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Sustainability Challenges in Industry

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1 Introduction

The UK automotive sector has relied heavily on crude oil for decades. The growing environmental and sustainability concerns regarding the use of petrol and diesel have reached tipping point. Within the last 5 years the UK government has decided to act upon this and devised a strategy to end the UK's dependency on fossil fuels. As a result, automotive manufacturers have investigated alternative fuels such as: biofuels, synthetic fuels, hydrogen and electric. This document details emissions, technology, logistics and sustainability surrounding these fuels and uses published statistics to provide insight to current progress.

2 Initial Literature Review

Fossil fuels (hydrocarbons) are separated in a fractional distillation column making many “fractions” of oil: marine fuel, bitumen, petrol, diesel and kerosene (Kelter, et al., 2008). Crude oil is heated to approximately 370 degrees Celsius where vapour cools as it rises and condenses back into liquids at various fractions depending on molecular size (figure 1). Once separated these hydrocarbons are broken down into shorter chains using heat in a process called cracking.

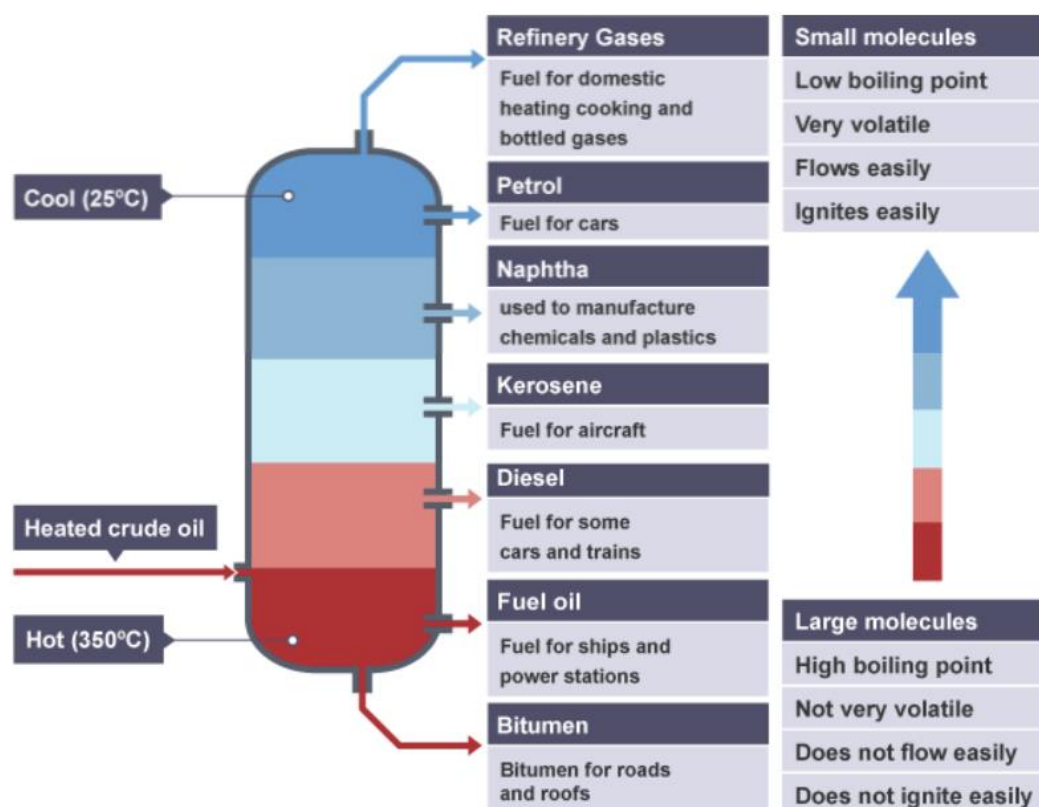


Figure 1: Crude Oil Fractional Distillation Column (BBC Bitesize, n.d)

High amounts of energy, equipment and staff are used to drill, process and transport crude oil and its resultant products with the logistics and combustion causing pollution (greenhouse gasses). Crude oils contribute to environmental disasters such as oil spills and blowouts, demonstrated by the “Deepwater Horizon” catastrophe devastating marine life and ecosystems (National Research Council, 2012).

2.1 Fossil Fuels Dependency

In 2022 officials determined 78% of the UK's energy for heating homes, fuelling vehicles and electricity generation was by fossil fuels (Environmental Audit Committee, 2023). In 2022 39.6% of electricity was fossil fuel based, 2023 (figure 2) saw a reduction to 32% with the majority from natural gas (Energy Dashboard, 2024).

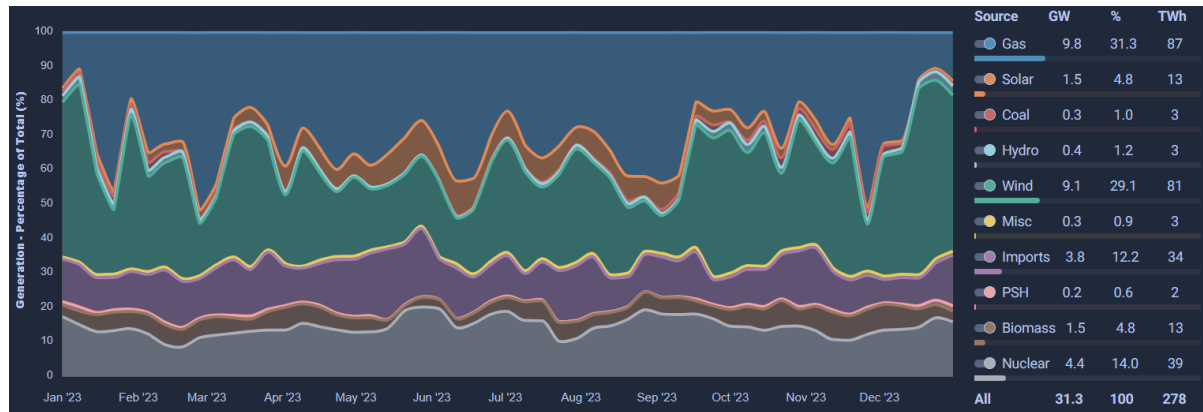


Figure 2: Electricity Generation 2023 (Energy Dashboard, 2024)

Car sale statistics show petrol and diesel powertrains (figure 3) are decreasing from previous years with battery electric vehicles (BEV) up 21% in quarter 2 of 2022 when compared to 2021 (Gov Uk, 2022). With the UK government dedicated to creating a carbon net zero country by 2050 and zero tailpipe emissions by 2035 (as of March 2024), automotive manufacturers are forced to invest and develop new or alternative fuels (RAC, 2023).

