

# Controls for Fuel Cells

## Simulation / Validation & Control

### DATA and VALIDATION NEEDS:

- Exchange data for model development and validation – address limits of non-access to data
  - Data Repository
- Develop a platform for actual demonstration and testing of control algorithms
- Develop a “theme” problem and sponsor a “competition” for solving/addressing the problem
  - Earthquake engineering example – benchmark problem(s)
    - Simulation – all done in Simulink/Matlab
  - Need to ground this in communication/collaboration with Industry
  - Need an Educational component
- For experiments in FC field, need to have a collaboration
  - Amongst universities
  - Between universities and industry
  - Between universities and National Labs (Larry Lawson invitation)

# Controls for Fuel Cells

## Simulation / Validation & Control

### OUTREACH / PUBLICATION NEEDS:

- Regular ACC or other technical conference sessions on the special topic (“theme” problem, or other)
- Special Journal issues on the topic of Controls for Fuel Cells (IEEE Trans. Control Sys. Tech., ASME J. Dyn. Sys. Meas. Control, )
- Levels of simulation – modeling may be first topic to address in the Journal and Technical Session followed by Controls
- Should have all levels, types of simulation together in the same venue (Journal/Session)
- Host additional workshops
  - Include student participation

# Controls for Fuel Cells

## Controls RESEARCH Needs – Systems & Simulation

### SYSTEMS DEVELOPMENT

- Understanding, insight, interoperability and control of three (3) main parts of FC Power Plant (Fuel Processor, FC Stack, Inverter and Power Electronics)
  - Problem of segmentation (different communities, industries, not working together)
  - Controls' community role is more than just control design, it is overall system design (design for controllability)
    - Somebody must be responsible for how all components and technologies work together
  - Industry still has real reasons for separation / segmentation / modularity
- Diagnostics and Failure Prognosis
- Cost and Complexity issues
  - Simulations can determine minimal set of sensors, actuators, and controls required for lowest cost system
- Identification of system, hybrid components required, additional controls required to match fuel cells to actual duty cycles, application needs

# Controls for Fuel Cells

## Controls Research Needs – Systems & Simulation

### SYSTEMS DEVELOPMENT (cont'd)

- Sensors for FC Controls
  - Expensive, non-existent, slow, ...
  - Various levels (lower level sensors, system level sensors)
- Actuators for FC Controls
  - Expensive, non-existent, slow, ...
  - Various levels (lower level sensors, system level sensors)
- Micro-actuation and control:
  - How could this address some of the fundamental problems of FC cost, performance, etc.
- Integration issues: Not just the components, but, integration/composite performance of:
  - Overall system design, AND
  - Component interactions, AND
  - Control strategy (sensors, actuators, controls approach), AND
  - End-use impacts and effect (e.g., car, utility grid, ...).
- We are in a “pre-controls” era

# Controls for Fuel Cells

## Controls Research Needs – Simulation

### SIMULATION TOOLS:

- Develop a common set of fuel cell simulation & controls building blocks
  - Develop better Lower order models
- Bridging between fully resolved and complex component models to lower order models used for controls development – need both, & means of validation Identification of level of model resolution (order of model) required for controls development
- Work with industry to determine key hurdles, key insights that are required for dynamic understanding, simulation and control
- Systems component models much more diverse than just a FC stack understanding
- Fuel cells are large, complex systems, multi-scale systems, in need of multi-scale simulation and hierarchical controls – classic controls issues that must be applied to FC systems

# Controls for Fuel Cells

## Controls for Fuel Cells Research Center Idea:

- Large systems, multi-scale systems, hierarchical controls – classic controls issues that are ideally applied to FC systems
  - Non-linearity
  - Distributed parameter controls
  - Uncertainty (Adaptive, Robust Control, )
- FC is the ideal platform for both simulation and controls - applications
- Time is now – systems are not yet defined, technology is young, we have an ideal opportunity for “designing for control”
- Usually controls are applied afterward to fix all of the design problems
- Cost and Complexity of FC systems can be significantly reduced by this process – THE KEY hurdle for FC viability contributions to economy and environment

# Controls for Fuel Cells

## What are the key Controls FUNDING Needs?

- MORE!!!
  - Workshops – (~\$100K/year for entire consortium, incl. students)
  - Curriculum development – (\$30K/university - ~\$200K)
  - Graduate student fellowships/education – (\$100K/university/year - ~\$1M/year need five years ~\$5M)
  - Modeling, Optimization and Control – (\$150K/university/year - ~\$1.5M/year need five years ~\$7.5M)
  - Experimental validation (much more leveraged, including national labs) – facilities at at least two universities, plus coordination, networking, travel, remote access capabilities at other universities – (\$??)

# Controls for Fuel Cells

## Funding Issues/Agenda

- Write a White Paper or Controls Review Technical Paper and provide to:
  - NSF – basic research
  - DOE – applied research
  - DoD – needs to be more applications oriented
    - Air Force, Army, Navy, Etc.
  - DoD research grant organizations: ONR, AFOSR, ARL, DARPA, ARO
- Encourage NSF to proceed with their collaboration/coordination with DOE and other agencies (similar to EPNES with ONR)
- Do a small collaborative proposal “first” (e.g., IGERT) then
- NSF Center Proposal– systems level center, time is right (FC technology, gov’t funding, industry, ...)
- Look to other opportunities:
  - MURI (Multiple University Research Institute) idea – little and big
  - State and local agencies:
    - Need their support for national initiatives
    - Looks good in proposals
- Pool current industrial supporters lists – impressive list from all Univ.

# Controls for Fuel Cells

## How can we best increase Funding Opportunities?

- Form and Multi-university consortium
  - could be leveraged with industry funding
  - Not a mature industry – little bit of funding could be garnered from each if national exposure was at stake (small amount could be widely accepted, agreed to)
  - Could be facilitated by NSF/DOE agency funding
  - E.g., MIT 42V Consortium
- Need to obtain strong industry support for any consortium
  - DOE may be first target – since they are managing the new FC money
  - NSF funding will not necessarily have a strong industry/applications focus – more science

# Controls for Fuel Cells

## How can we best increase Educational Opportunities?

- IGERT –
- Curriculum development – NSF / DOE supported
- Distance Learning
- Multi-university development of a suite of courses – then share the courses amongst universities
  - Systems level design:
    - Simulation
    - Optimization, and
    - Control

# Controls for Fuel Cells

## Educational Opportunities?(cont'd)

- Multi-university development of a suite of courses – List of System Level Simulation, Optimization and Controls Topics:
  - Electrochemistry Topics
    - Introduction and basics
    - Fuel cell electrochemistry
  - Chemical Engineering Topics
    - Chemical reactor design for fuel cells
    - Dynamics of fuel cell system chemical reactors
    - Fuel processing
  - Electrical Engineering Topics
    - Power Electronics for FCs
    - Systems Analysis and Control
  - Mechanical Engineering Topics
    - Thermodynamics for FCs
    - Fluid dynamics for FCs
    - Controls for FCs
    - Modeling and Simulation for FCs

# Controls for Fuel Cells

## How can we Best Develop Educational Resources?

- Distance Learning
  - Issues
    - get approval to allow students to take courses at other universities
    - Cross listing of virtual courses
    - Tuition and fees
    - Encourage students to take virtual courses
- Share individual course materials developed at respective universities
- Student exchanges – included in proposals and actual training goals, internships
- FCs are very multi-disciplinary
  - Need engineering, social science, environment, physical sciences
- For FC systems development very much need:
  - Chemists, physicists, materials scientists, ...