Hydrogen: fuel of the future or science fiction fantasy?

Introduction

For decades, hydrogen has been thought of as a potential fuel source: it is the most abundant element in the universe and it can be burned to release energy with the only byproduct being water (Johnston *et al.*, 2005). Unfortunately, hydrogen does not naturally occur on Earth and must be extracted from other primary sources, therefore it is not really an energy source but a store and carrier of energy. However, many people see it as a potential way of reducing reliance on fossil fuels and global warming caused by their burning. High costs and lack of expertise have slowed development though, and hydrogen powered technologies are still not mainstream. In recent years though, with government targets and subsidies to reduce greenhouse gas emissions, hydrogen technology has seen a surge in investment and is being trialled in many areas. This report will look at what is the current level of progress in hydrogen technology in the UK and around the world, what are its potential benefits and how likely the technology is to become adopted in a mainstream way. The sections will look at the problem hydrogen technology is trying to solve, the history of hydrogen technology, hydrogen cars, other forms of hydrogen transportation, hydrogen power for homes and businesses, the safety of the technology and finally, the potential joint industry of hydrogen and electricity.

The problem

"When the last tree is cut, the last fish is caught and the last river is polluted, when to breathe the air is sickening, you will realize, too late, that wealth is not in bank accounts and that you cannot eat money" – Alanis Obomsawin, Odanak reserve, Quebec

The UK emitted 379 million tonnes of CO_2 emissions in 2016 (almost 5.8 tonnes per person): CO_2 is linked to global warming, which leads to climate change, which could have serious negative consequences for the UK and the world (Solomon *et al.*, 2007). The Climate Change Act (2008) requires that by 2050, the UK's CO_2 emissions are reduced by 80% compared to 1990 levels. The largest sectors contributing to the UK's emissions are electricity generation and transport. It has been calculated that in order for the UK to reach its 2050 goal of reduced emissions, annual emissions per person will have to be about 1 tonne per year, which is equivalent to the CO_2 produced every 3000 miles by the average fossil fuel driven car (Valdes, 2018). Therefore, it is clear that there will have to be huge upheavals across all sectors to meet that reduction goal, especially in the electricity generation and transport sectors.

In addition to the need to reduce CO_2 emissions, transport powered by burning diesel has come under attack in recent years for the amount of particulate emissions and nitrous oxide that is being released. These pollutants have been linked to respiratory problems, allergies and asthma attacks (Leggett, 2018). It is hoped that moving to hydrogen based technologies will dramatically reduce emissions of greenhouse gases and particulates. Finally, regardless of the impact on health and the environment, fossil fuels are a finite source of energy and are important components of the essential chemical industry, so it would be wasteful to continue burning them when cleaner and more sustainable ways of powering vehicles and homes exist.

History and basics of hydrogen technology

"the airship will continue on in science fiction stories as this quick and easy visual cue that we're in a world that's like ours but a bit different, and perhaps also more wondrous" – Roman Mars, Broadcaster

Hydrogen may be the most abundant element in the universe and can be burned to release energy with the only byproduct being water, but it has never been adopted as a common fuel source in any industry except perhaps spaceflight. This is because it does not occur naturally on earth and requires more energy to produce than is released from its burning. When hydrogen is extracted, it is a gas at room temperature, which is extremely light: hydrogen is the lightest element in the universe. There are also difficulties in transporting the gas due to its flammability, and this is perhaps the element's most famous quality due to its association with the Hindenburg disaster. It was this disaster that brought down the entire hydrogen fuelled airship industry and for many people, led to hydrogen being forever associated with danger. When discussing hydrogen technology, the Hindenburg is always something of an elephant in the room and is always mentioned at some point. Roman Mars's description of airships as making the world "more wondrous" represents an attitude to hydrogen technology as a whole: it is rocket fuel and has been described as 'the fuel of the future', so talking about it is a viable energy source is often met with accusations of describing a fantasy. The truth is however, many people are working to make that vision a reality.

Hydrogen can release energy by being burned like natural gas in boilers or oil derived fuels in engines. The equipment needs to be adjusted to work with the new fuel, but no great advances in technology are needed to heat homes or drive engines with hydrogen. However, hydrogen as a fuel is most commonly associated with the electricity it can generate from a fuel cell. In a fuel cell, hydrogen reacting with oxygen in the air releases electrons, with the hydrogen and oxygen molecules forming the waste product: pure water. The fuel cell was invented in 1842 by the Welsh scientist, Sir William Grove, who called it the Gas Battery (Grove, 1843). It took another 100 years for Francis Bacon to develop a practical fuel cell, and the technology was further developed in the USA in the 1960s and 70s. Finally, fuel cells found a practical purpose, albeit a niche but high profile one, providing water and electricity to astronauts in space on the Apollo and Space Shuttle missions (Scott, 2009). Fuel cells have also been used on submarines of the German Navy since 2005.

