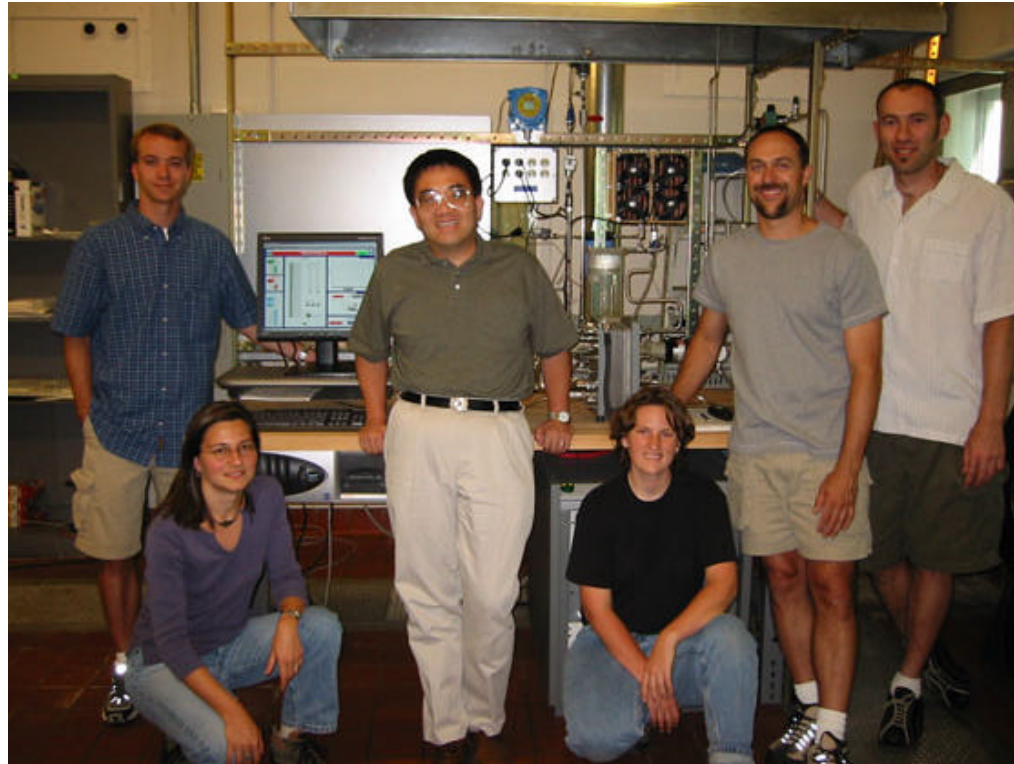


## Modeling and Control of PEM Fuel Cells



***Huei Peng and Anna Stefanopoulou***

***Department of Mechanical Engineering***

***The University of Michigan***

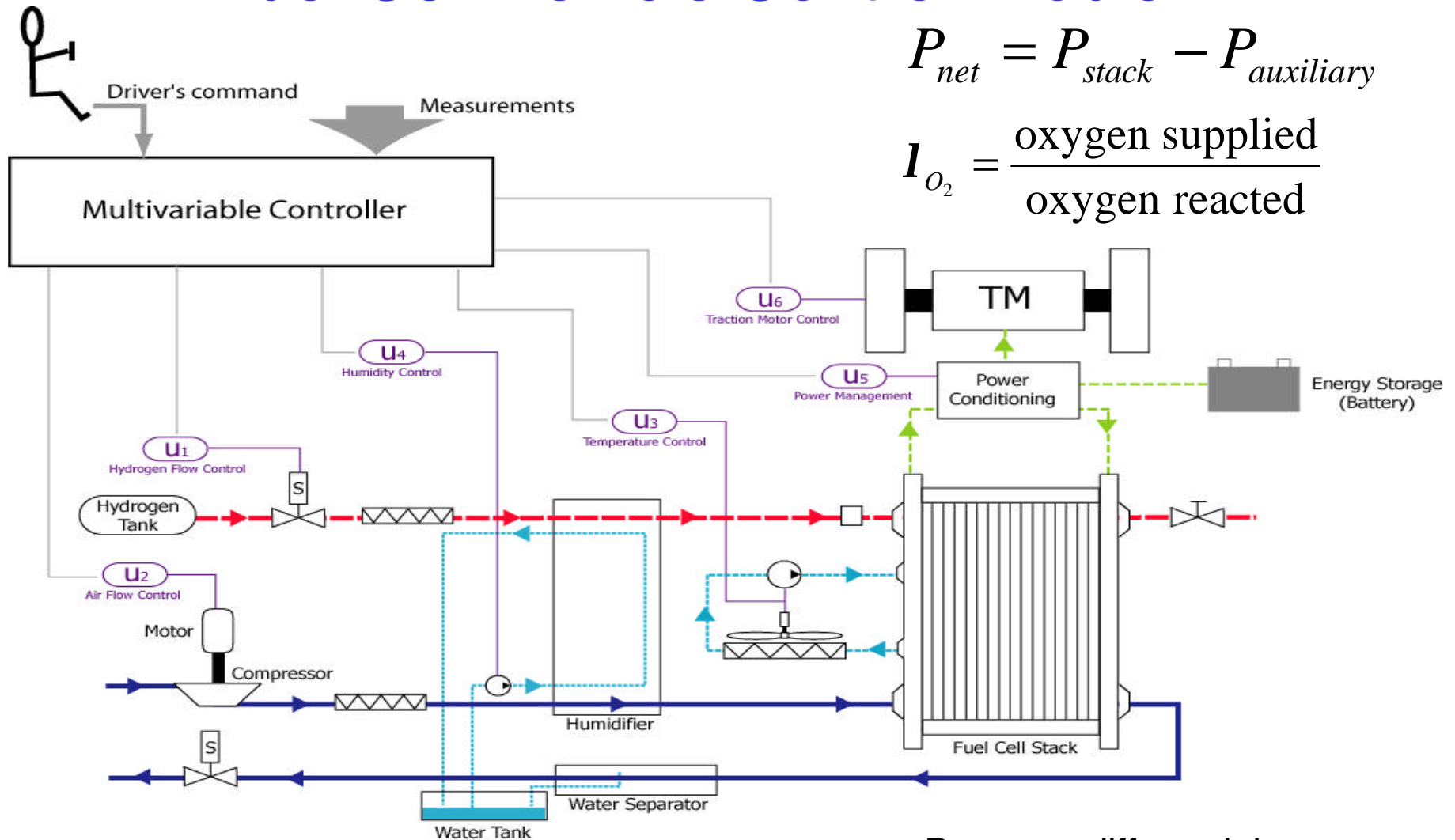
## Outline

- **Modeling of a PEM fuel cell system**
- Control of air supply loop (performance trade-off and control configuration study)
- Power management of fuel cell vehicles
- Laboratory facility

