

# Dynamic Modeling and Control

- A collaboration between Control group (F. Jabbari) and Dynamics Modeling Program of NFCRC (J. Brouwer, ...)
- Students:
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# Challenge

- High fidelity dynamic models for design of reliable distributed power generation
- Spatial resolutions, thermal effects in stacks

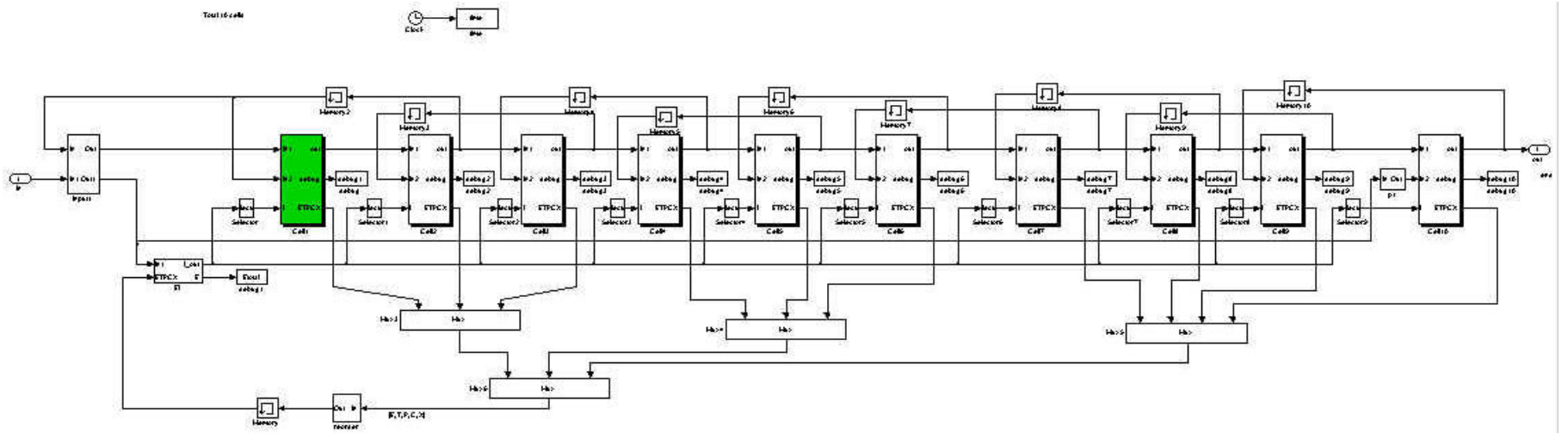
# Research Goals

- Develop capabilities for
  - Fundamental understanding of FC dynamic response/operations
  - Developing control methods for performance

