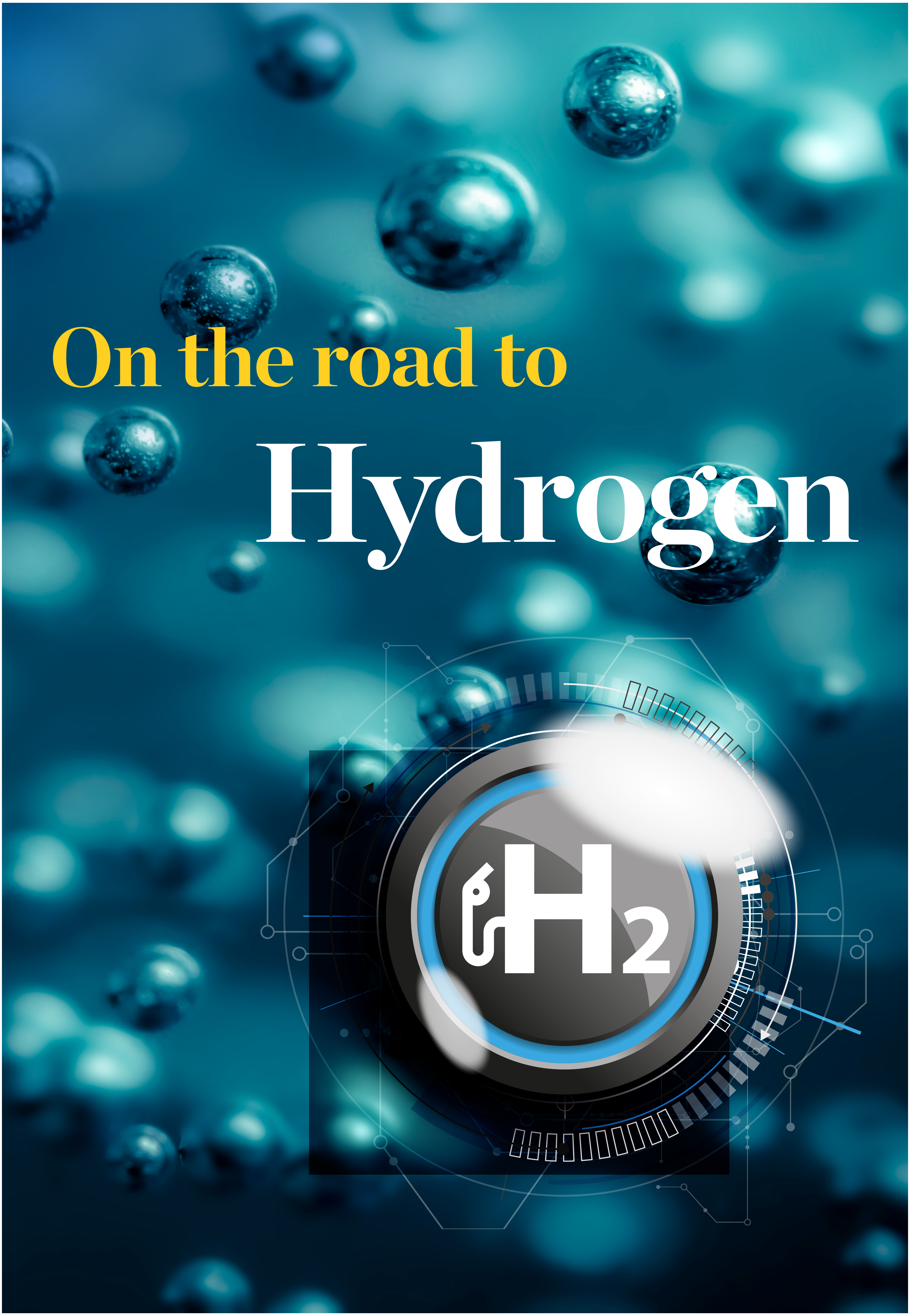
On the road to Hydrogen



Introduction

With eight years to go until the UK government's planned end to the sale of petrol- and diesel-powered vehicles takes effect, the transition away from internal combustion engines (ICE) towards alternative methods of propulsion is well underway.