# Fuel Cell Vehicle Control Problem

$$P_{net} = P_{stack} - P_{auxiliary}$$

$$I_{O_2} = \frac{\text{oxygen supplied}}{\text{oxygen reacted}}$$

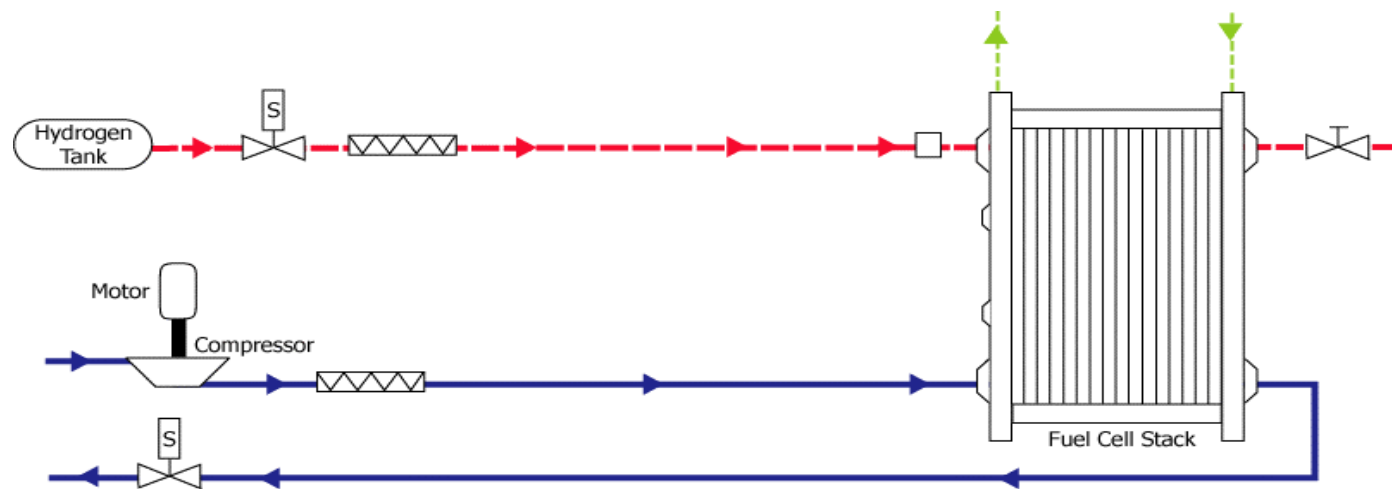


Pressure differential  
Humidity/Temperature

# Control of Air Supply

**Goal: To provide sufficient **air** flow to achieve fast transient response, and reduce auxiliary power consumption**

**Assumptions: Fast hydrogen loop,  
Perfect temperature and humidity control**



