Fuelling the future

Fuel cell vehicles have taken a back seat to battery and hybrid power in recent years. But hydrogen still holds promise in the long term, as Laura Howes finds out

'And what will they burn instead of coal?' asked Pencroft. 'Water,' replied Harding. 'But water decomposed into its primitive elements... yes, my friends, I believe that water will one day be employed as fuel, that hydrogen and oxygen which constitute it will furnish an inexhaustible source of heat and light. Water will be the coal of the future.'

Jules Verne, **The Mysterious Island***, 1874*

'Transport accounts for a quarter of emissions from fuel consumption and about 15 per cent of manmade emissions. And the amount of transport emissions is growing absolutely and relatively,' said Jack Short from the International Transport Forum think tank, at the low carbon vehicle partnership's annual conference this year. So with concerns surrounding climate change and increasing petrol costs, where are the transport alternatives? As a child, I was sure we'd be driving hydrogen powered cars by the time I was a grown-up – the fuel of the future with the only emissions being water. But as time went on, fuel cell vehicles always seemed to be 'five years away'. What happened and when will I get my fuel cell car?

In short

- **Fuel cell vehicles have been hailed as the future of transport for decades, but are only just emerging onto our roads**
- **H_2 has advantages over battery-powered electric cars, as the range and ease of refuelling are on par with hydrocarbon fuels**
- **It will require political support and investment on infrastructure for fuel cells to take off. Korea is so far the most committed to hydrogen power**

The early years

Despite me seeing fuel cells as the future, the basic principle has been around for over 150 years. In 1839, British physicist William Grove suggested that if electricity could split water into hydrogen and oxygen, it should also work in reverse – combining hydrogen and oxygen should give electricity – and he built the world's first fuel cell to prove it. In today's fuel cells, as in Grove's 'gas battery', hydrogen and oxygen can be combined to form water and give electrical energy, but over the years the technology has changed somewhat.

By the end of the 19th century, where transport was concerned, fossil fuels and the internal combustion engine had won, but there was still some interest in fuel cells. At the University of Cambridge, UK, in the 1940s and 1950s, Thomas Bacon resurrected and refined the technology that had changed little since Grove's work.

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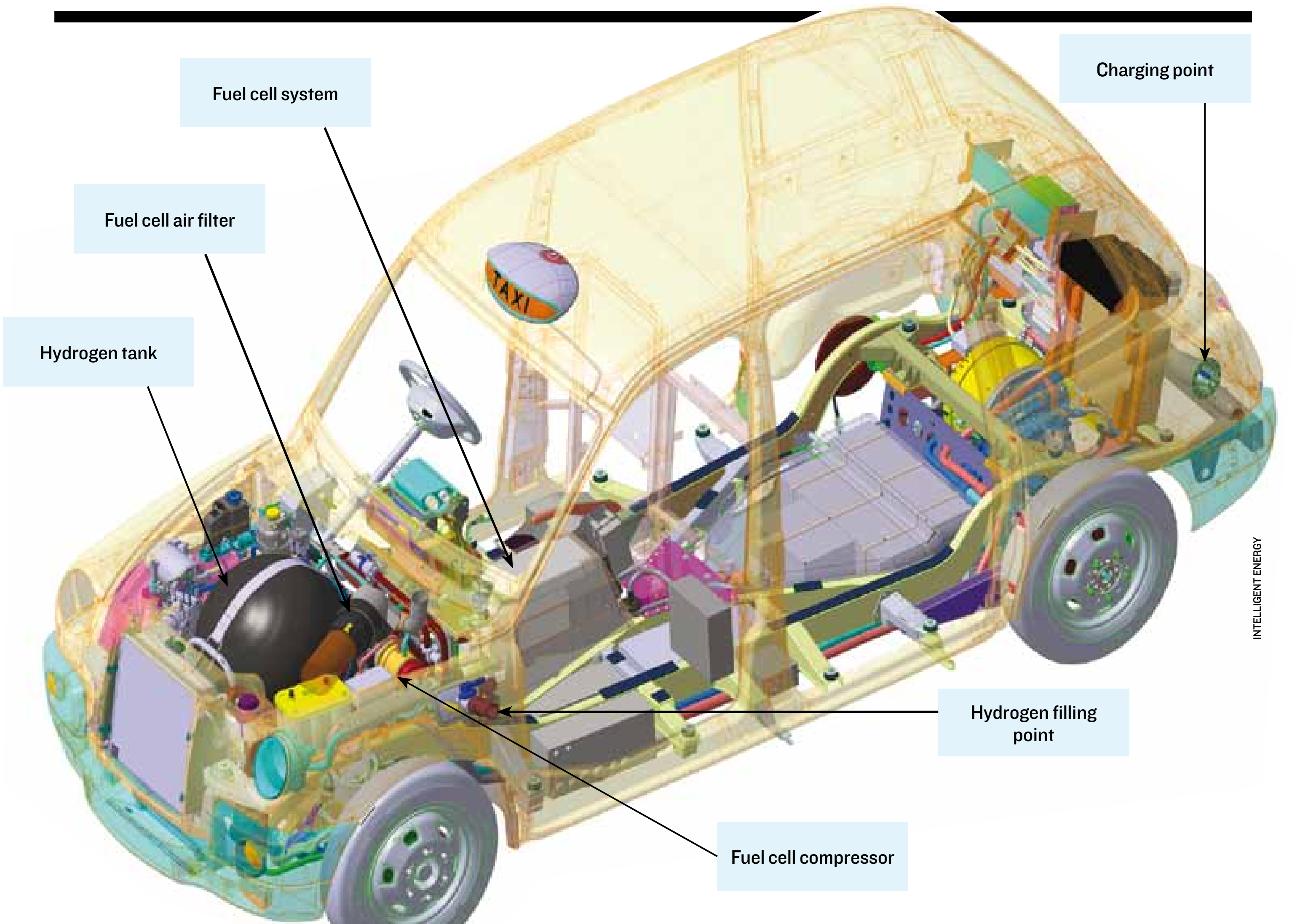
Thomas Bacon's alkali fuel cells powered Nasa's Apollo missions and the space shuttles