In a comparatively short space of time, consumers have begun to embrace electric vehicles (EV) as a mainstream choice for new vehicle purchases, a move which has seen a relatively nascent technology claim a 6.6% market share after just a decade. However, while EVs are becoming an increasingly popular choice for both private buyers and light commercial fleets alike, there is another branch of propulsion technology of equal potential which has until recently been largely overlooked – hydrogen power.

This white paper aims to give you a thorough introduction to hydrogen powered vehicles. An overview of the technology, its history and its current applications will be covered, as will both the potential areas for growth and drawbacks to its use. It aims to provide a reasonable knowledge base from which to objectively consider the use of hydrogen powered vehicles either now, or in the future as part of a future fleet strategy.

> *Every single major manufacturer is either looking at or working on hydrogen cars*

Jon Hunt, marketing manager for Toyota and head of commercialisation of hydrogen fuel cell vehicles[1]

[1]https://www.autoexpress.co.uk/car-news/electric-cars/93180/hydrogen-fuel-cell-do-hydrogen-cars-have-a-future

The road to 2030

and alternative fuels for the journey

The clock is ticking on the count down to the ban on ICE vehicles, while the focus of media attention has largely been on the rise of electric vehicle technology as a response to the end of petrol and diesel sales, this is not the only possible solution to the problem. Indeed, while it has many benefits, there are several friction points for users of EV tech which mean that other forms of propulsion could be of greater benefit.

Electric Vehicles

While the motoring public has been quick to welcome electric vehicle technology into the mainstream, helped in part by generous government funding and infrastructure grants, EVs still represent a small proportion of new and used vehicle sales in the UK, and a tiny proportion of commercial vehicle sales.

Although public acceptance is increasing rapidly, the most common friction points to EV adoption remain largely unchallenged for passenger vehicles. The lack of charging infrastructure across the country, both 'at home' and at publicly available charging points in towns are still the main reasons given for not choosing an EV for 67% of British motorists[2].

For commercial use, EV range remains a problem for all but urban and 'final mile' usage. With even leading LCV's struggling to reach 100 miles of real-world range[3] it is easy to see why the currently available technology is still some way behind traditional ICE when it comes to ease of use.

BioFuel

One option for clean propulsion which has both range and adoption-cost benefits compared to EV tech, is BioFuel. Already in use across the globe in both private vehicles and commercial fleets, BioFuel is simply a combustible fuel which has been produced from plants and crops. In 2020, biomethane accounted for 93% of all biofuels sold for the HGV sector. BioFuel is also used in passenger vehicles in the UK, with all petrol and diesel sold now containing up to 10% bioethanol blended into the fuel, and countries such as Brazil having run mainly on BioFuels for decades[4], the technology is widely accepted. Many engines will run easily on a blend of BioFuels with reasonably little adaptation, so the cost of adopting the technology is relatively low.

Because the plants and organic matter fermented to make the fuels are accepted to have sequestered carbon during their growth, the burning of BioFuel is theoretically carbon neutral, but in reality, it produces far fewer emissions both at the exhaust pipe and overall, when compared to fossil fuels.

The most immediate downside to this adoption in the UK is the current high cost of production when compared to fossil fuels, although this would lessen as economies of scale were applied to the process. A wider long-term problem for BioFuel is the large amount of land which is needed to produce BioFuel crops. Not only is long-term monoculture (repeated growth of a single species without crop rotation) bad for the environment in which it takes place, it also prevents fertile land for being used to grow food – putting increased strain on food production going forwards.

Hydrogen

If the UK is to hit the 2030 target with minimal disruption to everyday life and the economy, then non-fossil-fuelled propulsion needs to evolve to meet these needs. While EV tech is the current forerunner, there is an alternative power source which has been around for just as long as electricity, and which, although currently less popular than EV tech, could go a long way towards the road to Net Zero for drivers.

Step forward hydrogen technology...

[2]https://www.kwik-fit.com/press/pandemic-has-caused-almost-14-million-uk-drivers-to-change-their-car-buying-plans
[3]https://www.whatcar.com/mercedes-benz/e-sprinter/van/review/n22228
[4]https://news.mongabay.com/2019/11/brazil-sugarcane-growth-can-meet-biofuel-need-and-not-drive-deforestation-study/

Brief Overview of
Hydrogen technology

Covered in greater detail below, as a potential alternative to fossil fuels, hydrogen has several key benefits compared to Electric Vehicle technology. When mated to good infrastructure, hydrogen refuelling takes a similar time to conventional fuels. Compared to EV charging, hydrogen technology would not require upgrades to a national grid, or a charging point to be installed on every house and driveway.

