Micro Fuel Cells Potential

- Longer Duration for equivalent weight & volume → *Energy Density*
- Instant Charge
- Flat Discharge
- Low Self-Discharge
- Little Short-circuit protection required
- Cost Competitive (US$ 2-5 / Watt)
Samsung’s View

- DMFC Focus
- Moving from Conventional to MEMS technology

![Diagram showing portable power, notebook PC, 4G mobile device, and ubiquitous computing over time from 2002 to 2010 with fuel cell types and performance metrics]

Source: Samsung Advanced Institute of Technology

Development Activities

- ~ 100 companies active in the area (primarily stack focussed)
- Companies cluster according to system architecture and fuel choice
- Fuel Axis:
  - Methanol
  - Hydrogen
- Architecture Axis:
  - Miniaturized
  - Conventional
  - Novel
  - Microfabricated
The Motivation for Methanol

Table 6.1  Energy density comparison for methanol and the most important hydrogen storage technologies. Estimated mass of the reformer is included in the case of indirect methanol, where it is chemically reacted to produce H₂ in the ways outlined in Chapter 8

<table>
<thead>
<tr>
<th>Storage method</th>
<th>Energy density of fuel</th>
<th>Storage efficiency (%)</th>
<th>Net energy density</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂ at 300 bar pressure in composite cylinders</td>
<td>119.9 MJ kg⁻¹</td>
<td>0.6</td>
<td>0.72 MJ kg⁻¹</td>
</tr>
<tr>
<td>H₂ in metal hydride cylinders</td>
<td>33.3 kWh kg⁻¹</td>
<td>0.65</td>
<td>0.20 kWh kg⁻¹</td>
</tr>
<tr>
<td>H₂ from methanol – indirect methanol</td>
<td>33.3 kWh kg⁻¹</td>
<td>6.9</td>
<td>8.27 MJ kg⁻¹</td>
</tr>
<tr>
<td>Methanol in strong plastic tanks for direct use as fuel</td>
<td>19.9 MJ kg⁻¹</td>
<td>95</td>
<td>18.9 MJ kg⁻¹</td>
</tr>
<tr>
<td>Methanol in strong plastic tanks for direct use as fuel</td>
<td>5.54 kWh kg⁻¹</td>
<td></td>
<td>5.26 kWh kg⁻¹</td>
</tr>
</tbody>
</table>
DMFC -- PEMFC

- Anode Reaction
  \[ \text{CH}_3\text{OH} + \text{H}_2\text{O} \rightarrow 6\text{H}^+ + 6\text{e}^- + \text{CO}_2 \]

- Cathode Reaction
  \[ 1.5\text{O}_2 + 6\text{H}^+ + 6\text{e}^- \rightarrow 3\text{H}_2\text{O} \]

- 6 electrons/molecule of MeOH

\[
E = \frac{-\frac{\Delta_r g}{nF}}{\frac{10^3}{6F}} = 1.21\text{V}
\]
Stages Oxidation of Methanol

Anode Reaction
\[ \text{CH}_3\text{OH} + \text{H}_2\text{O} \rightarrow 6\text{H}^+ + 6\text{e}^- + \text{CO}_2 \]

Catalysis

- None of these reactions occur as readily as Hydrogen oxidation
  - Considerable activation overpotential at the Anode and Cathode (Oxygen reduction)
- Anode uses bimetal catalyst
  - Platinum, Ruthenium (usually 50/50 mix)
- Cathode uses Pt, as with H\textsubscript{2} Cell
Catalysis, contd.

- Catalyst loadings tend to be much greater than with $H_2$ cells, (up to 10 times the catalyst)
  - To reduce anode overpotential
  - Higher costs acceptable (consider batteries)
  - Helps with cross-over

DMFC — PEMFC

- Anode Reaction
  \[
  \text{CH}_3\text{OH} + \text{H}_2\text{O} \rightarrow 6\text{H}^+ + 6\text{e}^- + \text{CO}_2
  \]

- Cathode Reaction
  \[
  1.5\text{O}_2 + 6\text{H}^+ + 6\text{e}^- \rightarrow 3\text{H}_2\text{O}
  \]

- Water is consumed at the Anode, and produced more quickly at the Cathode

- **Pure MeOH cannot be used as a fuel**
  - DMFC Water Management issues
The OCV of a DMFC is considerably lower than a Hydrogen Cell, due to Fuel Cross-Over.
Cross-Over Continued

- Methanol mixes very readily with water
- Water is necessary for ionic conductivity (Nafion electrolyte)
- This methanol will react at the Cathode (Pt catalyst) → mixed potential, higher losses
- Fuel Utilization,
  \[ \eta_f = \frac{i}{i + i_c} \]
  - \( i_c \), cross-over current, current that would have been produced without cross-over

Cross-Over Contd.

\( \eta_f \) can be as high as 0.85 with proper management
- Make the anode catalyst as active as possible (if all the fuel reacts it cannot cross-over)
- Control the MeOH supply (low current → low supply) Optimal concentration at Anode
- Use thicker electrolytes (150-200μm)
Commercial Technology Map
(source: Ged McLean-Angstrom Power)

Conventional Architecture

Motorola, Fraunhofer, Ball

Japanese Electronics Manufacturers

MeOH H2

Polyfuel

Manhattan

Medis

Neah

Smart FC

Novel Architecture

Palcan, Jadoo, Novars
Lyntech, Masterflex

Microcell, IFCT, Universities

Air-Breathing Fuel Cells

• No oxidant distribution channels.
• No external humidification system.
• No cooling system.
• No hydrogen conditioning.
• No bipolar plates.
Air-breathing DMFC

