

University of Wales Trinity Saint David

Wales Institute of Science & Art



Use of Energy Carriers; Legislation & Practicality

Approach

Automotive Materials & Sustainability

ACHA6012

Oliver Nayler

1901161

1/04/2023

Table of Contents

1.0- Introduction.....	Page 2
2.0- UK Regulations & Legislation.....	Page 2
3.0- Energy Carriers.....	Page 3
3.1- Electric Vehicles.....	Page 3-4
3.2- Synthetic fuels.....	Page 4-5
3.3- Hydrogen.....	Page 5-8
4.0- Discussion.....	Page 9-11
5.0- Conclusion.....	Page 12

1.0- Introduction

Transportation is an essential aspect of modern-day life, however the current sustainability within this industry is poor making up for 7.3 billion metric tons of carbon dioxide (CO₂) emissions in 2020 (Ian Tiseo, 2023). Other emissions produced by the transportation sector such as Carbon Monoxide (CO) and Nitrogen Oxides (NO_x) can also cause serious health issues. Due to this, governments around the world have been implementing new legislation and regulations to improve the sustainability in this sector and reduce the number of emissions the transportation sector contributes to global warming.

This technical report critically analyses the current and future legislation, exploring how these legislations may affect technology and innovation in the automotive industry. Additionally, suggestions are made for the government's possible course of action in developing infrastructure for sustainable transport.

2.0- UK Regulations & Legislation

In November 2020, the UK prime minister announced that all new petrol and diesel vehicles will be phased out of production by 2030. This plan was aimed to put the UK on course to be the fastest nation in the G7 to decarbonise cars and vans (HM Government, 2021). The regulations in 2020 stated that cars are required to produce no more than 95g CO₂/km and vans 147g CO₂/km, these targets were then converted into Worldwide harmonized Light vehicles Test Procedure (WLTP) emissions targets in 2021. This means manufacturers will have to meet a 15% reduction in emissions for cars by 2025, then a further reduction of 37.5% for cars and 31% reduction for vans by 2030 (GOV.UK, 2020). After 2030 the sale of new petrol and diesel vehicles is to be phased out, however Hybrid vehicles can continue to be produced. Between 2030 and 2035 all new cars and vans will have to deliver significant zero emissions capability. Following this in 2035 all new cars and vans must be 100% zero emission at the tailpipe (HM Government, 2021). This plan is demonstrated in figure 1. The plan also states that by 2030 there will be 'at least 2,500 high powered charge points across the strategic road network'.

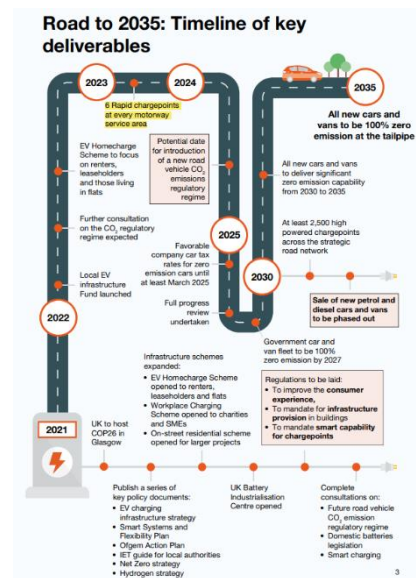


Figure 1- UK governments Timeline of Key Deliverables (HM Government, 2021)

3.0- Energy Carriers

To meet the standards set by the government, multiple companies within the automotive industry and motorsport industry have been researching and developing various energy carriers that will improve the sustainability of new and existing vehicles and to meet the new regulations that have been set out.

3.1- Electric Vehicles

Electric vehicles (EV) have been the most popular alternative powertrain over the past years, with the original vehicles developing from hybrids to fully electric vehicles. Development of EV's has improved significantly over the years, with the most recent development coming from Lucid Motors. Their new top spec Air sedan has an estimated range of 516 miles on a full charge, which is 111 miles more than its competitor the Tesla Model S which is capable of 405 miles on a single charge (Car and Driver, 2023). These statistics are however calculated using the ideal driving conditions, including weather, road conditions and driver input. An issue that these vehicles face is that the price range is very high for the average family within the UK, being priced from £73,000 and £112,000 (Car and Driver, 2023) these vehicles are out of the price range for the average UK income of £29,400 (Ons.gov.uk,2019). Other EV's are available at lower prices such as the Tesla Model 3 which retails at £35,500 but only has a range of 358 miles and the Hyundai Ioniq 6 at a price of £37,000 with a range of 361 miles (Car and Driver, 2023).