# Compressor and Manifolds Model

## Compressor

$$J_{cp} \frac{dw_{cp}}{dt} = \frac{1}{w_{cp}} (P_{cm} - P_{cp})$$

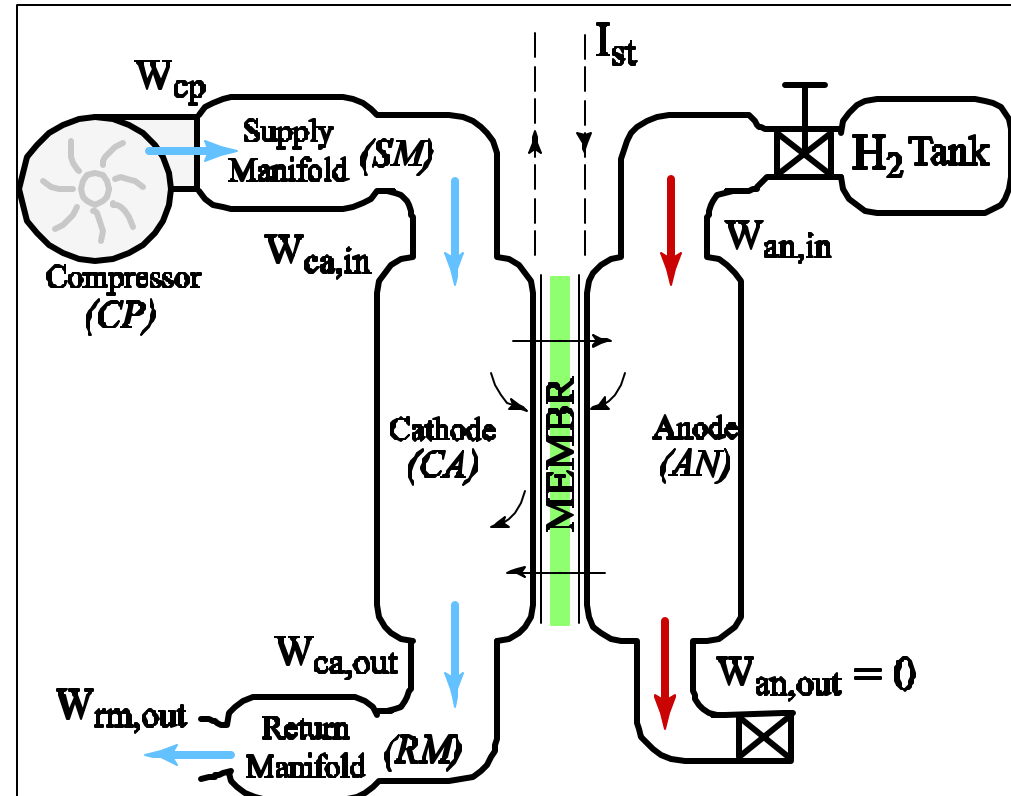
## Supply Manifold

$$\frac{dm_{sm}}{dt} = W_{cp} - W_{ca,in}$$

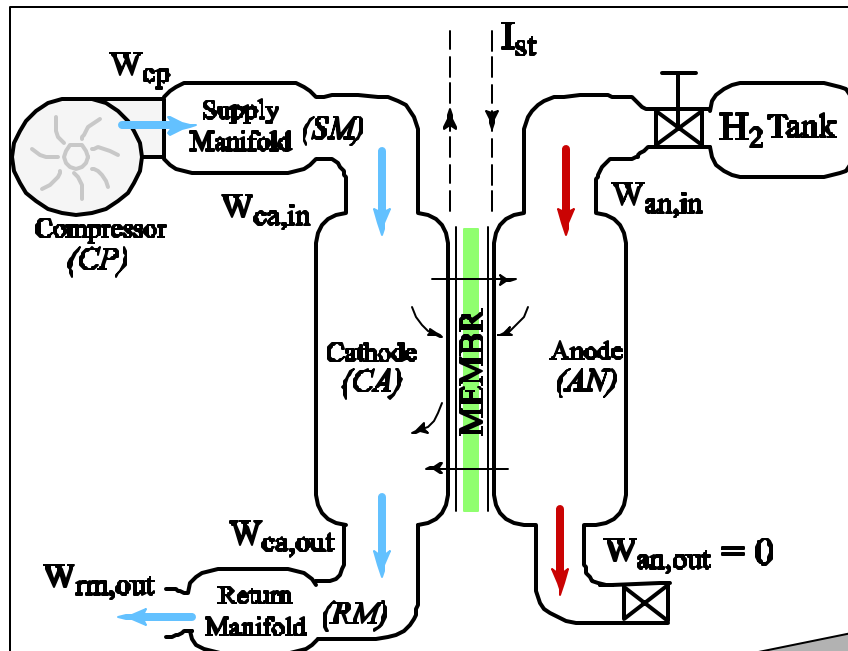
$$\frac{dp_{sm}}{dt} = \frac{gR_a}{V_{sm}} (W_{cp} T_{cp,out} - W_{ca,in} T_{sm})$$

## Return Manifold

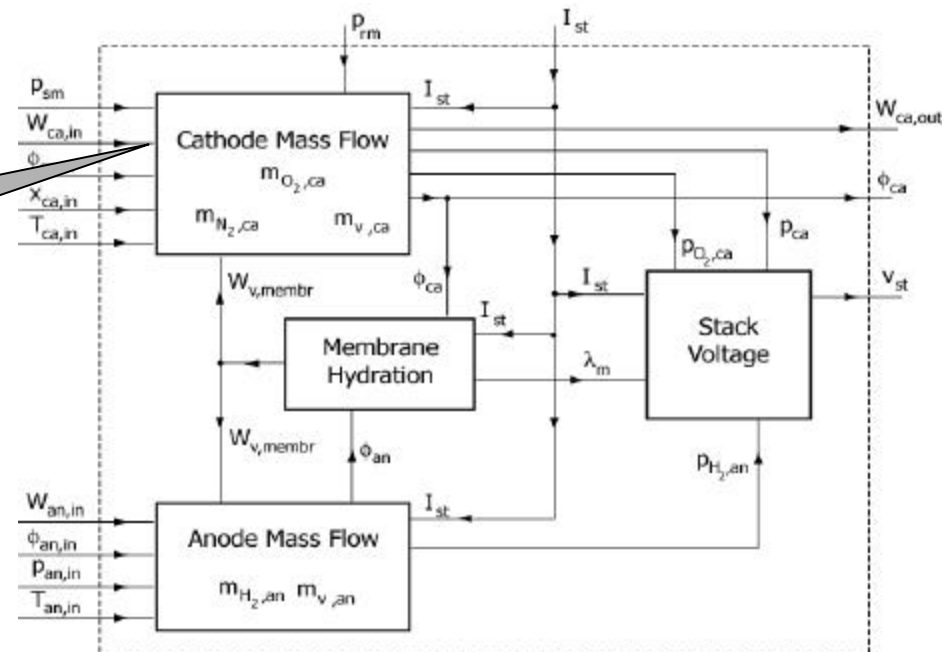
$$\frac{dp_{rm}}{dt} = \frac{R_a T_{rm}}{V_{rm}} (W_{ca,out} - W_{rm,out})$$