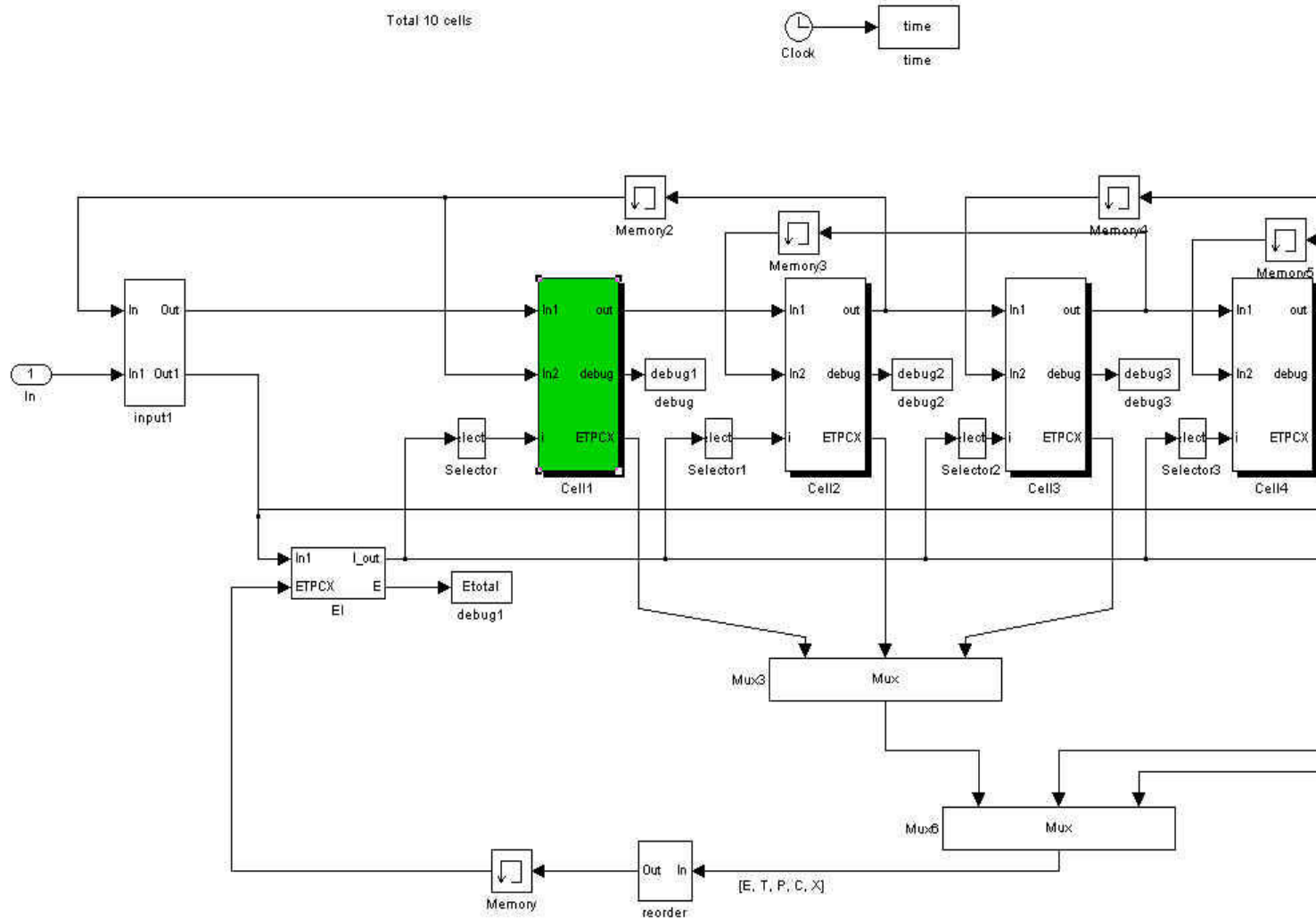
# Status

- SIMULINK environment
- Main assumptions: quasi-steady state electro-chemical (e.g., no intermediate species, etc)
- No turbulence! Focus on the the essential FC features (Nerst, voltage losses, species concentrations and momentum)