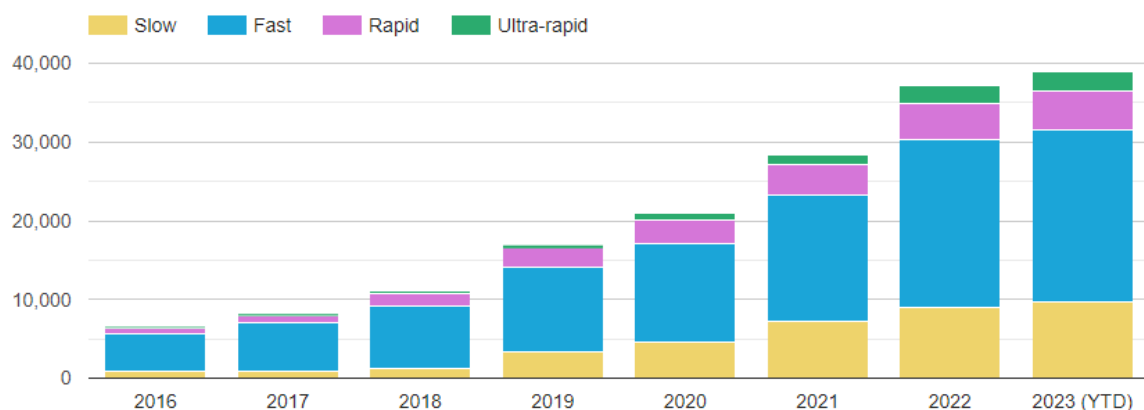


Figure 2- Number of public UK charging points by speed (2016 to date), (Zap-Map, 2023)

One of the biggest issues that EV faces is the infrastructure required to supply power to all vehicles on the road. Figure 2 shows the development of EV infrastructure from 2016 to date. This graph shows the rapid increase in chargers within the UK, increasing from around 6,500 in 2016 to now 39,000 in 2023.

Cumulative number of plug-in cars registered in the UK (2016 to date)

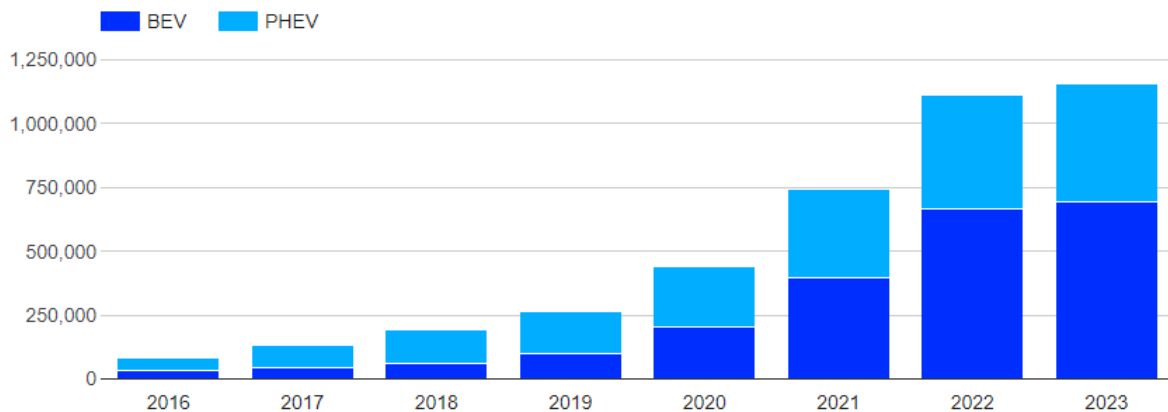


Figure 3-Cumulative number of plug-in cars in the UK (2016 to date), (Melanie, 2023).

However, Figure 3 shows the number of plug-in cars that are registered in the UK, this graph shows an increase from around 100,000 in 2016 to close to 1.2 million in 2023. This means that there are only enough public chargers in the UK to charge 3.25% of the UK's EV's.