It is already working well in commercial applications today, and is equally proven for passenger vehicles, although, for reasons outlined below, it has yet to achieve widespread adoption in this setting.

Gas Production

Hydrogen is the most abundant element in the universe, and it makes up around 75% of all the matter around us.

Hydrogen gas, however, is scarce and, unlike methane or even helium, it cannot be found in large scale natural deposits. As a result, any usable volume of hydrogen gas is created as a by-product of other chemical reactions, and currently, when hydrogen gas is formed in industrial volumes, it is usually created in one of two ways.

The most common method of production, accounting for the majority of global supply, is 'steam methane reformation.' During this process, steam is pumped at high pressure and temperature into a reformer, in which a nickel catalyst reacts with the methane and steam to produce hydrogen and carbon monoxide gasses.

While this method is cheap, its downside is the high quantity of carbon that is released during the reaction, as well as the energy required to begin the heating process to begin with. While modern carbon capture methods can largely eliminate the former via capture, every ton of hydrogen produced creates between nine and 12 tons of carbon dioxide.[5]

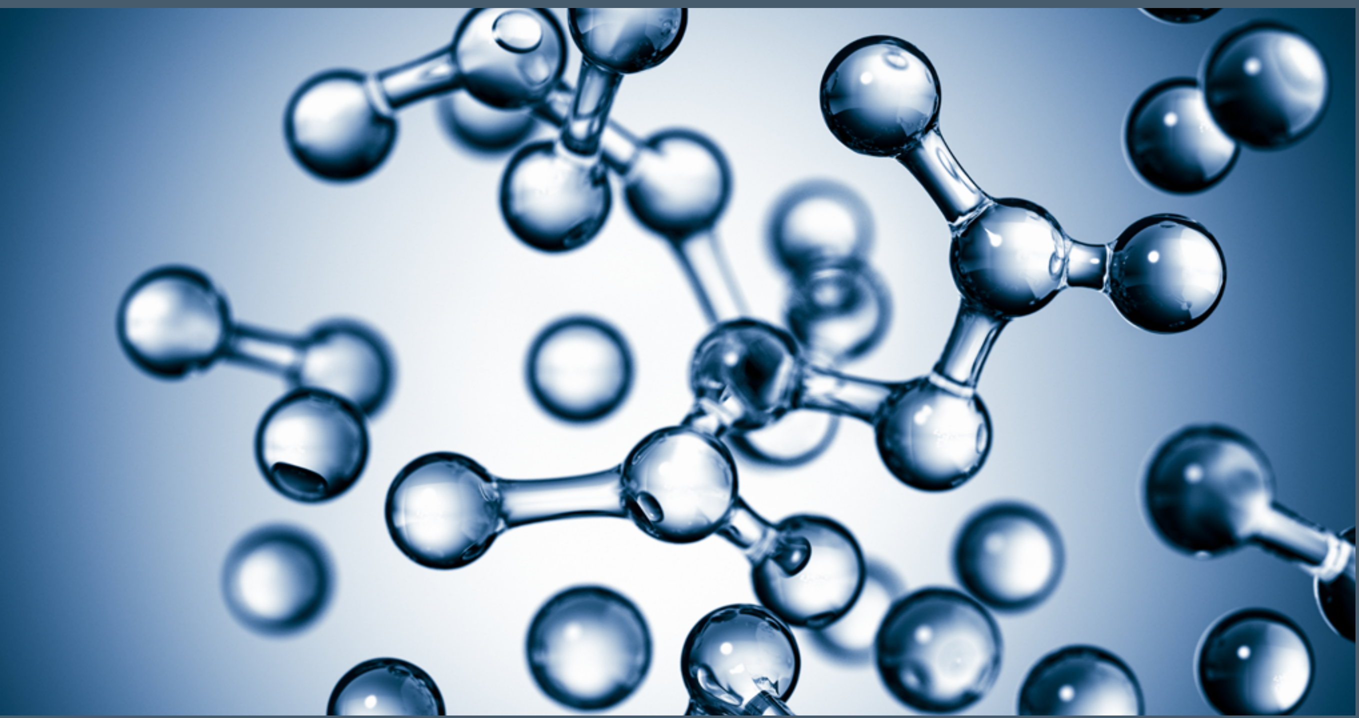
The second most common method of hydrogen production is electrolysis, in which hydrogen gas is split from water molecules by an electrical current, which creates no other by-products. Although this method accounts for just 5% of current hydrogen production, it is predicted to gain popularity as increased use through environmental pressures drives the price down to a competitive level for large scale production.