# Fuel Cell Stack Model



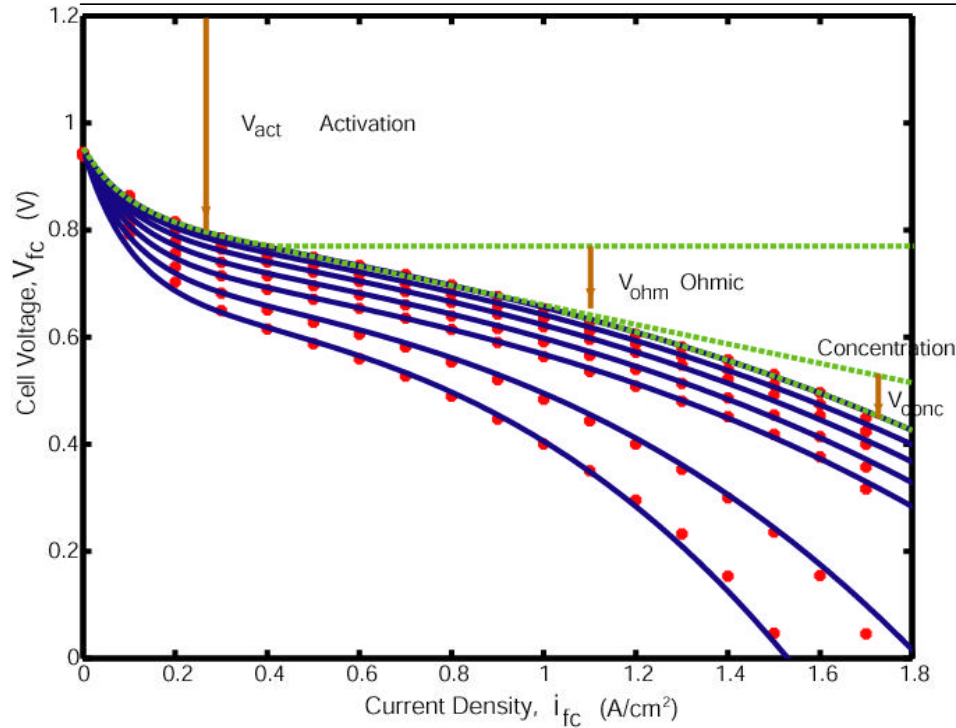
- Cathode Mass Flow Model
- Anode Mass Flow Model
- Membrane Hydration Model
- Stack Voltage Model



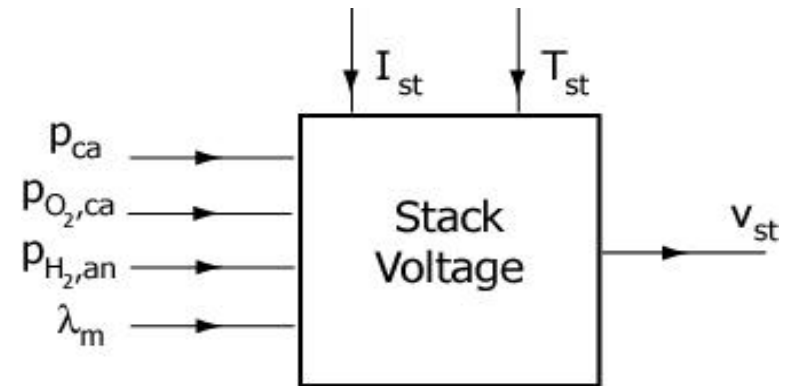
$$\frac{dm_{O_2}}{dt} = W_{O_2,in} - W_{O_2,out} - W_{O_2,react}$$

$$\frac{dm_{N_2}}{dt} = W_{N_2,in} - W_{N_2,out}$$

$$\frac{dm_{w,ca}}{dt} = W_{v,ca,in} - W_{v,ca,out} + W_{v,gen} + W_{v,membr}$$



- Cathode Mass Flow Model
- Anode Mass Flow Model
- Membrane Hydration Model
- **Stack Voltage Model**



$$\begin{aligned}
 V &= E - V_{act} - V_{ohm} - V_{conc} \\
 &= E - \left[ V_0 + V_a (1 - e^{-c_1 i}) \right] - [i R_{ohm}] - \left[ i \left( c_2 \frac{i}{i_{max}} \right)^{c_3} \right]
 \end{aligned}$$

$$E(T, p_{H_2}, p_{O_2}), V_{act}(T, p_{ca}, p_{O_2}), V_{ohm}(T, I_m), V_{conc}(T, p_{O_2})$$

## Outline

- Modeling of a PEM fuel cell system
- Control of air supply loop (performance trade-off and control configuration study)
- Power management of fuel cell vehicles
- Laboratory facility

