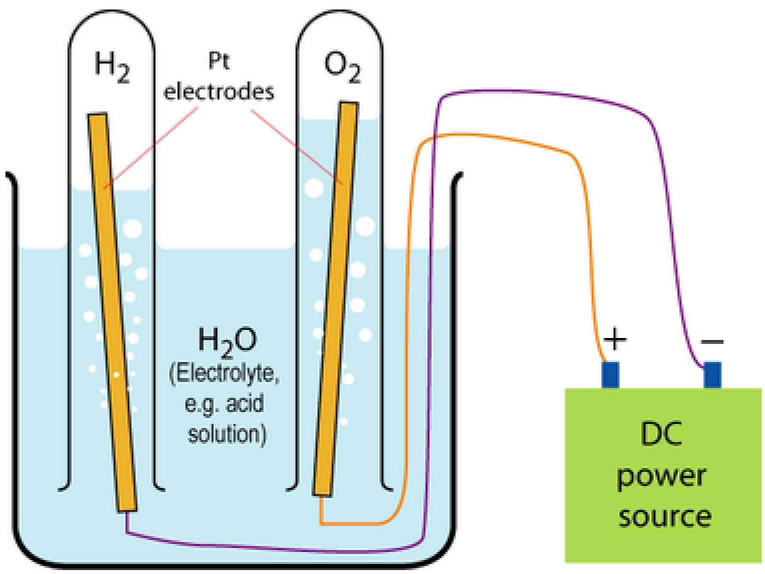
FUEL CELLS: Types

History of the technology

The fuel cell concept was first demonstrated by William R. Grove, a British physicist, in 1839. The cell he demonstrated was very simple, probably resembling this:



Electrolysis setup

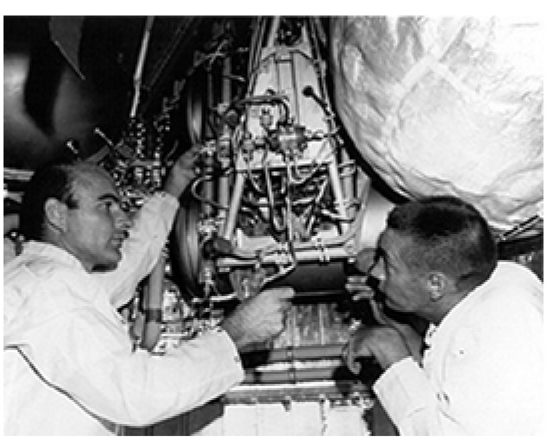
By application of a voltage across the two electrodes, hydrogen and oxygen could be extracted (the process is called **electrolysis**) and captured as shown (William Nicholson first discovered this in 1800). The fuel cell, or “gas battery” as it was first known, is the reverse of this process. In the presence of platinum electrodes, which are necessary as catalysts, the electrolysis will essentially run in reverse and current can be made to flow through a circuit between the two electrodes.

Nobody tried to make use of the concept demonstrated by William R Grove until 1889 when Langer and Mond tried to engineer a practical cell fuelled by coal gas.

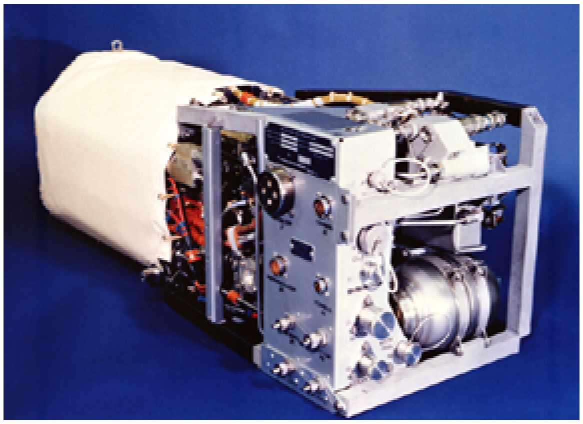
Further early attempts carried on into the early 1900’s but the development of the internal combustion engine made further research into the technology sadly unnecessary.