[5]Collodi, Guido (2010-03-11). "Hydrogen Production via Steam Reforming with CO2 Capture" (PDF). CISAP4 4th International Conference on Safety and Environment in the Process Industry. Retrieved 2015-11-28

Usage in Transport

Burned vs Fuel Cell Technology

As an abundant element and a highly combustible gas, it is little surprise that hydrogen propulsion is not a new idea. The first hydrogen engine was invented in the 1800s as an alternative to steam power, with various forms of hydrogen combustion having been proposed since then, of which the basics always remain the same.



The burning of hydrogen as a major part of 'town gas[6]' for heating, cooking and for vehicle propulsion was not uncommon in the UK until the advent of the North Sea gas production made it uneconomical in the 1960s. It was not pure H2 however, as it was a mixture of hydrogen, carbon dioxide and carbon monoxide, and as a result, it was not emissions free when burned.

As production methods have modernised to allow the production of pure gas, today, burning hydrogen gas in place of petrol or diesel is emissions free at the exhaust pipe.[7]

A further benefit to the use of hydrogen as ICE fuel, covered in greater detail below, is the low cost of adoption. Much like BioFuels, conventional engines can be adapted to run on compressed hydrogen gas without much alteration to the engine, making the technology more appealing to operators.

This would sound like the dream solution to all emissions problems in private and commercial transport, but similar issues to EV tech remain problematic to hydrogen when used as a burned fuel. Currently, the supporting infrastructure for refuelling hydrogen powered machinery is not where it would need to be for easy national adoption. There are relatively few gas production facilities in the UK, and even fewer places to refill a vehicle at the roadside.

At the time of writing, there are just 11 H2 filling stations in the UK[8], with the majority located around London and the south east of England. As such, running a machine which does a high mileage, or which does not operate on a fixed route is impractical in the current circumstances.

[6]https://www.nexant.com/resources/hydrogen-town-gas-industrial-gas-decarbonised-fuel
[7]https://www.epa.gov/emission-standards-reference-guide
[8]https://www.drivingelectric.com/your-questions-answered/1363/where-can-i-buy-hydrogen-and-where-my-nearest-hydrogen-filling-station