Hydrogen today is mainly produced as a byproduct of the fossil fuel industry, through reformation of natural gas. This involves reacting natural gas and steam to release the hydrogen from methane, but this also causes the carbon from methane and oxygen from water to bond, creating CO_2 (Planete Energies, 2015). With this method of production, the fuel's green credentials are immediately under threat, as while hydrogen may burn without releasing CO_2, CO_2 is released when the hydrogen is produced. Alexander Wokaun writes "Hydrogen will only represent an attractive transportation fuel to meet stringent CO2 reduction targets if it is produced from primary energy resources with zero or low CO2 emissions in the future energy system" (Wokaun *et al.*, 2011, p.212). Also, it seems unnecessarily complicated to convert energy from fossil fuels to hydrogen to electricity or heat when it can be converted straight from fossil fuels to electricity or heat. In response, the industry aims to produce hydrogen through electrolysis from the excess electricity generated by renewable energy (this will be discussed in a later section). Again though, critics question the wisdom of converting electricity to hydrogen and then back to electricity. Ultimately, researchers are interested in finding other ways of producing hydrogen: reacting water with aluminium is one area of research, and a recent development has come from accidentally dropping an aluminium alloy into water, which produced hydrogen in a very efficient reaction. Photoelectrolysis and microorganisms are also potential sources of hydrogen, but these are very much in the early stages of research (Planete Energies, 2015).

Since hydrogen doesn't exist as primary energy source to be found in a useful state, its use to humans is as an energy carrier: a way of capturing and transporting energy, like electricity. Scott Blanchett, the VP of hydrogen technology company, Nuvera says "hydrogen is portable electricity". The advantage of hydrogen as energy storage compared to electricity is that while electricity has to be stored in batteries which have limited storage capacity and are built of rare metals (with no real alternative technologies being seriously worked on), hydrogen is stored in simple tanks, like oil is and which can easily be expanded. Furthermore, hydrogen provides the best value for energy storage compared to its density: lithium-ion batteries have a specific energy of about 250 W/kg, compared to 12889 W/kg for petrol and 39443 W/kg for hydrogen. Many people see hydrogen and electricity as rivals to be the major mode of stored energy distribution in the future but the truth is more likely that they will complement each other and both be integral in the fight against pollution. It is possible though that consumer choices may lead to a technology 'lock-in' where one fuel dominates, but it is also possible that the technologies will be found to be appropriate to different niches of the industry.

Hydrogen cars

"Britain must invest in hydrogen fuel cell cars if we're to ditch fossil fuels by 2040" – Peter Thompson, CEO, National Physical Laboratory

The car is often described as the ultimate consumer product, but people are increasingly becoming educated to and concerned by the damaging environmental impacts of road vehicles. Environmental concerns are now a large part of car design and the market for hybrid and electrically fuelled vehicles in the UK has gone from non-existence 20 years ago to one of the most talked about sectors today. It seems natural then, that much discussion about hydrogen's potential as a fuel focuses on hydrogen cars, so this is the first hydrogen technology this paper will look at. Firstly, a clarification to be made: most working hydrogen vehicles like the Toyota Mirai use fuel cells to generate electricity (these are known as fuel cell vehicles, or FCVs for short) and the electricity powers motors to move the vehicle. FCVs are electrically driven vehicles: the other branch of electric vehicles, which are currently more mainstream, are battery electric vehicles (BEVs) like the Nissan LEAF. The main advantage of FCVs compared to BEVs is that they have a range and fuelling time comparable to petrol or diesel cars, whereas only top of the range BEVs can drive over 200 miles on a single charge and all models take hours to fully charge. Traditional technology improvement curves suggest that these technologies will improve and filter down to cheaper BEVs, but there are some scientists who are concerned that batteries are near their maximum performance with the materials we have today and no amount of experimenting can make them perform as well as companies would like. There are also concerns that if BEVs become too popular, the demand on the National Grid will become too much: in 2017, there were over 32m registered cars in the UK and if they were all to be replaced by BEVs, the UK would need to substantially increase its energy generating capacity to charge millions of cars simultaneously. Also, not all car parking locations have access to charging points and it would be unpopular for people who regularly park on street to cover the pavements in charging cables.

