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Hydrogen powered cars

Key words
electrolysis
fuel cell
fossil fuels
catalyst

This black cab is one of five in use in London which are powered by fuel cells.

Fossil fuels dominate our sources of energy, from petrol for our cars to the coal that fuels our power stations. When fossil fuels are burned, harmful by-products are emitted to the environment. Some, like carbon dioxide (CO_2) and nitrous oxides (such as NO_2), are known as greenhouse gas emissions and contribute towards the greenhouse effect and climate change. Other pollutants such as particulates cause more local pollution problems which can cause breathing difficulties to susceptible people.

The transport sector in the UK is responsible for emissions of the equivalent of 122.2 million tonnes of CO_2 annually, and 74% of this is due to cars, taxis and buses. Therefore we need to look at ways of improving our transport to reduce emissions.

A single-cell fuel cell

As this is so important for the future of the Earth, scientists from all over the world have been researching technologies to reduce our negative impact on the environment, and this is where the hydrogen fuel cell (HFC) comes in. It was first discovered by Welsh lawyer and amateur scientist Sir William Grove in 1839. He understood that through electrolysis, an electrical current can be passed through water (H_2O) to break it down into hydrogen (H_2) and oxygen (O_2) molecules.

Grove believed that the reverse of this electrolysis should be possible, and set up an experiment with platinum electrodes in two separate bottles containing H_2 and O_2. When he submersed the bottles into dilute sulphuric acid, he observed that the gases were consumed and an electrical current was produced when the gases recombined to form H_2O. Since its discovery nearly 200 years ago, the technology has developed to a level where it can now start to be applied in day-to-day activities, such as fuelling our vehicles.

Principles of the fuel cell

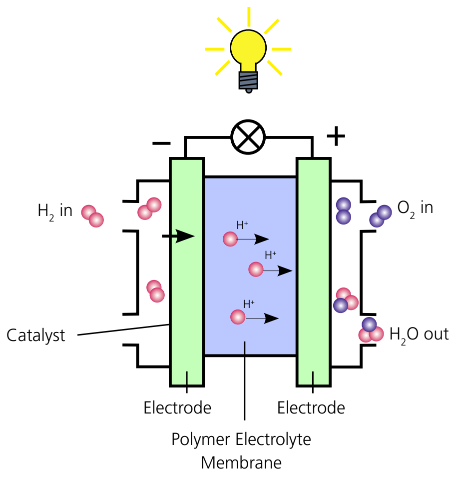
A fuel cell is an electrochemical energy generation device that directly uses H_2 and O_2 to create electrical and heat energy. The only by-product of the reaction is water that is so pure it has been used as drinking water when fuel cells were used on the Apollo lunar space missions by NASA.

Overall reaction:

$$H_2(gas) + O_2(gas) \rightarrow H_2O(liquid) + heat + electricity$$

The fuel cell reaction

At the negative electrode, H_2 is passed over the catalyst layer of platinum (Pt) nanoparticles which breaks the H_2 molecule down into hydrogen ions ($2H^+$) and electrons ($2e^-$), establishing an oxidation reaction. The electrons travel through the negative electrode to an external circuit to create the electrical current that can be used for work, such as to spin a motor.



This diagram shows the reactions that take place at the positive and negative electrodes in a hydrogen fuel cell. The electrode which gains H+ ions becomes the positive electrode of the cell. The other electrode gains electrons and so becomes the negative electrode

At the positive electrode, O_2 is passed over the Pt catalyst layer which breaks the O_2 down into two oxygen atoms with a negative charge, establishing a reduction reaction. The negative charge pulls the hydrogen ions through the electrolyte membrane to meet the electrons and oxygen atoms at the positive side where they form water, and complete the reaction (see diagram above).

The two half equations together complete the overall redox reaction of the fuel cell:

Negative electrode:

$H_2 \rightarrow 2H^+ + 2e^-$ oxidation reaction

Positive electrode:

$O_2 + 2e^- + 2H^+ \rightarrow H_2O$ reduction reaction

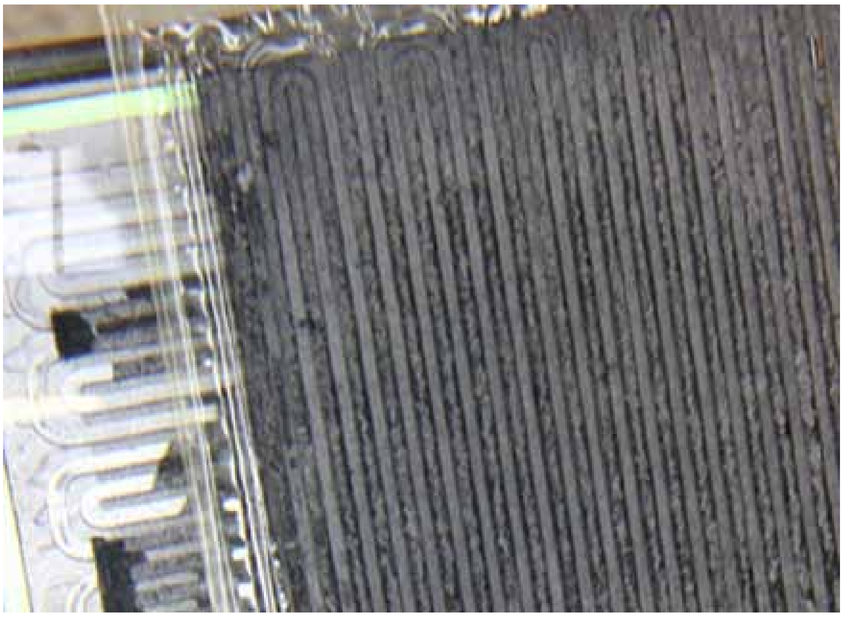
Producing hydrogen

Hydrogen is not found naturally on Earth and needs to be manufactured to be used in HFC vehicles. The majority of H_2 is currently produced by reacting H_2O with CH_4 through steam reformation to release CO_2 and H_2.

$$CH_4 + H_2O \rightarrow CO_2 + H_2$$

The emitted CO_2 can be captured and disposed of safely, which is far more environmentally friendly than the combustion of fossil fuels in an ICE.