3.2- Synthetic fuels

Another energy carrier being developed is synthetic fuels, these are also known as carbon neutral fuels that capture CO₂ and use it in the production process. During production synthetic fuels are made with the use of renewable energy, this energy is used to produce hydrogen from water. Carbon is then recycled from industrial processes or captured using filters from the air and added to the hydrogen to produce a liquid fuel. Combining these elements results in the production of the synthetic fuel which can be made to be, gasoline, diesel, gas, or kerosene (Bosch Global, 2017). Synthetic fuels provide the benefit of recycling more carbon in the production process than it emits when it is burnt in a vehicle, this allows for vehicles to technically run without producing extra carbon emissions.

The process of producing a synthetic fuel is demonstrated in Figure 4.

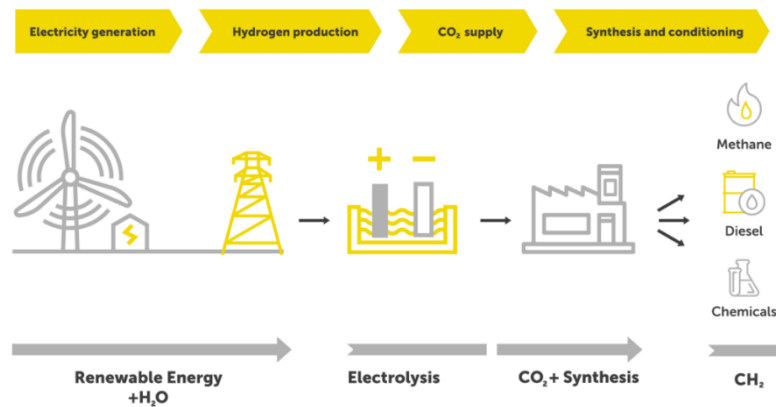


Figure 4- Synthetic Fuel Production Process (Diersch & Schröder, n.d.)

One of the main projects is the Haru Oni Joint project, which involves Porsche, Siemens Energy, and various other international partners. This project aims to produce the world's first integrated, large scale commercial plant in southern Chile, which will produce synthetic, carbon neutral fuel (Dr. Ing, 2022). Porsche plans to use these synthetic fuels in their fleet of combustion engine models, including their hybrid vehicles. This plant is set to produce around 130,000 litres of synthetic fuel per year, with Porsche planning on purchasing this volume in full for use in motorsport (Dr. Ing, 2022). One major benefit to this type of fuel is that other than production, the existing gasoline and diesel infrastructure can be used meaning no extra money needs to go into the distribution and refuelling of synthetic fuels.

3.3- Hydrogen

Hydrogen is an energy carrier that can be used in multiple applications within the automotive industry.

Fuel Cell Electric Vehicles (FCEV) are becoming more popular as technology starts to advance with the only product produced being H₂O when green hydrogen has been used. Toyota have been the leading company developing this technology with the Toyota Mirai. Other fuel cell vehicles have started to emerge as well such as the Hyundai Nexo and the Honda Clarity. The Toyota Mirai retails at £64,995, can store 5.6kg of hydrogen providing a range of 400 miles (Saunders, 2021).