On the other hand, one criticism of FCVs is that they rely on energy converted from electricity to hydrogen, then they convert the energy from hydrogen back to electricity, which results in energy loss and reduced efficiency compared to storing the electricity in a battery. In response though, hydrogen supporters point out that while it is more efficient to move power straight from a battery to a motor, the extra weight of batteries (which are very heavy in all BEVs) compared to a fuel cell and hydrogen tank means the hydrogen car makes more efficient use of the energy it carries.

For many British people, their introduction to FCVs was an episode of Top Gear in 2008. At the time, the presenters described it as the future of cars and mocked BEVs for their short range and high cost. Since then however, the BEV market in the UK has grown from 138 pure electric cars being newly registered in 2010, to 13597 in 2017 (SMMT, 2018). While that is still a tiny proportion of the 2.5m cars that were newly registered in 2017, it is a hundredfold increase in sales in just 7 years. Globally, there are even more impressive numbers for BEV sales, with over 140,000 sold in China in the first quarter of 2018, and in the same period, an amazing 48% of cars sold in Norway were electric (Boffey, 2018). Meanwhile, there were only 6475 hydrogen cars registered in total globally by the end of 2017. Given this state of affairs, one could reasonably assume that BEVs are the future of road transport, and FCVs have failed to become viable. People nowadays often dismiss hydrogen cars as either a pipe dream, or even a cynical ploy to discredit the viability of alternatively fuelled vehicles: Elon Musk, the founder of pioneering battery company Tesla has described FCVs as "very silly" and says "the best (future) hydrogen technology cannot compete against current battery technology," but he may be considered biased since has $57bn company has bet everything on battery technology.

So has the battle for the future of road transport been lost? Not according to major manufacturers like Toyota and fuel providers like Shell, who are continuing to invest in FCV technology. Toyota has brought the world's first mass produced hydrogen car to market, but that was only in 2015 and only 27 were available to buy in the first two years of UK sales. The company is reportedly expecting the car to take decades to be successful: it is no secret that new technology takes a while to catch on. Toyota knows this better than most: when they launched the world's first hybrid electric car, the Prius, they sold about 300 vehicles in the launch year of 1997. By the year 2000, sales were still below 20000 a year: then, they dramatically increased to 100000 a year by 2004 and a million a year by 2012. William Smith, the CEO of Infinity Fuel Cell and Hydrogen Inc says that while battery and hybrid electric car technology has jumped ahead of fuel cell car technology, this is not necessarily bad news for FCVs because they are also electric cars, so can benefit from that technology.

Proponents of hydrogen vehicles say owning and using a hydrogen car will be no different to the petrol and diesel cars we are used to: you can drive short or long distance and find a fuel station when you need to fill up, as it will only take 3 minutes to do so. The hydrogen in FCVs is loaded and stored as a high pressure gas. At the moment however, the refuelling situation is the main criticism levelled at hydrogen cars: while BEVs can be fuelled at home using existing infrastructure, hydrogen cars require fuelling at traditional petrol station style pumps, which is a new infrastructure which has been slow to appear. In 2017, there were only 15 hydrogen refuelling points in the UK, mostly in London, and there are none between Sheffield and Fife. So, for vast areas of the country, hydrogen cars are not viable at all currently which explains the low sales figures and Toyota's humble targets. The situation has often been described as 'chicken and egg', with fuel companies unwilling to supply hydrogen fuelling points because there are few cars running on it, and customers unwilling to buy cars because there are few places to refuel them.

Scepticism also arises from the industry's tradition of over promising: in 2010, the German government planned to have 1000 filling stations operational by 2020; by 2016 they had 20. Progress is being made though, slowly, with Honda and Hyundai planning on launching hydrogen cars in the UK later this year, and Shell has begun adding hydrogen pumps to their traditional forecourts in the UK. With the recent announcement of a government ban on new petrol and diesel cars from 2040, it is likely that suppliers of these fuels will be keen to invest in alternative fuels like hydrogen, as the demand for traditional fuels shrinks. If hydrogen cars have the backing of major energy companies, this could be the boost they need to compete with BEVs. Some commentators have said that the two technologies should not be viewed as rivals, but as complements, in the quest for less polluting transport. It could be the case that BEVs are more suitable for short trips within cities where they can be charged outside shops or offices, but FCVs are more practical for long distance driving.