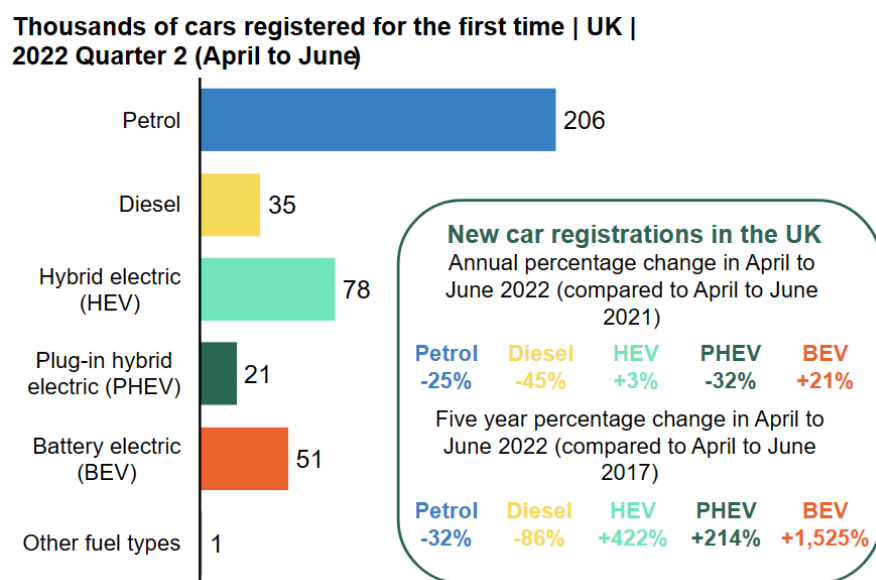


Figure 3: UK 2022 Vehicle Licensing Statistics (Gov Uk, 2022)

3 Environmental Impact

According to the Department for Energy Security and Net Zero (DESNZ) in 2021 transportation was responsible for 26% (figure 4) of the UK's carbon dioxide (CO₂) emissions (DESNZ, 2023). This equated to 109 metric tons of CO₂ (MtCO₂) with 57 MtCO₂ from cars and taxis alone (figure 5), this is over 52% of transportations total emissions (Gov UK, 2023). Both figures show transportation emissions decreasing; 2020 can be considered an anomaly due to Coronavirus Pandemic. However, this sector is the highest contributor to greenhouse gasses and subject to pressure groups to become more environmentally friendly. This ultimately has led to government bans on sales of petrol and diesel vehicles in 2035 (RAC, 2023).

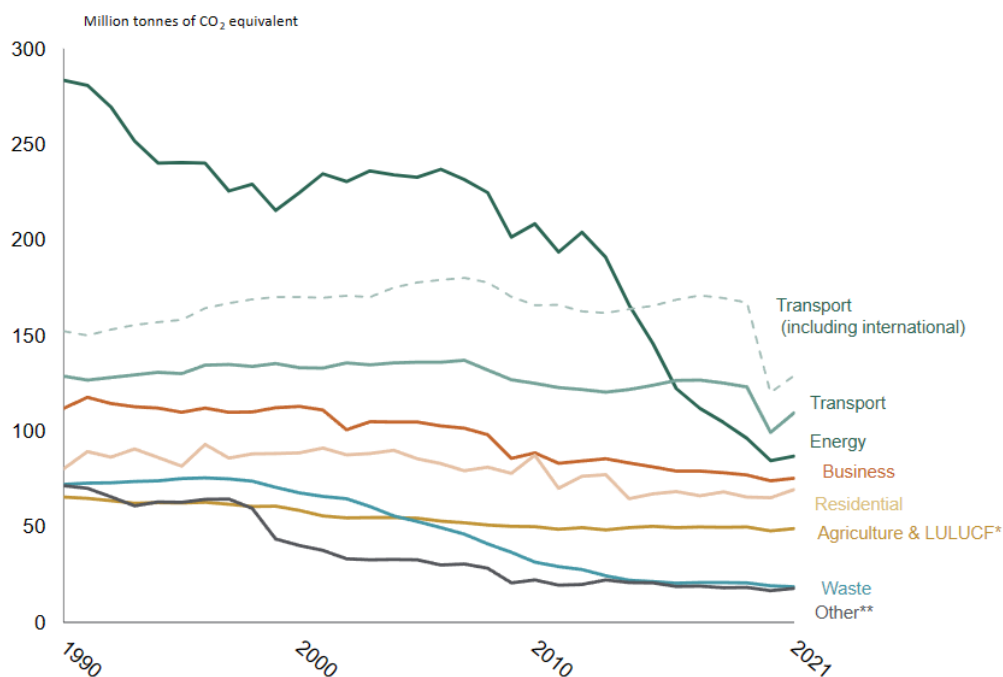


Figure 4: UK Carbon Dioxide Emissions in 2021 (DESNZ, 2023)

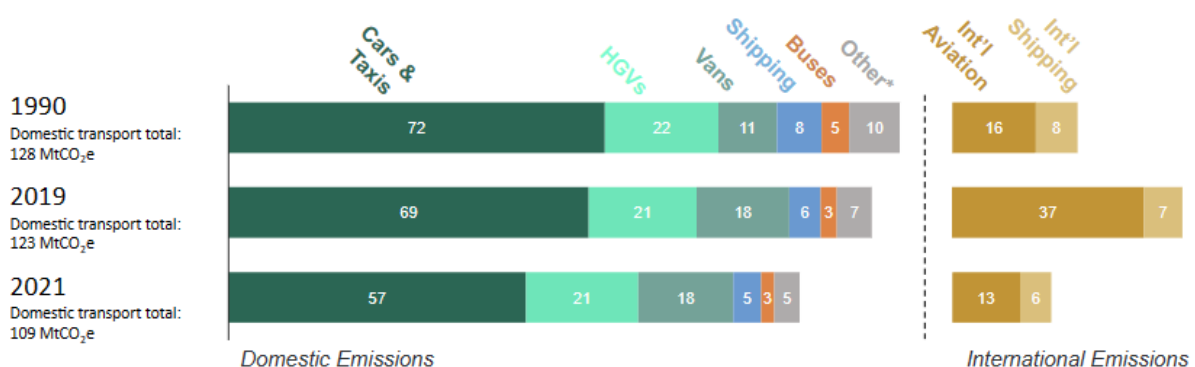


Figure 5: Transportation Emissions (Gov UK, 2023)

3.1 Fuel Sources and Production

Crude oil reserves are a finite non-renewable resource, which over the last 150 years have been depleting each day. According to BP, between 2019 and 2020 2.4 billion barrels of oil were used, leaving reserves at approximately 1732.4 trillion barrels (BP, 2021). At this rate it is predicted crude oil will last for 47 years. Currently, civilisation relies heavily on crude oil and the much-feared end date draws closer. It is a global concern to find alternative sources/solutions to the environmental damage caused by crude oils. As a result, alternative fuels are being introduced: hydrogen, biofuels, synthetic fuels, and 'electricity'.

Biofuels are an infinite and renewable fuel type, originating from crops and feedstock. However, biofuels produce greenhouse gases either in manufacturing (figure 6), combustion or both (U.S. Environmental Protection Agency, 2024). Due to high demand and production, biofuels generate a waste product glycerine, a sugar alcohol that must be disposed (Blaschek, et al., 2016).