The Bacon cell, in essence the first alkali fuel cell, was made of activated nickel electrodes either side of aqueous potassium hydroxide. In collaboration with local engineering firm Marshall of Cambridge and the National Research and Development Corporation, Bacon successfully developed a 3kW fuel cell powered by hydrogen and oxygen and demonstrated it on an electrical forklift truck. Eventually, an improved version of this cell was used to power Nasa's Apollo space vehicles, and alkali fuel cells were used to provide electricity and drinkable water to the recently decommissioned space shuttles.

Although Nasa used Bacon's technology, in the 1950s and 1960s it was also working to develop fuel cell technology of its own. The proton exchange membrane (PEM) fuel cell



A hydrogen tank and fuel cell replace the engine, but otherwise the difference is minimal

was used during the Gemini space project and it is mainly this technology, or a variation of it, that is being put into cars today. The main difference between PEM and alkali fuel cells is that alkali fuel cells are sensitive to contaminants in the gas streams – pure oxygen has to be used, or at least the carbon dioxide must be removed when using air, and this adds to the size and complexity of the cell. Because they use a membrane instead of an aqueous electrolyte that can react with trace gases, PEM cells can use air directly.

Thoroughly modern membranes

Instead of using an aqueous liquid, PEM cells use a solid proton exchange membrane as the electrolyte, either side of which is a platinum catalyst. Hydrogen is oxidised by the anode catalyst giving electrons and protons that migrate through the membrane to the cathode. Here the protons react with oxygen molecules and the electrons, producing water. The movement of electrons from one side of the fuel cell to the other provides the current that can be used to drive a car.

One of the most common proton membranes used in fuel cells is Nafion. This Teflon-based material with sulfonate groups spaced throughout can transfer protons and cations but not electrons or anions. Although the mechanism is not completely understood, we know that the hydrogens are passed from one sulfonic acid group to the next. One of the problems with membrane-based fuel cells is that they need to run at relatively low temperatures (<80°C) to prevent dehydration. This could be good when you're sitting near the fuel cell, but does lower the efficiency of the catalysts.

Of the two platinum catalysts, it's the cathode oxygen reduction catalyst that's the least efficient, but both are pricey and that's where a lot of current research is focused. 'Platinum is great but costly,' says Paul Shearing of the Centre for CO_2 Technology at University College London (UCL), UK, as he shows me around his lab. One of the approaches used to reduce this cost is making core-shell catalysts, with the expensive platinum coating a cheaper nanoparticle made of something like nickel.

'Fuel cells can vary their output quickly, so are suited for transport applications that need quick start-up and high power'

Hydrogen fuel cell stacks are already making their way into vehicles, but as Shearing points out, internal combustion engines are still being improved and it's the same for fuel cells. Today, PEM fuel cells operate at around 55 per cent efficiency, compared to an average of around 18–20 per cent for a conventional engine. The cells are also able to vary their output quickly, and so are suited for transport applications where quick start-up and high power are needed.

'I've seen the next generation of our fuel cells and they are really impressive,' says Ulrich Eberle of General Motors' Hydrogen Propulsion Centre in Germany. Eberle claims that these next generation fuel cells are 50 per cent smaller and lighter than currently used fuel cell stacks.