Hydrogen can also be manufactured using the electricity generated by solar panels and wind turbines to electrolyse H_2O. This could dramatically reduce carbon emissions of the transport industry.



These are the gas channels that distribute the gases (hydrogen at one electrode, oxygen at the other) to the active areas on the membrane.

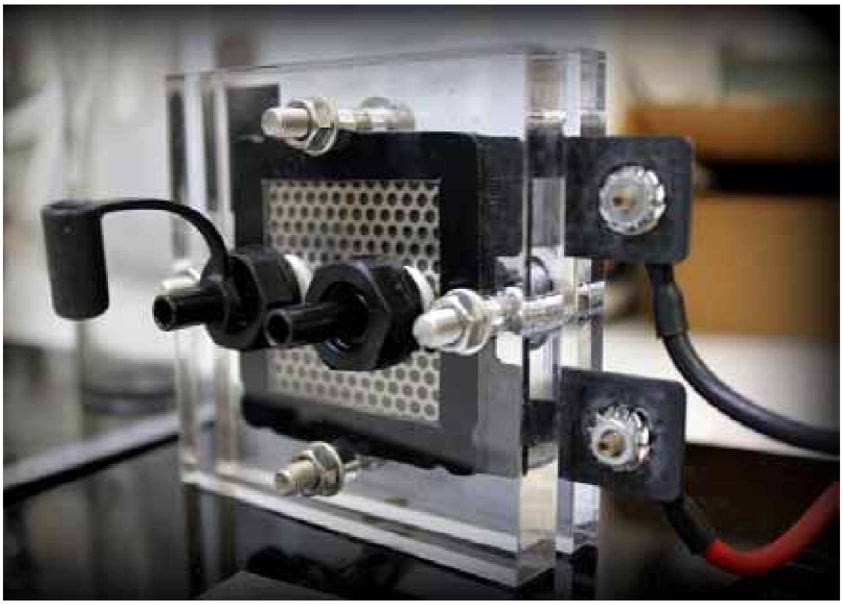
Materials in a fuel cell

The electrolyte membrane, made of the polymer PTFE. This forms the central part of the fuel cell and allows H+ ions to pass through, but not the electrons or gases.

The electrolyte membrane at the core of a hydrogen fuel cell (HFC) is made of polytetrafluoroethylene (PTFE), commonly known as Teflon® and used as a non-stick coating on frying pans. The PTFE core is hydrophobic which means that it repels water, and this aids with the removal of excess water during the reaction. The core material is modified to have side chains ending with sulphonic acid (HSO_3) which is hydrophilic, meaning that it attracts water. The combination of a hydrophobic and hydrophilic material means that the material can remain hydrated but expel excess water. The ability to do this is fundamental to the transport of the H^+ ions through the electrolyte membrane. The H^+ ions achieve this by bonding to a H_2O molecule in the hydrated membrane forming a hydronium ion (H_3O^+), this way they can 'piggyback' across the membrane to meet the electron at the other end.

$$H^+ + H_2O \rightarrow H_3O^+$$

To create a useable amount of energy, cells are arranged in large stacks. This design allows the power output to be as high as desired.



A single cell fuel cell. The end plates are made of transparent acrylic allowing us to see the electrode that collects the current and distributes it to the electrical wires on the right. It is perforated to allow the gas to flow through the cell. The black openings are for the gas inlet and outlet feeds.

A fuel cell stack, comprised of 64 individual cells. The black tie bars clamp them tightly together to reduce gas leakage from the cells to the environment. Note the gas feed on the left and electrical wires on the right.

Fuel cells in vehicles

This fuel cell bus travels between some of London's major tourist sites. You can see the six hydrogen fuel tanks on its roof.

HFC's can be used in any application where electricity is used and, as such, they are becoming more and more popular as a power source in cars, buses and taxis. Conventional vehicles use an internal combustion engine (ICE) that burns fossil fuels such as petrol and diesel to run. These ICE's have limited efficiency and can only use around 20-25% of the fuel's energy to propel the car. HFC vehicles are not limited in the same way and can have efficiency rates of up to 60%, making them a preferable technology to ICE's.

In previous years HFC vehicles have not been very popular due to a few key issues; cost, durability and performance.

Cost: As a HFC uses rare materials such as Pt, they are very expensive to produce. Scientists have got around this issue by reducing significantly the amount of Pt needed as a catalyst in a fuel cell.

Durability: In the past, Fuel cells haven't been able to last as long as conventional ICE's. Scientists are addressing this using highly complex computer simulation and experiments to make fuel cells last equally as long, and indeed longer, than an ICE.

Performance: HFC vehicles can now be designed to have far greater power outputs than in the past, so they can be used in applications that require large power outputs such as trains and buses.

Conclusion

HFC vehicles offers a great opportunity to dramatically reduce our emissions of harmful greenhouse gases but still have the same levels of performance and comfort as the conventional ICE vehicle.

There are still many questions that need answering in the HFC field, and the industry needs new, young scientists to undertake research to help with the development and commercialisation of this fascinating technology.

Michael Whiteley is a Doctoral Researcher at Loughborough University. He is looking at the degradation and lifetime analysis of hydrogen fuel cells in an automotive environment.
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