One company that is trying to bring hydrogen cars to the UK is Wales based startup Riversimple. They have received funding from the Welsh government and EU and they are not only trying to bring a new car to the market, but also a new model of car ownership based around all-inclusive monthly payments (including fuel and maintenance). Founder Hugo Spowers says, “we cannot have really sustainable transport if companies are profiting from obsolescence and selling new and replacement parts.” Their first model, the Rasa, is entering beta testing and the first 20 vehicles and drivers should be visible around south east Wales from October. Ed Wiseman, Assistant Motoring Editor of The Daily Telegraph said of the Riversimple Rasa, “It’s not perfect, but it works. No one technology will decarbonise mobility, and hydrogen is a long way off becoming the mainstream fuel choice. But with organisations such as Riversimple becoming the de facto architects of sustainable transport, it’s hard not to be excited about the role hydrogen will play in the future of motoring”

<u>Other forms of hydrogen transport</u>

While cars are often at the centre of discussions around pollution, as per person they are the most polluting form of transport, buses, lorries and trains also run on diesel fuel and reducing their emissions will be important to cutting emissions nationally. Some people think that even if hydrogen cars never become widely adopted due to the lack of infrastructure, hydrogen public transport stands a better chance. This is because buses and trains only take on fuel from a limited number of depots anyway, so only a small amount of new infrastructure would have to be built. In addition, while a battery electric car can be charged while the owner is at work or shopping, buses and trains need to operate all day, so it is not practical for them to be out of service for hours while they charge. Currently, hydrogen buses are being trialled in London and Aberdeen, and the Aberdeen operator FirstGroup recently announced they intend to buy 10 more hydrogen buses for the city, indicating a confidence in the technology (Cryle, 2017).

Next to arrive will probably by hydrogen trains. French train manufacturer Alstom has demonstrated a fuel cell version of its Lint model called the iLint and 14 have already been ordered by Lower Saxony’s transport authority. Battery electric trains are not a viable option for long distance or heavy trains because the weight and therefore cost of the battery would have to be so great: the iLint meanwhile has a range of 1000km and the appearance of a typical diesel multiple unit train. Alstom also has a contract with the Greater Anglia railway to convert some of their existing trains to run on hydrogen. UK rail minister Jo Johnson has said he would like to see diesel trains phased out of the UK by 2040, echoing the government’s commitment to banning diesel cars by then.

In response, Rail Freight Group Executive director Maggie Simpson has said, “(hydrogen power) for heavy duty freight is at best unproven and setting an arbitrary deadline of 2040 could well therefore be counterproductive”. There is also concern in the industry that the focus on hydrogen and battery electric trains is distracting from what should be the primary goal of railway improvement, which is electrification of the UK’s rail network (Shirres, 2018). Electric trains are more powerful, have no limits on range, are easier to maintain and use less energy because their regenerative braking can return power to the grid. Yet the government has been scaling back its promises for electrification due to its high cost. David Shirres writing for Rail Engineer UK said alternative fuels were, “unrealistic for busy core routes that require high power traction… electrification is the only option that offers the prospective of zero-carbon rail traction as an increasing proportion of Britain’s electricity becomes generated by renewals”. He admitted that “hydrogen and batteries can decarbonise rail traction. However for very real engineering reasons, they can only be part of the solution” and accused the government of making misleading statements to justify its cutbacks to electrification. Even if all the UK's main lines were to be electrified though, there are still smaller branch lines where it does not make economic sense to electrify and these are the places where hydrogen trains could be useful.

Plate 1: The UK's first fuel cell ferry in the Bristol Floating Harbour

The shipping industry has been highlighted as an area where hydrogen could really make a difference. At the moment, many large vessels burn fuel oil, a highly polluting fuel, and emissions from ships face little international regulation. Bringing this industry to clean energy would be very beneficial for the environment. On an even larger scale than with trains, hydrogen's advantage over electricity is the amount of energy that can be stored. A major shipping company says the world's biggest batteries could not power their ships for a day, yet they need to sail for weeks. This same company has built a small vessel, the world's first ocean going hydrogen boat, which uses a hydrogen fuelled internal combustion engine. It is expected that these more conventional engines, not fuel cells, will power large hydrogen ships in future. In Bristol, where the public transport network includes ferry boats, one operator currently uses a fuel cell hydrogen boat, which can be seen in plate 1. The interest around hydrogen boats seems to be growing fast: in February, the Scottish government awarded money to a feasibility study for a hydrogen ferry for the country's west coast, and the international company Viking Cruises has announced plans for a 900 passenger vessel fuelled by liquid hydrogen.