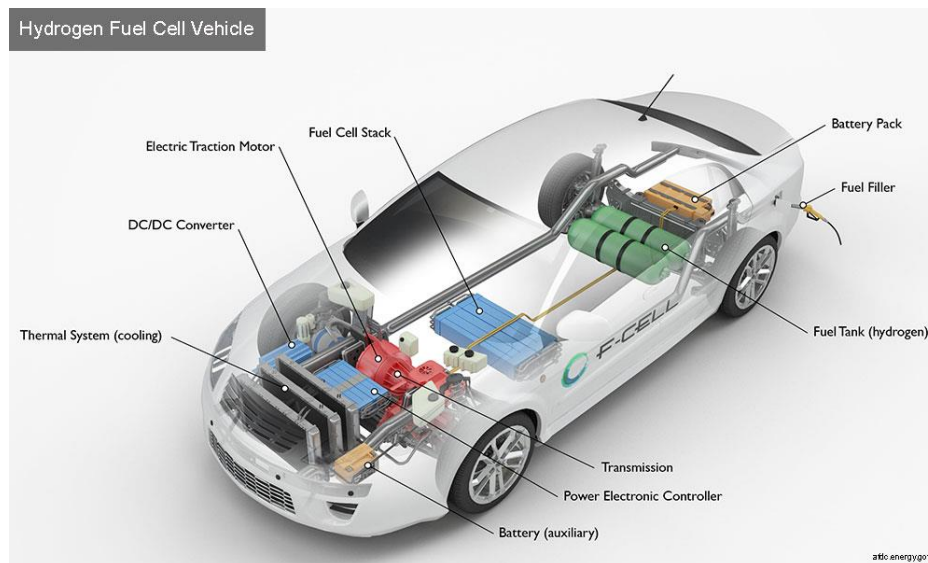


Figure 5- Hydrogen Fuel Cell Vehicle diagram (US Department of Energy, 2019)

Figure 5 shows how a FCEV works, at the rear of the car are two hydrogen tanks specially designed to keep hydrogen at the required pressure of 350-700 bar (energy.gov, 2010), these tanks also need to withstand the pressure and temperature changes when refuelling, along with preventing the permeation of hydrogen. When looking at the storage used in a Toyota Mirai, it uses Carbon Fibre Reinforced Plastics (CFRP) due to its lightweight and durable properties (Hwang and Varma, 2014), with an internal liner made of UBENYLON 1218IU to prevent any permeation (UBE Corporation, 2014). These vehicles can be refuelled roadside at any hydrogen refuelling station where it can be filled in under 10 minutes providing around 200-300 miles of driving. The hydrogen is then converted to electricity on board through the fuel cell stack, powering the motor. Most FCEV also feature a Kinetic Energy Recovery System (KERS) which recovers the power from braking storing it in the battery pack and providing the power to the motor during short acceleration events (US Department of Energy, 2019).

Hydrogen can also be used as an alternative fuel that can be burnt in Internal Combustion Engines (ICE). Multiple companies have been developing hydrogen combustion vehicles over the years such as BMW and Mazda, however most recently the leading developer for hydrogen combustion engines is Toyota.

Toyota have been able to develop their hydrogen 1.6-liter 3-cylinder turbocharged engine through motorsport and started their development journey at the 2021 Fuji 24 hours in Japan. The Corolla with a modified fuel storage and fuel delivery system was able to complete 358 laps with an average speed of 67.963km/h, with 12 hours of racing, stopping 35 times for repairs and refuelling (Lyon,

n.d.). This car was then further developed and entered the same 24-hour endurance series where it made significant improvements.

In 2022 the same developed car completed 478 laps with an average speed of 90.687km/h, making 40 pit stops, with an average stint of 11.7 laps compared to the 10.2 laps in 2021

(www.motorsport.com, n.d.). Since this series Toyota have further developed their hydrogen combustion vehicles releasing a hydrogen fuelled Corolla Cross SUV powered off the same 1.6 turbo engine as in the race series. This car features the same technology as the Mirai ensuring that the fuel storage is maximised, without affecting the cabin and luggage space (Weaver, 2022).

One of the biggest issues that hydrogen faces is the current infrastructure around the world. Many projects have started to develop and assess hydrogen infrastructures such as the HyNor project in Norway, where a hydrogen highway is being created between Oslo and Stavanger to provide public transport and road vehicles with hydrogen refuelling stations (Hydrogen Cars Now, n.d.). Another project focusing on the infrastructure for hydrogen is the Get H2 Initiative. RWE Generation SE, Siemens, ENERTRAG, Stadtwerke Lingen, Hydrogenious Technologies, Norwega, Forschungszentrum Julich and the IKEM institute for climate protection Energy and Energy Mobility have all come together to develop and demonstrate this initiative in Lingen, Germany (FuelCellsWorks, n.d.).