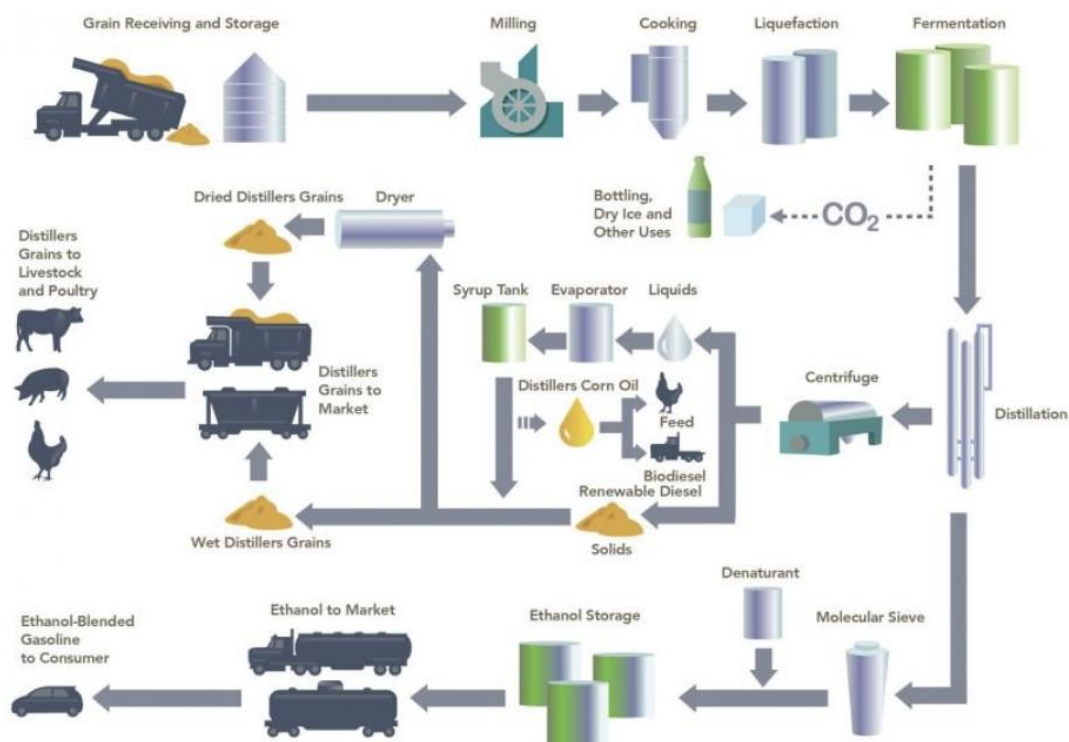


Figure 6: Ethanol Biofuel Manufacturing (RFA, n.d)

Hydrogen can be a renewable and sustainable alternative fuel, depending on manufacturing method (National Grid, 2023). As hydrogen is processed from water using electrolysis, there is no limit to availability. Hydrogen can be manufactured in different ways and are detailed in section 5.1, however, grey hydrogen production has waste byproducts of CO₂. Unfortunately, hydrogen production efficiency is worse than most alternative fuels (figure 7).

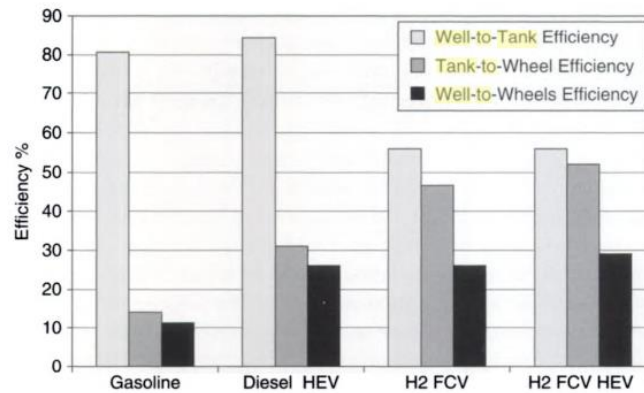


Figure 7: Alternative Fuels Production Efficiency (Evans, 2007)

Synthetic fuels are considered sustainable and infinite carbon neutral fuels that use water and CO₂ as raw materials (figure 8). Water is separated using electrolysis leaving hydrogen to react with captured CO₂ to manufacture synthetic fuels (Repsol, n.d). These fuels can use existing crude oil infrastructure (refuelling stations) for delivery to consumers, causing minimal disruption to existing networks. Depending on manufacturing method some gaseous substances are waste byproducts.

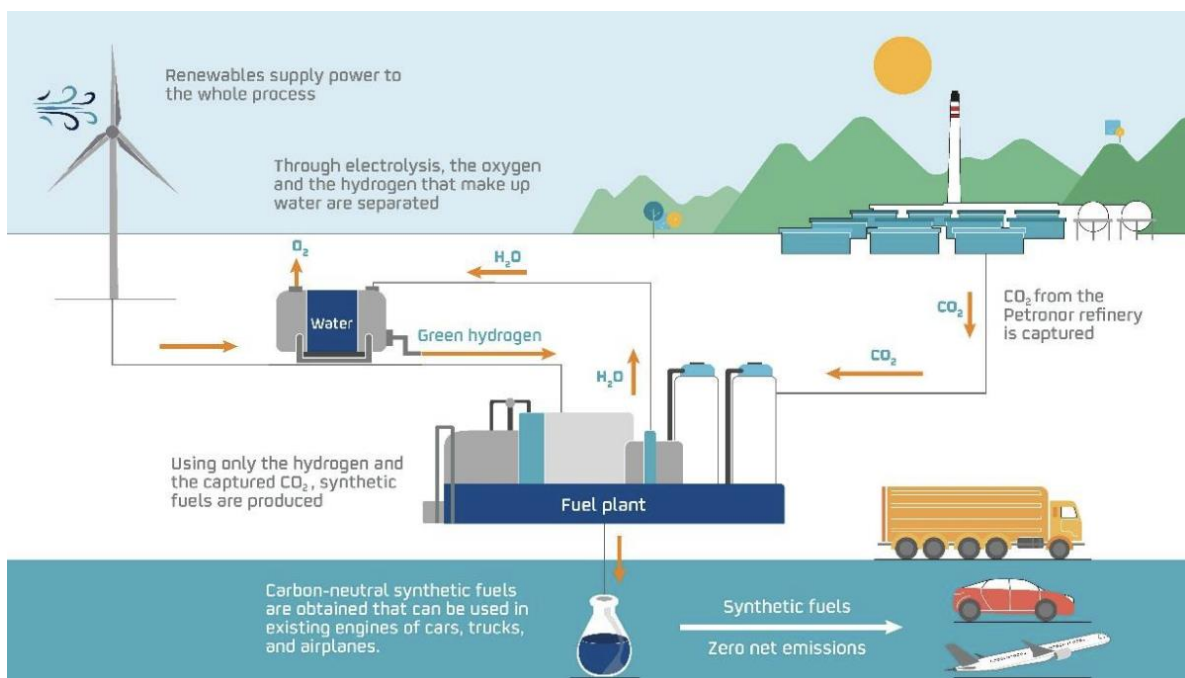


Figure 8: Manufacturing Synthetic Fuels (Repsol, n.d)

3.2 Fuel Logistics

Carbon footprints of fuels or electricity for vehicles are considered with a life cycle analysis (LCA). Modelling an LCA can assist in determining environmental impacts at certain points during manufacturing. Figure 9 demonstrates LCA examples: “well-to-tank” (fuel extraction through to distribution), “tank-to-wheel” (onboard combustion of fuel) and the whole process “well-to-wheel” (Ahmad, et al., 2024). Energy is consumed at all stages and given specific definitions: “feedstock energy” the energy contained in raw materials ending up directly in final fuel, “process energy” defined as energy used within the well-to-tank LCA and “fuel product energy” is energy within the final fuel (calorific value). Previous statistics estimate “1.2MJ of primary energy is used to make 1MJ of diesel fuel” (Majewski & Jääskeläinen, 2023), excluding distribution the LCA energy efficiency is 83%. This source also states renewable fuels such as ethanol have varying energy consumption based on assumptions within analysis. The following energy inputs contributing to manufacturing emissions of crop-based fuels are: biomass production, labour, transportation, fertilizer, seeds and machines. The US Department of Agriculture conducted an LCA in 2002 which determined corn-based ethanol saw a 34% energy return gain, when reconducted in 2004 this increased to 67% (Shapouri, et al., 2002). However, other studies showed corn-based ethanol to be non-renewable as it utilised more energy than it provided (requiring 29% more fossil fuel energy). A study in Brazil using sugarcane-based ethanol yielded 3.7 times (270%) more energy than consumed in manufacturing, these changes in fuel source and geology demonstrate multiple factors to consider in production of biofuels (Dias De Oliveira, et al., 2005).

