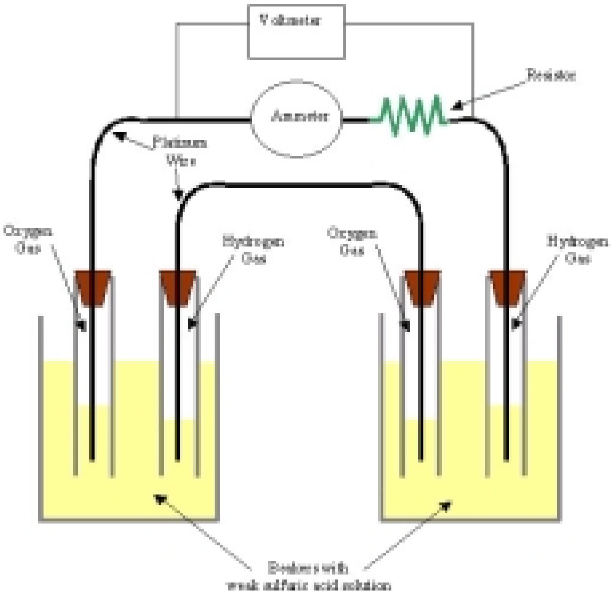
Mech 449-Fuel Cell Technology

Brief Historical Overview of Fuel Cell Technology

The Beginnings

- Volta invents the first electrochemical battery in 1800; almost at the same time, Sir Humphrey Davy makes first attempt to obtain electricity from a fuel. [1]
- In 1839, Sir William Grove discovers that the chemical energy in a fuel can be converted directly into electricity [2]. Three years later, he published his work on a *"gaseous voltaic battery",* i.e. a fuel cell, consisting of a bank of fifty cells [3].



Grove's Experiment

- In 1855. A. C. Becquerel used platinum and carbon electrodes immersed in a molten alt (a nitrate) to produce current [4]
- The late 1800s and early 1900s saw a number of large scale attempts to produce electricity by oxidizing coal and coal gas. Ludwig Mond and his associate Charles Langer, while presenting their work on such a system, coined the term *fuel cell.*
- In 1896, W. W. Jacques published his work on the first fuel cell specifically designed for residential use [5]. This device was based on Becquerel's idea, but used phosphoric acid as the electrolyte.
- Early developments where plagued by unreliability, material problems and short life. Lack of understanding of electrode mechanisms prevented progress.

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[1] Davy, H., Nicholson's Journal, **144** (1802).

[2] Grove, W. R., Phil. Mag., **14**, 127 (1839).

[3] Grove, W. R., Phil. Mag., **21**, 417 (1842).

[4] Becquerel, A. C., Traité d'Electricité, I, Paris (1855).

[5] Jacques, W. W., Harper's Magazine, **94,** 114 (1896).

- Erwin Baur was one of the first to realise the importance of electrode kinetics. In 1921, he built the first molten carbonate fuel cell operating at 1,000°C [6]. The design was quite robust but corrosion and other material problems associated with high temperature operation were showstoppers.

First Successes to Space Applications

- In 1932 Francis T. Bacon developed the first successful (alkaline) fuel cell with porous metal electrodes. By switching to an alkaline electrolyte, he was able to use less expensive nickel catalyzed electrodes. This design was later the basis of the first prototypes developed for the US space program.
- Bacon's contribution went far beyond developing one the first practical FC system: he was also one of the first to explore the parameter space in FC operation. He recognised that at higher temperature and pressure, nickel would be sufficiently active to eliminate the need for additional catalyst. In addition to using porous gas diffusion electrodes to allow increased surface area of three-phase interface, he devised electrodes two layers of different porosities to accommodate differential pressure fluctuations in the cells. By 1959, he built a working 6 kW system that was demonstrated in powering a forklift truck.