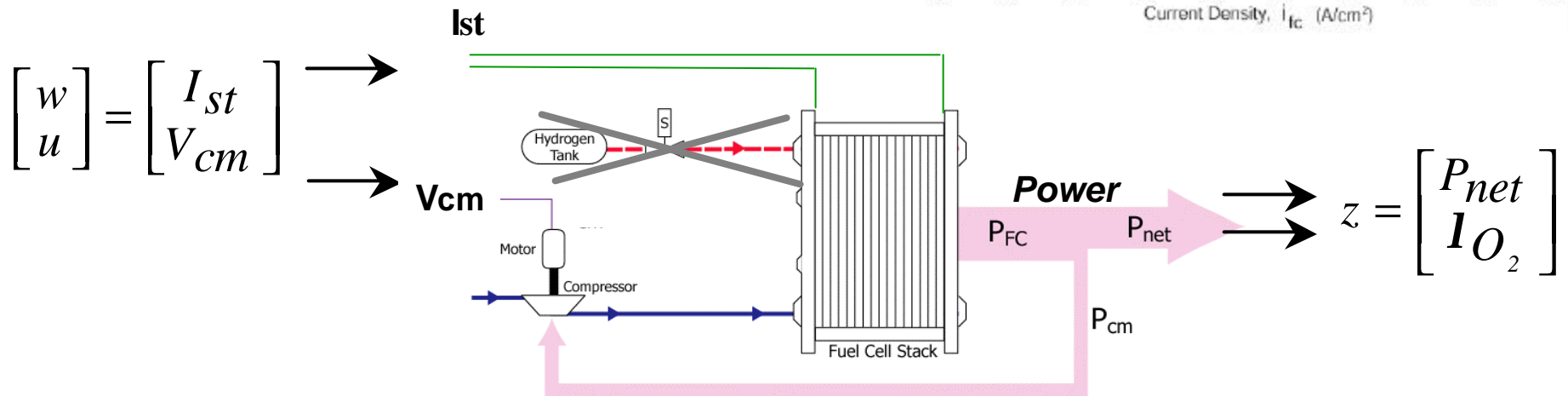
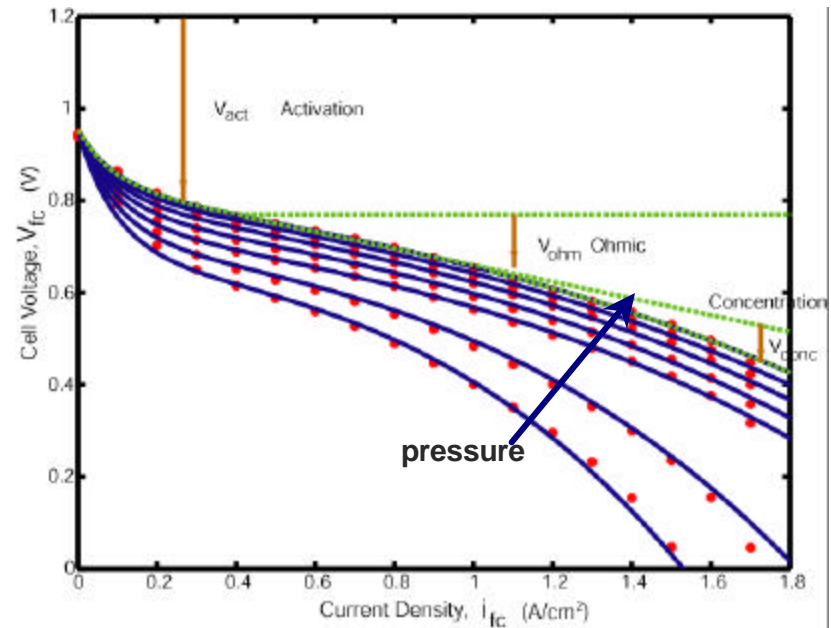
# Control Objectives