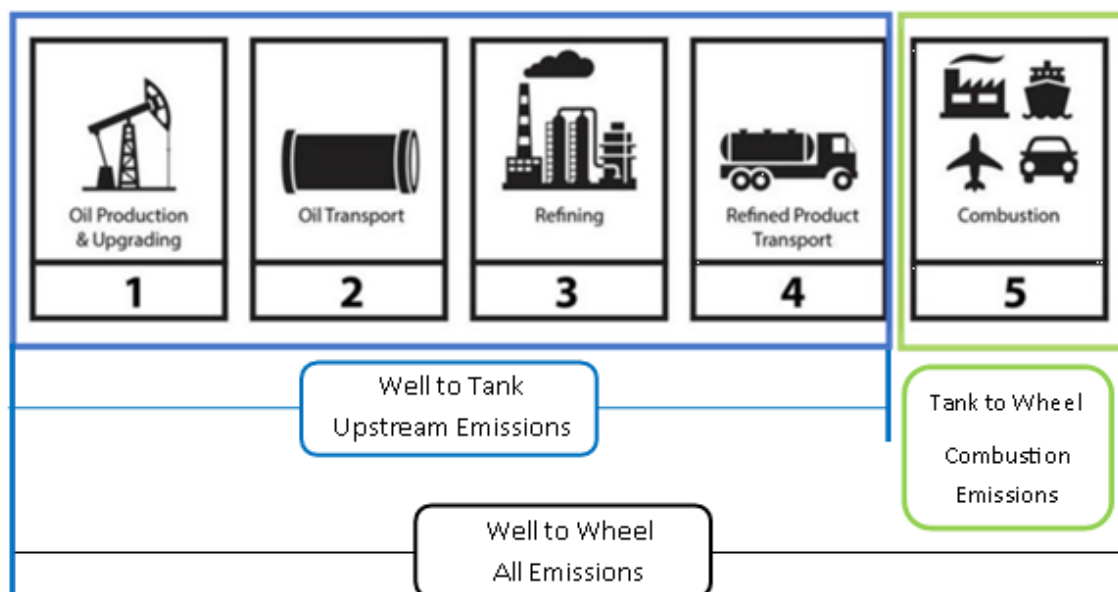
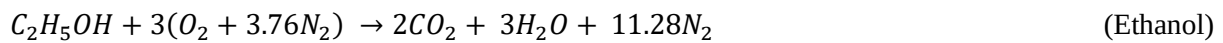
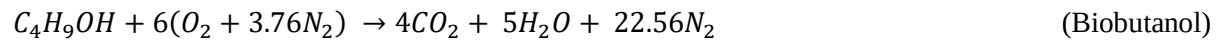
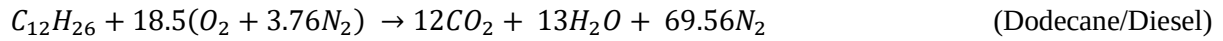
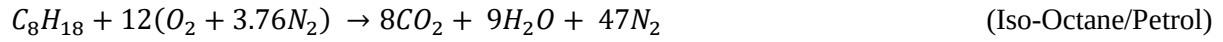


Figure 9: Fuel Logistics

3.3 Alternative Fuel Emissions

Resultant products from combustion depend on the fuels chemical compound and impact emissions differently. The chemical equations below represent stoichiometric combustion of alternative fuels:



CO₂ is a by-product of hydrocarbon combustion and the amount produced per kilogram of burnt fuel changes based on fuel. Iso-octane produces the most at 3.1kg of CO₂ (figure 10) when compared to ethanol (1.9kg) or hydrogen (0kg). Although CO₂ production is lower for ethanol and biobutanol, the calorific values are lower and therefore reduce fuel economy.

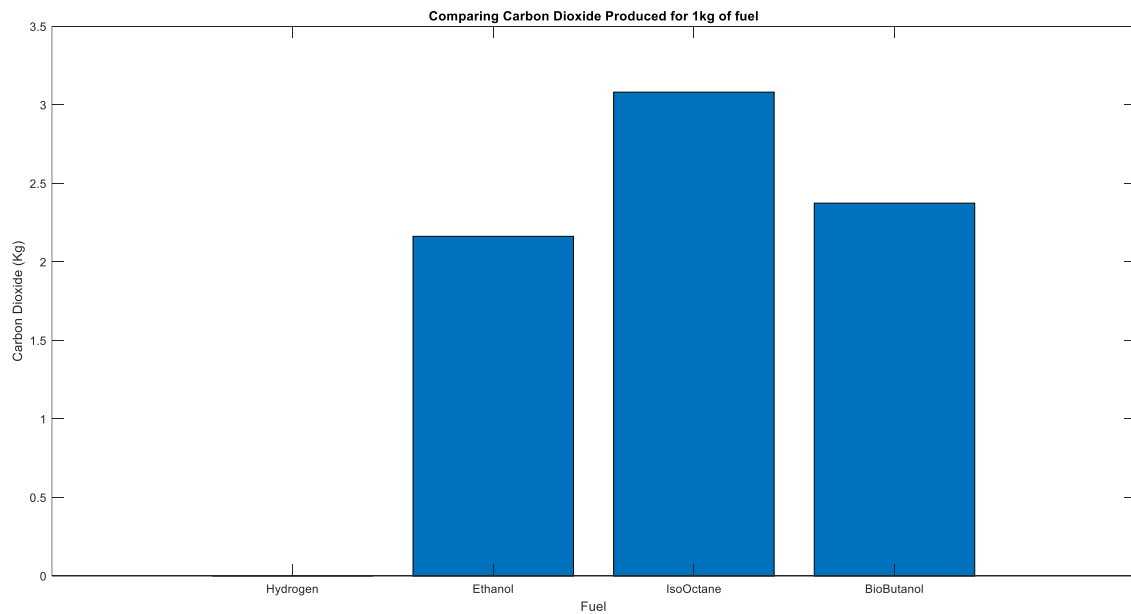


Figure 10: Stoichiometric Combustion Carbon Dioxide Produced

Nitrogen oxide (NO_x) increases when lean and carbon monoxide (CO) increases when rich; this is aside from hydrogen that only produces NO_x. Particulates such as NO_x, sulphur oxide and ammonia have serious health and environmental impacts: visibility, breathing, water quality, acid rain and Earth temperature (ADEQ, n.d.). Figure 11 demonstrates reduced emissions for alcohols butanol and ethanol regarding CO and NO_x (Wigg, et al., 2011).