Francis Bacon developed the first successful fuel cell in 1932, running on pure O_2 and H_2 and using an alkaline catalyst and nickel electrodes. It was not until 1959 that Bacon and his colleagues first demonstrated a 5 kW device; the 27 year delay is perhaps an indication of just how difficult it is to make progress in this field of development. Harry Karl Ihrig demonstrated a 20 bhp fuel cell tractor in the same year.

Around about this time, NASA started researching the technology with a view to produce a compact electricity generator for use on spacecraft. Due to their astronomical budget, it was not long before they got the job done. The Gemini program used early PEM fuel cells (PEMFCs) in its later missions, and the Apollo program employed alkaline fuel cells. On a spacecraft the water produced by the reaction was available for the spacemen to drink. NASA continued to use alkaline cells in the space shuttle until the 90’s when PEMFC development meant a switch back to PEMs was considered a possibility, however, the high cost of design, development, test and evaluation prevented the switch, in spite of several technical advantages.




PEM fuel cells being installed in a Gemini 7 spacecraft (Source: Smithsonian Institution, from the Science Service Historical Images Collection, courtesy of General Electric)



The alkaline fuel cell system as used on the space shuttles. Three such modules were installed in each shuttle

Recent developments are thick and fast as the technology begins to come to fruition. Automotive applications are high on the agenda due to the huge consumer market and the need for an environmentally friendly, renewable alternative to the internal combustion engine and fossil fuels.

Types of fuel cells :

Fuel cells are categorised according to their type of electrolyte, since it is the property-determining component. The six main types of fuel cells are outlined below.

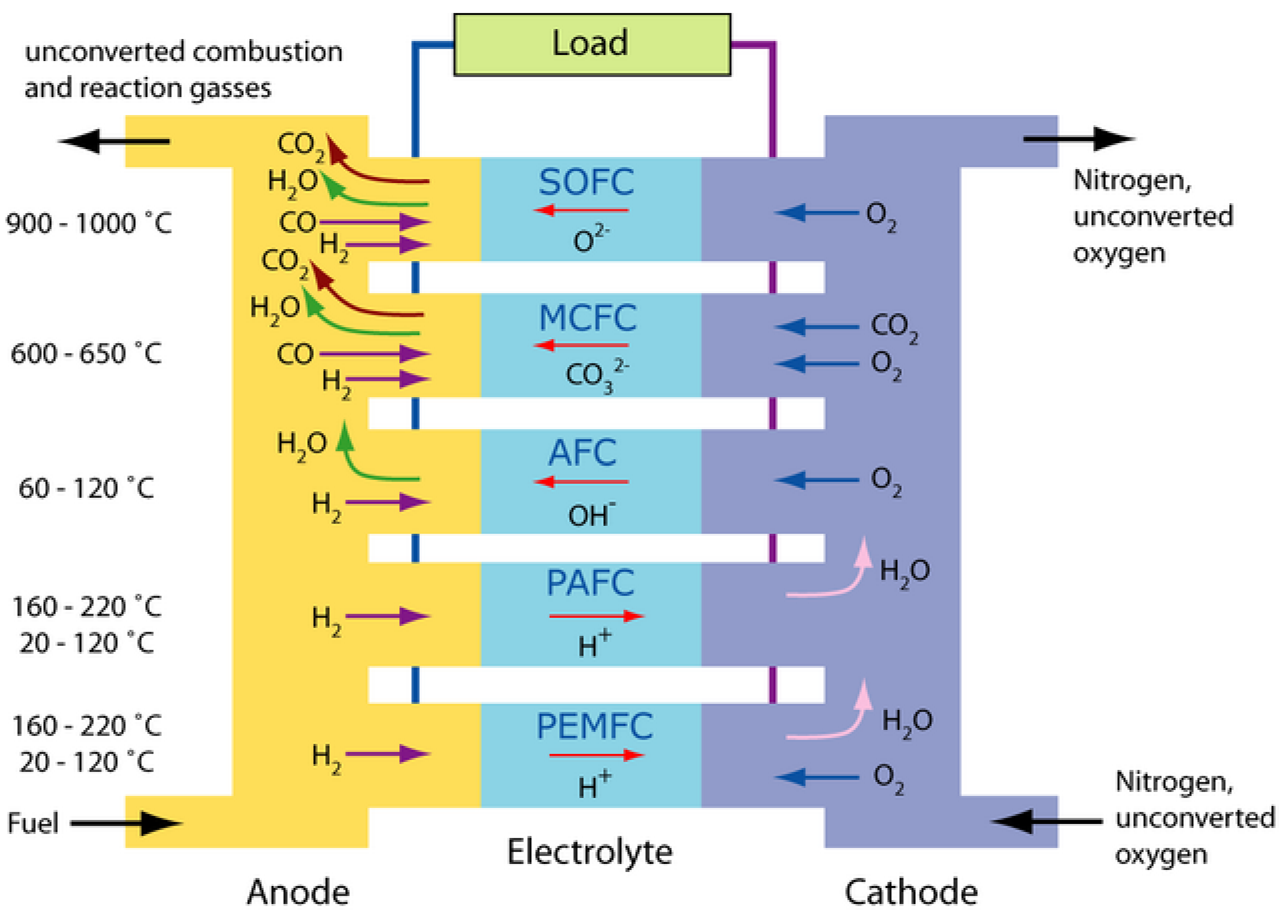
Fuel cell type	**DMFC**	**PEMFC**	**AFC**	**PAFC**	**MCFC**	**SOFC**
Electrolyte type	Polymeric ion exchange membrane	Polymeric ion exchange membrane	Immobilised alkaline salt solution	Immobilised liquid phosphoric acid	Immobilised liquid molten carbonate	Ceramic
Operating temperature (°C)	20 – 90	30 – 100	50 – 200	~220	~650	500 – 1000
Charge carrier	H^+	H^+	OH^-	H^+	CO_3^{2-}	O^{2-}
Power range (W)	1 – 100	1 – 100k	500 – 10k	10k – 1M	100k – 10M+	1k – 10M+
Applications and main advantages:						
Portable	Higher energy density					