## Net Power

$$P_{net} = P_{FC} - P_{CM}$$

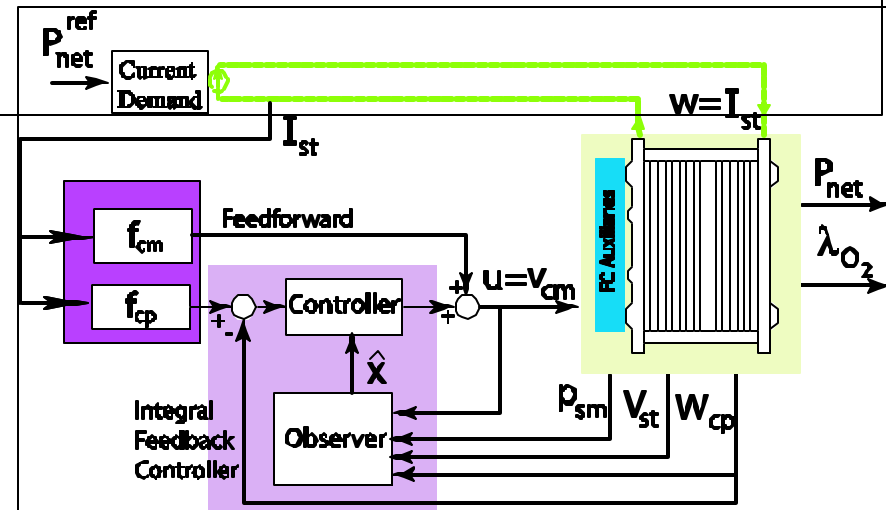
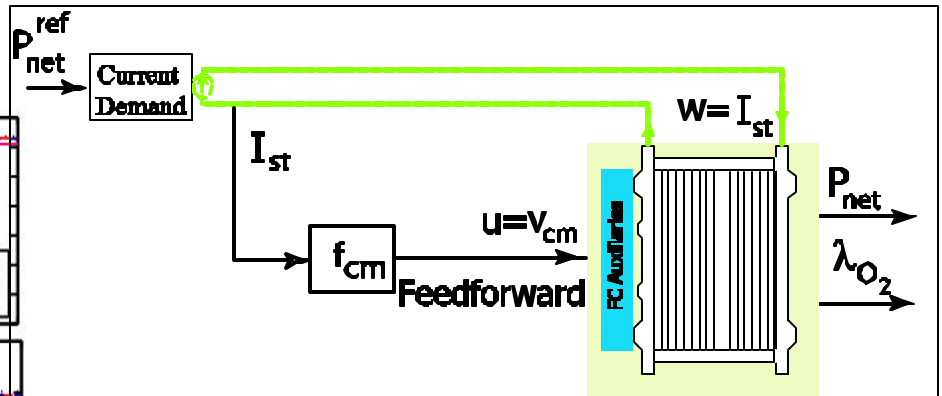
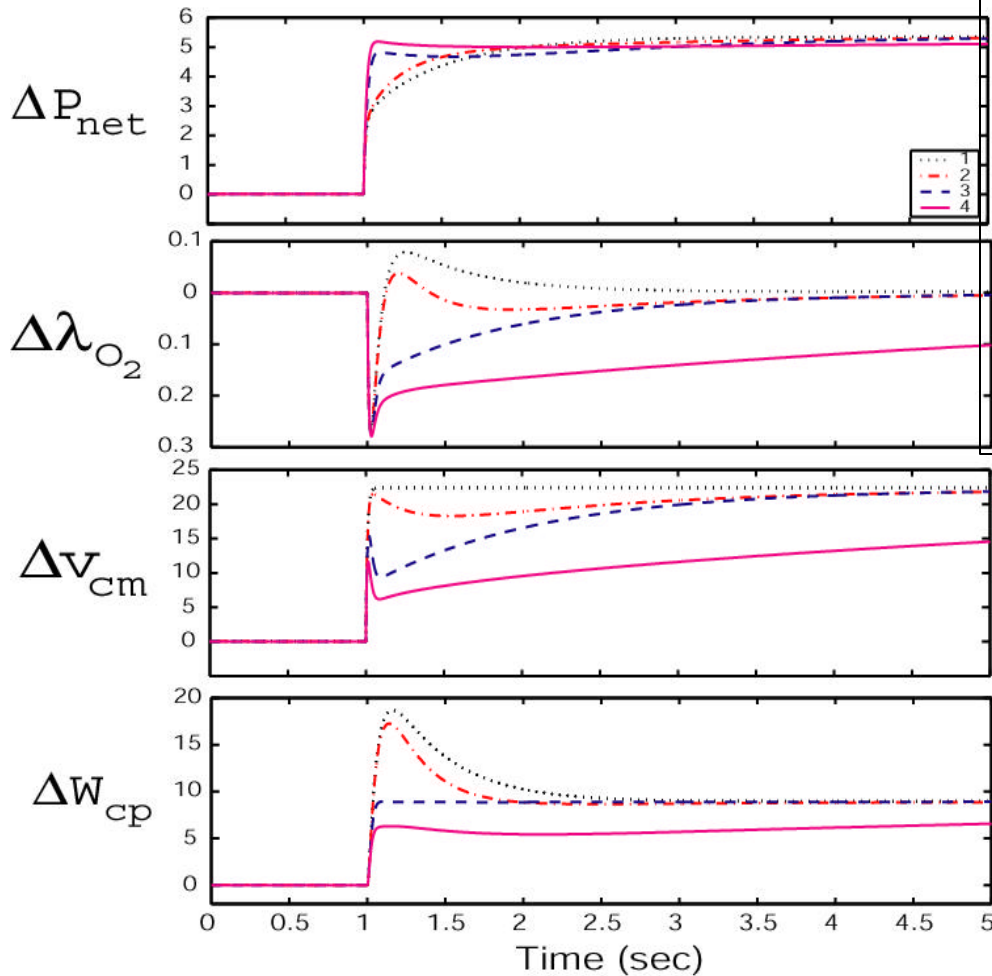
## Oxygen Excess Ratio

$$I_{O_2} = \frac{\text{oxygen supplied}}{\text{oxygen reacted}} = \frac{W_{O_2,in}}{W_{O_2,react}}$$