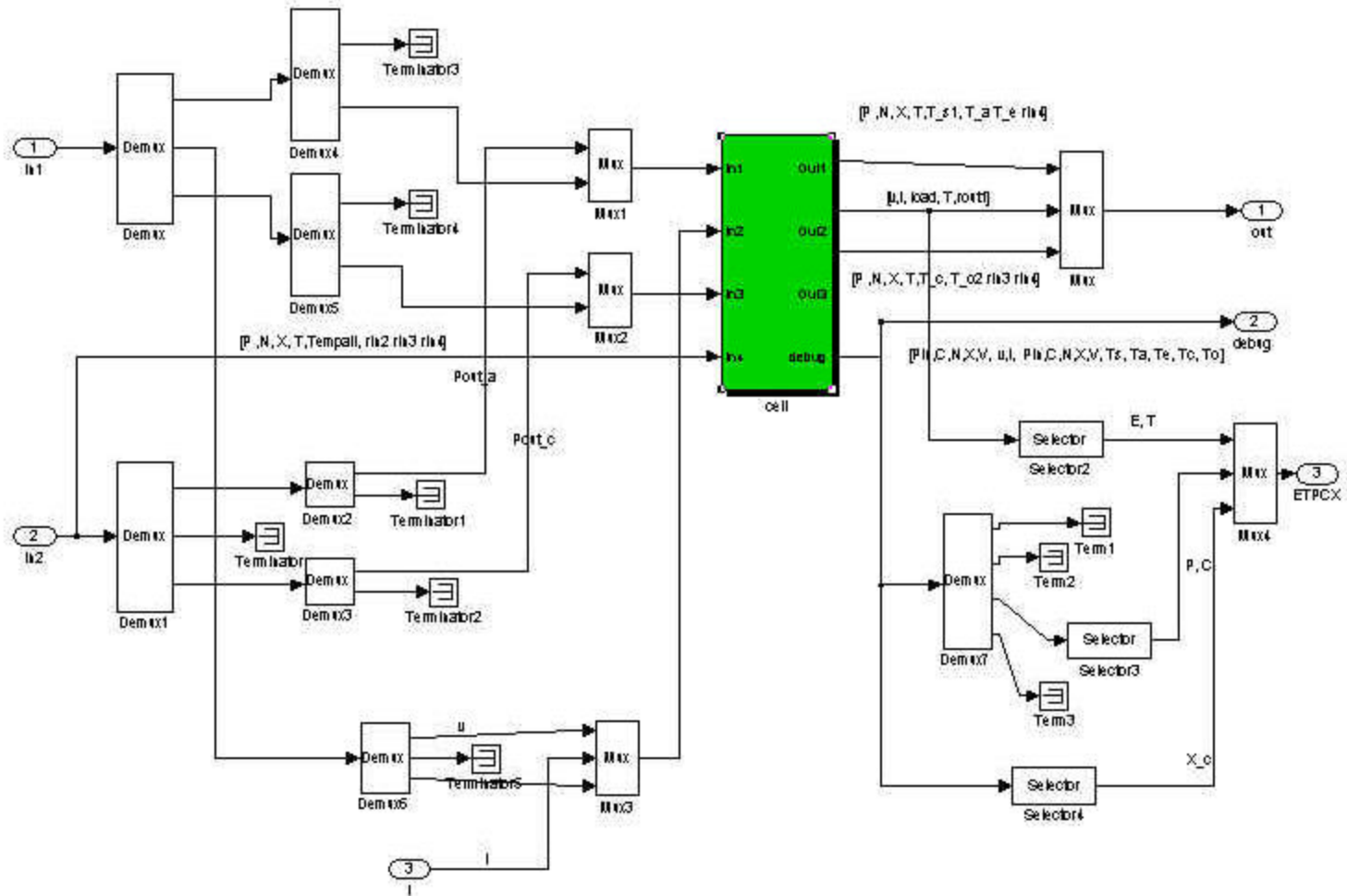
# Nodal Layout of Model



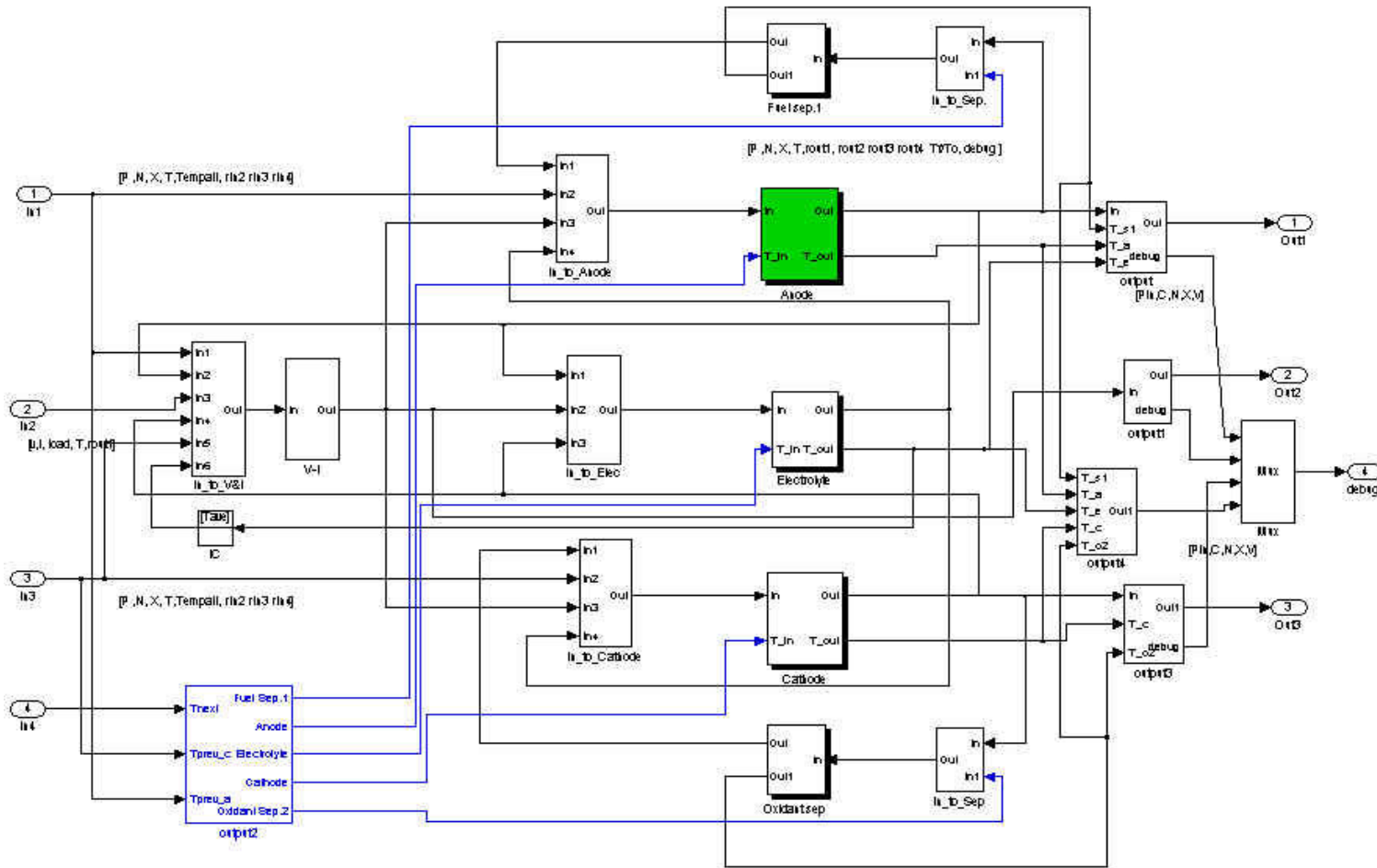
# Nodal Layout of Model: A Closer Look



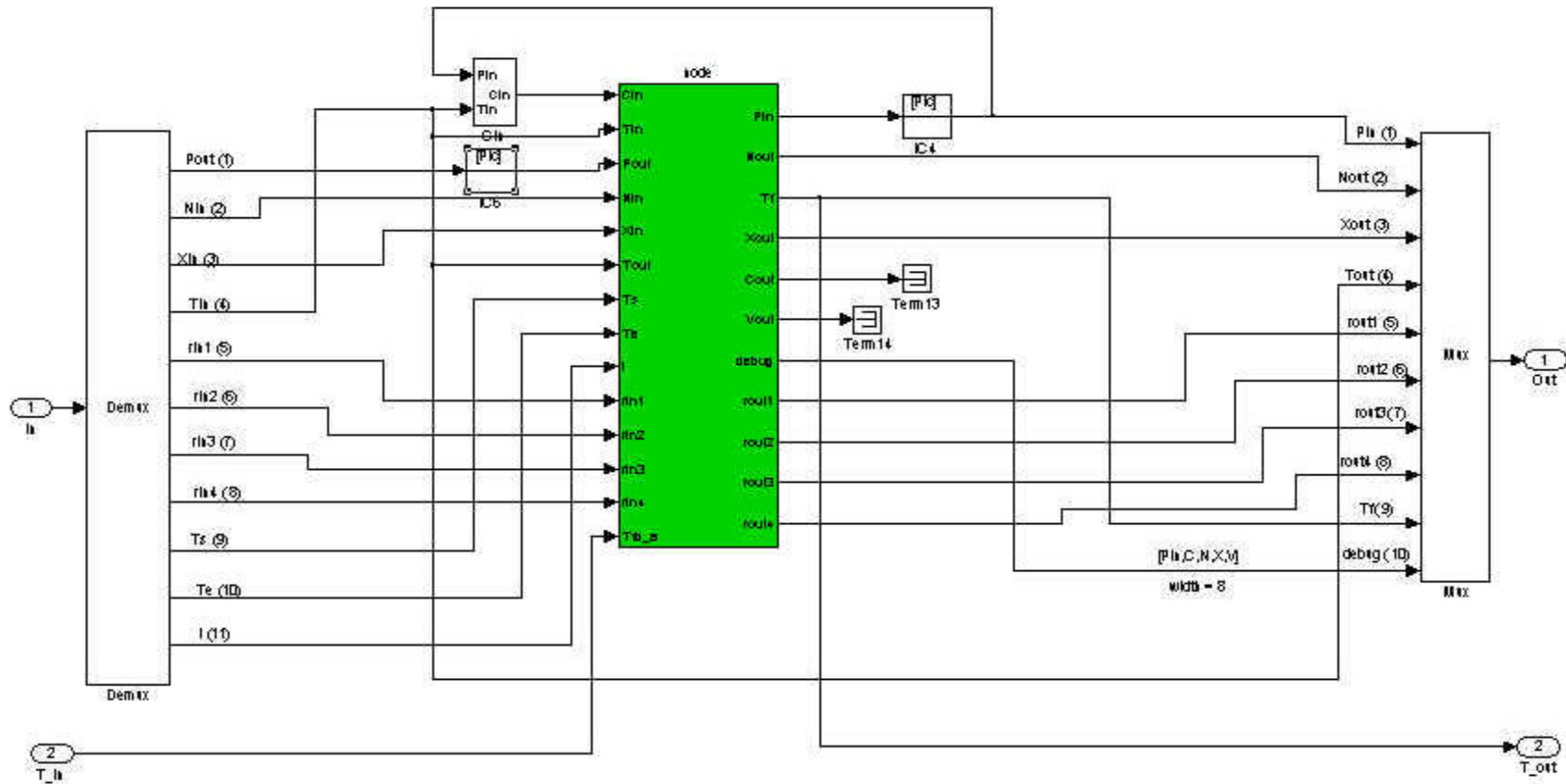
# Schematic of a Single Node



# Sub Nodal Components ( Anode, Cathode, Electrolyte, etc)



# Anode (similar to Cathode)



# MODELING EQUATIONS

For species conservation:

$$V \frac{dC_i}{dt} = N_{i_{inlet}} - N_{i_{outlet}} + R_i$$

For momentum conservation:

$$V \frac{d(\rho \bar{v})}{dt} = P_{inlet} A_{inlet} - P_{outlet} A_{outlet} - F_s$$

Voltage Losses :

