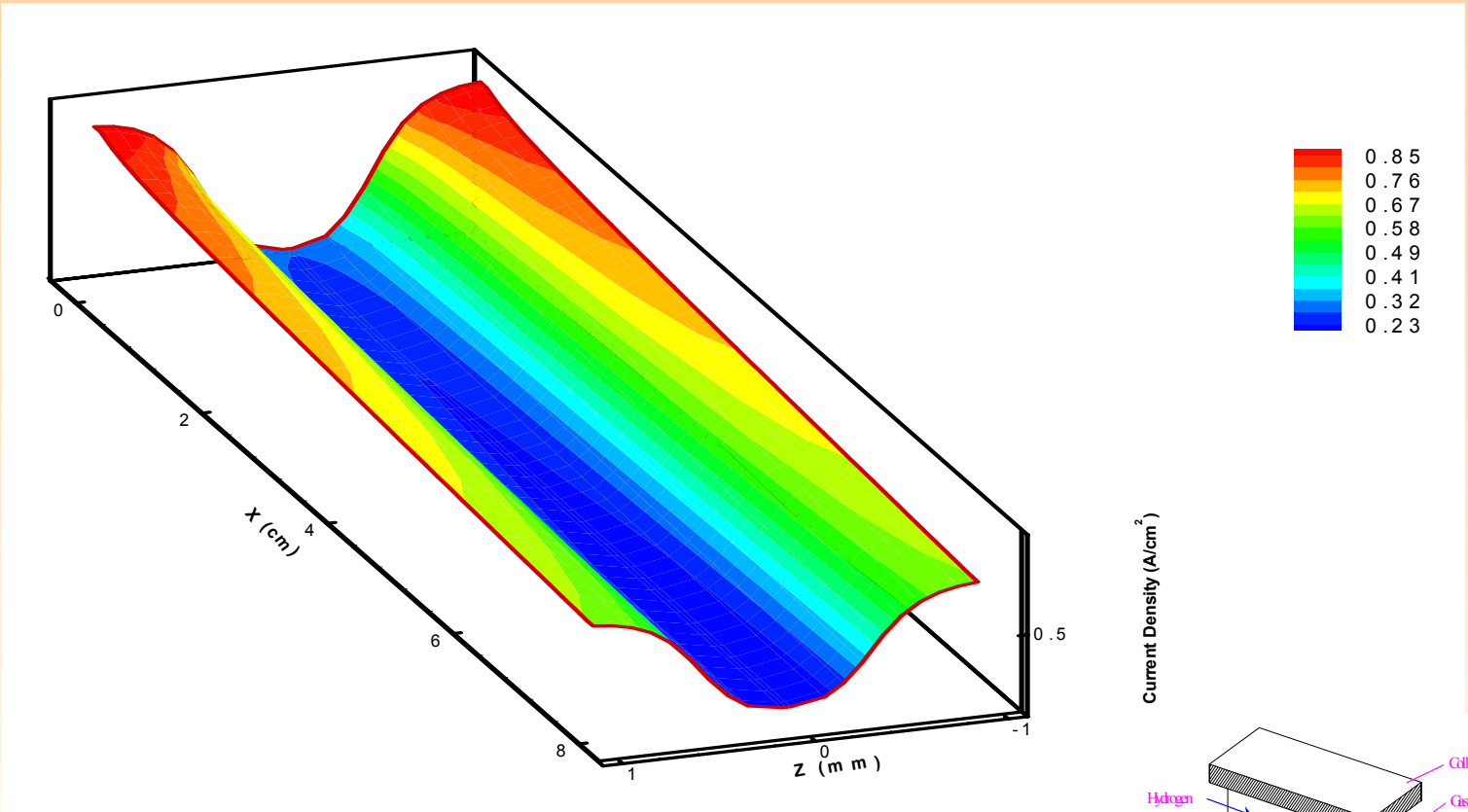
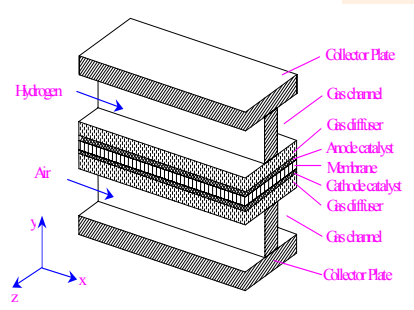
Current density distribution