# Performance Tradeoff

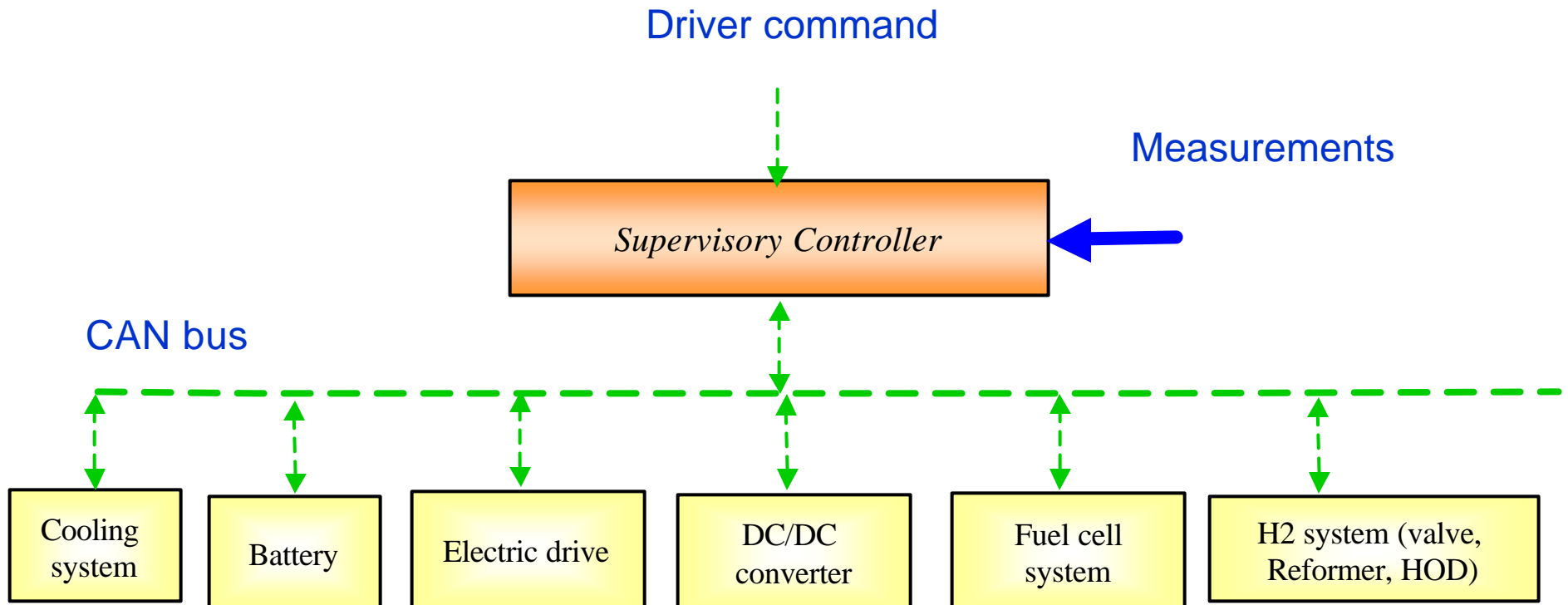
$$J = \int_0^{\infty} z^T Q_z z + u^T R u + q^T Q_q q dt$$



## Outline

- Modeling of a PEM fuel cell system
- Control of air supply loop (performance trade-off and control configuration study)
- **Power management of fuel cell vehicles**
- Laboratory facility