On the road

So if vehicles are already running on fuel cells, what are they like? Shearing describes them as almost 'boringly mundane'. He recently travelled in one of the fuel cell powered taxis that will be used in London for the 2012 Olympics and explains that the car is exactly the same as normal but with the petrol engine removed and a fuel cell put in its place. It's a little bit more complicated than that, but not by much.

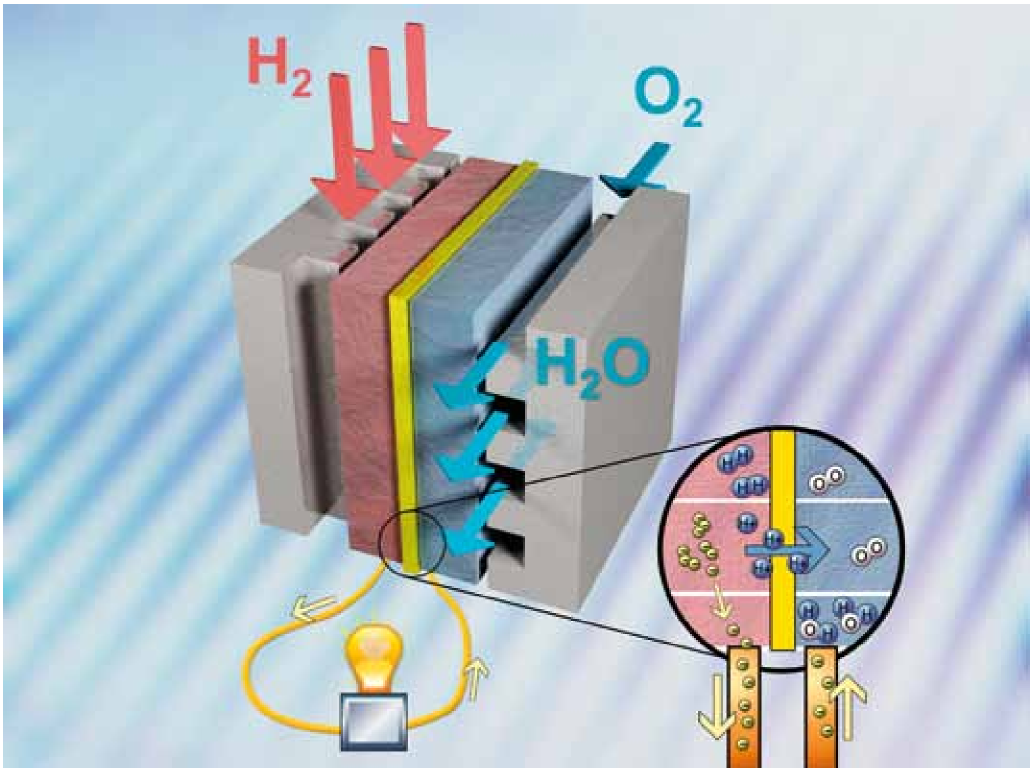
If you want to travel in a fuel cell vehicle today, your best bet is either to lease one of the fuel cell cars where a trial scheme is taking place, or for slightly less investment you can catch a bus. The Cleaner Urban Transport for Europe trial tested the feasibility of fuel cell powered buses in nine European cities. In the UK, Transport for London added fuel cell powered buses to their fleet for the trial, and have kept them on, working a route between Tower Hamlets and Covent Garden.

Of course, all fuel cell vehicles have had to undergo testing before being judged road legal but the idea of driving around with a pressurised tank of hydrogen in the car makes some people feel uneasy. And at the moment, that's what all hydrogen fuel cell cars use, a pressurised tank of gas, despite all the work on alternative hydrogen storage solutions.

'For the 2015 timeframe we want to have the compressed gas technology ready to be rolled out, but on a research level we are looking at all kinds of advanced hydrogen storage,' says Eberle. These hydrogen storage efforts include metal organic frameworks and metal hydride solutions, like sodium alanate or ammonia boranes, but so far none of the proposed solutions works on all the fronts needed for hydrogen storage on a vehicle. 'We're actively working on [hydrogen storage] alternatives, but that's on a post 2020–2025 timeframe. For early commercialisation we believe that compressed gas technology is the right solution.'

So what of the safety concerns of having a pressurised gas cylinder in the back of your car? 'We believe there are no such issues,' explains Erbele, 'we have to certify all vehicles and they have to comply with the same rules as any vehicle.' In long term trials of fuel cell vehicles using real people as drivers, for example in California, US, crashes have happened and so far there have been no great problems. In fact, at the pressures of the tanks, it is hard for enough oxygen to get into the mix to allow an explosion – leaking fuel burns as a relatively cool jet of flame rather than exploding or even setting fire to the rest of the vehicle. There have been industrial explosions involving hydrogen reported, but those tend to be tanks exploding under pressure rather than combusting.