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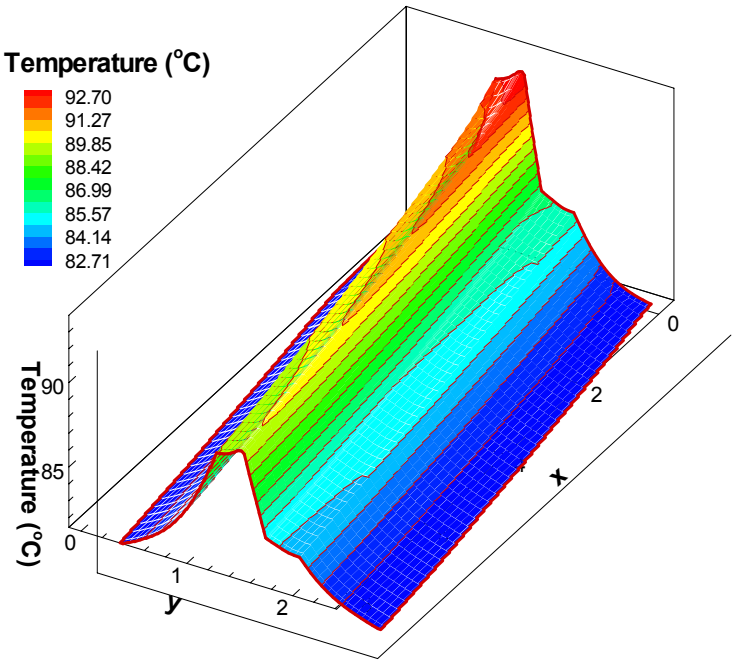
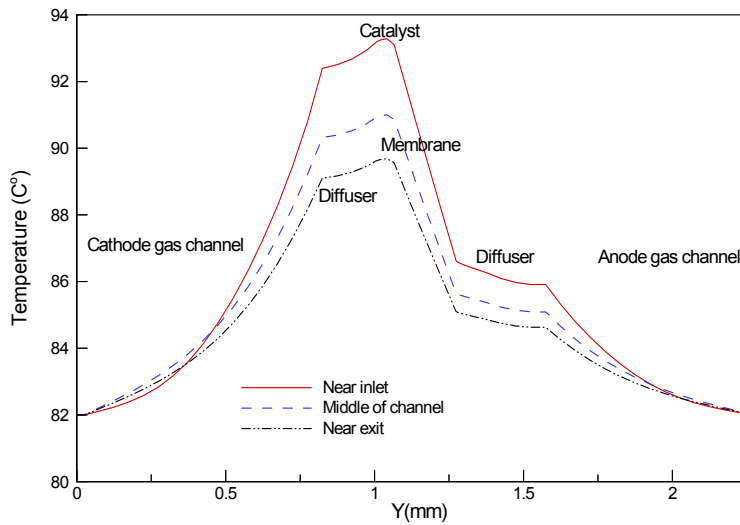
Temperature profiles across the fuel cell





