

# Controls for Fuel Cells

## What are the key Controls Research Needs?

- Having models that aid in control design and analysis
- Interface between models at different scales
- Capabilities for model validation (experiments)
- Sensing and actuation technologies
  - Gas composition
  - Fast time scale sensing and actuation small scale

# Controls for Fuel Cells

## How Can We Best Increase Funding Opportunities?

- State of Ohio
  - \$125 million over the next 3 years
    - \$20 million for experimental facilities
      - Fundamental research
- Where is the fuel cell going?
  - Automotive companies are interested in funding experiments and modeling (high order computational model)
    - Validation of models
- Manufacturing, materials,
- Where can academia make a difference and get funding

# Controls for Fuel Cells Research

- Controls and Design for Manufacturing
  - Includes controls for the manufacturing process itself
- Process of developing a control system
  - Takes five years for diesel engine
  - Control for performance, emissions over a large operating range.
- Still searching for a natural configuration for the fuel cell, like the cylinder of ICE
- Fuel cells have more controls involved than conventional technologies
- Developing a foundation of models.
  - High order – fundamental understanding, controls
  - Low order – control systems design/application level
  - Various scales and levels of simulation required
  - 3-D PDE, 1-D PDE
    - Too difficult for control engineer use, but, useful for insight/validation
- Use smart design for control (passive?)

# Controls for Fuel Cells Research

## Multi-scale Modeling for Control

- Solving problems at the *nano-scale*
  - Materials, physical science, reaction rates
  - Manufacturing concerns
  - Pass the nano-scale calculations/understanding to the next level
  - Control material properties
  - Catalysis physical transport mechanisms
- Solving problems at the *micro-scale*
  - Flow, Heat transfer, Reaction
  - Design for manufacturing
  - Control by design
  - Control
    - Transport process tailoring (e.g., diffusion layer)
    - 2-phase flow resistance
    - Heat transfer

# Controls for Fuel Cells Research

## Multi-scale Modeling for Control (cont.)

- Solving Problems at the *Channel Level*
  - Design, manufacturing, heat, mass, momentum transfer
  - active control
    - MEMs sensor and actuator
      - Temp, H<sub>2</sub>O, Flow, Mole Fraction, Pressure
    - Water management (e.g., PEM drying and flooding)
- Solving Problems at the *Cell Level*
  - Design, manufacturing, controls, heat, mass, momentum transfer
  - Control by design
  - Control via sensing and actuators
    - Heat removal, H<sub>2</sub>O management

# Controls for Fuel Cells Research

## Multi-scale Modeling for Control (cont.)

- Solving Problems at the *FC Stack Level*
  - Design, manufacturing, integration, gradients
    - Sealing and compactness
  - Control by sensors/actuators
    - Cell balance, flow rate control
    - Temp, H<sub>2</sub>O, pressure
    - Transient control (warm-up, shut-down internally)
- Solving Problems at the *Fuel Cell System Level* (Engine/Power Plant)
  - Design, manufacturing, integration, interoperation, dynamics
  - Control by design
  - Control by sensors/actuators
    - Voltage, current control, fuel supply flow, temperature, H<sub>2</sub>O

## Description of Various Scales for Control / Sensors / Actuators / Models

<b>Model scale</b>	<b>Control</b>	<b>Control functions</b>	<b>Sensing and diagnostics needs</b>	<b>Actuation needs</b>	<b>Model type</b>	<b>Modeling tools</b>
<b>Vehicle</b>	Active and passive	Driveability, performance, energy use	?	?	Quasi-static, Low-order lumped	Matlab Simulink
<b>Power-plant</b>	Active and passive	Meet demand, energy conversion efficiency,	Voltage, Power, Temperature, Humidity, flow, other	Valves, Regulators, temperature, voltage, power, motor controllers, etc.	Low-order lumped	Matlab Simulink
<b>Fuel cell</b>	Active and passive	Voltage and current (AC, DC), fuel supply flow, temperature humidity	Gas composition Humidity Temperature Flow rates Other?	Valves, Regulators, Temp. voltage, power, controllers, etc.	Low-order lumped High-order lumped	Matlab Simulink, CFD – component level
<b>Stack</b>	Active and passive	Fuel supply: flow, temperature, humidity; internal stack transient control (start-up/shut down); energy conversion efficiency	Gas composition Humidity Temperature Flow rates	?	High-order lumped 1-D PDEs 3-D PDEs	CFD, Finite Element, Thermal Stress
<b>Cell</b>	Active and passive	Heat removal/humidity,	Gas composition Humidity Temperature Detailed diagnostics	?	High-order lumped 1-D PDEs 3-D PDEs	CFD, Finite Element,
<b>Channel</b>	Active and passive	Humidity, temperature, mole fraction (bulk flow), pressure	Gas composition Humidity Temperature Detailed diagnostics	MEMS	1-D PDEs 3-D PDEs	CFD, Finite Element,
<b>Micro</b>	Passive	Thermal and molecular transport processes, gas diffusion layer, 2-phase flow resistance	Gas composition Humidity Temperature Detailed diagnostics	MEMS	3-D PDEs	?
<b>Nano</b>	Passive	Nanostructure and materials properties (e.g.: surface reactivity, catalysis, catalyst transport processes)	Gas composition Humidity Temperature Detailed diagnostics	?	?	?

# Automotive FC Controls Research

- Power plant
  - Meet demand of energy and efficiency
  - Meet dynamic load demands
  - Fuel cell system integration and design
- Automobile
  - Drivability
  - Performance
  - Energy efficiency
- Modeling tools
  - Develop a strategy that will allow all of the models at all levels to communicate

# Automotive FC Controls Research

- PEM or SOFC?
  - SOFC operates at too high a Temperature
    - Cannot handle transient Temperature changes
    - Acceptable for APU - Large trucks
  - Automotive is going towards PEM for traction applications
    - Better Power density
    - Handle transients better
    - Lower temperatures (easier start-up)
  - Platinum
    - Is there enough platinum for a large fleet of automobiles?
    - Recyclable and to what level?
  - Mass production will introduce problems
    - Need a system that is robust and can be easily controlled

# Automotive FC Controls Research

- Drivers to what automotive companies say
  - Publicly want to invest in green technologies
    - Toyota says 20% by 2010 will be hybrid cars
  - From well-to-wheel
    - Diesel and fuel cell hybrids have a difference in efficiency of ~5%.
    - Are FCs worthy of investment at this level of potential improvement?
- Fuel cells will be part of the mix for automobiles

# Controls for Fuel Cells Funding

## What are the Key Controls Funding Needs?

- *Experimental facilities*
- *Fellowships that Attract students*

## What are the Key Controls Funding Agencies?

- NSF
- DOE
- DOD
- State initiatives (Matching for Federal)
- Private Industry (OEM, Suppliers)