(1) NATIONAL FUEL CELL RESEARCH CENTER

(2) FUEL CELL RESEARCH CHALLENGES
NATIONAL FUEL CELL RESEARCH CENTER

• FOUNDED IN 1992
  DEPARTMENT OF ENERGY
  CALIFORNIA ENERGY COMMISSION

• MISSION
  TO FACILITATE AND TO ACCELERATE THE DEVELOPMENT AND
  DEPLOYMENT OF FUEL CELL TECHNOLOGY AND FUEL CELL
  SYSTEMS

  TO PROMOTE STRATEGIC ALLIANCES THAT ADDRESS THE
  RESEARCH AND MARKET CHALLENGES ASSOCIATED WITH THE
  INSTALLATION AND INTEGRATION OF FUEL CELL SYSTEMS INTO
  THE BUILT ENVIRONMENT

• MEMBER SUPPORT
• FOUR COMPONENTS

INTERNATIONAL BASED MEMBERSHIP

− AGENCIES
  • U.S. DEPARTMENT OF ENERGY
  • U.S. DEPARTMENT OF DEFENSE
  • CALIFORNIA ENERGY COMMISSION
  • CALIFORNIA AIR RESOURCES BOARD
  • SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT
− INSTITUTES
  • ELECTRIC POWER RESEARCH INSTITUTE
  • CALIFORNIA INSTITUTE FOR ENERGY AND EFFICIENCY
− INDUSTRY
  • SOUTHERN CALIFORNIA EDISON
  • SOUTHERN CALIFORNIA GAS COMPANY
  • TOYOTA
  • PARKER-HANNIFIN
  • CHEVRON-TEXACO
  • SIEMENS WESTINGHOUSE POWER CORPORATION
  • FUEL CELL ENERGY INCORPORATED
  • HORIBA LIMITED
  • CAPSTONE TURBINE CORPORATION
  • LOS ANGELES DEPARTMENT OF WATER AND POWER
  • PLUG POWER
  • AIR PRODUCTS
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- MEMBER SUPPORT
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OUTLINE

(1) NATIONAL FUEL CELL RESEARCH CENTER

(2) FUEL CELL RESEARCH CHALLENGES

− UNIVERSITIES FOR FUEL CELLS

− FUEL CELL ANALYSES TOOLS

− HYBRID TECHNOLOGY

− HYDROGEN INFRASTRUCTURE
UNIVERSITIES FOR FUEL CELLS

• NFCRC OUTREACH INITIATIVE
  DEPARTMENT OF ENERGY
  DEPARTMENT OF DEFENSE

• MISSION
  – INITIATE UNIVERSITY AWARENESS AND PROGRAMS IN BOTH RESEARCH AND CURRICULA
  – ADDRESS FUNDAMENTAL FUEL CELL ENGINEERING AND SCIENCE CHALLENGES
  – DEVELOP WORK FORCE FOR NATION’S INDUSTRY

• SIX RESEARCH FOCI

  √ MATERIALS
  √ POWER ELECTRONICS
  √ CONTROLS

  SYSTEMS & ANALYSES
  INFORMATION TECHNOLOGY
  FUEL PROCESSING

• Results at: http://www.nfcrc.uci.edu/UfFC

RESEARCH CHALLENGES: MATERIALS

• General materials issues
  – E.g., Nano-scale materials, composites, ionic and electronic conductivity, thermal expansion

• Materials processing
  – E.g., thin films, chemical synthesis, ceramic processing, tape casting, screen printing, heat treatment

• Fundamental understanding
  – E.g., point defect chemistry, interdiffusion, oxidation, demixing, grain boundary transport, polarizations

• Materials features and performance
  – E.g., materials stability, interface stability, differential thermal expansion, adhesion, sulfur tolerance, direct hydrocarbon oxidation

• New materials
  – E.g., solid acids, mixed conductors, ionically conducting oxides, lower temperature operation, low activation energy materials, proton conducting perovskites