Hydrogen for homes and businesses

Some companies are looking into using hydrogen to replace the supply of natural gas to homes in the UK. It has been thought that supplying UK homes with hydrogen instead of natural gas could reduce the UK's heat emissions by 70%. Arup Engineering has announced a £23m feasibility study to look at converting a village to run on just hydrogen. Cadent has announced an ambitious plan to supply industrial plants in the north west with hydrogen and mix up to 20% hydrogen into household gas, as this is compatible with current household boiler technology: the company plans to get its hydrogen from steam but bury the CO2 emissions in old gas fields beneath the sea (Vaughan, 2017).

One market where hydrogen vehicles are rapidly increasing in popularity is forklift trucks in warehouses: Amazon and Wal-Mart have recently announced their intentions to purchase fleets of hydrogen forklifts, in an example of FCV supplanting BEV technology. The advantages of hydrogen forklifts are that they are faster to refuel than battery models and as the battery models usually operate by replacing the batteries instead of charging the vehicles themselves, space in the warehouse needs to be dedicated to batteries. Hydrogen forklifts spend less time idle in battery changes, enabling higher productivity and allow more space to be used for goods storage in the warehouse instead of battery storage. It is estimated that around 3% of forklifts operating warehouses in the US are hydrogen powered in 2018.

Safety

Hydrogen's ability to burn efficiently is both a blessing and a curse. The image of the Hindenburg airship in flames is still used to question the viability of the industry today. Of course, safety regulations today far exceed those in the day of the airship tragedy. Rigorous testing of fuel tanks ensures that they are far tougher than those used to contain petrol, which is itself a highly dangerous chemical that we have accepted into our daily lives. Perhaps the most interesting point about hydrogen safety is the fact that the molecules are so light that if they escape from the tank, even in flames, they will immediately dissipate upwards, unlike oil which will puddle on the ground. So in the event of a fire, leaking hydrogen is arguably safer than leaking petrol (Sackler, 2017).

Plate 2: US Department of Energy car experiment

An experiment by the US Department of Energy is shown in Plate 2. Two identical cars were given leaks in their fuel tanks and set on fire. The car on the left in the images has a hydrogen fuel tank whereas the car on the right has a petrol tank. The images are startling: the hydrogen car shoots out jets of flame but sustains no damage itself, while the petrol car is burnt to the ground in just 60 seconds. The impact of a fire in a hydrogen vehicle and one in a BEV is also very different: in a BEV, the energy from the battery cannot be dissipated quickly, so adjacent battery cells can catch fire or explode even some time after the accident (Leachman, 2017).

Overall, hydrogen vehicles, petrol vehicles and BEVs should not be seen as more or less safe as each other, they all have different aspects that are safe and dangerous and the operators should be aware of these things.

<u>The joined up energy industry?</u>

"Hydrogen is a very interesting opportunity because it has the ability to join sectors together: the electricity sector, the gas sector and the transport sector" – Matthew McCloud, Hydrogen Lead for Toyota Australia

Although much has been made in journalism of a competition between hydrogen and batteries to be the dominant energy carrier and store, professionals in the hydrogen industry speak excitedly about the benefits of integrating the industries. What these people are particularly excited about is hydrogen's ability to benefit from the great hindrance of renewable energy: its unreliability. Hydrogen advocates envisage facilities producing hydrogen from electrolysis being linked to wind farms, so that when conditions are ideal for electricity generation, excess electricity can be used to produce hydrogen, rather than letting it go to waste which is what happens at present. This hydrogen could be stored for as long as necessary or transported around the world, then converted back to electricity when it is needed. Although Tesla is working on batteries that are also aiming to store off peak power, Martin Hablutzel of Siemens says that while batteries can store energy efficiently for hours, to store energy for months it needs to be in chemical form (AEMO, 2018).

The process of converting electricity to gas is known as power-to-gas (P2G). If this technology were to become widely adopted and gas networks modified to run on hydrogen, then a truly joined up energy sector could be created, where all power is derived from renewables like wind, solar and tidal power, without worry about the consistency of supply, and all appliances, from cookers to televisions to cars would ultimately be reliant on renewable energy. David Jones of the Australian Energy Management

Organisation (AEMO) has said hydrogen could lead to a shift from thinking about gas and electricity to just energy as a whole.