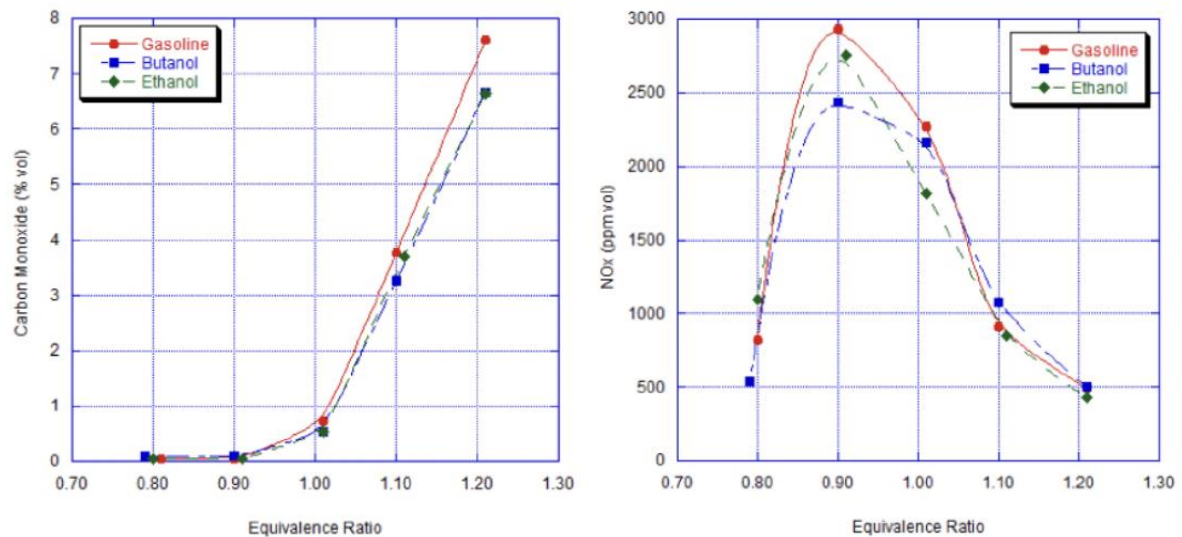


Figure 11: Hydrocarbons Fuel Emissions Comparison (Wigg, et al., 2011)

Although hydrogen is a positive alternative with no CO or CO₂ byproducts, NO_x production is still a problem. Although optimising/controlling combustion conditions and exhaust systems can reduce NO_x, complete elimination is not currently achievable (Alastair, 2021). Electric vehicles (EV) do not produce any tailpipe emissions; however, manufacturing and charging causes concerns.

4 Sustainable Practises and Legislation

During 2020 the UK Government planned to ban sales of new petrol and diesel cars/vans in 2030 (this date was later changed) and a zero-tailpipe emissions target set for 2035. The government stated “The UK is firmly at the forefront of the electric vehicle revolution”, they continue saying it will “improve air quality in our towns and cities, and improve our domestic energy security by removing our reliance on imported fossil fuels” (Office for Zero Emission Vehicles, 2023). In 2017, ‘The Alternative Fuels Infrastructure Regulations 2017’ was introduced to give the government power to support infrastructure of the following alternative fuels: electricity, hydrogen, liquid or gaseous biofuels, synthetic fuels, natural/liquified petroleum gas (Gov UK Legislation, 2017). Despite this case, focus seems set on EV’s and hydrogen with other fuels neglected. Other countries (Germany and Japan) are considering hydrogen, synthetics and biofuels due to influence from manufacturers BMW, Porsche, Toyota and Mazda (BMW Group, 2023).

NO_x is caused from high burn zone temperatures during lean combustion. To reduce NO_x production exhaust gas recirculation (EGR) has been implemented into engine design for years. EGR recirculates small amounts of exhaust gases into the combustion chamber to consume volume in place of air. This lowers the air-fuel ratio, burn zone temperature and therefore NO_x (figure 12) production (Ashok, 2021). Due to EGR’s success, the Road Vehicles (Construction and Use) Regulations (Regulations 61(7) and 61A(3)) states it is an offence to use a modified vehicle on public roads which does not comply with “air pollutant emission standards it was designed to meet” (DVSA, 2018).

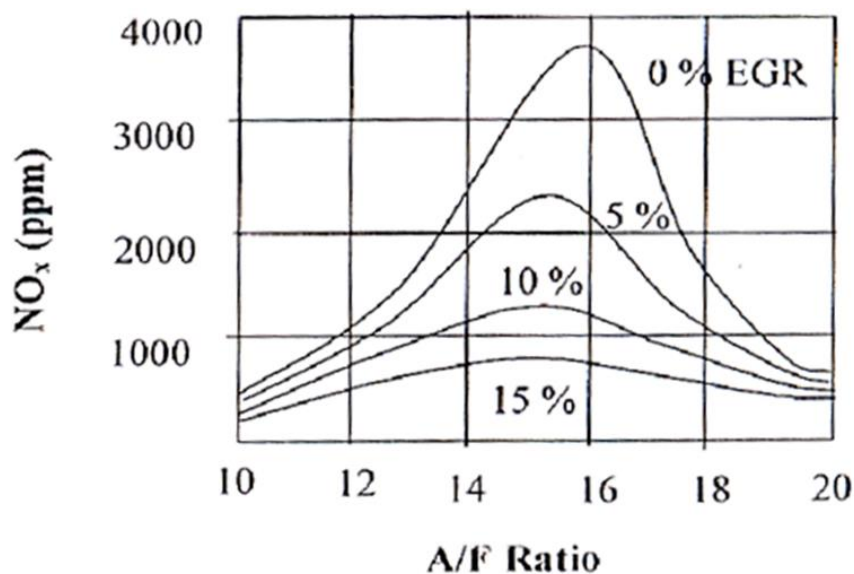


Figure 12: EGR Effects on NO_x (Srinath, et al., n.d)

4.1 Sustainable Practises

The government's dedication to EV's adds additional strain on the National Grid (figure 13). Plans are underway to increase renewable energy supplies for UK electricity in the aim of carbon net zero. Reduction in CO₂ emissions of the energy sector (figure 4) are due to wind, tidal and solar farms replacing traditional coal power stations (HM Government, n.d.). A vehicle-to-grid charging system is designed to reduce strain on the Grid where EV owners can sell energy back during peak times. EVs will therefore act as virtual powerplants, this 'payback' may incentivise people to buy EVs (figure 14).

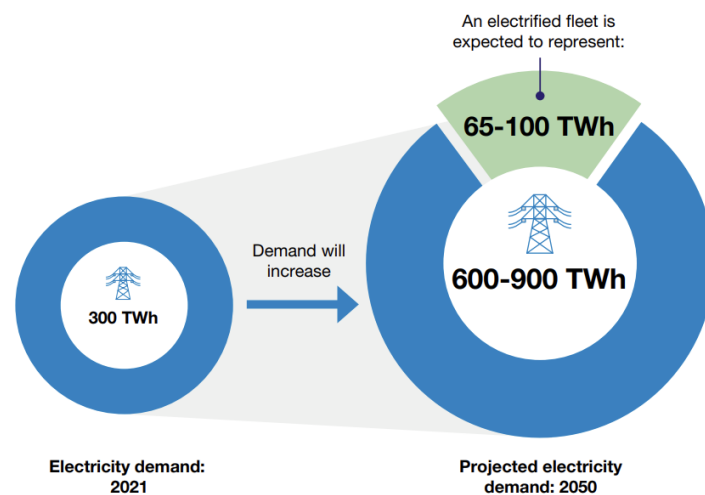


Figure 13: Projected Electricity Demand (HM Government, n.d.)

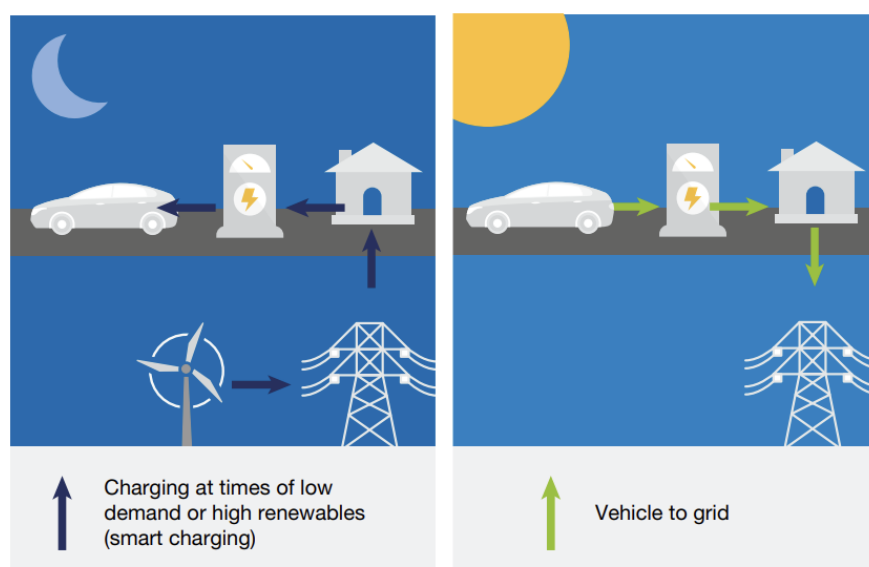


Figure 14: Vehicle-to-Grid Charging (HM Government, n.d.)