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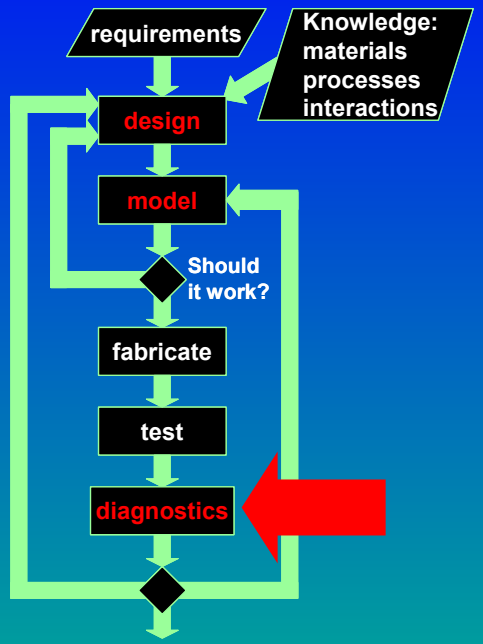
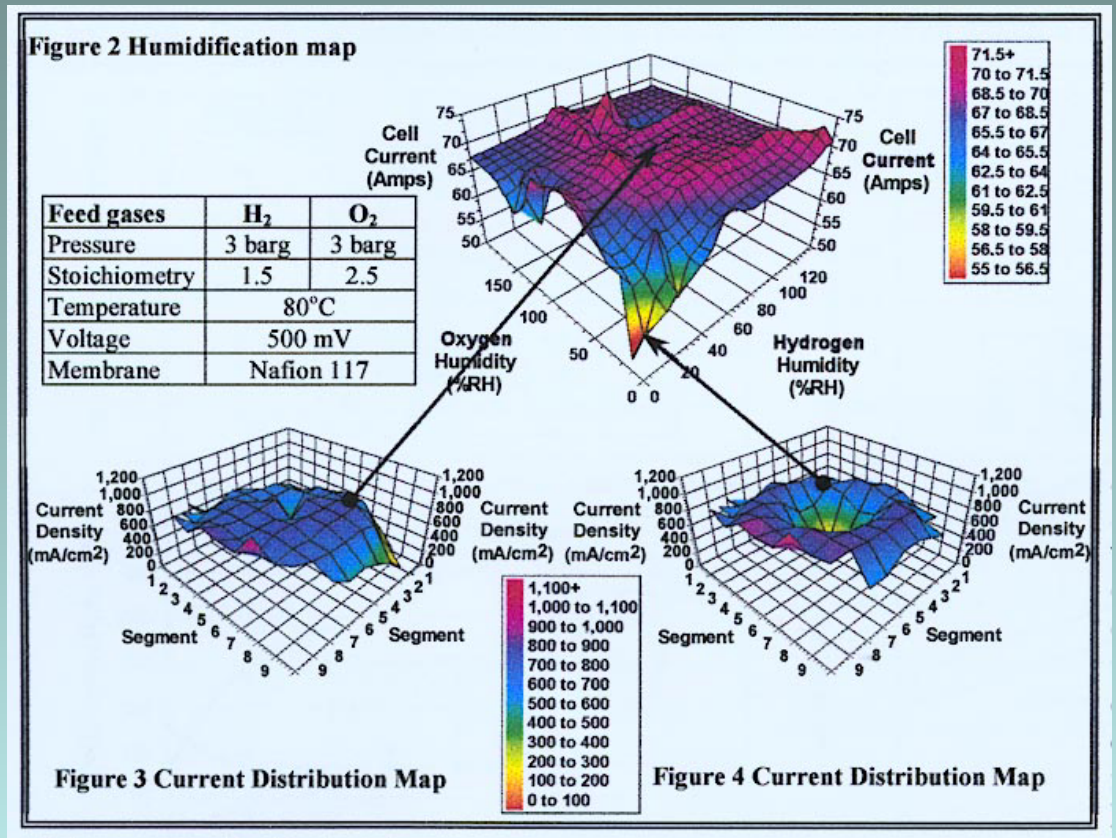
Diagnostics as a design tool

- Polarization curve
- Current interrupt
- AC impedance
- Pressure drop
- Polarization curve hysteresis
- Comparative polarization curves
- Current density mapping

