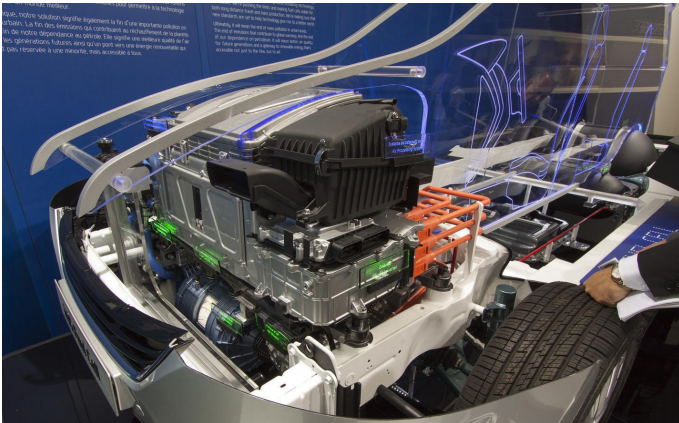


# Automotive Fuel Cell Technology



Fuel cell technology for automotive applications is an attractive prospect for automotive manufacturers and consumers alike as it provides a low carbon solution to mobility without the limited range associated with battery electric vehicles. However cost issues and a lack of infrastructure currently prevent commercialisation. This POSTnote describes the technology in more detail, identifies the cost barriers and how they can be overcome and then examines the current strategy for developing the UK hydrogen infrastructure.

## Background

There are a number of fuel cell technologies that exist which have varying energy densities, efficiencies and can utilise a variety of fuels. Automotive applications lean towards proton exchange membrane (PEM) fuel cells due to their low temperature operation and high efficiency. Box 1 explains the operating principle of PEM fuel cells and some of the system architectures that can be employed in a vehicle. Investment in FCVs is being motivated by the carbon savings they can achieve as well as their ability to make use of electricity generated from low-carbon sources.

Although battery technology for vehicle application is more mature and has seen some commercial success, there are inherent issues preventing such technology being utilised as the prime mover for a vehicle. This is primarily down to the low energy density, thus the limited range. It is in this arena that fuel cell technology is able to gain ground. In addition, they are more familiar to the consumer due to some of the parallels that can be drawn with internal combustion engines, such as a similar refuelling process.

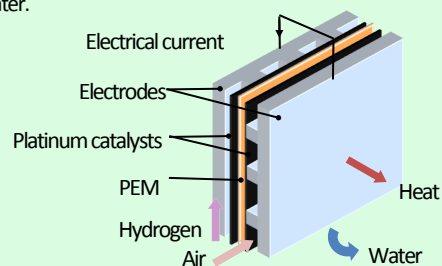
The UK is bound to cut greenhouse gas emissions by 80% relative to 1990 baseline by 2050<sup>2</sup>. In 2007, the government commissioned the King Review of low-carbon cars. It was concluded in the report that low-carbon vehicles would be necessary to achieve this target. However, widespread usage of FCVs is not expected until 2030. In order to reduce the time to commercialisation system cost needs to be

## Overview

- Fuel cell vehicles (FCVs) are more efficient than their petrol or diesel counterparts with as much as 60% of the energy stored in the hydrogen going to the wheels compared with 20% of ICEs.
- The carbon emissions of a FCV depend on how the hydrogen used to fuel them is generated and the only tailpipe emission from a FCV is water.
- Research indicates that the total CO<sub>2</sub> emissions for an FCEV can be 75% less than the equivalent diesel vehicle in 2030<sup>1</sup>, on a path to zero carbon by 2050.
- Currently, the main barriers preventing commercialisation of the fuel cell for automotive use are system cost (relative to combustion engines) and a lack of refuelling infrastructure.
- Some automotive original equipment manufacturers (OEMs) such as Hyundai and Toyota are investing in fuel cell technology, with vehicles expected to be on UK roads as early as 2015.

### Box 1. PEM Fuel Cell Operating Principle and System Architectures

A fuel cell electrochemically combines hydrogen and oxygen to form electricity with the only emission being water. The oxygen can be taken from the air, however a high pressure tank is required to feed the hydrogen. There are two internationally recognised pressure standards for hydrogen for automotive applications—350 bar and 700 bar. This requires strong, lightweight tanks which are challenging to package inside the vehicle. The operating temperature of PEM fuel cells is around 70°C. Although heat is generated in the process it is not particularly useful due to its relatively low temperature, as such it is simply expelled into the environment with coolant air. The PEM is called such as the membrane allows only hydrogen protons across, while electrons pass along an external circuit. The hydrogen protons, electrons and oxygen recombine on the other side of the membrane to form water.



In order to operate the fuel cell at its most efficient, it is often used in conjunction with a battery. The battery forms a reservoir that the fuel cell tops up, this is managed with a complex control system. The battery can also be used to store energy from regenerative braking. Alternative systems include mating the stack to a bank of capacitors which, due to their rapid charge and discharge rates, provide a good source of energy during acceleration or when moving off. It is anticipated that some FCVs will utilise all three technologies to produce a highly efficient and responsive vehicle.

reduced.

It is expected that OEM solutions for affordable customer use will exist on a lease basis in the order of £300–£500 per month. This cost covers the maintenance of the vehicle and in some cases the refuelling. This is of value to the OEM as it provides an ideal research platform to further improve fuel cell technology.