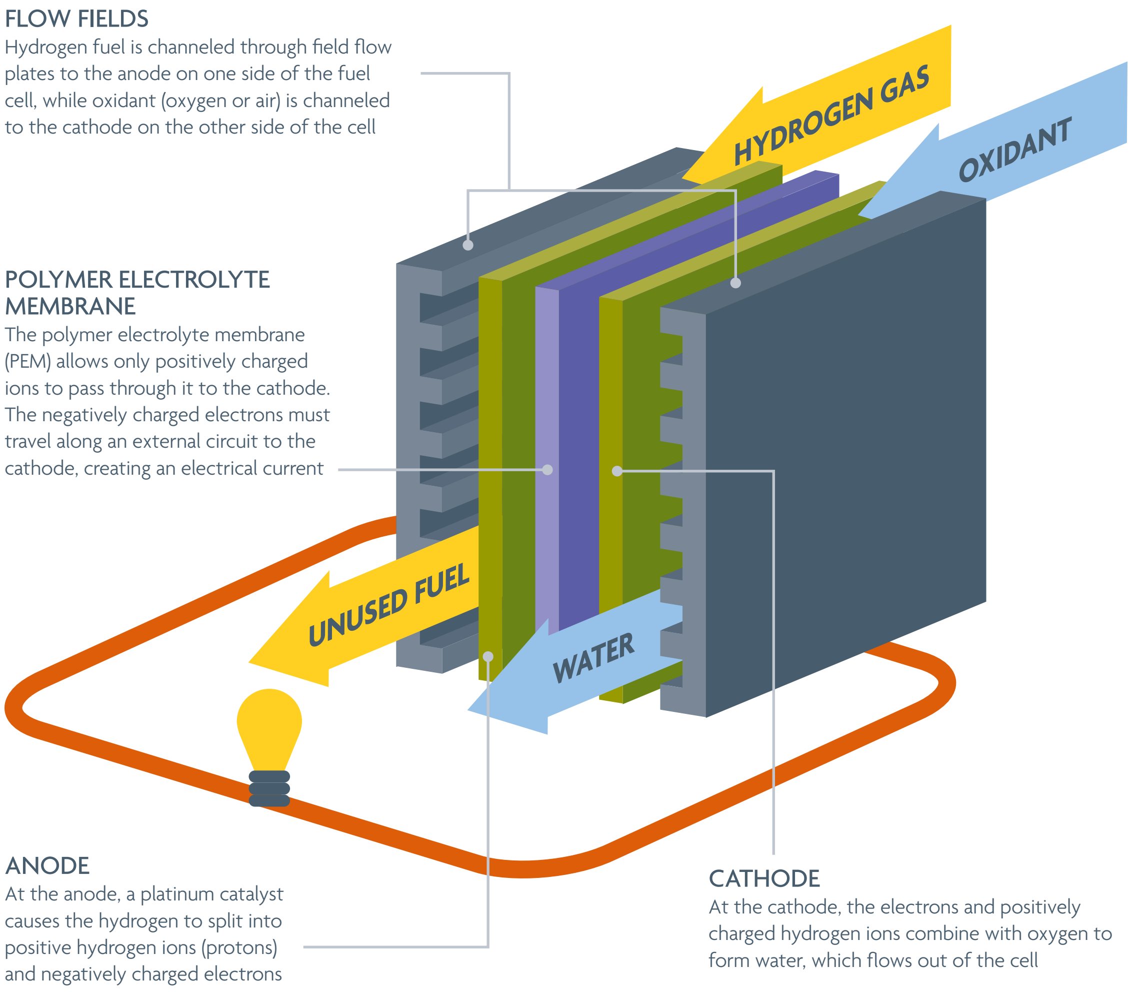
Fuel Cell Technology

Unlike ICE running on hydrogen, Hydrogen Fuel Cell Electric Vehicles (HFCEV) run on electricity, in the same way as Battery Electric Vehicle (BEV). While a BEV must stop and recharge its batteries at static charging points, a HFCEV is able to produce its own electricity on the move however, thanks to fuel cell technology.

To create electricity in a fuel cell, pressurised hydrogen gas is stored in the vehicle in tanks, much like petrol or diesel would be with an ICE. Inside the fuel cell itself, the hydrogen and oxygen undergo a reaction across a membrane, in which the electrons are split away from the protons to form an electrical current. The only bi product of the reaction is water.

How do hydrogen fuel cells work?

As hydrogen gas is relatively energy-dense, the supply of hydrogen needed to form electricity for movement gives a far greater driving range than is possible in a traditional BEV. Re filling hydrogen tanks is a faster process than charging a battery, meaning that drivers are not faced with potentially long waits during journeys. As an added benefit, the need for heavy lithium-ion batteries within the car is eliminated, meaning that vehicle efficiency is also increased.



[9]https://www.setra.com/blog/what-is-a-hydrogen-fuel-cell-and-how-does-it-work

Current
State of Play

In the last decade, HFC technology has begun to gain traction amongst car and truck makers alike. Driven partly by the need to investigate alternatives to pure EV technology, and spurred on by governmental incentives, the last three years have seen a step change in the application of the technology in the commercial sector, as well as the arrival of several big players into the passenger car marketplace.

From refuse collection trucks, buses, taxis, light vans, and passenger vehicles, the 2020s look set to be the decade in which hydrogen fuel cell technology comes of age.

Commercial Vehicles

For reasons to be covered in greater depth further on, it is the commercial vehicle sector in which hydrogen fuels have the fewest barriers to adoption, and the most immediately tangible benefits to its use.

Hydrogen can be used commercially both as a combustible fuel, and as part of a fuel cell system. Both are already in use across several areas of transport, and with several large manufacturers around the world now committed to further investment in the tech, this is likely to grow in the coming years.

JCB – "the future lies with hydrogen fuel"

JCB, the pre-eminent UK commercial machinery manufacturer, has invested heavily in hydrogen technology. As a global brand supplying heavy machinery for the construction industry, JCB has stated that it believes the future of zero emissions machinery lies entirely with hydrogen fuel, and not EV technology.