• Modeling and simulation
  – E.g., combinatorial approaches, thermal-mechanical effects, finite element stress analyses, fracture mechanical properties, computational chemistry
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RESEARCH CHALLENGES: POWER ELECTRONICS

- Fundamental understanding of FC/PEL interactions
- Real-time protocol for fuel cell interfaces
- Dynamic modeling of fuel cell systems & components
- Fuel cell specific PEL topology & device design
- Identification of degree to which resolution should/can be integrated into the FC interface design
- Modeling and architecture of multiple and hybrid systems, micro-grids, storage, other components, ...
- Understanding of fuel cell characteristics germane to PEL (e.g., Ripple,...)
- Systems integration (stability, reliability, economics, ...)  
- Parasitic effects of FCs and relation to PEL, EMC
- Management of Interconnect with utility grid
- Mass customization
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### RESEARCH CHALLENGES: CONTROLS

- Developing models that aid in control design and analysis
- Interfaces between models at different scales / resolution
- Capabilities for model validation (experiments)
- Sensing and actuation technologies
- Understanding, insight, interoperability and control of three (3) main parts of a Fuel Cell Power Plant
- Diagnostics and Failure Prognosis
- Cost (design for manufacturing) and Complexity (design for control) issues
- Identification of system, hybrid components or additional controls required to apply fuel cells to actual duty cycles and applications
- Integration issues: Not just the components, but, integration and composite performance
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**Control / Sensors / Actuators / Models**

<table>
<thead>
<tr>
<th>Model scale</th>
<th>Control / Sensors / Actuators / Models</th>
<th>Control Functions</th>
<th>Sensing and diagnostics needs</th>
<th>Actuation needs</th>
<th>Model type</th>
<th>Modeling tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle</td>
<td>Control / Sensors / Actuators / Models</td>
<td>Driveability, performance, energy use</td>
<td>Voltage, Power, Temperature, Humidity, flow, other, etc.</td>
<td>Valves, Regulators, temperature, voltage, power, motor controllers, etc.</td>
<td>Quasi-static, Low-order lumped</td>
<td>Matlab, Simulink</td>
</tr>
<tr>
<td>Power-plant</td>
<td>Control / Sensors / Actuators / Models</td>
<td>Meet demand, energy conversion efficiency</td>
<td>Voltage, Power, Temperature, Humidity, flow, other</td>
<td>Valves, Regulators, temperature, voltage, power, motor controllers, etc.</td>
<td>Low-order lumped</td>
<td>Matlab, Simulink</td>
</tr>
<tr>
<td>Fuel cell</td>
<td>Control / Sensors / Actuators / Models</td>
<td>Voltage and current (AC, DC), fuel supply flow, temperature</td>
<td>Gas composition, Humidity, Temperature, Flow rates</td>
<td>Valves, Regulators, Temperature, Voltage, Power, Motor controllers, etc.</td>
<td>Low-order lumped</td>
<td>Matlab, Simulink</td>
</tr>
<tr>
<td>Stack</td>
<td>Control / Sensors / Actuators / Models</td>
<td>Heat removal/humidity, Gas composition, Humidity, Temperature</td>
<td>Detailed diagnostics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cell</td>
<td>Control / Sensors / Actuators / Models</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Char</td>
<td>Passive</td>
<td>mole fraction (bulk flow), pressure</td>
<td>Humidity, Temperature, Detailed diagnostics</td>
<td></td>
<td>3-D PDEs, Finite Element</td>
<td></td>
</tr>
<tr>
<td>Micro</td>
<td>Passive</td>
<td>Thermal and molecular transport processes, gas diffusion layer, 2-phase flow resistance</td>
<td>Gas composition, Humidity, Temperature, Detailed diagnostics</td>
<td>MEMS</td>
<td>3-D PDEs</td>
<td>?</td>
</tr>
<tr>
<td>Nano</td>
<td>Passive</td>
<td>Nanostructure and materials properties (e.g.: surface reactivity, catalysts, catalyst transport processes)</td>
<td>Gas composition, Humidity, Temperature, Detailed diagnostics</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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   - HYDROGEN INFRASTRUCTURE