5 Sustainability and Technological Challenges

Alternative fuels require refuelling stations to deliver fuel to the public. Depending on fuel type, storage and delivery methods vary. Petrol and diesel are well established with approximately 7000 refuelling stations across the UK (Hughes, 2022). Due to commonality and short refuelling times, supply and demand can be met without the need for more refuelling stations. On average a traditional car is refuelled in minutes, this is the same for synthetic and biofuels whereas, EVs take significantly longer. Most existing storage tanks would be suitable for blends up to and including B100 (full biodiesel), but compatibility should be checked for with manufacturers and fuel suppliers, figure 15 is a petrol forecourt system suitable for biodiesel (NREL, 2023). With small infrastructure changes required, economic investment would be minimal compared to hydrogen. Although fuel storage systems would remain similar, ICEs would need adaptations to prevent premature erosion damage to engine seals and hoses from corrosive alcohols and biofuels corroding plastics such as: Polypropylene, Polyvinyl and Tygon (NREL, 2023).

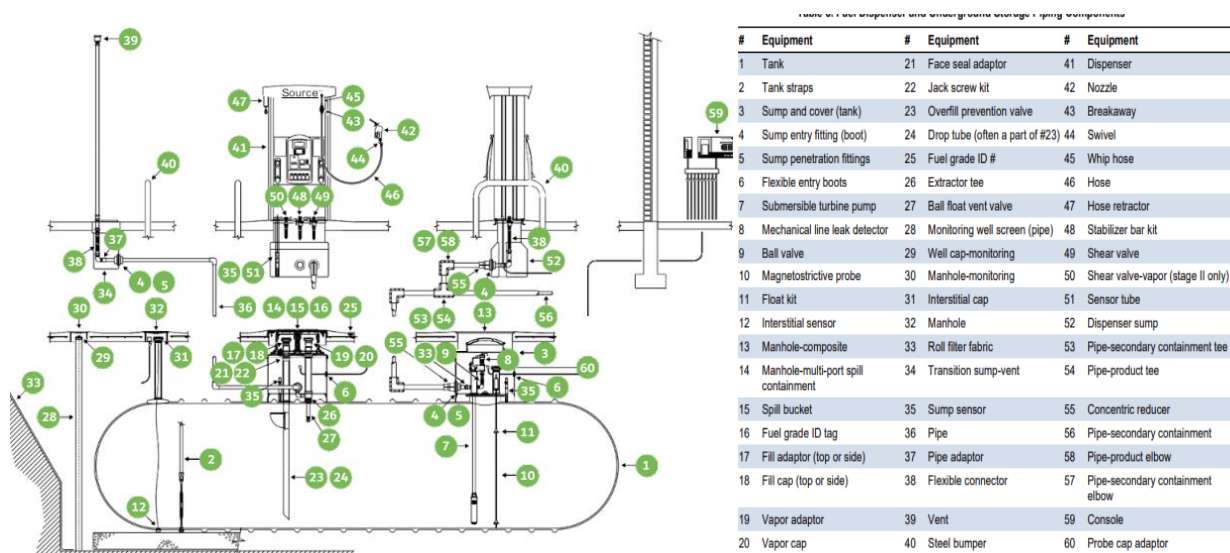


Figure 15: Fuel Storage and Dispenser System (NREL, 2023)

5.1 Hydrogen Vehicles

Hydrogen production, refuelling and storage technology is developing constantly. However, supporting infrastructure is lacking and a country switchover to hydrogen is improbable for the foreseeable future. Whilst new funding for public hydrogen refuelling stations (HRS) are given out (recently to Tees Valley Middlesborough), it seems to be aimed at HGVs delivering locally and not across the country. This is to reduce short trip emissions and fast track research with local universities, providing jobs for local communities (DESNZ, 2024). Hydrogen production methods are categorised based on manufacturing fuel. The three main categories are: green which is obtained by electrolysis from renewable electricity, blue hydrogen is produced from fossil fuels where CO₂ is captured, and grey hydrogen from fossil fuels with CO₂ released to atmosphere. The National Grid breaks this down further into 8 (figure 16) categories (National Grid, 2023). Certain production methods have sustainability questions based on the fuel used in manufacturing and storage technique, these are current technological challenges and implications of current facilities.



Figure 16: Hydrogen Colour Spectrum (Examples, n.d)

Hydrogen has two storage methods, physical or material based. Hydrogen for automobiles is stored in physical form as liquids or compressed gas. Being a volatile compressed gas, safe storage is compulsory. This commonly leads to compression in large-volume, high-pressure composite vessels. These large storage vessels are suitable for larger models (SUV) but challenging for smaller compact cars. The U.S. Department of Energy (n.d.) demonstrates this (figure 17) where hydrogen can be seen to have the highest energy content by mass (calorific value) of 120 mega joules per kilogram, nearly 3 times iso-octane. However, on a volume basis “the situation is reversed; liquid hydrogen has a density of 8MJ/L whereas gasoline has a density of 32MJ/L.” (U.S. Department of Energy, n.d.) Therefore manufacturing and refuelling stations are very different to crude oils (figure 18). The economic implications of this are high due to the inability in repurposing existing ‘petrol’ stations.

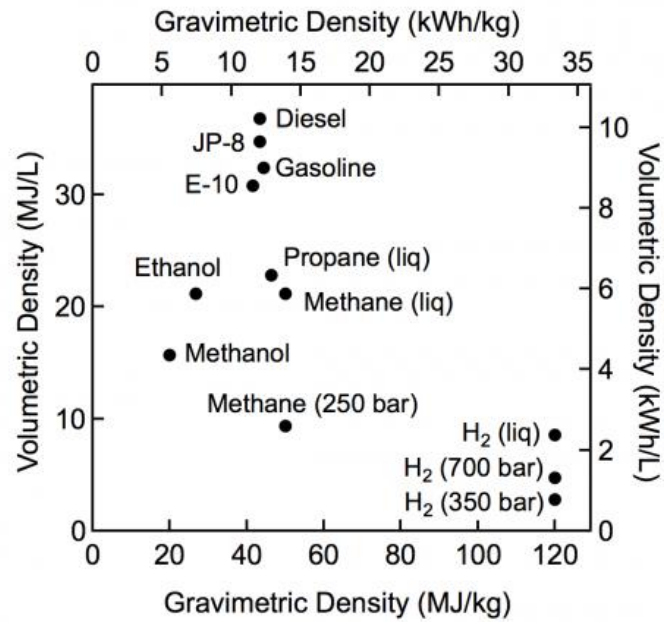


Figure 17: Comparing Fuel Energy (U.S. Department of Energy, n.d.)