With a range of proprietary hydrogen engines in development and testing, JCB have announced their intention to meet the 2030 net zero deadline via hydrogen combustion, stating the three main reasons for doing so in place of EV tech.

Time: according to the research carried out by JCB, the average UK family car is used for around 300 hours per year. With a mixture of commutes and reasonably short journeys, down-time for recharging is not usually a major problem for most drivers. Commercial machinery, whether agricultural or industrial is usually operated for long periods of time, and often in inaccessible locations.

A 20 tonne JCB excavator is operated for an average of 8000h per year, which is not dissimilar to the hours worked by many trucks, coaches, and tractors. In these circumstances, not only is the operational range of critical importance, but also the commercial downtime needed to re-charge a battery (even on a fast charge) must be considered as having a major impact on profitability for operators. Unlike batteries, which can take a minimum of 20 minutes, and up to 28 hours to charge (depending on the power source available) hydrogen gas tanks can be refilled in a similar time to that of a conventional fuel tank.

While hydrogen filling stations are currently rare in the UK, hydrogen refuelling 'hubs' can be produced to be transported with relative ease to construction sites or transport yards in the same way that commercial diesel tanks are currently, allowing any machines on site to be filled in the usual manner.

A secondary consideration is that of weight. According to Lord Bamford of JCB, converting a conventional 20 tonne excavator to EV power would require an additional 8 tonnes of batteries to be fitted to the machine. While this addition might be acceptable in industrial applications, the same is not true for HGV, LGV or bus operators, where operational weight limits are strict. Under current legislation, operational weights are fixed, so an additional 8 tonnes of battery would result in less available payload.

The third consideration for commercial operators is cost. Both EV and especially HFCEV technology is vastly more expensive than the current ICE on sale. JCB has estimated that if it were to adapt all of its current range to run on EV tech, prices would rise by an average of 130% per vehicle on alike for like basis.

Conversely, its new range of hydrogen powered engines will cost broadly the same as their diesel-powered equivalents. As added benefits, power figures will also be comparable, and the engines will be able to be maintained by any mechanic familiar with JCB products with only a minimum of training required.

Wrightbus hydrogen fuel cell powered bus

The Northern Ireland based Wrightbus company, has just announced that its latest hydrogen fuel cell powered bus, the Hydroliner, has been purchased by Transport for London for use as part of the London bus fleet.

Developed as part of an EU-wide initiative for hydrogen vehicles, the double-decker Hydroliner is powered by a fuel-cell, an 1100 litre hydrogen tank and a 48kWh battery, giving it a range of up to 280 miles with a refuelling time of just eight minutes.

The initial fleet of 20 buses will run across London, powered by hydrogen created as a by-product of a chemical plant in Kent. By 2023 they will be able to run on truly 'green' hydrogen, thanks to electrolysis derived gas, produced via an offshore windfarm.

Wrightbus has stated that this initial roll-out of 20 will pave the way for a new wave of cheaper hydrogen powered buses across the UK in the future as part of the Joint Initiative for hydrogen vehicles across Europe (JIVE). This initiative is seeking to deploy 139 new fuel cell buses, and all associated refuelling infrastructure across five countries in Europe (including the UK) in the coming years.

CaetanoBus tests hydrogen fuel cell electric buses

Caetano, the Portuguese manufacturer, has also been testing a range of Hydrogen Fuel Cell Electric Vehicle Buses, which have been developed in conjunction with Toyota.

Using the same fuel cell technology as Toyota's Mirai passenger car, with a 1.6 kWh battery pack, hydrogen powered fuel stack generator and a 180kW electric motor, the Caetano City Gold H2 bus has proved reliable in trials in both London and Paris. The French operator, RATP is set to order a fleet of these buses for use in Paris, although TFL, its British counterpart, will likely go with its home market supplier, Wrightbus.

Passenger Vehicle Manufacturers

Hyundai

The Korean manufacturer has been quietly developing its HFCEV tech for 23 years. When the ix35 Fuel Cell SUV was launched in 2013, it was the world's first mass production HFCEV. With an operational range of over 350 miles, and a refuelling time of under three minutes, the ix35 was well received by press and public alike.