3% wt MeOH


Power and Energy Density

Typical portable computer
Rechargeable Li-ion battery
1-W average power DMFC
1-W average power DMFC
5-W average power DMFC

50 x 70 x 14mm

Other DMFC Systems

Smart Fuel Cell

MTI Micro

Air-Breathing Hydrogen PEMFCs

cathode plate
assembled cell
anode plate

anode plate with attached MEA
diffusion layer

C. Hebling, Fraunhofer ISE
Nov. 6 2007

Performance of air-breathing DMFC

University of Victoria
Department of Mechanical Engineering

Performance of air-breathing PEMFC

University of Victoria
Department of Mechanical Engineering
Performance of air-breathing PEMFC

Nov. 6 2007

University of Victoria
Department of Mechanical Engineering
IES Vic
Fuel Cell Topology

- Conventional Fuel Cell consists of 8 parallel layers:
  1. Fuel Flowfield
  2. Gas Diffusion
  3. Catalyst
  4. Electrolyte
  5. Catalyst
  6. Gas Diffusion
  7. Oxidant Flowfield
  8. Separator + Seals
Membrane Penetrating Designs

- Manhatten Scientifics porous filled electrolyte with planar fuel cells
- Fraunhofer Banded F.C.

Cell Interconnect is very difficult. Not conducive to microfabrication.

Continuous Membrane Designs

- Avoid penetrating electrolyte or assembling multiple electrolyte sheets
- Motorola planar design uses edge tabs to provide series connection of cells.
Flip Flop Stack (Stanford)

Problems with Planar Designs

- Plates and explicit seals still persist
- All these designs are edge collected, severely limits flexibility of design
- Generally these designs increase the complexity of the supporting hardware rather than decreasing it.
Angstrom Micro-structured Unit Cell

Air → 0.5O₂ → H₂O

Gas Diffusion Layer → H₂ → Catalyst Layer

H₂ → e⁻

Circulating Ambient Air

Dry H₂ Gas

P

B

H

University of Victoria
Department of Mechanical Engineering
IES Vic
Increased Power Density

Planar Fuel Cell

Active Area

Membrane

Microstructured Fuel Cell

Active Area

Equivalent Active Area

HIGHER POWER DENSITY or a SMALLER FUEL CELL

Effect of GDL Width

Planar Area and Thickness constrained to that of the planar fuel cell. Volume is also constrained by those parameters.

<table>
<thead>
<tr>
<th>GDL Width</th>
<th>Number of Cells</th>
<th>Ratio of Active Area to Planar Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 µm</td>
<td>29</td>
<td>1.765</td>
</tr>
<tr>
<td>150 µm</td>
<td>23</td>
<td>1.364</td>
</tr>
<tr>
<td>200 µm</td>
<td>19</td>
<td>1.111</td>
</tr>
<tr>
<td>230 µm</td>
<td>16</td>
<td>1.000</td>
</tr>
</tbody>
</table>
Active Area Polarization Curves

For same active area, better performance with microstructured fuel cell due to better humidification.

Performance drops with thinner GDLs due to higher volumetric heating that reduces humidity.

Relative Humidity

Variation in relative humidity due to the diffusion of product water vapor.

Relative humidity contours have shifted downward.
Local Polarization Curves

- High humidity and membrane conductivity.
- Low humidity and membrane dry-out.

Planar Area Polarization Curves

- Increased efficiency: Higher voltages for same power density.
- Increased maximum power densities.
- Performance improves over entire polarization curve as the GDL gets thinner.
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**Temperature vs. Power Density**

- **Planar**
- $W_{GDL} = 100 \, \mu m$
- $W_{GDL} = 150 \, \mu m$
- $W_{GDL} = 200 \, \mu m$
- $W_{GDL} = 230 \, \mu m$

**7K Drop in Temperature**

Max power density of the planar fuel cell.

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**Relative Humidity vs. Temperature**

**Microstructured fuel cell insulates humidity with the high aspect ratio GDL.**
Non-Planar Microstructured Fuel Cells

Advantages:
- Increased active area.
- Higher maximum power density.
- Higher efficiency.
- Reduced operating temperatures.

Note:
- Performance improves with thinner GDLs.
- GDL width reduction is limited by oxygen mass transfer, flooding, and manufacturability.
Integrated Fuel / Tubular Designs

Micro Solid Oxide Fuel Cell

<table>
<thead>
<tr>
<th>Diameter (mm)</th>
<th>Surface Area of the Stack (m²/litre)</th>
<th>Estimated Power (W/lit) (VPD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 (2,000μm)</td>
<td>0.82</td>
<td>2,050</td>
</tr>
<tr>
<td>1 (1,000μm)</td>
<td>1.64</td>
<td>4,100</td>
</tr>
<tr>
<td>0.5 (500μm)</td>
<td>3.28</td>
<td>8,200</td>
</tr>
</tbody>
</table>

Partho Sarkar
Alberta Research Council
μSOFC Single Cells

Micro-fuel Cells: Some Issue

- Gas Permeability
- Crossover
- Reactant Distribution
- Mechanical properties
- Durability
- Refuelling
Diverse System Alternatives

1. DMFC with on-board mixing
2. Passive DMFC
3. Methanol Reformer w/ PEMFC
4. Methanol Reformer w/SOFC
5. SOFC
6. Hydrogen with Hydride Storage
7. Other Fuel (ethanol, ammonia)
8. Biological (enzyme electrolyte)

Micro Fuel Cells & The Environment

- Small/negligible GHG emission reductions and environmental premium?
- For applications >300W the fuel cell competes with small IC engines: more significant impact
- Battery recycling is effective
- Why micro-FCs then?