Fuel Cell Systems Analysis

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Objectives and Approach

• Objectives
  ✓ Identify key design parameters and operating efficiencies
  ✓ Assess design, part-load, and dynamic performance
  ✓ Support DOE/FreedomCAR development efforts

• Approach
  ✓ Develop, document, and make available an efficient, versatile system design and analysis code
  ✓ Develop models of different fidelity
  ✓ Apply models to issues of current interest
# Reviewers’ Comments

- **Emphasize code development rather than code utilization**
- **Analyze cold start-up of fuel processors**
- **Focus on transient modeling**
- **Investigate effects of driving protocols on system performance**
- **Conduct sensitivity and trade-off analyses**
- **Make model available at minimum cost**

- Developed several new component models
- Fast start fuel processor initiative
- Load following fuel processor
- Pressurized direct H₂ system on FUDS and FHDS
- High temperature membrane systems
- No cost to DOE contractors

Argonne Electrochemical Technology Program
Component Model Development in FY2002

- New application package for analysis of data on catalytic reactions
- Generic model for metal hydrides: kinetics with heat transfer
- Desulfurization with ZnO sorbent
- Auto-thermal reforming of iso-octane with ANL catalyst

Heat transfer coefficients for desuperheating & condensing sections
GCtool Simulations for Rapid-Start Fuel Processors

- Our simulations showed that for rapid startup, the catalytic reactors must be heated in parallel rather than sequentially.
- Analyzed effect of start-up energy on cycle efficiency.
PSAT-GCtool Integration for Fuel Cell Vehicle Analysis

• PSAT and PSAT-Pro: Hybrid vehicle simulation codes (FreedomCAR and Vehicle Systems)
  ✓ “Forward” model: driver to wheel
  ✓ Consistent rapid control prototyping, hardware-in-the-loop and vehicle control system integration

• GCtool_ENG: Engineering models of FC systems based on GCtool architecture
  ✓ Speed and accuracy appropriate for fast transients
  ✓ Component maps from models in GCtool or test data
  ✓ Translator to port GCtool_ENG models to MATLAB

• Applications
  ✓ Multi-platform study
  ✓ Fuel Cell–Battery/Supercap hybridization

Argonne Electrochemical Technology Program
80-kW Direct Hydrogen System (for SUV Application)

- Compressed hydrogen fuel
- CEM performance data from DOE contract
- Pressurized stack at 3 atm, 80°C, 0.7 cell potential at design point
  - Stack polarization curve from LANL and GCtool
- Anode and cathode feeds heated/cooled to 70°C, humidified to 90% RH at stack temperature
  - Stack coolant used for controlling anode and cathode feed temperatures
- Fuel cell – battery hybrid on SUV platform

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Water Management in Pressurized Fuel Cell Systems

- Reformed gasoline systems:
  - Condenser needed to recover process water at all conditions
  - Dew point is a function of ambient pressure and O$_2$ stoichiometry
- Direct hydrogen systems:
  - Condenser needed only at part load
  - Water also recovered at stack and condenser exits
Condenser and Air Heater Duties in Pressurized Direct Hydrogen Systems

• For design pressure ratio of 3, condenser cooling load is highest at 20% of rated flow
• Condenser duty is a strong function of cathode stoichiometry
• Cathode air heater/humidifier duty is also highest at part load
Performance of Pressurized Direct Hydrogen System

- DOE Phase I data for CEM: design pressure ratio of 3
- Stack at 80°C and 0.7 V cell potential at design point
- 70% efficiency for condenser and radiator fans

[Graph showing power factor and efficiency with lines and symbols indicating data points for different ambient temperatures]
Parasitic Losses in 80-kW Pressurized Direct Hydrogen System

- CEM and radiator fan account for much of the parasitic power
- Auxiliary power is affected by the ambient temperature
### Efficiencies With and Without Expander for 80-kW Direct Hydrogen System

- Efficiencies and power at high ambient temperature (320 K)

<table>
<thead>
<tr>
<th></th>
<th>50% O₂ Utilization</th>
<th>40% O₂ Utilization</th>
<th>30% O₂ Utilization</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>With GT</td>
<td>W/O GT</td>
<td>With GT</td>
</tr>
<tr>
<td>Power to CEM</td>
<td>7.5 kW</td>
<td>21.2 kW</td>
<td>9.3 kW</td>
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<tr>
<td>Efficiency at Rated Flows</td>
<td>45.6%</td>
<td>39.4%</td>
<td>44.8%</td>
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<tr>
<td>Efficiency at 50% Flows</td>
<td>59.6%</td>
<td>56.3%</td>
<td>59.3%</td>
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<tr>
<td>Stack Size</td>
<td>100 kg</td>
<td>116 kg</td>
<td>102 kg</td>
</tr>
<tr>
<td>Condenser Heat Duty</td>
<td>9 kW</td>
<td>13 kW</td>
<td></td>
</tr>
</tbody>
</table>
Dynamic Response of the Pressurized Direct Hydrogen System

- In current simulations, dynamic response is determined by the CEM and the integral controller.
- Extended period of stack operation at very low current densities over FUDS cycle.
Temperature Response Over the FUDS Cycle

- Cold start at 300 K
  - Condenser and radiator fans remain off over one FUDS cycle
- Warm start at 300 K
  - Radiator fan remains off at low power
  - Condenser fan cycles off and on
Dynamic Efficiency on FUDS Cycle

- Beside ambient temperature, pressure, and load, dynamic efficiency depends on the control algorithm and the state of the FC system.
Current and Future Work

- Model validation with data from Nuvera system
- Ambient pressure direct hydrogen systems
- Direct hydrogen systems with physical / chemical hydride hydrogen storage
- Reformed liquid fuel systems on drive cycles
- Fast-start and load-following fuel processors
- High temperature membrane systems
- Alternative system configurations
- Detailed component models

- Interactions with A.D. Little, Nuvera, others