$$L_R = R_u i$$

$$L_A = \frac{R_u T}{n a F} \ln(i / i_o)$$

$$L_C = -\frac{R_u T}{n F} \ln(1 - i / i_L)$$

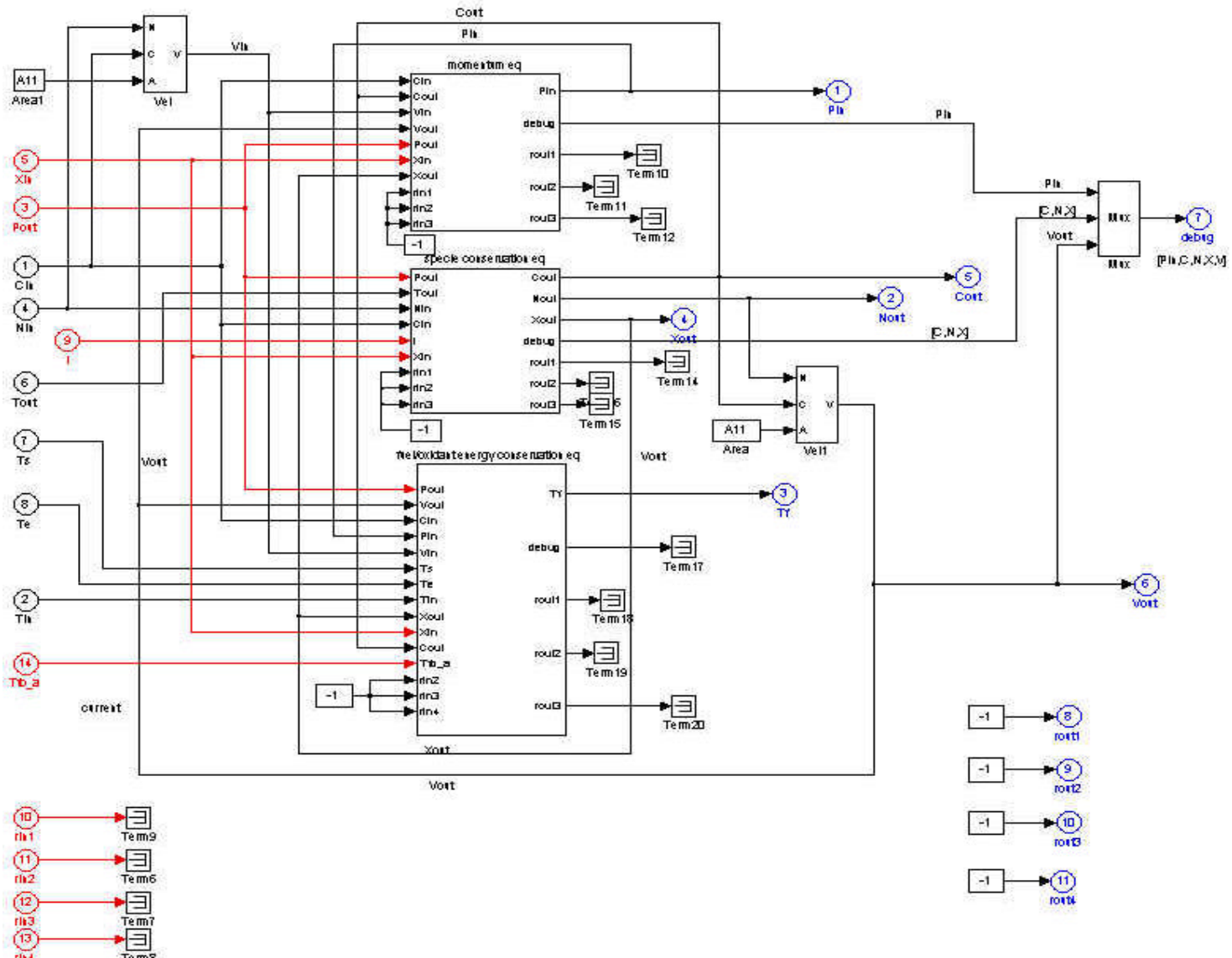
$$V_{cell} = E - L_R - L_C - L_A$$

Nernst Equation :

$$E = E^\circ + \frac{R_u T}{n F} \ln \left[ \frac{[y_{H_2}][y_{O_2}]^{1/2}[y_{CO_2,c}]P^{1/2}}{[y_{H_2O}][y_{CO_2,a}]} \right], P_c = P_a = P$$