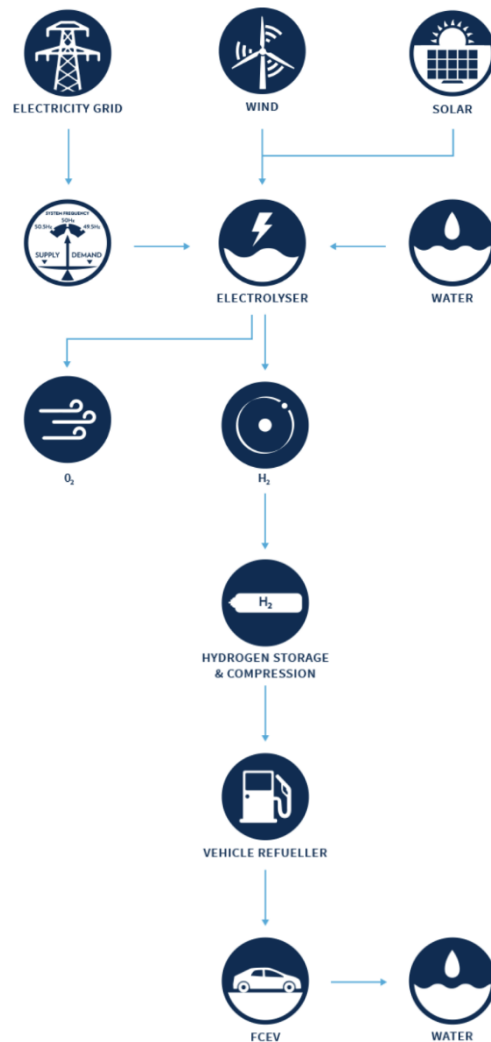


Figure 18: Hydrogen Manufacturing (Hydrogen Mobility Europe, 2020)

5.2 Electric Vehicles

Much controversy has surrounded EVs, predominantly charging times and vehicle fires. The type of charging facility, battery size, current charge and environment conditions all determine charging time and can be estimated with formula below. Determined in the formula, battery power is proportional to charge time, if battery power increases so does charge time (RAC, 2021).

$$\frac{\text{Battery Size (kWh)}}{\text{Charge Power (kW)}} = \text{Charging Time (hours)} \quad (\text{EV Charging Time})$$

Throughout the UK attempts are being made to add additional charging facilities. Table 1 shows charging rates available, estimated charging time and quantity of chargers. Figure 19 demonstrates installation progression of public charging points. However, this progression rate is not high enough to convert the country to EVs. Government officials stated “its electric vehicle infrastructure strategy in which it stated that although the UK is a leader in the EV transition, the current pace of rollout is still too slow” (Transport Committee, 2023).

Table 1: EV Charging Points (Edwards, 2024)

Charging Point	Charging Power (kW)	Estimated Charge Time	Quantity in UK (2024)
Slow	3-7	6 - 12 hours	33,571
Fast	8-49	1 - 5 hours	12,752
Rapid	50-149	20 - 60 minutes	6,770
Ultra-rapid	150+	20 minutes or less	4,197

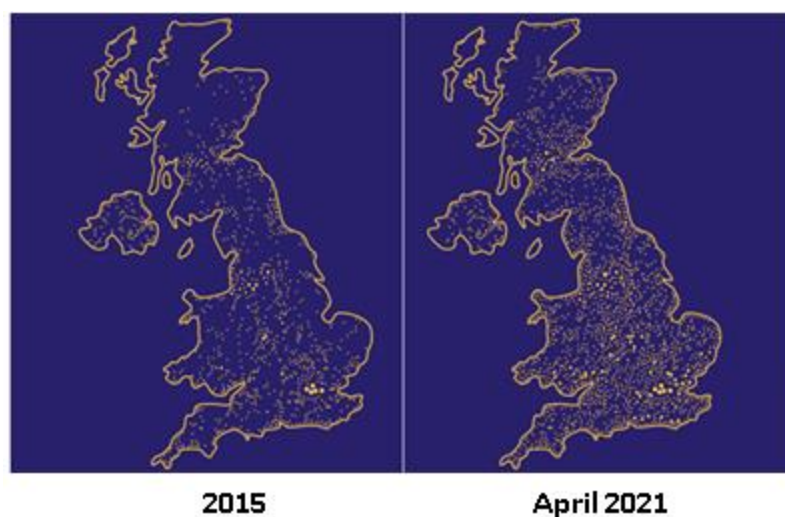


Figure 19: UK Public Charge Points Progression (HM Government, n.d.)

6 Future Outlook

The UK government's alternative fuels sustainability model for transport is based on three ideas/documents: "UK Hydrogen strategy", "Transitioning to Zero Emission Cars and Vans" and "Net Zero Strategy" (HM Government, n.d.). These state the UK's heading for alternative energies and sustainability model. A "Roadmap" to 2035 (figure 20) is given as guidance for the transportation sector.

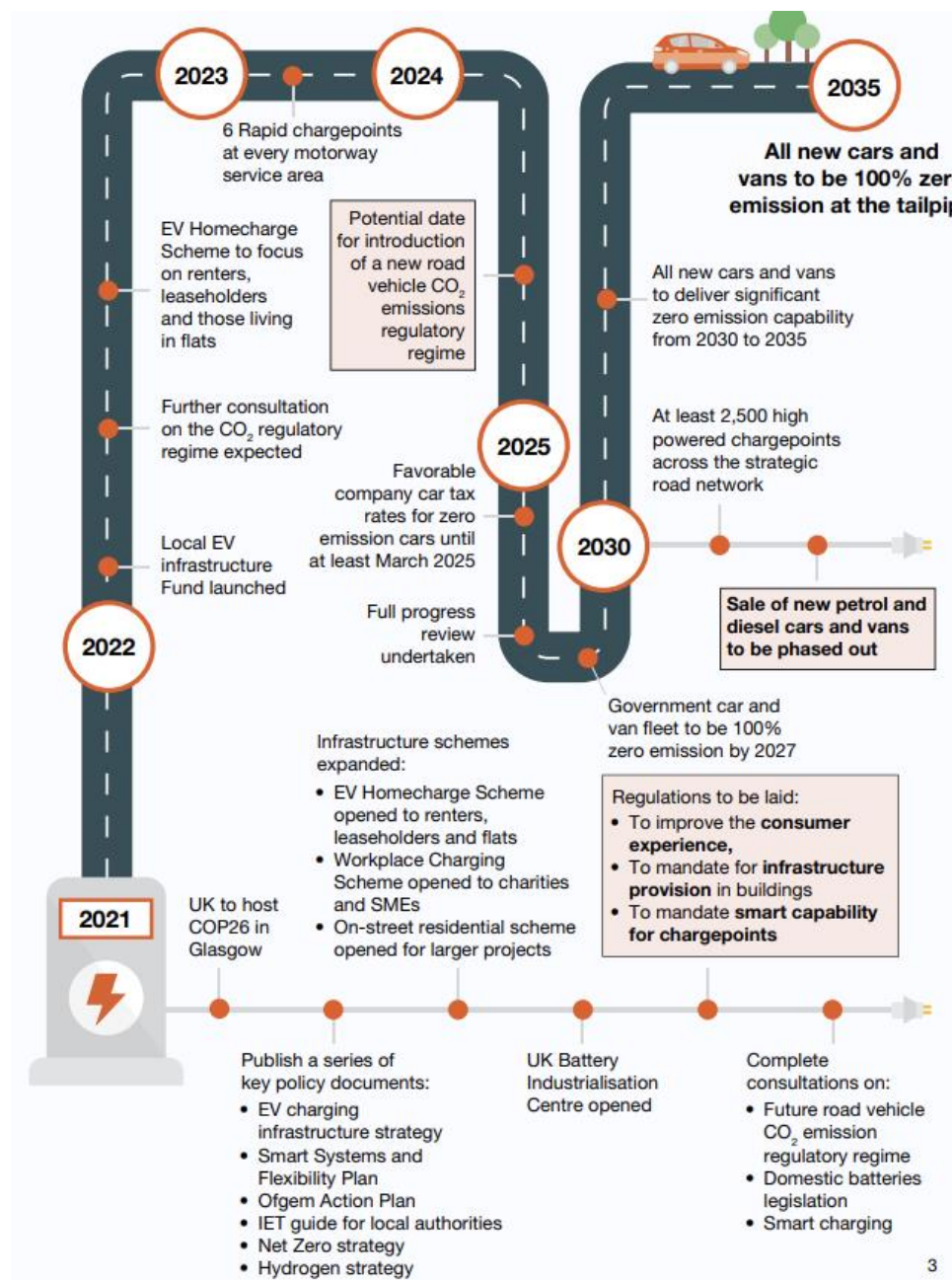


Figure 20: Roadmap to 2035 (HM Government, n.d.)