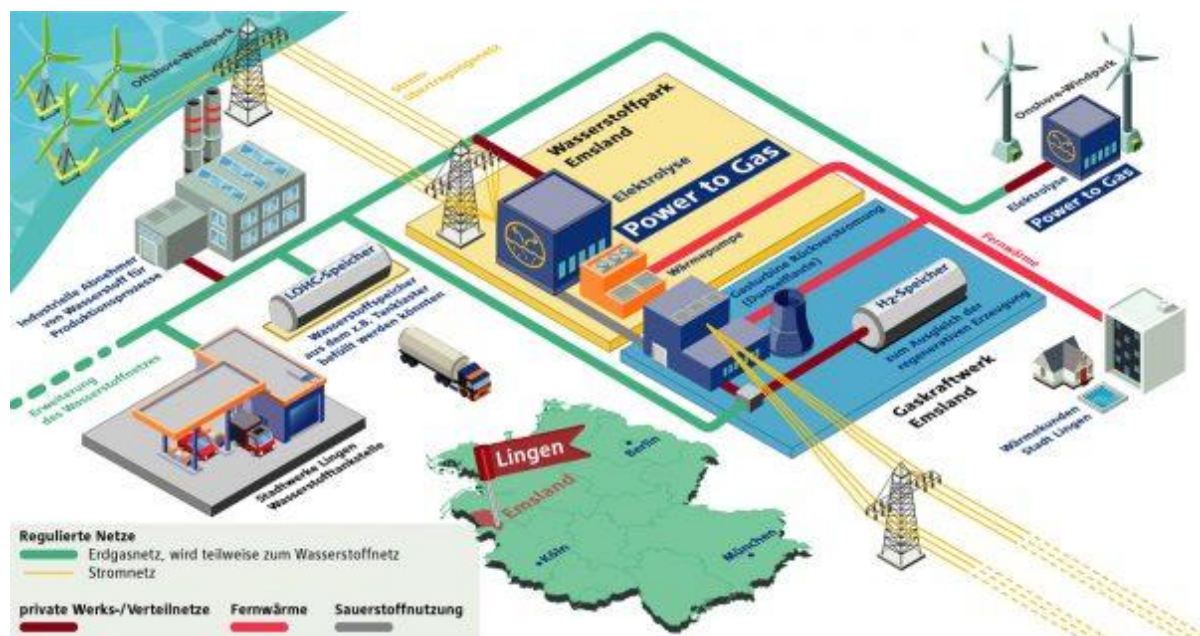


Figure 6- Get H2 Initiative (FuelCellsWorks, n.d)

Figure 6 shows the infrastructure plan set out for the Get H2 Initiative, the figure shows the implementation of green energy production using wind power, this power is then fed to

electrolysers that can produce hydrogen from H_2O . The existing gas pipeline for the city is then used to distribute this hydrogen to factories that use hydrogen in their production process, Fuelling stations for public transport and personal vehicles. It also includes storage facilities, including one Liquid Organic Hydrogen Carrier (LOHC) facility for distribution outside the pipeline area. Any hydrogen that is produced and unused will then be fed to a gas turbine facility where the hydrogen can be turned back into electricity which will supply the power grid. Finally, the heat produced by the electrolysis plants is distributed to heat local businesses and homes reducing the amount of gas being used within households.

4.0- Discussion

Going back to section 2.0, in a report by 'HM Government' titled 'Transitioning to zero emission cars and vans 2035 delivery plan', it states that due to the departure of the European union it has allowed for the UK government to put the UK on course to be the fastest nation in the G7 to decarbonise cars and vans (HM Government,2021). However, is this the best course of action or have the UK government rushed into the introduction of EV without the supporting infrastructure and appropriate research? After completing research on the current EV technology, availability, infrastructure, and number of EV's within the UK it was proven that this statement may be correct. The infrastructure for EV's had to be started from nothing due to there being no similar infrastructure in place already. The research conducted showed that out of the 1.2 million plug in electric vehicles on the road in 2023 only 39,000 would be able to use public chargers at once, this is only 3.25% of the UK's electric vehicles. With the ICE ban only 7 years away and the ever-increasing popularity of EV's the current rate of increase in the infrastructure available is not adequate for the amount of EV's that will be on the road. EV's are however available to be charged at home, meaning that this issue can be slightly resolved however may still cause issues when vehicles need to be charged while away from home or on long journeys. EV's may provide zero emissions when driving, however when using non-renewable energy to charge an EV, 0.23314 Kg of CO₂ per kWh is being produced (RenSmart, 2016). If this is applied to a Hyundai Ionic 5 the battery needs 73kWh to charge to 100% (Harris,2022), this means that one full charge would emit 17.019 Kg CO₂ (RenSmart, 2016). However, this figure is still significantly lower than the average 45L petrol tank which produces around 103kgs CO₂.