Today, the Hyundai NEXO is claimed to be the next generation of fuel cell vehicles. A mid-sized SUV, the NEXO boasts a 1.56kWh battery, which is mated to a 120kW electric motor to gives it a 414-mile range.

Toyota

Toyota has been a front-runner in HFCEV tech for a considerable length of time. Having begun research and testing of its fuel cell tech in the 1990s, it unveiled its first commercially available passenger vehicle, the Mirai, in 2014. The model has since gone on to sell over 10,000 units globally, before an all new Mirai Mk. 2 went on sale at the end of 2020.

A mid-sized passenger saloon the Mirai is driven by a 113kW electric motor, mated to a 1.6kWh battery. Although a heavy vehicle for it size, the Mirai enjoys a good range of 312mi to a tank of hydrogen, which equates to a combined real-world fuel economy of 66mpg.

Future passenger HFCEV players

Other manufacturers have announced their exploration of the technology however, proving that the hydrogen powered passenger vehicle concept is far from dead. BMW began testing its i Hydrogen NEXT SUV on European roads in June 2021[10] at the same time as Jaguar Land Rover announced its development of an all new HFCEV SUV, based on the Defender, which is due to begin testing later this year[11].

[10]https://www.press.bmwgroup.com/global/article/detail/T0334225EN/everyday-testing-of-bmw-i-hydrogen-next-with-hydrogen-fuel-cell-drive-train-begins?language=en
[11]https://www.cnbc.com/2021/06/15/jaguar-land-rover-is-developing-a-hydrogen-powered-vehicle.html

Barriers to the success of hydrogen, and ways to overcome them.

It is clear that as it stands today, there are two main challenges in the way of wide-spread adoption of hydrogen vehicle technology: cost and lack of infrastructure. Neither can be solved overnight, and neither will be able to be resolved without governmental and commercial intervention.

Even if both were to be fully implemented, it would still take several years to bring the UK's hydrogen infrastructure to a level even half-way approaching the current EV infrastructure, which is itself accepted to be in need of significant further development. However, in the last 24 months, several key developments have occurred which could see this course accelerate.

UK Government hydrogen initiatives

The UK Government has been investigating hydrogen technology as an alternative to fossil fuels and EV tech in the run up to its announcement of the 'Net Zero' target. Seeing the switch to green tech as a huge potential boost to the UK economy, the Prime Minister, Boris Johnson released a statement as he set out a plan for the road to 2050.

"Imagine how our Green Industrial Revolution could transform life across our United Kingdom. You cook your breakfast using hydrogen power before getting in your electric car, having charged it overnight from batteries made in the Midlands. Around you the air is cleaner, and the trucks and trains, ships and planes are running on hydrogen or a synthetic fuel. British towns and regions – Teeside, Port Talbot, Merseyside, and Mansfield – have become synonymous with green technology and the jobs they bring. This is where Britain's ability to make hydrogen and capture carbon pioneered the decarbonisation of transport, industry and power."[12]

In order to achieve this vision, a detailed 10-point plan, was published for "A Green Industrial Revolution" of which three points are relevant to the future of hydrogen vehicles.

- **2. Driving the growth of low carbon hydrogen:** a £240 million Net Zero Hydrogen Fund created to fund investment into supply chains, infrastructure, and related industries.
- **4. Accelerating the shift to Zero Emissions Vehicles:** a £2.8 billion support package for British manufacturers will be pumped into supporting emissions free vehicle technology and manufacturing.
- **10. Green Finance and Innovation:** a £1 billion Net Zero Innovation Portfolio is being launched, alongside the aim of investing 2.4% of GDP into green projects by 2027. This will include a significant investment into an experimental 'Hydrogen Hub' in the Tee Valley.

Added to this, the Government has published a detailed hydrogen strategy, along with a £30 million investment into hydrogen vehicles, supply chains and technology. Of this pot:

- £9.4 million of government funding is allocated for 22 studies to develop innovative automotive technology, including hydrogen vehicles and a lithium extraction plant.

Private Investment

In-line with the government's new focus on the need to invest in hydrogen, several key global brands have also stated their intentions to invest in the space. As the technology is currently an outlier as a fuel for general consumption, the potential return on private investment is huge.