## Cost Issues

Ultimately the cost issue associated with fuel cells is proportional to the required reliability, durability and stability of the fuel cell stack. The US DoE target of \$50/kW (compared to a current ICE cost of \$10/kW) has become the benchmark with a target lifetime for automotive applications of 5000 hours. The operating conditions of dynamic loading, start up and shut down events and freeze–thaw cycles make this lifetime target challenging to achieve.

### Components

The heart of the fuel cell, which is composed of a polymer proton conducting membrane and platinum catalysts, contributes approximately 60% to the total fuel cell cost<sup>3</sup>. This component is known as the membrane electrode assembly (MEA). Johnson Matthey (Swindon) has established itself internationally at producing high quality MEAs, however costs are still high. This prevents more extensive research being carried out on manufacturing processes and decay mechanisms.

Another costly component is the gas flow field plate which is typically made of high quality graphite. The component delivers fuel and air to the cell heart while managing heat, conducting charge and providing some structural rigidity. This component can be as much as 20% of the total fuel cell cost<sup>3</sup>. Alternatives, such as coated steel plates are currently being researched by Teer Coatings (Droitwich). This should increase the stack volumetric energy density and reduce cost.

### System Degradation

As with the ICE, the fuel cell is subject to decay with time. Although mechanical decay is a concern, it is voltage decay that is benchmarked and is the definition of end of life once 10% degradation has been observed<sup>5</sup>. Acceptable rates of degradation are in the order of millionths of volts per hour, however unusual operating condition or the smallest inconsistencies during manufacture can greatly accelerate degradation. For this reason, the cost of the system can be very high, this allows the manufacturer to cover warranty costs such as replacement or repair.

Ultimately, system degradation issues are intrinsically linked to the maturity of the technology. While fuel cells have garnered much attention over the last 2 to 3 decades, the gaps in knowledge associated with manufacturing and degradation issues pose risks which are mitigated with high retail costs, thus preventing the route to commercialisation.

## Infrastructure

Unlike fossil fuels, hydrogen does not exist in large quantities in nature in the concentration required for PEM fuel cell application. The specific energy of hydrogen is 123 MJ/kg which is significantly more than gasoline's 46 MJ/kg. The specific energy indicates the energy released when the fuel is combusted, however in fuel cells this is not the case i.e. an electrochemical process produces energy as opposed to combustion. As such, it is better to consider hydrogen as an energy carrier and a medium which efficiently stores electricity.

Although electricity produced from renewable sources provides a

zero-carbon energy source, the irregularity of supply causes active shut-down requests to prevent the overloading of the national grid. This is due to a lack of energy storage systems. Hydrogen presents a useful solution which can store the electricity that the national grid is unable to use. This hydrogen could be stored in tanks and pumped into hydrogen refuelling stations (HRS). Box 2 describes some of the hydrogen production technologies available.

Currently, a state of the art HRS operates at the Honda manufacturing plant in Swindon which was commissioned in August 2011, supported by BOC. This station can refuel at both 350 and 700 bar pressures and is capable of refilling up to 4 cars per hour. Across the UK there are currently less than 20 operational HRSs, most of which are used for research and demonstration purposes by Universities. However, there are plans underway to expand the UK hydrogen refuelling infrastructure.

The UK H<sub>2</sub> Mobility project brought together a number of key stakeholders in 2012 to understand the challenges of developing the hydrogen refuelling infrastructure and identify the key needs. The analysis and network modelling undertaken within the project indicated that 65 stations across the UK could provide sufficient initial coverage, with full national coverage by 2030 consisting of 1,150 stations.

It is anticipated that the HRS network will not be profitable initially but will be able to cover operating costs by the early 2020s. The total financing required up to the break-even point is £418m, of which £62m is required before 2020.

Using the project fact base, the analysis showed that a mix of hydrogen production methods (51% water electrolysis, 47% steam reforming, 2% existing capabilities. see Box 2) could deliver hydrogen to the driver at a cost competitive with diesel, yet 60% lower CO<sub>2</sub> emissions in 2020 and 75% lower in 2030<sup>1</sup>.

### Box 2. Hydrogen production technologies<sup>4</sup>

- **Steam Reforming** — a commonly used hydrogen production method where a hydrocarbon gas, such as methane, is mixed with steam at high temperature and pressure. It is possible to produce the hydrocarbon gas using biomass products by heating to high temperatures in the absence of oxygen, this is known as gasification. Some portable applications of fuel cells reform hydrogen on board, evidently this requires high temperature operation. As such, solid oxide fuel cell technology is best suited to such an on-board system.
- **Partial Oxidation** — heavier hydrocarbons such as oil and coal are reacted with oxygen and steam. This commercially available process is favoured in regions of the world with ample coal resources.
- **Electrolysis** — electric current is used to split water into hydrogen and oxygen. This process has the potential to use excess electricity rejected by the national grid and then convert and store it in the form of hydrogen. It is also possible to use this process for domestic purposes. ITM Power have developed electrolyzers that use an inverse fuel cell principle i.e. apply current to a fuel cell to produce hydrogen.
- **Biological methods** — there are several types of algae and bacteria that produce hydrogen, although this method has commercial potential it is still at an R&D stage.

### Endnotes

1 UK H<sub>2</sub> Mobility—Synopsis of Phase 1 Results, February 2013

2 POSTnote Number 365—Electric Vehicles, October 2010

3 Manufacturing Fuel Cell Manhattan Project

4 POSTnote Number 186—Prospects for a Hydrogen Economy, October 2002

5 A review of PEM fuel cell durability: Degradation Mechanisms and mitigation strategies, Wu et al, March 2008