This roadmap plans for all new vehicles after 2030 to be either Hybrid or EV's, however there is nothing within this plan to reduce the emissions that are caused by existing petrol and diesel vehicles. These existing vehicles will still be run on roads within the UK for decades to come. In 2021 it was recorded that there was 19,085,249 petrol cars and 12,852,314 diesel cars on the road (Erin Yurday, 2022). If these vehicles were to be phased out slowly by increasing tax, fuel, and part prices for these vehicles, then this would also cause a significant amount of waste as these vehicles will eventually end up in scrap yards with only small amounts of the car being recycled.

An alternative energy carrier that should be considered as the UK's main energy carrier is hydrogen. Hydrogen is beneficial to the automotive sector as it provides a completely carbon free fuel as green hydrogen is used. However, a hydrogen infrastructure can also benefit other sectors such as having

the ability to reduce carbon output in factories that use hydrogen and can also heat homes. Hydrogen FCEV are completely carbon neutral when green hydrogen is used, and hydrogen combustion vehicles only give off NOx emissions which can be significantly reduced with Air Fuel Ratio (AFR) adjustments.

There are two types of vehicles that can be used with hydrogen, these are fuel cell electric vehicles and hydrogen combustion vehicles. Hydrogen fuel cell vehicles are already in use within the UK. Twenty hydrogen double-decker buses have been manufactured by Wright bus and will service on route 7 between East Acton and Oxford Circus (SMMT, 2021). Fifteen Hydrogen buses have also been used in Aberdeen where they have



Figure 7- London Hydrogen Bus ((www.alexander-dennis.com, 2019)

been



Figure 8- Toyota AE86 hydrogen (Biermann, 2023)

able to save 170,00Kg CO2 from being released into the atmosphere (www.lapv.co.uk, 2021). Fuel cell vehicles such as the Toyota Mirai are also available to purchase within the UK. Along with existing hydrogen vehicles there is also the opportunity to push the development of new vehicles, or to develop existing vehicles. Toyota have been focussing on the technology to be able

to retrofit hydrogen fuelling systems to run existing ICE

vehicles and is shown in figure 8. This demonstrates this technology which modifies the fuel storage and delivery system including fuel lines and injectors. This is done by using the same technology found in the Mirai. This technology has the opportunity to be developed further, allowing for costs of conversions to be reduced and could possibly save existing ICE vehicles from ending up in land fill and save existing ICE vehicles emitting CO2 after the 2030 ICE ban.

The most important development that is needed for hydrogen to become the UK's main energy carrier is infrastructure development. The UK currently has some hydrogen infrastructure with development being pushed in areas to generate power and to use hydrogen for heating homes. Figure 9 shows the UK's public hydrogen fuelling stations that are open or planned.



Figure 9- Hydrogen Infrastructure in the UK today (H2Mobility, 2023)

This map is presented by the UK

H2Mobility consortium, who are a leading UK industrial partnership with an interest in hydrogen mobility, while working with the government to try and make hydrogen fuelled transport a reality (www.ukh2mobility.co.uk, n.d.). The main benefits towards a hydrogen infrastructure over an EV infrastructure is that most of the infrastructure is available in existing fuelling stations and gas lines. Looking back to figure 6, the Get H2 initiative has made use of Germany's existing gas lines to transport hydrogen all over the country, it is also making use of existing fuel stations and service stations, making modifications to storage and fuel nozzles to adapt to hydrogen. These pipelines also lead to storage facilities where the hydrogen is stored as a liquid and can be distributed to anywhere in the country where existing fuel pipelines do not access. The Get H2 initiative infrastructure also includes the distribution of hydrogen to factories that can use hydrogen to remove CO2 from their production process.

This is something the UK government have already started developing claiming 'hydrogen could play an important role in decarbonising polluting, energy-intensive industries like chemicals, oil refineries, power and heavy transport like shipping, HGV lorries and trains, by helping these sectors move away from fossil fuels' (GOV.UK b, 2021). Get H2 also included gas turbines, this allows for excess hydrogen to produce electricity to be distributed back to the power grid. The main piece of infrastructure that needs to be developed is electrolysis sites, this is where the hydrogen will be created and distributed from. However, these sites need to be powered by a renewable energy source to ensure the hydrogen produced and being used has no carbon footprint. Due to this, one downside to this infrastructure is that hydrogen production rates will be determined by weather conditions that supply renewable energy sources such as wind and solar power.