P2G technology has the potential to disrupt geopolitics. As almost all countries can generate some form of renewable energy, it is possible that hydrogen technology could make all countries energy self-sufficient and reduce the disproportionate global importance of oil and gas exporting countries. One of the reasons that the EU is investing in hydrogen technology is to reduce its dependence on natural gas from Russia. Countries or regions that are particularly well endowed with natural resources and low energy usage could benefit enormously in economic terms from P2G. The Orkney islands in Scotland have been a testbed of tidal power generation, which has been converted to hydrogen using electrolysis and is stored and converted back to electricity when demand rises (Ward, 2018). Nepal has been highlighted as a potential hydrogen exporter, due to the country's enormous potential for hydroelectric generation (Ale and Bade Shrestha, 2008).

Conclusion

"You never change something by fighting the existing reality. To change something, build a new model that makes the existing model obsolete" – Buckminster Fuller, Architect and inventor

To help sum up everything what has been discussed in this report, the table below gives a short summary of where hydrogen technology is today in various fields, and what its supporters hope it will achieve in future:

Energy user	Current hydrogen usage	Planned future hydrogen usage	Potential future hydrogen usage
Cars	Small number of cars sold (45 Toyota Mirais registered in the UK currently)	Vehicle sales to slowly increase as production increases and refuelling points are installed	Hydrogen vehicles could supplant petrol and diesel vehicles which would allow the government's petrol and diesel ban to be achieved
Buses	Small number of hydrogen buses operating in London and Aberdeen	As above	As above
Trains	No trains currently operating, but Alstom's demonstration unit shows the feasibility of the technology	Abellio Greater Anglia has planned for 25 trains to be converted to hydrogen running by Alstom	Hydrogen trains could provide transport on all non electrified UK rail lines
Shipping	Small boats operate in Bristol and Antwerp	Feasibility studies are ongoing for large hydrogen powered passenger and cargo vessels	Hydrogen ships could supplant fuel oil burning ships, especially if regulations are introduced to reduce pollution from shipping
Forklifts	Hydrogen forklifts are available for	Many companies have large numbers of	Hydrogen forklifts could become the

	mainstream usage and are already common in some warehouses	hydrogen forklifts on order	dominant technology in this industry
Homes	No gas grids currently rely on hydrogen but the technology to convert them to is not complicated	Trials are planned for mixing hydrogen into household gas and also to run villages on entirely hydrogen	Homes could be converted to run on hydrogen allowing it to replace natural gas as the standard national energy supply
Electricity generation	Electricity is only generated from hydrogen in experimental settings	There are plans for windfarms to include electrolysis facilities to store and export hydrogen so it can be used to generate electricity when demand peaks	The electricity and gas industries could become linked, creating a single energy industry

The next table shows the possible future relationships between electricity and hydrogen in the area of energy storage and distribution:

Energy store and carrier mix	Requirement from hydrogen technology	Requirement from electric technology
Maximum hydrogen and minimum electric reliance	Massively increased investment in technology and widespread adoption of P2G technology	No new developments in battery technology or other forms of electricity storage (eg. compressed air)
Moderate hydrogen and electric reliance	Moderately increased investment and adoption of P2G technology	Reasonable developments in battery technology or other forms of electricity storage
Minimum hydrogen and maximum electric reliance	No increase in investment or no adoption of P2G technology	Massive developments in battery technology (beyond what is thought possible with current materials) or other forms of electricity storage

In conclusion, hydrogen technology has arrived, though it is far from mainstream. Hydrogen is a viable fuel for transport, but it needs a better distribution network and a cleaner source to be widely adopted and be a cleaner alternative to current fuels. The P2G industry could redefine household energy and global politics, but it is still more of an idea than a fledgling industry. If a new type of battery were invented tomorrow that could be charged instantly, weighed next to nothing and wasn't made of rare earth metals, the need for a hydrogen economy may disappear instantly. However, there is nothing to suggest that that invention is close, and current battery technology cannot meet those criteria, no matter how much time and money is invested in improving it. Overall then, it seems that hydrogen technology is the best chance we have at creating a clean, sustainable and joined up energy economy, and while progress may be slow on bringing the technologies into our daily lives, they are coming, one fuel cell at a time.

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