'Of course public perception is another thing,' adds Erbele. 'For that reason we are trying very hard to convince the public that it is safe.' That's even involved getting Count von Zeppelin, ancestor of the von Zeppelin who pioneered the airships that did much to harm the reputation of hydrogen, to drive around in a hydrogen fuel cell car to demonstrate its safety.



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Proton exchange membrane fuel cells are the most likely candidates for vehicle power

INTELLIGENT ENERGY

A fleet of hydrogen powered taxi cabs will transport VIPs for the London 2012 Olympics

Fuel cell vs battery

One of the complaints that people make about battery powered vehicles is the lack of comparable range to petrol cars, and when the batteries do run out, charging your car up from a household socket takes hours. In contrast, filling up a tank from a pressurised hydrogen source takes minutes. And the London taxi, for example, boasts a range of 250 miles before needing a refill, which is not that dissimilar from my own car. However, Shearing describes the competition between battery vehicles and fuel cell vehicles as artificial. 'In the early 1990s fuel cells gave batteries a kick up the bum, and then battery cars happened first,' he explains, 'but ultimately both technologies are working towards the same aim, and are complementary.'

The complementarity is certainly something echoed by a recent report from management consultants McKinsey, commissioned by a consortium of car manufacturers. 'When we read that report we jumped for joy,' says Dan Brett, who also works at UCL. The report concludes that based on proven technologies available today, both battery and fuel cell vehicles have the potential to 'significantly reduce CO_2 and local emissions'. The report suggests a portfolio approach: batteries, with their limited range and long recharge time are best suited to small cars and short trips, with fuel cell vehicles for long drives and larger cars .

Eberle broadly agrees with these conclusions, although he goes further: 'In our opinion, extended range vehicles [various hybrid systems] and pure fuel cell vehicles will ultimately dominate. We're a bit sceptical about pure battery vehicles because of the limitations of battery technology, resulting in range limitations.'

What's keeping them?

So if the technology has been demonstrated, what's next? Investment and infrastructure. In a letter of understanding in 2009, several major car manufacturers set out their intention that a few hundred thousand fuel cell vehicles will be on the roads by 2015 and asked that energy companies and governmental organisations build up a hydrogen infrastructure to support this market. The suggestion was that the networks start in Germany, Japan, Korea and one part of the US.

FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

So are these networks being built? The UK opened its first public hydrogen fuelling station in Swindon on 20 September, and there are a few popping up elsewhere. But progress is slow except in Korea. 'They're just going for it,' says Brett. The country already has 10 stations built, based on the cluster model that centres on cities. 'If you want to roll out infrastructure you need a certain density, so you need to start somewhere and then expand into different locations,' explains Eberle. 'Our colleagues at Hyundai in Korea are being quite aggressive with their targets.'

The German government also supports the plan, but not everyone sees hydrogen as the future, including David Kennedy from the committee on climate change, an independent body that advises the UK government. 'We think at the moment, looking at the technical and economic analysis, that electric vehicles are the most promising option to decarbonise transport. We're not ruling out a role for hydrogen, but for us battery vehicles look more promising,' he said at the low carbon vehicle partnership's annual conference.

And there is also another concern with hydrogen – where it comes from. Most hydrogen at the moment comes from refining methanol or electrolysis of water, so the power from that should be renewable – otherwise the problem is just being transferred to a different part of the chain. Eberle argues that hydrogen is the perfect energy storage medium for wind power, with its variable output, producing truly green hydrogen for chemical energy storage.

The success of hydrogen powered vehicles will depend on government support to establish the required infrastructure

'In the early 1990s fuel cells gave batteries a kick up the bum, and battery cars happened first. But the technologies are complementary'

Chicken and egg situation

So we can already travel in fuel cell powered vehicles. The technology is here and working and being pushed by the major car manufacturers as well as small start-ups and university projects. But as Eberle explains, for early commercialisation there will need to be government subsidies to promote wide adoption, as to begin with it will be 'significantly more expensive to buy a fuel cell vehicle than a conventional vehicle, although if you compare it to an electric vehicle it is not so different'.

Ultimately, says Brett, it's a chicken and egg situation. So when will I be getting a hydrogen fuel cell car? 'We've made progress,' laughs Eberle. 'We're telling you it's now four years away!' But that depends on quite a few ifs along the way. It certainly seems like the technology is ready and waiting, it's politics that will ultimately decide.