Finally, the last benefit to this infrastructure is that the waste heat produced by electrolysis plants can be distributed via a district heating network to heat homes and workplaces.

5.0- Conclusion

To conclude, hydrogen technology has developed rapidly over the past few years, with more countries around the world exploring and testing the limitations of hydrogen and its required infrastructure, making it a viable option as a main energy carrier around the globe. After reviewing the findings of this report, it has shown that EV's may have been the future, but as technology improves other fuels pose significant benefits over EV's. Although the report suggests other pathways should be considered, EV development should not be halted, but should continue alongside the development of another energy carrier, as limiting a country to one type of energy carrier will eventually result in shortages, such as public charge points, or even a shortage of electricity. If the UK were to work alongside other countries and businesses, a hydrogen future could help save jobs, create jobs, recycle infrastructure, and improve the transportation sector around the world, reducing our CO2 levels and help to have a more positive impact to help save our planet.

References

Admin zap-map (2023). *How many charge points are there in the UK 2020*. [online] Zap-Map. Available at: <https://www.zap-map.com/statistics/#points>.

Bosch Global (2017). *Synthetic fuels — The next revolution?* [online] Bosch Global. Available at: <https://www.bosch.com/stories/synthetic-fuels/>.

Car and Driver. (2023). *Electric Cars with the Longest Driving Range, Ranked*. [online] Available at: <https://www.caranddriver.com/features/g32634624/ev-longest-driving-range/>.

Dr. Ing (2022). *eFuels*. [online] Available at: <https://media.porsche.com/mediakit/innovation-sustainability-performance/en/innovation-sustainability-performance/synthetic-fuels>.

energy.gov (2010). *Hydrogen Storage*. [online] Energy.gov. Available at:
Erin Yurday. (2022). *Number of Cars in the UK 2022*. [online] Available at: <https://www.nimblefins.co.uk/cheap-car-insurance/number-cars-great-britain#:~:text=By%20the%20end%20of%202021%2C%20petrol%20and%20diesel>.

FuelCellsWorks (n.d.). *GET H2 Initiative Kicks Off Germany-Wide Hydrogen Infrastructure - FuelCellsWorks*. [online] Available at: <https://fuelcellsworks.com/news/get-h2-initiative-kicks-off-germany-wide-hydrogen-infrastructure/> [Accessed 21 Feb. 2023].

GOV.UK b, (2021). *UK government launches plan for a world-leading hydrogen economy*. [online] Available at: <https://www.gov.uk/government/news/uk-government-launches-plan-for-a-world-leading-hydrogen-economy>.

GOV.UK. (2020). *CO2 emission performance standards for new passenger cars and light commercial vehicles*. [online] Available at: <https://www.gov.uk/government/consultations/regulating-co2-emission-standards-for-new-cars-and-vans-after-transition/co2-emission-performance-standards-for-new-passenger-cars-and-light-commercial-vehicles>.

HM Government (2021). *Transitioning to Zero Emission Cars and vans: 2035 Delivery Plan Contents*. [online] Available at:

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1005301/transitioning-to-zero-emission-cars-vans-2035-delivery-plan.pdf.

<https://www.energy.gov/eere/fuelcells/hydrogen-storage>.

Hwang, H.T. and Varma, A. (2014). Hydrogen storage for fuel cell vehicles. *Current Opinion in Chemical Engineering*, 5, pp.42–48.

Hydrogen Cars Now. (n.d.). *Norway HyNor Project*. [online] Available at:

<https://www.hydrogencarsnow.com/index.php/norway-hynor-project/> [Accessed 21 Feb. 2023].

Ian Tiseo, 2023, *Global transport CO2 emissions breakdown 2020*. [online] Available at:

<https://www.statista.com/statistics/1185535/transport-carbon-dioxide-emissions-breakdown/#:~:text=Published%20by%20Ian%20Tiseo%2C%20Feb%206%2C%202023%20The> [Accessed 29 Mar. 2023].

