Power to the People

Fuel Cells

UNIVERSITY OF BATH

Background. Fuel cells have been around for a long time. William Grove first demonstrated a workable fuel cell way back in 1839. So why the delay in practical applications? Until recently the materials needed to ensure that fuel cells work reliably to generate electricity for long periods were unavailable or too expensive. Improvements in materials performance stemming from fundamental breakthroughs in the chemical sciences means that practical, affordable fuel cells are now being launched on the market. This will help break the dependency on fossil fuels that produce greenhouse gases.

What is a fuel cell? Like a combustion engine, a fuel cell uses a chemical fuel (such as hydrogen) to generate power. But like a battery, the chemical energy is converted directly to electricity, without the combustion step which makes engines so inefficient and polluting. Fuel cells can therefore be used as a clean energy generator for all kinds of situations, from power stations to portable devices.

Types of fuel cells. There are a number of different fuel cell types being developed around the world, differentiated primarily by the materials used to form the cell's active components. Today, two types generally stand out as the most promising: solid oxide fuel cells and polymer-based fuel cells.

Solid oxide fuel cells (SOFCs). These are made from inorganic, crystalline materials and operate at much higher temperatures (>800ºC) than polymer fuel cells. This makes them suitable for heat and power generation in homes, hospitals, office buildings, and other stationary applications (figure 1). The higher temperatures also make them more efficient than polymer fuel cells, but they are unsuitable for portable applications.

Polymer-based fuel cells. Also known as proton exchange membrane (or PEM) fuel cells, these are for use in cars, buses, and other modes of transport (figure 2), as well as mobile applications such as laptop computers. They use organic polymers that operate well at or near room temperature, so this fuel cell type doesn't require external heating equipment.

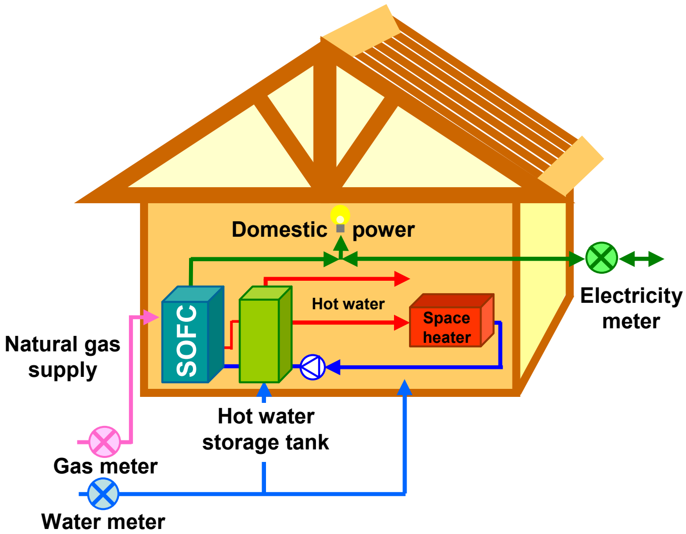

Figure 1: *A solid oxide fuel cell (SOFC) providing electricity, hot water and heating in a home.*

How does a fuel cell work? A fuel cell electro-chemically combines a fuel (such as hydrogen, H_2) with an oxidising agent (usually oxygen, O_2). It does this by splitting the molecules of fuel and oxygen into ions, transporting them through its centre, and combining them at the other side. During this process, electrons are produced which can be extracted as useful energy in the form of electricity (figure 3).