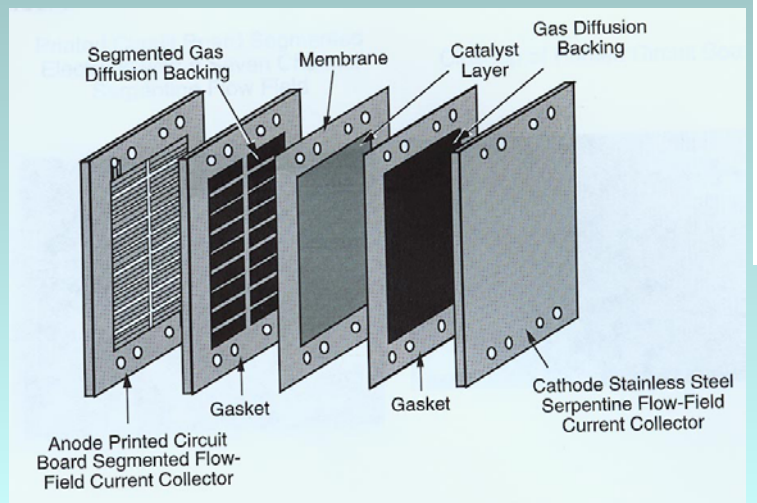


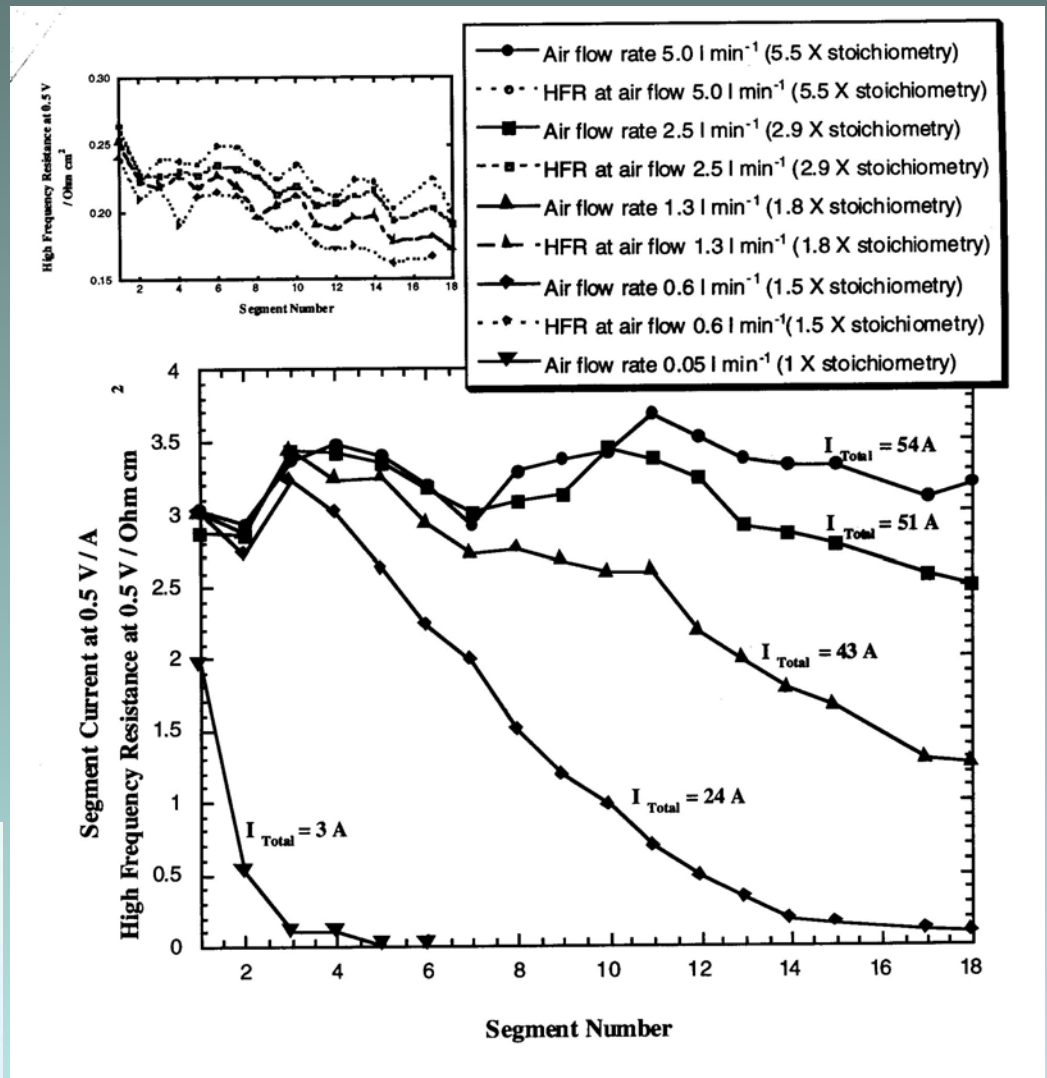
Current density mapping



M. Potter, S.Shaw, P. Adcock, and J. McGuirk, Loughborough University, Computer Modelling of Solid Polymer Fuel Cells, 1998

Current density mapping





S.J.C. Cleghorn, C.R. Derouin, M.S. Wilson, and S. Gottesfeld, A Printed Circuit Board Approach to Measuring Current Distribution in a Fuel Cell, J. Appl. Electrochem., 1997

Diagnostics as a design tool

- Polarization curve
- Current interrupt
- AC impedance
- Pressure drop
- Polarization curve hysteresis
- Comparative polarization curves
- Current density mapping
- Temperature mapping
- Flow visualization
- Neutron imaging
- Post-mortem analyses

Fuel Cell R&D Opportunities

- Development of new membrane material
  - Less expensive
  - Retains water or does not rely on water for proton conductance
- Development of new (less expensive) catalyst material
- Effect of catalyst layer structure on fuel cell performance
- Engineering of catalyst layer structure

Fuel Cell R&D Opportunities – cont. (2)

- Investigation of surface quality and interface conductivity
- Better understanding of thermal effects inside the fuel cell
  - temperature distribution
  - phase change
- Design of fuel cell as a heat exchanger
- Design of a humidifier/heat exchanger
- Investigation of 2-phase flow characteristics

Fuel Cell R&D Opportunities – cont. (3)

- Understanding of fuel cell degradation/aging/failure
- Development of methods for accelerated life-testing
- Development of diagnostic methods and tools
- Development of standardized methods for characterization of fuel cell materials/subcomponents (pre-installation & post mortem)
- Development of advanced control algorithms

Acknowledgment

My thanks to Dr. Hongtan Liu, Department of Mechanical Engineering, University of Miami for letting me use his slides for this presentation.

I also used the slides or materials from:

- Mahlon Wilson, Los Alamos National Laboratory,
- Simon Cleghorn, W.L.Gore&Assoc., (formerly with LANL)
- Marcus Potter, University of Loughborough.