MID CAREER COLLEGE
AN INTRODUCTION TO FUEL CELLS
1 - Fuel cell generator stack
2 - Hot water storage tank
3 - Heat exchanger & burner
4 - Fuel / air pre-treatment
5 - Waste heat recovery
6 - Mains power converter & controls
A SIMPLE FUEL CELL

Combines hydrogen and oxygen in a chemical reaction producing water and releasing energy

Hydrogen IN → anode → electrolyte → cathode → Oxygen IN

Water OUT

flow field

H+
Hydrogen fuel

Anode: $2H_2 \rightarrow 4H^+ + 4e^-$

Cathode: $O_2 + 4e^- + 4H^+ \rightarrow 2H_2O$

H$^+$ ions through electrolyte

Oxygen, usually from the air

Load e.g. electric motor

Electrons flow around the external circuit
PEM fuel cell electrode
Interdigitated Flow Geometry

- Inlet and outlet channel systems are discontinuous
- Reactant is forced to flow through the GDL
- Water is purged from the GDL
- Geometry leads to high back-pressures
Water will be produced within the cathode.

Water will be dragged from the anode to the cathode sides by protons moving through the electrolyte.

Water may back-diffuse from the cathode to the anode, if the cathode side holds more water.

Water may be supplied by externally humidifying the hydrogen supply.

Water may be supplied by externally humidifying the air supply.

Water will be removed by evaporation into the air circulating over the cathode.
Figure 4.2  Structure of polyethylene.

Figure 4.3  Structure of PTFE.
Water collects around the clusters of hydrophilic sulphonate side chains.
Hydrogen fed along these vertical channels over the anodes

Positive connection

Negative connection

Air or oxygen fed over the cathodes through these channels
A fuel cell stack is a series of cells stacked together. Depending on the number and size of cells, a stack can produce from watts to megawatts of power.
A FUEL CELL SYSTEM

- DATA DISPLAY
- POWER CONVERSION
- CONTROL COMPUTER AND ELECTRONICS
- GAS CONTROL VALVE
- BATTERY PACK
- HEAT EXCHANGER
- FUEL CELL STACK
- GAS SHUT-OFF VALVE
- FUEL PURIFIER
- GAS SHUT-OFF VALVE
- AIR BLOWERS
<table>
<thead>
<tr>
<th>Application of fuel cell types</th>
<th>Range of POWER in Watts</th>
<th>Main advantages</th>
<th>Typical applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMFC</td>
<td>1</td>
<td>Higher energy density, Zero emissions, Faster recharging</td>
<td>Portable electronics and domestic generation, CHP also buses, CHP</td>
</tr>
<tr>
<td>PEMFC</td>
<td>10</td>
<td>Higher efficiency, Higher efficiency</td>
<td>Cars, boats, Distributed power generation, CHP</td>
</tr>
<tr>
<td>AFC</td>
<td>100</td>
<td>quieter</td>
<td></td>
</tr>
<tr>
<td>SOFC</td>
<td>1k</td>
<td>Less pollution, Higher efficiency</td>
<td></td>
</tr>
<tr>
<td>PAFC</td>
<td>10k</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MCFC</td>
<td>100k</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1M</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10M</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CH$_3$OH $\rightarrow$ CH$_2$O + 2H$^+$ + 2e$^-$  

The methanal then reacts to form methanoic (formic) acid via another ‘right’ and another ‘down’ step:

CH$_2$O + H$_2$O $\rightarrow$ HCOOH + 2H$^+$ + 2e$^-$

Finally, via another ‘one step right, one step down’ in Figure 6.2, the formic acid is oxidised to carbon dioxide:

HCOOH $\rightarrow$ CO$_2$ + 2H$^+$ + 2e$^-$
Performance to be expected from a good hydrogen-fuelled PEMFC