Fuel cell development in the 1960s was greatly spurred by the US space program. NASA Recognized the advantages of FCs awarded several research contracts to industry and universities:

- Operation under high g acceleration.
- No moving parts; quiet operation and no vibration
- High thermodynamic efficiencies and energy densities
- Production of potable for astronauts

The first type of fuel cell for space applications was developed by General Electric using a polystyrene electrolyte membrane. These cells were used for auxiliary power in the Gemini program. These were replaced in the Apollo program by the more mature and reliable Alkaline FCs d by Pratt & Whitney. The design power density of these stacks was about 0.014 kW/kg, compared to the 0.275W/kg achieved later for the 7kW stacks of the space shuttle.

4.3 Further Developments

- 1960s: Dow develops Nafion membrane (perfluorinated sulfonic acid polymer)
- 1970: Kordesh builds and operates hybrid AFC-battery car
- 1970s: R&D focus on PAFCs
- 1980s: R&D focus on MCFCs and later SOFCs
- 1990s: High power densities achieved in PEMFCs

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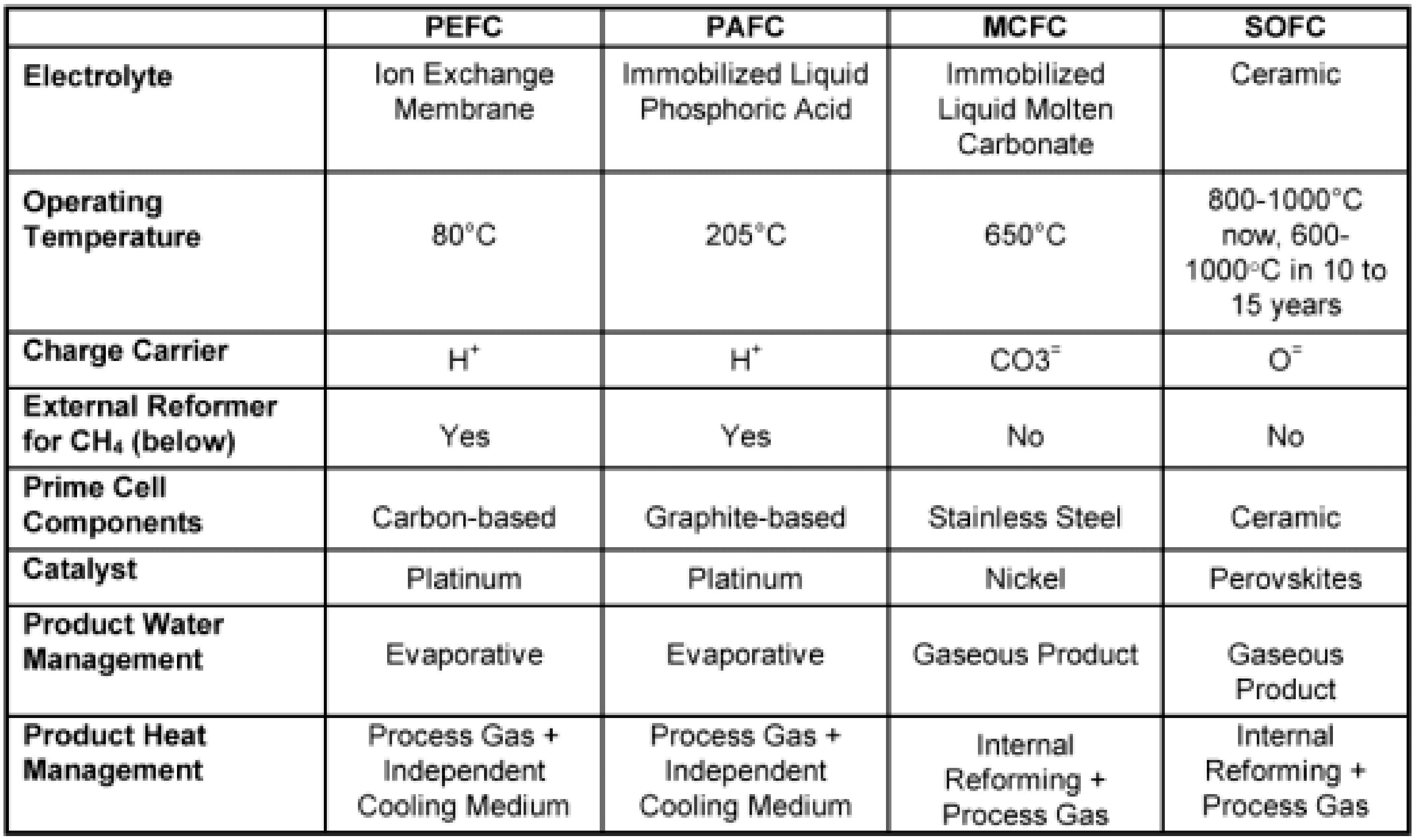
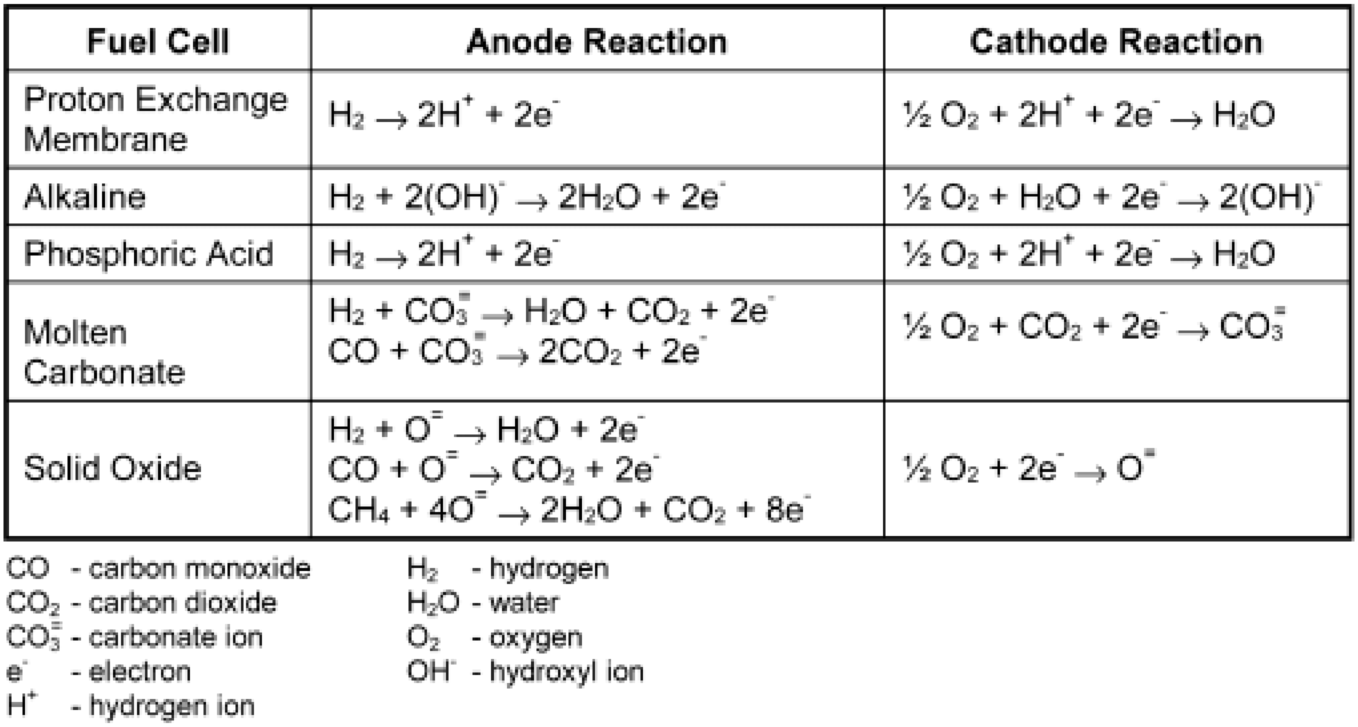
[6] Baur, E., W. D. Treadwell, and G. Trumpler, Z. Elektrochem., **27**, 199 (1921).