Figure 2: *A fuel cell bus powered by hydrogen being trialled in London.*

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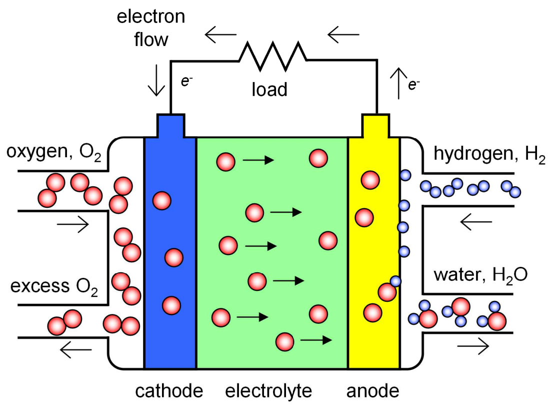

Figure 3: *How a solid oxide fuel cell works.*

A fuel cell is constructed like a sandwich, with an electrolyte between two electrodes, known as the anode and cathode. The job of the electrolyte is to move ions from one side of the fuel cell to the other, where they can react at the electrodes. The ideal fuel for a fuel cell is pure hydrogen, H_2, but other hydrogen-rich fuels can also be used, such as methane (CH_4), methanol (CH_3OH), and ethanol (C_2H_5OH). When hydrogen is used, the only by-product is water, H_2O! (See figure 4.)

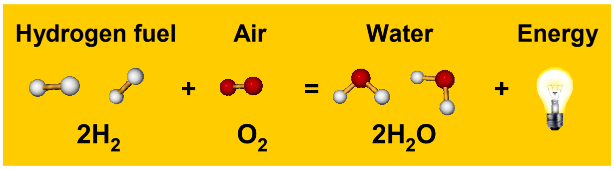

Figure 4: *Chemical reaction behind fuel cells.*

PEM fuel cells and SOFCs differ by the type of ion transported through the electrolyte. In PEMs, the polymer transports hydrogen ions, H^+ (also known as protons), from one side of the cell to the other. In SOFCs, the solid electrolyte transports oxygen ions, O^{2-}.

KEY TERMS

Electrochemistry: The study of the relation of electricity to chemical changes and the inter-conversion of chemical and electrical energy.
Crystalline solid: A material made up of ordered arrays of atoms, molecules or ions.
Electrolyte: A substance that is a good conductor of ions but not electrons.
Anode: The electrode where fuel is broken up to give off electrons.
Cathode: The electrode where oxygen molecules combine with electrons to form ions.

Challenges. Despite the urgency to break our dependency on fossil fuels that contribute to global warming, there are still major challenges facing the widespread application of fuel cell technology. The major barrier to overcome is cost; compared to the combustion engine, fuel cells are expensive, because their processing is difficult and the materials costly. For SOFCs, this cost can be lowered, and the overall efficiency of the system improved, if the operating temperature is brought down to 400-700ºC. The conventional electrolyte material in SOFCs, zirconia (ZrO_2) containing small amounts of other elements, only works above 800ºC. The challenge for scientists is to develop new ion conducting materials with superior properties to ZrO_2.

Work at the University of Bath. The research group of Professor Saiful Islam uses super-computers to build atomic-scale models of materials that help us understand their structures and behaviour. Modelling can reveal information that is difficult to extract from experiment alone, such as unravelling the motion of ions in solids. This can be used to design new, improved materials before they are tested in the laboratory.

Promising alternatives to current fuel cell materials include novel "apatite" compounds that have recently been discovered to support fast-ion conduction through their beautiful, complex crystal structures (figure 5). You may one day see some of these materials used in solid oxide fuel cells. Such fuel cells in our homes could make clean "power to the people" a reality for future generations!

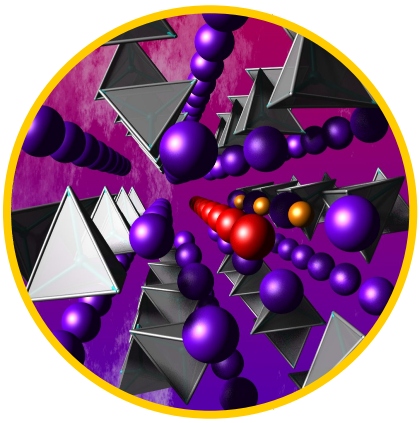

Figure 5: *Crystal structure of a new silicate-based apatite material for solid oxide fuel cells.*

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