6.1 Proposal Strategy

Public opinion disagrees with EVs being the sole solution for light vehicle transport. Instead, many believe the answer is a range of alternative fuels; potential problems of this theory occur due to varying infrastructure requirements of these fuels. EVs concern the public with charging duration and lack of charging facilities, in some cases people suffer from “charge” or “range” anxiety (National Grid, 2022). This increase in electricity consumption will cause strain on the National Grid and with aims for carbon net zero in 2050 additional renewable power sources will be required. However, increases in sustainable and renewable electricity production will provide energy for BEVs and carbon neutral manufacturing of synthetic fuels. Although synthetics do not meet zero tail pipe emissions, the infinite and sustainable manufacturing process which utilises trapped CO₂ gives advantages over biofuels which take up land for crops. With additional hydrogen electrolysis facilities (figure 21), local communities and economy will benefit from additional jobs (HM Government [2], n.d). A viable suggestion is a combination of fuel technology: EVs for short journeys/city usage, hydrogen for HGVs and SUVs and synthetic fuels for long distance car journeys with already available motorway refuelling stations.

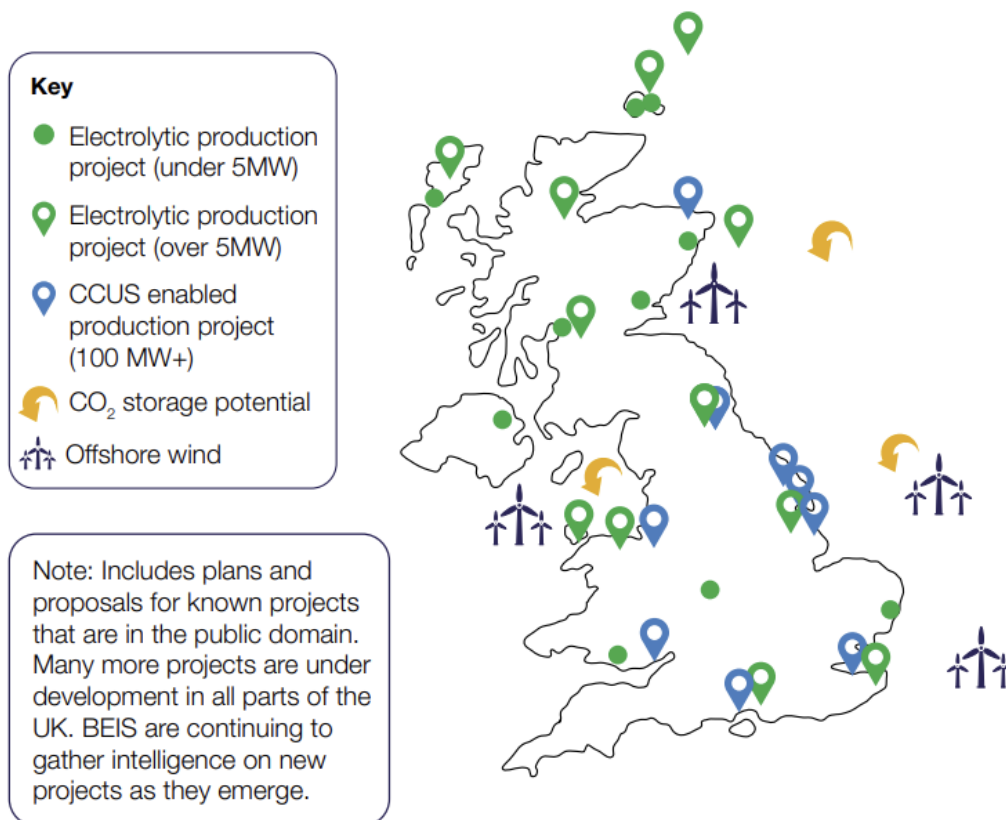


Figure 21: Proposed UK Electrolytic Hydrogen Production (HM Government [2], n.d)

Social concern consensus of BEVs are fires and mining of precious metals lithium and cobalt. EV fires are caused by a “thermal runaway event in which a lithium-ion battery self-heats uncontrollably” (Shackelford, 2023). Scaling and production of these vehicles should be reduced or halted until working fire extinguishing methods have been introduced. Sustainability concerns for precious metal mining of lithium for batteries deters some people from purchasing an EV. It would be beneficial to develop alternative battery materials and technology or educate the public of EVs break-even point and lithium-ion battery recycling (figure 22).



Figure 22: Lithium-Ion Battery Life Cycle (Tschödrich, et al., 2022)

Aerodynamicists insist on shifting focus to reducing vehicle drag, this decreases fuel consumption (combustion engines) and increases EV range (Bull, 2024). Tesla has conducted many studies where reduced drag coefficient is seen to increase range due to lower drive forces overcoming less drag (figure 23). If all manufacturers adopt this technique, range of EVs could increase benefitting consumers with lower recharging bills and governments with lower demands on National Grids (Fuhs, 2008).

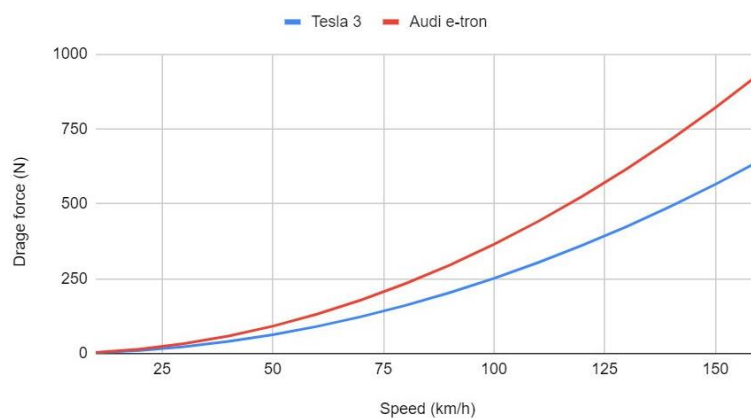


Figure 23: EV Aerodynamic Drag Comparison (Kmet, 2022)

7 Conclusion

In conclusion, crude oil and fossil fuel usage is ending in the UK over upcoming years. Automotive manufacturers must invest large amounts of time and money to research and develop alternatives. Statistics over the last three years show reduction in usage of fossil fuels and implementation of alternative fuel and powertrain technology. BEVs have been the government and automotive manufacturers focus. However, some consumers and manufacturers are not sold on electric; instead a combination of hydrogen, synthetic fuels and biofuels. Statistics show the reduction in greenhouse gas and NOx emissions from the transportation and energy sector which demonstrates the progress in technology to a renewable, environmentally friendly self-sustainable Britain.

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