

## Fuel cells: 2. Types of Fuel Cells

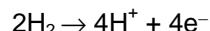
In the previous application note, the principle of a fuel cell was described and some of the problems in their use as viable technology were discussed. To overcome the various technical problems, many different fuel cell types exist (Table 1). In this application note proton exchange membrane, direct methanol and solid oxide fuel cells are discussed in more detail.

### Proton Exchange Membrane (PEMFC)

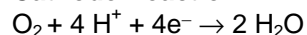
Also known as the Polymer Electrolyte Membrane Fuel Cell, this type of fuel cell consists of a thin plastic sheet (proton conducting membrane or a conducting polymer), such as perfluorosulphonic acid polymer as the electrolyte, sandwiched between two porous electrodes impregnated with highly dispersed metal alloy particles (typically platinum based) that are active catalysts. The back of the electrodes are coated with a hydrophobic compound, such as Teflon, which provides a gas diffusion path to the catalyst layer.

Within the cell, the following electrochemical reactions take place:

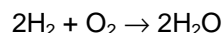
**Anode Reaction:**



**Cathode Reaction:**

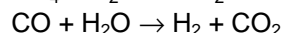
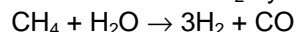


**Overall:**



The protons produced at the anode solvate with water molecules and diffuse through the membrane to the cathode.

PEMFC operates on hydrogen, and if a hydrocarbon such as natural gas is used as a fuel, it is reformed to form  $\text{H}_2$  by the following reactions:



The Pt catalyst at the anode can tolerate only a few ppm of CO at its operating temperature 80°C. To prevent electrode poisoning, the unconverted CO needs to be removed to concentrations below 10ppm before introducing it in the fuel cell.

#### PEMFC system advantages

- Operation at high current densities
- Ability to start very quickly
- Compact and light weight design
- No corrosive fluid spillage hazard as the only liquid present in the cell is water

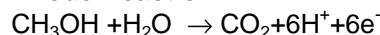
#### PEMFC system challenges

- CO Tolerance of the anode
- Improvement in cathode kinetics
- Need for higher temperature membranes
- Cheaper membranes and membrane electrode assemblies

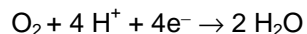
### Direct Methanol (DMFC)

These cells are similar to the PEM cells in that they both use a polymer membrane as the electrolyte. However, in the DMFC, liquid methanol is oxidized to form protons, eliminating the need for a fuel reformer.

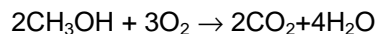
**Anode Reaction:**



**Cathode Reaction:**



**Overall Reaction:**



DMFC can typically operate in a temperature range of 50-100°C, making it attractive for small to mid-sized applications such as cellular phones and laptops.

One of the main problems in the commercial application of the DMFC is slow kinetics of the methanol oxidation reaction resulting in relatively low performance in comparison to hydrogen fuelled PEMFC.

Another problem is that of methanol crossover, the permeation of methanol through the polymer membrane to the cathode where it is oxidized reducing the cathode potential. This occurs because the cathode catalyst, typically Pt, is electro-active to methanol oxidation.

#### Direct Methanol System advantages

- Liquid fuel results in high storage efficiency

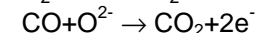
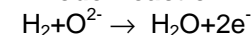
#### Direct Methanol System challenges

- Improvement in methanol oxidation kinetics
- Improvement in cathode kinetics
- Higher temperature membranes with lower crossover

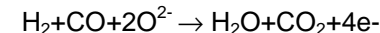
### Solid Oxide (SOFC)

The solid oxide fuel cell or SOFC is used in high-power applications such as large electricity generating stations.

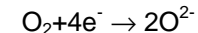
**Anode Reaction:**



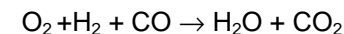
**Combined Anode Reaction:**



**Cathode Reaction:**

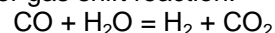


**Overall Reaction:**

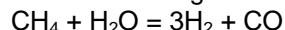


In a SOFC instead of a liquid, a hard ceramic material is used as electrolyte, allowing operating temperatures up to 1000°C. The electrolyte consists of a solid, nonporous metal oxide, typically Y<sub>2</sub>O<sub>3</sub> stabilized ZrO<sub>2</sub> with the anode made from CoZrO<sub>2</sub> or NiZrO<sub>2</sub>, while the cathode is made from Sr doped LaMnO<sub>3</sub>. The cell operates at 650 to 1000°C allowing the conduction of oxygen ions through the electrolyte.

CO and hydrocarbons such as CH<sub>4</sub> can also be used as fuels in an SOFC. Because of the high temperatures within the cell, it is feasible for the water gas shift reaction:



and the steam reforming reaction:



to take place to produce H<sub>2</sub> that is easily oxidized at the anode.

**SOFC advantages**

- The SOFC with its solid state components can in principle be constructed in any configuration
- No liquid electrolyte with its associated corrosion and electrolyte management problems
- Internal reforming can be achieved due to operating temperature greater 600°C
- High temperatures (1000°C) exhaust heat from the SOFC can be used for the generation of steam for cogeneration purposes
- The high temperature is also conducive to fast reaction kinetics without requiring any precious materials

**SOFC system challenges**

- The high temperature of the SOFC places stringent requirements on the materials of construction
- The materials that can be used in the SOFC need to be chemically stable in extreme oxidizing and/or reducing conditions. They also require good thermo-mechanical properties at high temperatures
- The cell components must be capable of withstanding thermal cycling

**Table 1:** Data for some of the important types of fuel cells

Type	Fuel	Charge carrying ion	Operating temperature	Application areas
Alkaline (AFC)	H <sub>2</sub> pure	OH <sup>-</sup>	50 - 200 °C	Space, military
Polymer Electrolyte (PEMFC)	H <sub>2</sub>	H <sup>+</sup>	30 - 100 °C	Mobile and stationary – small to medium power range
Direct Methanol (DMFC)	CH <sub>3</sub> OH	H <sup>+</sup>	20 - 90 °C	Portable electronics
Phosphoric Acid (PAFC)	H <sub>2</sub>	H <sup>+</sup>	220 °C	Stationary–medium power range
Molten Carbonate (MCFC)	CH <sub>4</sub> , H <sub>2</sub> , CO	CO <sub>3</sub> <sup>2-</sup>	650 °C	Stationary–medium power range
Solid Oxide (SOFC)	CH <sub>4</sub> , H <sub>2</sub> , CO	O <sup>2-</sup>	500-1000 °C	Stationary – small to large power range