electronics	than batteries and faster recharge.					
Cars boats and spaceships		Zero emissions and higher efficiency.				
Domestic CHP			Efficiency and reliability			
Distributed power generation, CHP, busses					Efficiency, emissions and less noise	
Able to internally reform CH_4 (see Fuelling section)	×	×	×	×	√	√

The phosphoric acid fuel cell (PAFC) is not covered in detail in this package. It was however the first type of fuel cell to be commercially produced and enjoys widespread terrestrial use. Many 200 kW systems are in place in USA and Europe.

This package also doesn't cover the alkaline fuel cell (AFC) in any detail. These particular cells use potassium hydroxide solution as the electrolyte. This means that any CO_2 at the cathode, even the levels present in the air, will react with the OH^- in the solution to produce carbonates and prevent the cell functioning. This isn't a huge problem in spacecraft, where pure oxygen can be supplied to the cathode reliably, but this characteristic flaw makes the AFC unsuitable for practical terrestrial use.

The diagram below shows the mechanisms by which the different fuel cell types operate:



What’s the catch?

As fossil fuel resources become more and more pressed upon to deliver the worlds energy needs, as CO_2 and global warming loom ever nearer and as cities become ever increasingly crowded with polluting automobiles the fuel cell seems to offer a golden solution to the world's energy problems. It’s efficient, it’s clean, hydrogen can be produced by renewable energy and the technology wouldn’t require any huge change in our way of life.

So why don’t we all drive fuel cell cars already? The technology has two fundamental flaws:

- Slow reaction rate, leading to low currents and power.
- Hydrogen is not a readily available, or easily stored fuel.

We’ll discuss ways of getting around these problems in the package. Each type of fuel cell has a different solution, but also brings its own set of difficulties.

Temperature differences

High temperature cells (solid oxide and molten carbonate electrolytes) operate by very different mechanisms to low temperature cells, and have different applications accordingly. The requirements of the “balance of plant” (i.e. the additional fuel processing equipment necessary to fuel a fuel cell) are also different. We therefore split the TLP in two and consider high temperature cells separately from low temperature cells.