FUEL CELL ANALYSES TOOLS

• Planar MCFC Dynamic Data
• Dynamic MCFC Model (Simulink®)
• Electrochemical Transient Response – 3 Pressures

Cell Voltage vs. Time Following a Resistance Load Change
From 0.1533 to 0.0692 Ohms at 650 C
FUEL CELL ANALYSES TOOLS

• Dynamic Tubular SOFC Model (Simulink®)
• FC Stack Thermal Transient Response
  • uncontrolled current demand increase at 4000 seconds

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FUEL CELL ANALYSES TOOLS

• Dynamic planar MCFC Model (Simulink®)
• FC Stack Thermal Transient Response
  • uncontrolled current demand increase at 3000 seconds
RESEARCH CHALLENGES: ANALYSES

• Fundamental understanding
  – E.g., pore diffusion, polarizations, coupled electrochemistry, reformation, heat and mass transfer, flooding, drying

• Materials level modeling and simulation
  – E.g., thermal-mechanical modeling, finite element stress analyses, fracture mechanical properties

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HYBRID
   - High Fuel-to- Electricity Efficiency
     - Theory: 75 - 80%
   - NFCRC Roles:
     - First (only) SOFC-GT Proof-of-concept
     - Integration & Demonstration
     - Simulation and Analyses
DISTRIBUTED GENERATION

220 kW
Partners: Siemens Westinghouse, Southern California Edison
World Record Proof-of-Concept: 53% (fuel-to-AC electricity)

CENTRAL PLANT

• MAJOR DOE PROGRAM: “VISION 21”
• DESIGN NEXT GENERATION CENTRAL POWER PLANT
• PRODUCE ELECTRICITY AT ULTRA HIGH EFFICIENCY
  - NATURAL GAS - 75% (LHV)
  - COAL - 60% (HHV)
• CO-PRODUCE TRANSPORTATION FUELS
  - FISHER-TROPSCH LIQUIDS
  - HYDROGEN
• MINIMIZE ENVIRONMENTAL IMPACT
MAJOR DOE PROGRAM: "VISION 21"

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MINIMIZE ENVIRONMENTAL IMPACT

CENTRAL PLANT

300MW "HYBRID" VISION 21 PLANT

76% fuel-to-electricity efficiency

LPC: Lower Pressure Compressor
HPT: Higher Pressure Turbine

GT Working Fluid
Water
Natural Gas
Humidifier
Recuperator
Economizer
Stack Gas
Cooling Water
 Blowdown
Intercooled Gas Turbine

Air

Intercooler

From Water Treatment
Natural Gas
RESEARCH CHALLENGES: HYBRIDS

• HIGH
  – Turbine compatibility
  – Hybrid behavior
    – Load loss
    – Load following
    – Thermal management
    – System optimization
  – High temperature fuel cell behavior
  – Safety, training

• STRONG
  – Sensors and controls
  – Fuel flexibility, reformation
  – Invertors and power electronics
  – Analyses
    – Steady-state models
    – Dynamic models
    – Market

• “MODEST”
  – Combustors

SOURCE: SECOND ANNUAL DOE/UN HYBRID CONFERENCE, APRIL 2002, CHARLOTTE
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• DECEMBER 24, 2002

• MR. GREGG KELLY
  PRESIDENT AND CEO
  ORTHODYNE ELECTRONICS
• HYDROGEN REFUELING

Orange County

• JANUARY 7, 2003
THANK YOU!

NATIONAL FUEL CELL RESEARCH CENTER
UNIVERSITY OF CALIFORNIA
IRVINE, CA 92697-3550
http://www.nfcrc.uci.edu