In the last 24 months, one key initiative has emerged for hydrogen transport, which looks to accelerate the introduction of hydrogen powered trucks across the UK and Europe. A joint venture between OMV Oil & Gas, Daimler, Volvo and IVECO, the H2Accelerate Program, has been set up to initiate a decade-long scale up of hydrogen power in HGVs.

Elisabeth Brinton, EVP for Shell's New Energies unit, stated: "The prize is clear. By boosting scale in a big way, hydrogen-fuelled trucks will need to become available to customers at or below the cost of owning and operating a diesel truck today. This means truck customers will need to have access to a fully zero-emissions vehicle with a similar refuelling time, range and cost range compared to the vehicles in use today."

Intermediate steps to aid earlier adoption

Even with the huge investment taking place in the years to come, the infrastructure needed for more wide scale use is still a long way off where it needs to be. The 11 hydrogen filling stations that are available across the UK will not allow for any more than localised use by a few vehicles.

While this makes the free movement of passenger and Light Commercial Vehicles next to impossible, for vehicles which operate around a centralised hub, this obstacle can be overcome with relative ease and a reasonable investment.

As shown by the JCB hydrogen vehicles, reasonably portable hydrogen refuelling tanks can be created and installed in central locations to allow for the refuelling of multiple vehicles as needed. While this does not work for long-range applications, smaller hydrogen hubs can and would be perfectly placed to service many types of vehicle use including but not limited to:

- Construction site vehicles
- Refuse collection trucks
- Urban delivery vehicles, in particular cold-chain supply to and from supermarkets
- Airport service vehicles

In these scenarios, the greatest friction points to the immediate conversion to hydrogen technology, whether burned or fuel-cell are removed, as vehicles can be refuelled within minutes whenever they return to their hubs. Vehicle downtime is kept to a minimum, and multiple vehicles can be serviced by one central refuelling hub within a short space of time.

The change has already begun, with major UK construction company MACE having announced its intention to switch from diesel powered site generators to hydrogen powered generators by 2022 and it is thought that several more are considering making the same switch, it seems that hydrogen technology may be adopted sooner than anticipated.

[12]https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution/title

Summary

In order for the UK to be ready for the ban on the sale of petrol and diesel-powered cars in 2030, and the phased withdrawal of hybrid powered vehicles thereafter as a move towards the stated aim of being 'Net Zero' by 2050, it is clear that many and significant changes are needed to the landscape of the UK's current transport provisions.

While electric vehicle technology has proven popular with the public and is fast gaining a significant market share among passenger vehicle sales, the current technology is not appropriate for use in many commercial settings for reasons of range, re-charging time and the high cost of buy-in to the batteries.

BioFuel is also a possible alternative to fossil fuels, it comes with a low cost of adoption, is renewable and can be integrated into the current infrastructure without much trouble. However, BioFuel is problematic environmentally as a lot of land would be needed for crop growth, purely to meet the possible demand. On top of which, even though it is arguably carbon neutral over its life cycle, the burning of BioFuel still produces carbon emissions at the point of ignition, which means that it is not seen as a truly 'clean' solution to the UK's transport needs.

Hydrogen propulsion, whether as a burned gas or in a fuel cell, has very strong potential to solve many of the issues above, and could do so in a relatively short time frame. When used as either a liquid fuel, or in a fuel cell, the result is emissions free, and with the ability to produce hydrogen gas in a green manner already available to us, emissions need not be "hidden" elsewhere in the energy production process.

Both forms of hydrogen propulsion technology are already well developed and proven in their respective fields. There are already three hydrogen powered passenger vehicles on sale to the public, and commercial use in buses, trucks, generators, and other equipment is already being seen across the world, with great results.

The biggest single barrier to adoption of hydrogen technology is that of a lack of infrastructure. The UK lacks gas production, transport, storage, and dispensing facilities on any usable scale. While there is huge investment into all of these from both the public and private sector, building and scaling these networks will not be an instant project.

Until this infrastructure is widely available, and the adoption of hydrogen power reaches a critical mass, it will remain an outlying technology in the next few years, with a higher cost of use born by the early adopters in its "pre commercial" phase.

These initial barriers to success aside, when viewed in its entirety as a highly anticipated, and well-funded solution to transport and power needs in an emission's free environment, the next ten years could well be the decade in which hydrogen technology comes of age.

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Published September 2021