Fuel Cell
Mobile Electric Power

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Agenda

- Overview of fuel cell technology
- DARPA / Army Mobile Electric Power Program
- Mobile fuel cell system power conditioning
Fuel Cell Operating Principal

Oxidant - Air

<table>
<thead>
<tr>
<th>Cathode</th>
<th>Electrolyte</th>
<th>Anode</th>
</tr>
</thead>
</table>

Fuel

DC Electric output

External Load

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Fuel Cell Development Expenditures

- Planar SOFC: Intermediate Development
- Tubular SOFC: Advanced Development
- PEM/MCFC: Demonstration
- PAFC: Early Commercial

Time

$
# Attributes of Fuel Cells

<table>
<thead>
<tr>
<th></th>
<th>AFC</th>
<th>PAFC</th>
<th>PEMFC</th>
<th>MCFC</th>
<th>SOFC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrolyte</strong></td>
<td>KOH</td>
<td>Phosphoric Acid</td>
<td>Sulfonic Acid Polymer</td>
<td>Molten Carbonate Salt</td>
<td>Yittria stabilized Zirconia</td>
</tr>
<tr>
<td><strong>Temperature</strong></td>
<td>100°C</td>
<td>200°C</td>
<td>100°C</td>
<td>650°C</td>
<td>850°C</td>
</tr>
<tr>
<td><strong>Fuel</strong></td>
<td>H₂</td>
<td>H₂</td>
<td>H₂</td>
<td>H₂/CO</td>
<td>H₂/CO</td>
</tr>
<tr>
<td><strong>FC Efficiency (H₂ fuel)</strong></td>
<td>60%</td>
<td>55%</td>
<td>60%</td>
<td>55%</td>
<td>55%</td>
</tr>
<tr>
<td><strong>Power Density</strong></td>
<td>&lt;5 kW/ft³</td>
<td>~3 kW/ft³</td>
<td>~40 kW/ft³</td>
<td>&lt;5 kW/ft³</td>
<td>~30 kW/ft³</td>
</tr>
<tr>
<td><strong>Cell Life</strong></td>
<td>5 yrs</td>
<td>5 yrs</td>
<td>5 yrs</td>
<td>3 yrs</td>
<td>5 yrs</td>
</tr>
<tr>
<td><strong>Start-up</strong></td>
<td>Fast</td>
<td>Moderate</td>
<td>Fast</td>
<td>Moderate</td>
<td>Slow</td>
</tr>
</tbody>
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 MEP Generator Program
MEP Program Description

- Four-year program sponsored by DARPA and U.S. Army Research Office

- Application
  - 10 kWe mobile generator for Army Lightweight Multipurpose Shelter

- Key project elements
  - Compact, lightweight system for mobile applications
  - Fuel processor development (JP-8, DF-2)
  - Power system integration with SOFCs
  - Demonstration of 5 - 10 kW SOFC power system
DARPA / Army MEP
Generator
Program to demonstrate a multi-kWe planar SOFC mobile electric power generator using DOD logistics fuel

- Phase 1: Developed preliminary system design based on steam reforming (complete)
- Phase 2: Demonstrated logistics-fueled SOFC MEP breadboard system (complete)
- Phase 3: Demonstrate a multi-kW integrated SOFC MEP generator. Design a prototype 10 kW SOFC generator (in-progress)
MEP System Test Facility

Purpose:
- Long-term integrated system testing
- Prototype product development

B&W Research Center, Alliance, Ohio
SOFCo Patented CPn Design

- Staged oxidation provides enhanced electrical efficiency
- New manifold design provides improved fuel utilization
- kW-Class stack demonstrations
Multi-Thousand Hour Stack Endurance Demonstrated

Voltage/cell, V

Time, Hrs

0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9

0 1000 2000 3000 4000 5000 6000 7000 8000

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Stack Performance

Stack Performance doubled in the last year

Volts/Cell, V

Temperature: 850°C
Electrolyte: 170 µm

Current Density, A/cm²

Jan. 96
Apr. 97

1.38 ohm-cm²
10x10 cm
800°C

3.06 ohm-cm²

1.68 ohm-cm²

2.27 ohm-cm²

1.34 ohm-cm²

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MEP Accomplishments

- **Phase 1**  
  Developed layout for Army MEP, (complete)  
  Demonstrated bench-scale sulfur-tolerant steam reforming

- **Phase 2**  
  Demonstrated integrated system of (complete)  
  JP-8 fuel processor and fuel cells,

  Demonstrated conversion of JP-8 to hydrogen-rich gas for 400 hrs using compact 10 kWe partial oxidation fuel processor.
MEP Phase 3

- Technology Readiness Demonstration (9/97)
  - Continuous operation of 10 kWe JP-8 fuel processor for 100+ hrs
  - >100 hr operation with on-line maintenance
  - Fuel conversion efficiency of 75% (HHV)

- Multi-kW Generator Demonstration (Aug ‘98)
  - Net system efficiency >30%
  - Transient and load following operation
Mobile fuel cell system power conditioning

- **DC/AC Conversion**
  - Army application requires
    - 10 kW AC at 0.8 power factor
    - 60 Hz AC at 120 V 1-Phase and 240 V 1-Phase, 3-wire
  - Fuel cell module configured for 50 VDC

- **Dual Fuel Cell/Battery Source**
  - Start-up, Back-up
  - Peaking service
Mobile fuel cell system power conditioning (Cont)

Electrical loads
- Motors, Generators, Motor drives
- Actuators/Actuator drives
- Energy storage
Mobile fuel cell system power conditioning (Cont)

- Steady-state electric output
  - Frequency variation:
    - 2% bandwidth over 30 sec, 3% over 4 hour

- Voltage variation under load
  - Less than 2% over 30 sec, 3% over 4 hr

- Waveform deviation factor
  - Less than 6%

- Individual harmonic deviation factor
  - Less than 3%
Mobile fuel cell system
power conditioning

(Cont)

- Transient electric output
  - Recovery from application of rated load
    - Less than 20% reduction in voltage
    - Less than 3% reduction in desired frequency
    - Less than 3 seconds
  - Recovery from rejection of rated load
  - Application of motor load
    - Less than 35% decrease in voltage
    - Less than 5 seconds
Mobile fuel cell system power conditioning (Cont)

- **Physical**
  - Volume - 10 kW/ ft³
  - Weight - 0.5 kW/ lb

- **Environment**
  - Thermal
  - Shock
Fuel Cell/ PEBB Demonstration

Fuel Cell DC Supply

PEBB Demonstrator

60Hz Inverter
400 Hz Inverter

60Hz Motor Controller
400Hz Motor Controller
DC Motor Controller
3 Phase Rotary Actuator
Single Phase Linear Actuator

DC to DC Buck Converter
DC to DC Boost Converter

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