Typical performance from a good direct methanol single cell

Power = 60 mW cm$^{-2}$
Carbon monoxide fuel

Anode: $2CO + 2CO_3^{2-} \rightarrow 4CO_2 + 4e^-$

$CO_3^{2-}$ ions through electrolyte

Cathode: $O_2 + 2CO_2 + 4e^- \rightarrow 2CO_3^{2-}$

Oxygen and carbon dioxide

Electrons flow round the external circuit

Load e.g. electric motor
Hydrogen fuel

Anode: $2H_2 + 2O^=} \rightarrow 2H_2O + 4e^-

Product water as steam, available for steam reformation of fuel

Cathode: $O_2 + 4e^- \rightarrow 2O^=

Oxygen, usually from the air

Carbon monoxide fuel

Anode: $2CO + 2O^=} \rightarrow 2CO_2 + 4e^-

Oxygen, usually from the air

Cathode: $O_2 + 4e^- \rightarrow 2O^=

Electrons flow round the external circuit
Siemens-Westinghouse Tubular

- 8YSZ electrolyte by EVD
- LCCr interconnect by plasma spray
- Porous LSM extruded and sintered support tube
- Ni slurry coat followed by EVD YSZ

- 2.2 cm diameter
- 150 cm active length
- one closed end
- operating temperature 1000°C
- 210 W per tube at 85% fuel utilization
- 0.35 W cm⁻² at 0.7 V and 0.5 A cm⁻²
- ASR = 0.4 ohm cm⁻²
Planar SOFC

Advantages
- Higher volumetric power density
- Simpler manufacture—cheap

Disadvantages
- Edge sealing and manifolds
- Current collection
- Assembly tolerances
WHERE WILL THE HYDROGEN COME FROM?

- Fossil fuel
- Renewable energy
- Nuclear power
- Biological methods
- Reforming
- Electrolysis
Figure 8.24 Schematic representation of different types of carbon nanofibres: (a) graphitic platelets, (b) graphitic ribbons, (c) graphitic herringbone, (d) single-walled nanotube and (e) multi-walled nanotube.
In recent centuries there has been a trend to use fuels with higher proportions of hydrogen.
**Fuels for Fuel Cells**

Energy contained in fuel (kWh/litre)

- Hydrogen (compressed 350 Bar): 1.0
- Hydrogen (Metal Hydrides): 1.8 - 3.5
- Natural Gas (compressed 250 Bar): 2.5
- Methanol: 4.5
- Propane: 6.8
- Gasoline: 8.8
<table>
<thead>
<tr>
<th>Gas species</th>
<th>PEM fuel cell</th>
<th>AFC</th>
<th>PAFC</th>
<th>MCFC</th>
<th>SOFC</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂</td>
<td>Fuel</td>
<td>Fuel</td>
<td>Fuel</td>
<td>Fuel</td>
<td>Fuel</td>
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<tr>
<td>CO</td>
<td>Poison</td>
<td>Poison</td>
<td>Poison</td>
<td>Fuel</td>
<td>Fuel</td>
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<tr>
<td></td>
<td>(&gt;10 ppm)</td>
<td></td>
<td>(&gt;0.5%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH₄</td>
<td>Diluent</td>
<td>Diluent</td>
<td>Diluent</td>
<td>Diluent</td>
<td>Diluent</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂ and H₂O</td>
<td>Diluent</td>
<td>Poison</td>
<td>Diluent</td>
<td>Diluent</td>
<td>Diluent</td>
</tr>
<tr>
<td>S (as H₂S and COS)</td>
<td>Few studies, to date</td>
<td>Unknown</td>
<td>Poison</td>
<td>Poison</td>
<td>Poison</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(&gt;50 ppm)</td>
<td>(&gt;0.5 ppm)</td>
<td>(&gt;1.0 ppm)</td>
</tr>
</tbody>
</table>

--- The fuel requirements for the principal types of fuel cells
Annual Number of Units and MW installed

Number of Units


Installed MW Per Annun

0 5 10 15 20 25 30

Units  MW

2003 2004 2005 2006 2007