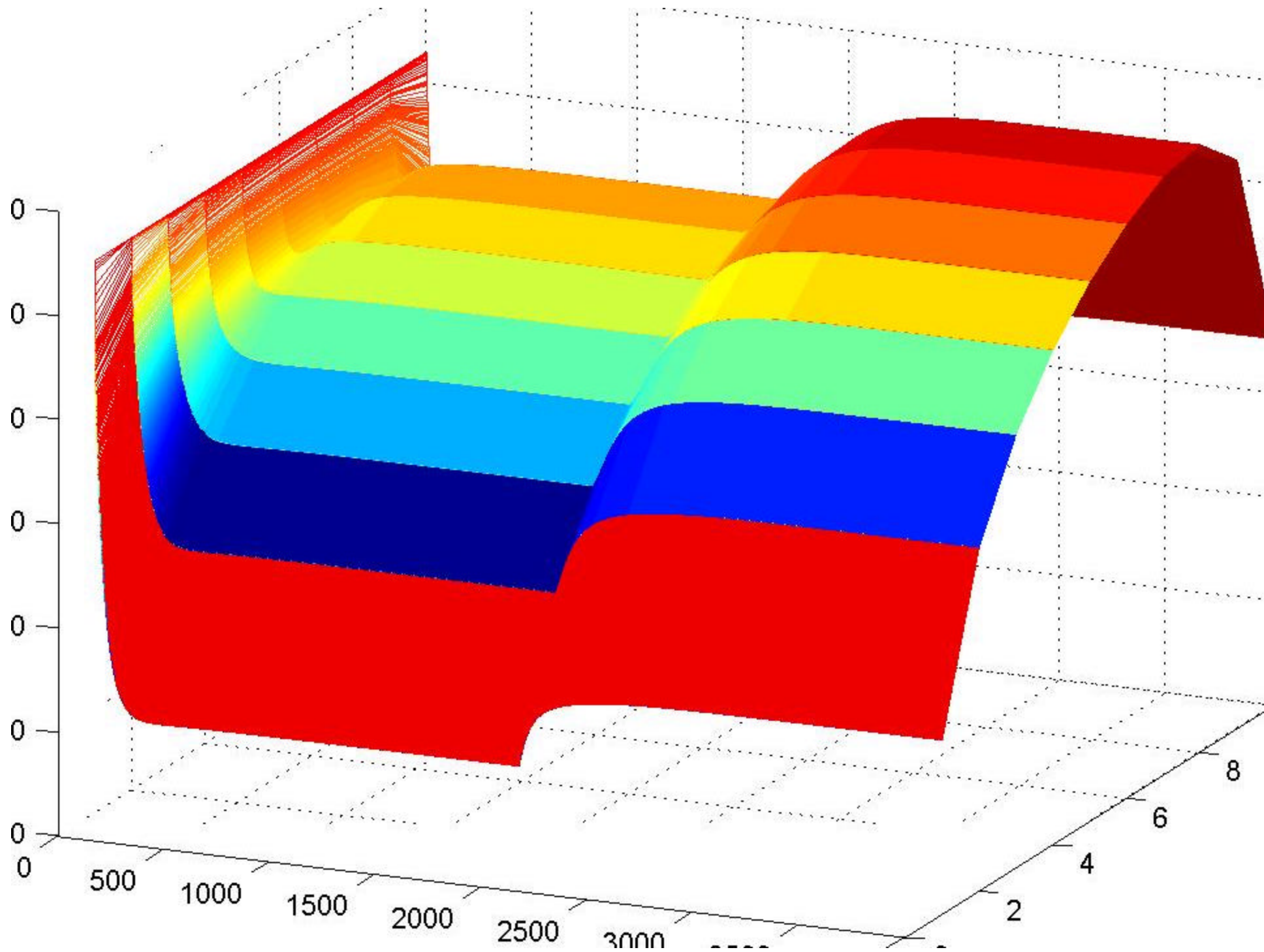
$$\left\{ \begin{array}{l} C_{out} = \frac{P_{out}}{RT_{out}} \\ N_{out} = N_{in} + N_R - \frac{d(C_{out}V)}{dt} \\ (X_{H_2})_{out} = \frac{N_{in}(X_{H_2})_{in} + R_{H_2} - \frac{d(C_{H_2}V)}{dt}}{N_{out}} \\ (X_{CO_2})_{out} = \frac{N_{in}(X_{CO_2})_{in} + R_{CO_2} - \frac{d(C_{CO_2}V)}{dt}}{N_{out}} \\ (X_{H_2O})_{out} = \frac{N_{in}(X_{H_2O})_{in} + R_{H_2O} - \frac{d(C_{H_2O}V)}{dt}}{N_{out}} \\ (X_{N_2})_{out} = \frac{N_{in}(X_{N_2})_{in} - \frac{d(C_{N_2}V)}{dt}}{N_{out}} \end{array} \right.$$

# Anode Equations



## Challenges

- Heat transfer (energy) terms – relatively slow time scales
- Do we really need it?
  - The ‘non-minimum phase’ property
  - How and where does it show up
  - What does it do?



# Model $i_o$

- Based on experimental fits:

$$L_A = \frac{R_u T}{n a F} \ln (i / i_o)$$

$$i_o = a P + b T + c PT + d$$

# Validation

