Advances in Materials and System Technology for Portable Fuel Cells

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Desirable Characteristics:
• Long operating times (always “ON”)
• Zero Recharge time (always “Ready”)
• Lightweight (high energy density, >120 Wh/kg)
• “Zero Worry” logistics (battery replacement, inventory, recharging)
Technology Solution

- Li-Ion rechargeable battery: 150 Wh/kg

High Energy Fuels:
- Methanol, 6000 Wh/kg
- Hydrogen, 32000 Wh/kg

Fuel Cell Technology:
- High-efficiency direct conversion of chemical energy to electrical energy in fuel cells
  - Not limited by Carnot efficiency
- Products are non-polluting; CO₂ and water
Portable Hydrogen Systems

Gaseous Hydrogen Storage (2%) 1998

Sodium Borohydride Storage (2-3%) 2005

Indirect Methanol Based (5-6%) 2006

- Ballard 50 W: 200 Wh/kg
- Protonex 50 W: 300 Wh/kg
- Ultracell 25W: 330 Wh/kg
Direct Methanol Fuel Cell

- High Energy Liquid Fuel
- Simple System
- Starts up instantly

Cell Reaction
\[
\text{CH}_3\text{OH} + \frac{3}{2} \text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}
\]
Overview of DMFC R&D at JPL

Liquid Feed DMFC
With Polymer Electrolyte

Catalysts, MEA and Performance Improvements
Membranes with reduced crossover (in collaboration with USC)

1-1000 W Stack Demonstrations
Novel Stack concepts

System Design and Demonstrations of overall system concept, stack designs
New materials

- 220 mW/cm² @90°C
- 75 mW/cm² 0 psig, 60°C
- 30 mW/cm² 25°C

- Large Membrane
- PSSA-PVDF IPN membrane
- 80 cm² MEA

High Pressure 120 Watt Stack (94)
Basic concept 120 Watt Stack (94)
220 mW/cm²
0 psig, low flow
60°C
Free Convection
300-Watt Portable Fuel Cell for Army Applications

High Specific Energy Solution >600 Wh/kg for DoD
Scalable from 50 Watts – 1kW
DMFC units from Smart Fuel Cell Inc, Germany

Use: for charging Pb-Acid Batteries

Dimensions: 13 x 15 x 26 cm

Mass: 8 kg

Nominal Power Output: 50 Watts

Specific energy based on methanol fuel: 960 Wh/kg
## DMFC Status and Prospects

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Status</th>
<th>Target</th>
<th>Benefit</th>
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</thead>
<tbody>
<tr>
<td><strong>Performance</strong></td>
<td></td>
<td></td>
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<tr>
<td><strong>Power Density</strong></td>
<td>20 W/kg, 15-20%</td>
<td>100 W/kg 30-35%</td>
<td>Light-weight Compact, high-energy density</td>
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<td><strong>Efficiency</strong></td>
<td></td>
<td></td>
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<tr>
<td><strong>Durability</strong></td>
<td>100-500 hours</td>
<td>5000 hours</td>
<td>Meeting lifetime requirements</td>
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<tr>
<td><strong>Cost</strong></td>
<td>$15000/kW</td>
<td>$1000/kW</td>
<td>Increased market potential Reduction in life cycle costs</td>
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Challenges

- Electrocatalytic oxidation kinetics
- Polymer Electrolyte Membrane
- Lightweight System Design
- Durability
- Cost reduction

Processes in a Direct Methanol Fuel Cell

- CO$_2$ rejection
- Proton Diffusion
- Oxygen Transport
- Water Rejection
- Methanol Transport
- Methanol permeation
- Catalyst layer
- Electrolyte membrane

Diagram showing components such as Air blower, CO$_2$ vapor cooler, methanol sensor, Gas separator, Air in, Air out, Air/water return, pure methanol, feed pump, circulation pump, cold-start heater, stack, sump pump, and vent.
Rapid Screening of Well-Controlled Catalyst Compositions

Multi-Electrode Array Screening

- 60 °C, 5 mV/Sec, in 1 M sulfuric/methanol
- Multiple cycles collected until equilibrium reached
- All current densities normalized to electrode area

Potentiostatic: Cells held at 0.45 V vs.RHE after 300 seconds

- Smooth profile relating performance to composition
  - Indicative of solid solution,
  - No oxides or phase separation to provide “spikes”
- Significant performance differential at elevated temperature
Screening of Ni-Zr-Pt-Ru alloys

Potentiostatic Data:
0.45 vs. NHE after 300 seconds

Ni(31)Zr(13)Pt(33)Ru(23) is similar in activity to the best Pt-Ru catalyst
Issues with New Membranes

- Compromise of proton conductivity to lower methanol permeability
- Poor mechanical properties in dry state
- Poor membrane-electrode interface properties
- Modest reduction in crossover rate
Membranes With Reduced Methanol Crossover

PSSA-PVDF Membrane

CH\(_3\)OH + \(\frac{3}{2}\)O\(_2\) → CO\(_2\) + 2H\(_2\)O

Challenges:

- Compromise of proton conductivity to lower methanol permeability
- Poor mechanical properties in dry state
- Poor membrane-electrode interface properties
- Modest reduction in crossover rate

- Reduces Methanol crossover by 75%
- Inexpensive Membrane Material
- Demonstrated in 80 cm\(^2\) stack

Temperature = 55 °C
0.50 M CH\(_3\)OH
0.10 L/min Air
Stacks

Bipolar Designs

- JPL 80-cell 300 Watt
- Ambient Pressure 1.4 kW (01)
- 1.4 kW by Giner Inc. for JPL.

Monopolar Designs

- Lightweight stack operating on natural convection at 50 W/kg at 30°C, 120W/kg at 60°C

Stack power density is 55-80 W/kg for operation at 55°C-60°C

Stack power density can be enhanced to 120-150 W/kg
Watts/kg can be significantly improved by hybridizing with batteries.
Small Compact Systems

- Controlled delivery of concentrated Methanol
- Relying on Back Diffusion to Supply Water
- Forced Convection at Low Back Pressure
- Higher Power Density of Stack (Anode catalysts)
- Membranes with low methanol crossover for catalyst loading reduction
- Integration with High Power Batteries for Load Management
Durability

- Improve inherent instability of catalysts (DuPont MEA, ~2000 hours)
- Prevent loss of hydrophobicity of the cathode
- Accumulation of impurities in the liquid stream
- Reliability of components (pumps, valves)
Stack and System Parameters for Various Applications

- Current DMFC
- 25 Watt, 1 kg Portable Power Pack
- 2 W, 50g Cellular Phone Power Source
- 1 W, 50g Cellphone Pack
- 100 mW/50g Battery Charger
- 100 W, 6 kg Soldier Power Source
- 100 W, 10 kg Power Source
Acknowledgements


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