# Main-loop Fuel Cell Vehicle Control



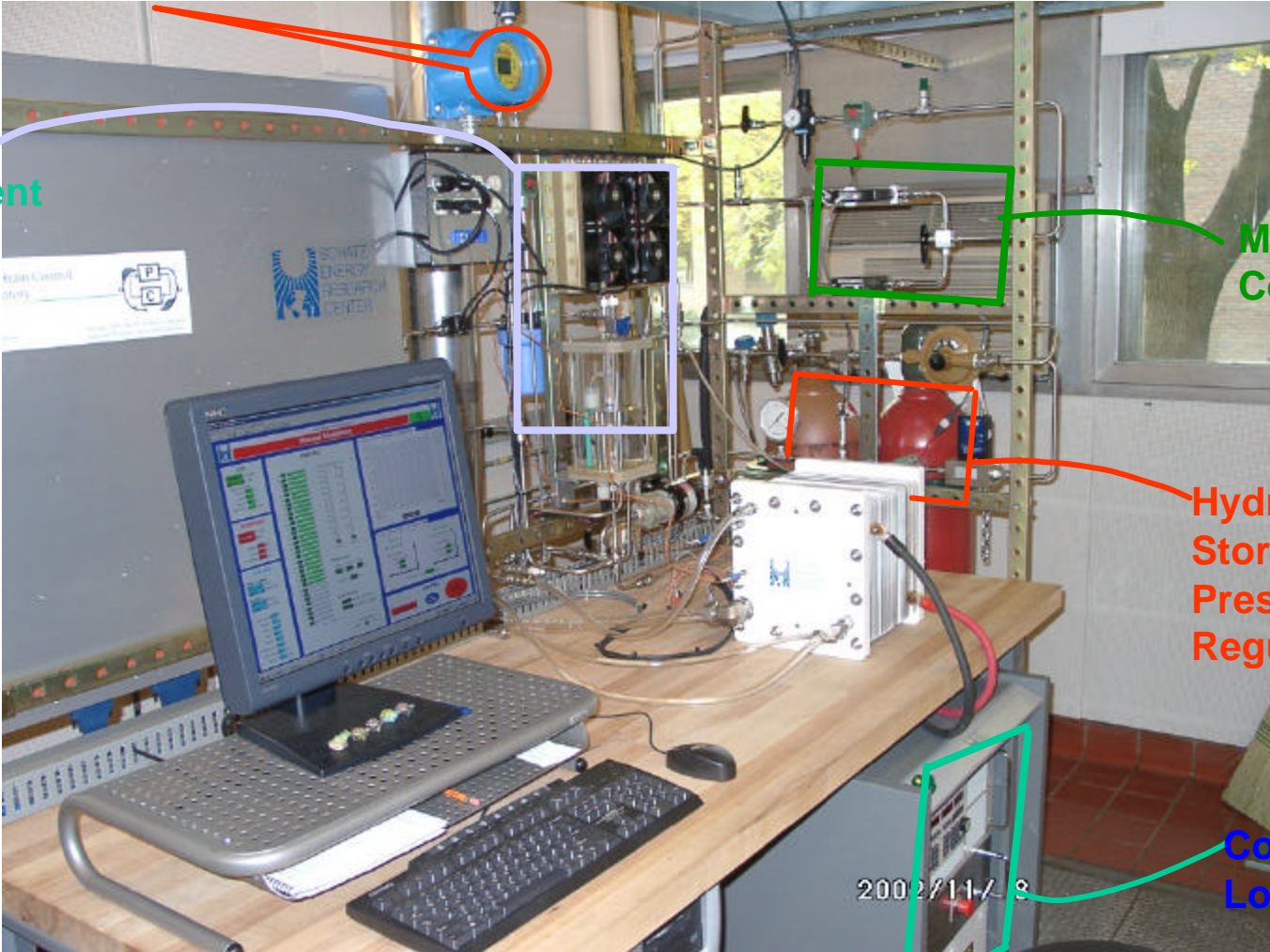
## Outline

- Modeling of a PEM fuel cell system
- Control of air supply loop (performance trade-off and control configuration study)
- Power management of fuel cell vehicles
- **Laboratory facility**

# Fuel Cell Control Test Station

Hydrogen Sensor

Thermal Management

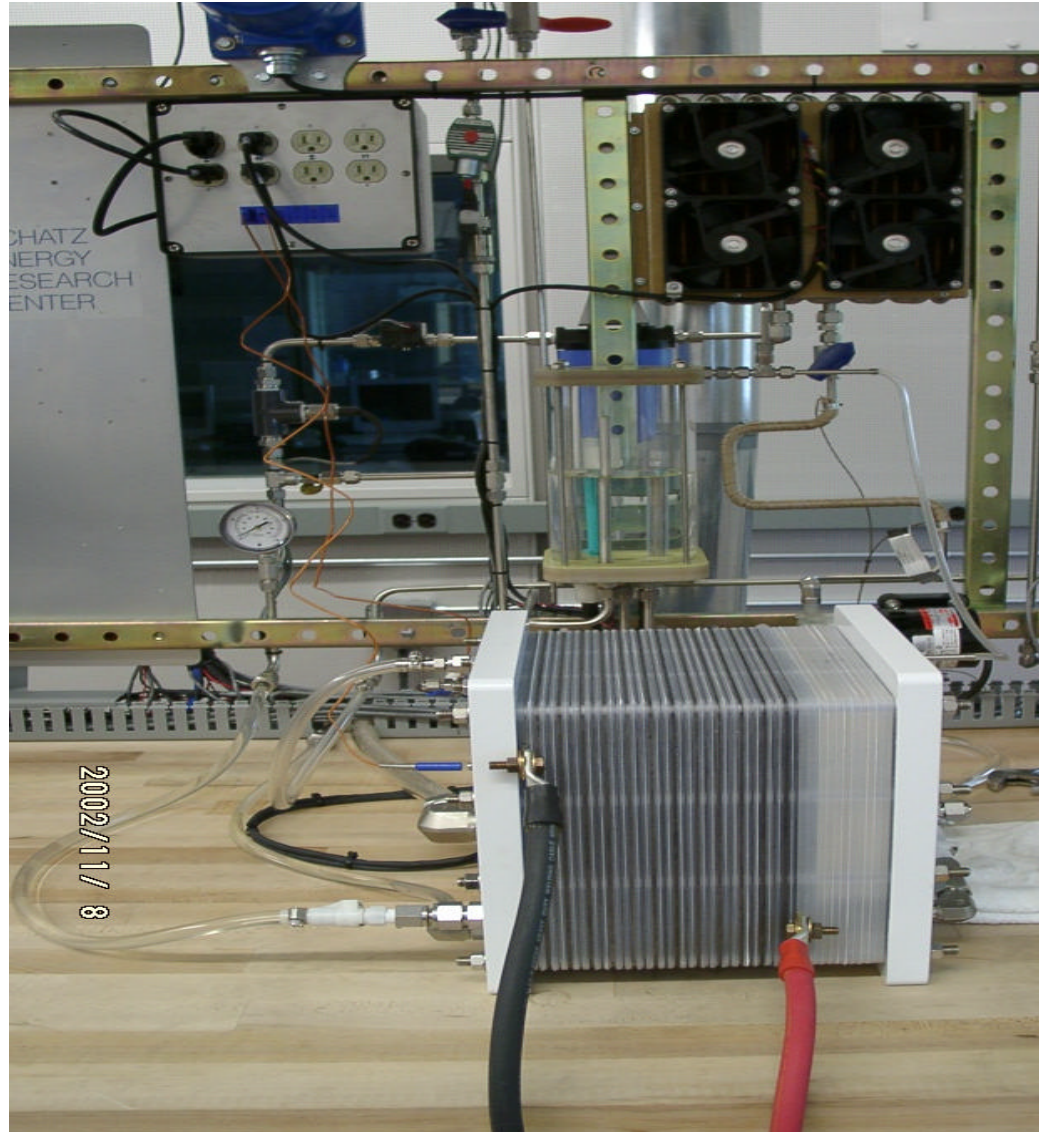


Mass Air Controllers

Hydrogen Storage and Pressure Regulation

Controllable Load

## PEM Fuel Cell (24 cells, 2.5 kW)



# Electronics



## Major Thrusts

- FCS level MIMO control
  - Understand fundamental characteristics and performance limit (e.g., due to NMP zeros)
- FC vehicle Power Management
- Models for improved membrane humidity management and purging—stack durability and efficiency.