Lyon, P. (n.d.). *Toyota Races World's First Hydrogen Race Car To Promote Alternative To Electric Cars*. [online]

Forbes. Available at: <https://www.forbes.com/sites/peterlyon/2021/05/28/toyota-races-worlds-first-hydrogen-race-car-to-promote-alternative-to-electric-cars/?sh=465c75fd2f2c> [Accessed 29 Jan. 2023].

Matt Saunders. (2021). *Toyota Mirai review*. [online] Available at: <https://www.autocar.co.uk/car-review/toyota/mirai>.

Melanie, S. (2023). *How many electric cars are there in the UK 2022*. [online] Zap-Map. Available at:

<https://www.zap-map.com/ev-market-statistics/>.

Ube Industries, 2014, UBE Nylon Resin Used in High-Pressure Hydrogen Tank of Toyota Mirai Fuel Cell

Sedan. [online] Available at:

https://www.ube.co.jp/ube/en/news/2014/20141208_01.html#:~:text=UBENYLON%201218IU%20will%20be%20used%20in%20the%20high-pressure [Accessed 21 Mar. 2023].

Ons.gov.uk. (2019). *Average household income, UK - Office for National Statistics*. [online] Available at:

<https://www.ons.gov.uk/peoplepopulationandcommunity/personalandhouseholdfinances/incomeandwealth/bulletins/householddisposableincomeandinequality/finan>

RenSmart (2016). *KWH-to- CO2*. [online] Rensmart.com. Available at:

<https://www.rensmart.com/Calculators/KWH-to-CO2>.

Roger Biermann, (2023). *Toyota Reveals Two AE86 Concepts With Hydrogen Combustion And Electric Power*. [online] Available at: <https://carbuzz.com/news/toyota-reveals-two-ae86-concepts-with-hydrogen-combustion-and-electric-power> [Accessed 31 Mar. 2023].

Rowan Harris. (2022). *How Much Electricity (kWh) Does It Take To Charge An EV?* [online] Available at: <https://www.leasefetcher.co.uk/guides/electric-cars/how-many-kwh-to-charge-a-car>.

SMMT. (2021). *England's first hydrogen bus fleet hits the road*. [online] Available at: <https://www.smmt.co.uk/2021/07/englands-first-hydrogen-bus-fleet-hits-the-road/#:~:text=The%20Mayor%20of%20London%2C%20Sadiq%20Khan%2C%20has%20launched> [Accessed 31 Mar. 2023].

UBE Corporation. (2014). *UBE Nylon Resin Used in High-Pressure Hydrogen Tank of Toyota*
ukh2mobility, (2023). *Stations | UK H2Mobility*. [online] Available at: <https://www.ukh2mobility.co.uk/stations/>.

US Department of Energy (2019). *Alternative Fuels Data Center: How Do Fuel Cell Electric Vehicles Work Using Hydrogen?* [online] Energy.gov. Available at: <https://afdc.energy.gov/vehicles/how-do-fuel-cell-electric-cars-work>.

Weaver, J. (2022). *Hydrogen Corolla Cross begins testing in Japan*. [online] Toyota UK Magazine. Available at: <https://mag.toyota.co.uk/hydrogen-corolla-cross/> [Accessed 16 Feb. 2023].

www.alexander-dennis.com. (n.d.). *Liverpool City Region launches £6.4m hydrogen bus project | Alexander Dennis*. [online] Available at: <https://www.alexander-dennis.com/media/news/2019/march/liverpool-city-region-launches-64m-hydrogen-bus-project/> [Accessed 31 Mar. 2023].

www.lapv.co.uk. (2021). *Aberdeen's hydrogen bus fleet notches up first 100,000 miles - LAPV*. [online] Available at: <https://www.lapv.co.uk/Aberdeens-hydrogen-bus-fleet-notches-up-first-100000-miles/2982> [Accessed 31 Mar. 2023].

www.motorsport.com. (n.d.). *Toyota eyes liquid hydrogen move after Fuji 24 Hours finish*. [online] Available at: <https://www.motorsport.com/super-taikyuu/news/toyota-liquid-hydrogen-fuji-finish/10317290/> [Accessed 29 Jan. 2023].

www.ukh2mobility.co.uk. (n.d.). *UK H2Mobility | Hydrogen: Fuelling Cleaner Motoring*. [online] Available at: <https://www.ukh2mobility.co.uk/>.