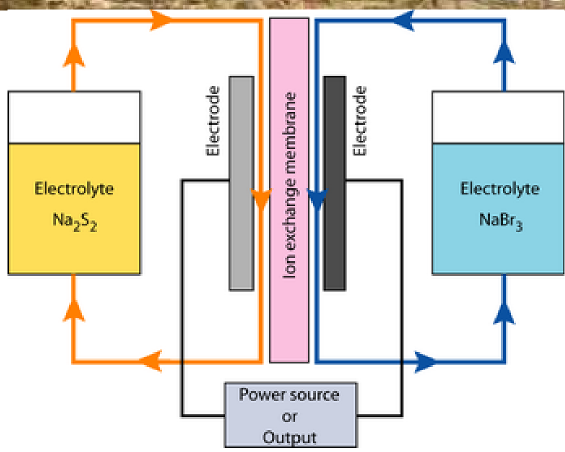
Other types of fuel cells:

A fuel cell is defined as an electrochemical device that converts chemical energy to electrical energy (and heat) as long as reactants are supplied to its electrodes. In contrast to batteries, this implies that neither the electrodes or the electrolyte are used up by the operation of the cell, hence the fuel cell should keep running (wear and tear excepted) as long as fuel is supplied. These examples of "fuel cells" don't all fulfil this criterion but are commonly mislabelled anyway.

- A "**biological fuel cell**" is still at the very early stages of development but shows promise in the long term. They would use an organic fuel such as natural gas or an alcohol. The key feature of this type of cell is that they would use enzymes rather than chemical catalysts (e.g. Pt) to facilitate the electrode reactions. This idea seeks to replicate nature, but it's a long way from practical application.
- **Metal/air cells** such as the zinc air battery use an alkaline salt solution to act as an electrolyte with OH^- as the charge carrier. At the anode, zinc is slowly corroded away to zinc oxide in the solution. The cell could be "refuelled" by adding more zinc to the electrode, but the fact that electrodes are consumed means that this is a battery rather than a fuel cell. Such cells do have high energy density and are commonly used for long life, low power applications. They are often called fuel cells because the cathodic reaction is identical to that in the fuel cell.

Wind turbine

Britain is the windiest country in Europe, so why are we not using wind turbines to supply a larger portion of our energy needs? The problem is that wind is a gusty phenomenon that is intrinsically inconsistent. Energy storage on a large scale must be a realisable technology before such energy sources can be utilised. **Redox fuel cells** are being developed as a means of storing energy.



A *Regenesys* plant which was under construction near Cambridge (Left) and the principle behind a Redox fuel cell (Right).

Two different solutions are contained in two tanks. When energy is required, a solution of Na_2S_2 is fed to the anode, and $NaBr_3$ to the cathode. The anodic reaction is:

$$2Na_2S_2 \rightarrow Na_2S_4 + 2Na^+ + 2e^-$$

The electrons flow around the external circuit so that at the positive electrode, or more precisely the cathode (remember, the definition is that the anode is the site of oxidation), we see:

$$NaBr_3 + 2Na^+ + 2e^- \rightarrow 3NaBr$$

As energy is drawn from the system, the sodium sulphide becomes sodium polysulphide and the tribromide becomes sodium bromide. This reaction is reversed when current is supplied to the cells. The system is called a fuel cell because the electrodes are just a surface for the reaction, and are not consumed by it. They are also fed and energy containing liquid. The electrolytes however are not really fuels and they are changed during the process. This system should probably be called a strange-battery.

- **Proton Exchange Ceramic (PEM) fuel cells** do exactly what they say on the tin. They will utilise fossil fuels directly, at around 700 °C, reducing them at the anode and conducting protons across a ceramic electrolyte. They are at the very early stages of development, but potentially have a great advantage over the low temperature PEM cells in that high temperature exhaust gases can be used in a turbine hybrid system to generate more electricity and push the system's efficiency up to around 80%.

Source: http://www.doitpoms.ac.uk/tlplib/fuel-cells/types.php