Stationary & Transportation Fuel Cell Applications

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What Are Fuel Cells?

• Fuel cells produce electricity through electrochemical reactions
• Converts chemical energy of reactants (fuel and oxidizer)
• Similar to batteries but are continuously supplied fuel and oxidizer
• Unlike thermal generators (steam power plants, engine/generators, and gas turbines)
• Low voltage direct current electricity
• Nearly zero air emissions
Fuel Cell History

• Natural Fuel Cells
  – Electric Fish
  – Galvanic Corrosion
• Gaseous Voltaic Battery Sir William Grove, 1839
• Fused Salt Electrolyte, A.C. Becquerel, 1855
• Hydrogen/Oxygen Fuel Cell, Francis T. Bacon, 1932
  – Alkaline Electrolyte
  – 5 kW System Developed, 1959
• 750 W FC for Underwater Vessel, Allis-Chalmers 1959-1963
• Space Programs, 1960 - today
Fuel Cell Stack Construction

- Fuel cell stacks made of many individual cells.
- Each cell consists of
  - cathode
  - electrolyte
  - anode
  - separator plate
- Thermal, electrical, chemical & mechanical tolerances
Fuel Cell Power Plant Systems
General Configuration

Fuel Processing Unit

CO₂

H₂ Rich

Fuel Cell Stack

Air

O₂

H₂O

DC Power

Natural Gas
Methanol
Town Gas
Biogas
Off-Gas

Electrical Load

AC Power

Power Conditioning
# Fuel Cell Types & Performance

<table>
<thead>
<tr>
<th>Type</th>
<th>Electrolyte</th>
<th>Operating Temperature</th>
<th>Electric Efficiency (LHV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkaline Fuel Cell (AFC)</td>
<td>Potassium Hydroxide</td>
<td>65°C - 220°C</td>
<td>70% (Pure H2)</td>
</tr>
<tr>
<td>Proton Exchange Membrane Fuel Cell (PEM)</td>
<td>Sulphonated Solid Fluoropolymer</td>
<td>80°C</td>
<td>40%</td>
</tr>
<tr>
<td>Phosphoric Acid Fuel Cell (PAFC)</td>
<td>Phosphoric Acid</td>
<td>205°C</td>
<td>40%</td>
</tr>
<tr>
<td>Molten Carbonate (MCFC)</td>
<td>Molten Alkali Carbonate</td>
<td>650°C</td>
<td>50%</td>
</tr>
<tr>
<td>Solid Oxide Fuel Cell (SOFC)</td>
<td>Zirconia-Based Ceramics</td>
<td>800-1000°C now, 600-1000°C in 10 years</td>
<td>60% (Hybrid)</td>
</tr>
</tbody>
</table>
Fuel Cell Applications

- Remote Generation Applications
- Power Quality, Reliability, UPS and Telecom
- Military Power Applications
- Rural Residential Generation
- Load-Following Residential Generation
- Baseloaded Residential Generation
- Commercial & Light Industrial Cogeneration
- Large Stationary Generation
- Automotive Engine

Price ($/kW)

Market Demand (kW)

- PORTABLE
- STATIONARY
- TRANSPORTATION

- $1,000 - $1,500/kW
- $1,000 - $10,000/kW
- $800 - $1,000/kW
- $600/kW
- $50/kW

Source: PlugPower w/ Modifications by AESC, Inc.
Fuel Cell Applications

STATIONARY

TRANSPORTATION
Stationary Fuel Cell Applications

- Small residential or micro-application PEM fuel cells
  - 1 kW -> 5 kW
  - Natural gas, propane, town gas
- Commercial combine heat and power (CHP) PAFC and MCFC
  - 50 kW -> 500 kW
- Industrial CHP PAFC, MCFC & SOFC
  - 200 kW -> +1 MW
- Distributed utility PAFC, MCFC & SOFC
Residential Applications

* Simple Cycle 1-5 kW Load Following
* Natural Gas, Propane, Town Gas
* Waste Heat Utilization
Commercial/Industrial CHP

* 50 - 500 kW Base Load or Load Following
* Natural Gas, Propane, Town Gas
* Space Heating/Cooling, DHW, Process Heating
Distributed Utility Applications

- DU is the deployment & coordinated operation of small onsite & “in-grid” generators, with load management.
- 50 kW - 10 MW fuel cell power plants
- Conventional & renewable fuels (land-fill gas, off-gas, digester gas)
Distributed Utility Fuel Cells

- 300 kW Hybrid SOFC
  Source: SiemensWestinghouse

- 3 MW Molten Carbonate Fuel Cell
  Source: FuelCell Energy
Transportation Fuel Cell Applications

- PEM fuel cells are primary technology under development for vehicle power.
- Bus & personal vehicle applications are targeted.
- Compressed H₂, ethanol & methanol.
- Fuel cell power plant cost goals more aggressive than stationary (US$50/kW vs US$1,000/kW)
- Power plant life shorter than stationary (5,000 hrs vs 40,000 hrs).
Fuel Cell Bus Applications
Fuel Cell Bus Drive System

Fuel Cell 115 kW → FC Accessories 15 kW → Bus Accessories 20 kW → Bus AC 17 kW
DC to DC Converter → Motor 185 kW → Motor Controller → Battery 550-650 V

XCELL SiS 100 kW Methanol-Fueled PEMFC Bus Engine Efficiency

Net Efficiency (%) vs. Net Power Output (kW)

Based on LHV of methanol and with FCS accessories included.
Personal Fuel Cell Vehicles
Fuel Cell Vehicle Drive Train

- Critical Operating Parameters
  - Time to startup/warm-up
  - Miles between fueling
  - Acceleration
  - Miles between maintenance
  - Maintainability
Why Fuel Cells?

• Fuel cell electric generation is clean, no or little air emissions.

• Fuel cells are efficient. They are not limited by Carnot theoretical efficiency.
Fuel Cell Challenges to Commercialization

• COST
  – Fuel cell power plant capital cost currently too high.
  – Requires higher power density systems.

• COMPLEXITY
  – Fuel cell power plants are complex & require specialized maintenance.

• FUEL PROCESSING
  – Reforming of natural gas & other “simple” hydrocarbons commercial.
  – On-board reforming for transportation adds complexity & cost.
  – Direct hydrogen fuel cells require H₂ storage & infrastructure.
Key Concurrent Events

• Advances in transportation fuel cells will accelerate stationary applications.

• Stationary applications will deploy commercially before transportation.

• Recent developments in hydrogen storage (sodium borohydride & nanotubes) could provide “break-limit” for transportation.