Summary of Major Differences of the Fuel Cell Types



	PEFC	PAFC	MCFC	SOFC
Electrolyte	Ion Exchange Membrane	Immobilized Liquid Phosphoric Acid	Immobilized Liquid Molten Carbonate	Ceramic
Operating Temperature	80°C	205°C	650°C	800-1000°C now, 600-1000°C in 10 to 15 years
Charge Carrier	H^+	H^+	$CO3^=$	$O^=$
External Reformer for CH_4 (below)	Yes	Yes	No	No
Prime Cell Components	Carbon-based	Graphite-based	Stainless Steel	Ceramic
Catalyst	Platinum	Platinum	Nickel	Perovskites
Product Water Management	Evaporative	Evaporative	Gaseous Product	Gaseous Product
Product Heat Management	Process Gas + Independent Cooling Medium	Process Gas + Independent Cooling Medium	Internal Reforming + Process Gas	Internal Reforming + Process Gas

Electrochemical Reactions in Fuel Cells



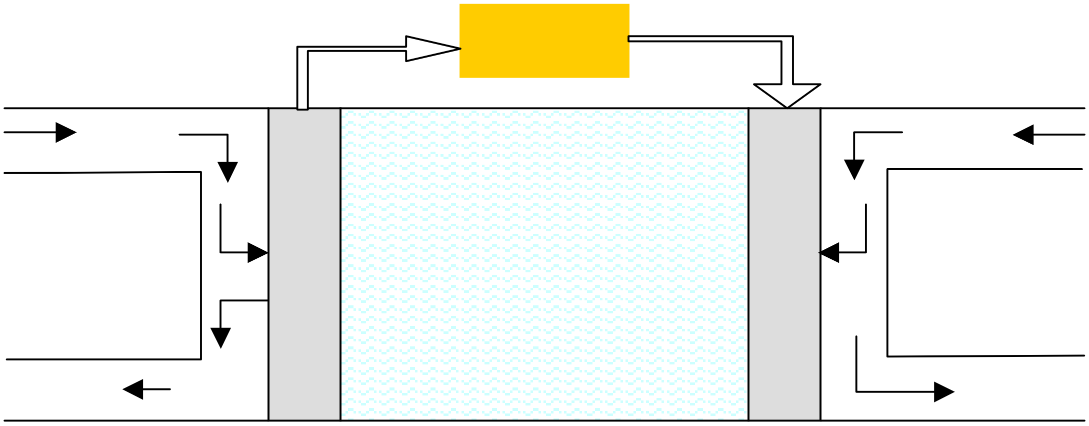
Fuel Cell	Anode Reaction	Cathode Reaction
Proton Exchange Membrane	$H_2 \rightarrow 2H^+ + 2e^-$	$\frac{1}{2} O_2 + 2H^+ + 2e^- \rightarrow H_2O$
Alkaline	$H_2 + 2(OH)^- \rightarrow 2H_2O + 2e^-$	$\frac{1}{2} O_2 + H_2O + 2e^- \rightarrow 2(OH)^-$
Phosphoric Acid	$H_2 \rightarrow 2H^+ + 2e^-$	$\frac{1}{2} O_2 + 2H^+ + 2e^- \rightarrow H_2O$
Molten Carbonate	$H_2 + CO_3^= \rightarrow H_2O + CO_2 + 2e^-$ $CO + CO_3^= \rightarrow 2CO_2 + 2e^-$	$\frac{1}{2} O_2 + CO_2 + 2e^- \rightarrow CO_3^=$
Solid Oxide	$H_2 + O^= \rightarrow H_2O + 2e^-$ $CO + O^= \rightarrow CO_2 + 2e^-$ $CH_4 + 4O^= \rightarrow 2H_2O + CO_2 + 8e^-$	$\frac{1}{2} O_2 + 2e^- \rightarrow O^=$

CO - carbon monoxide
CO_2 - carbon dioxide
$CO_3^=$ - carbonate ion
e^- - electron
H^+ - hydrogen ion

H_2 - hydrogen
H_2O - water
O_2 - oxygen
OH^- - hydroxyl ion

Exercise: Complete the Diagrams Below showing direction and transfer medium using information from Tables

Alkaline Fuel Cell



Proton-Exchange Membrane Fuel Cell