

BEng Motorsport Engineering

Automotive Materials & Sustainability

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Introduction

An analysis into carbon footprint, resource depletion, pollution and waste generation will be made all the way from extraction to the end product of being burned within an ICE. Each stage will include an in-depth look using statistics and relevant data, with a comparison between industries. Sustainable practices and legislations pertaining to fossil fuels will be discussed with current and future ones being analysed. Sustainability and technological challenges will be discussed and what will happen in the future with an alternative propulsion type.

Environmental Impact

The environmental impact of internal combustion engines (ICE), specifically fuels will be evaluated and considered due to a big push from global powers to become low or zero emission producing, since the Paris Agreement in December 2015, which subsequently entered force in November 2016. It was adopted by 196 parties at the UN Climate change Conference (COP21) (United Nations Climate Change, n.d.). Low or zero emissions based on CO_2 and other harmful pollution such as NO_x which is a combination of nitric oxide (NO) and nitrogen dioxide (NO_2).

As Gasoline (Petrol) is produced using crude oil (Petroleum), which is a raw natural resource which is composed of hydrocarbon deposits and organic material which is compressed and forms at depths of 2,000m below sea level, where temperatures reach and exceed $100^\circ C$. Due to gasoline and diesel being made from crude oil, there is only a limited supply, which has an estimated oil reserve of 1.56 trillion barrels in proved crude oil reserves as of 2022 (Statistica Research Department, 2023), which has continued to climb steadily since 2010 according to Statistica as shown in figure 1.

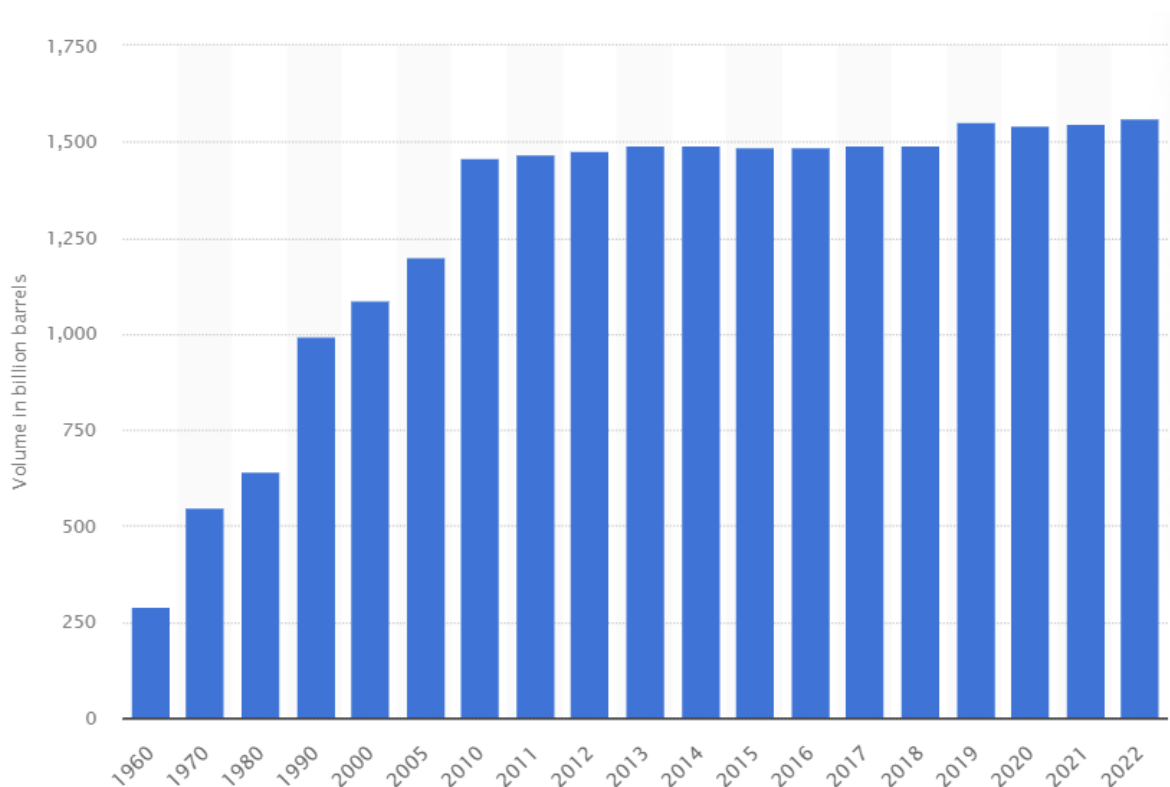


Figure 1 - Statistica Proved crude oil reserves (Statistica Research Department, 2023)

Based on the information within figure 1, there is an expectation that current oil reserves will continue to steadily increase.

As muds are buried, they compact, lose porosity, and are lithified into shales or mudstones (Selley R. 2003). The organic matter that is contained within the mudstones goes through many changes which can be categorised by into three stages. Diagenesis, catagenesis and metagenesis. Diagenesis occurs in the shallow subsurface at near normal temperatures and pressures. Methane, carbon dioxide, and water are driven off from the organic matter to leave a complex hydrocarbon termed kerogen. Kerogen is a hydrocarbon that is insoluble in normal petroleum solvents, but expels petroleum when heated.

Oil and natural Gas extraction

On land oil rig construction

In the life cycle of hydrocarbon fuels, extracting oil and natural gases is the beginning. However, the first step is preparing the rig site, the above ground infrastructure such as roads and buildings are setup. Traffic plans, designated access roads, noise barriers alongside safety procedures and everything else is carefully planned and monitored according to laws that pertain to the area that it is based in.

Offshore oil rig construction

More than 90% of the UK's oil production occurs offshore within the central and northern sections of the North Sea. Installing an offshore oil platform is a more difficult task than on-land. Once the sniffer equipment and trace amounts of oil and natural gas have been found in the water, a magnetic survey on the seafloor will usually determine if there is oil below or seismic equipment can be used to survey which sends shock waves through the seafloor and depending on if the frequency or amplitude of the shock waves change it can then be determined if there is in fact oil or natural gas below. The change in shock waves is due to the medium and how they travel through different fluids or solids.

Once the location has been established, exploratory wells are installed taking 2 to 3 months to install. These are used to take samples of the rock layers underneath the seafloor a similar process to building large buildings on land, just with the added difficulty of being thousands of feet underground.

United Kingdom laws around oil and natural gas extraction will be discussed in the next section.

The drill rig is then brought to the location, 20 to 30 trucks required to transport all the parts. Once constructed, a well is drilled straight down into the ground beneath the pad. First step is drilling the surface hole down to a depth of 100ft below the deepest known aquifer. A steel casing is then cemented in place to reduce the risk of polluting the water aquifers. The transporting of the parts required for building the oil rig well produces a large amount of pollution not just from the diesel engines, but even though they do produce greater quantities of particulate matter than petrol engines (HSE, 2023) and equipment such as cranes, but also from the tyres, which wear quickly due to the weight and load of the vehicles.

The long hole is then drilled and after reaching a depth around 1000ft above the underground area where the oil and natural gas is trapped, the hole is directionally steered to turn it horizontal and out around 1 to 2 miles. In order to access the oil and natural gas across a larger distance and not just directly under the well pad.

Horizontal drilling minimises the impact and scale of aboveground land disturbance by allowing drillers to use only one drill pad for multiple wells. These technological advancements mean that far fewer well sites are required in comparison to 10 to 20 years ago.

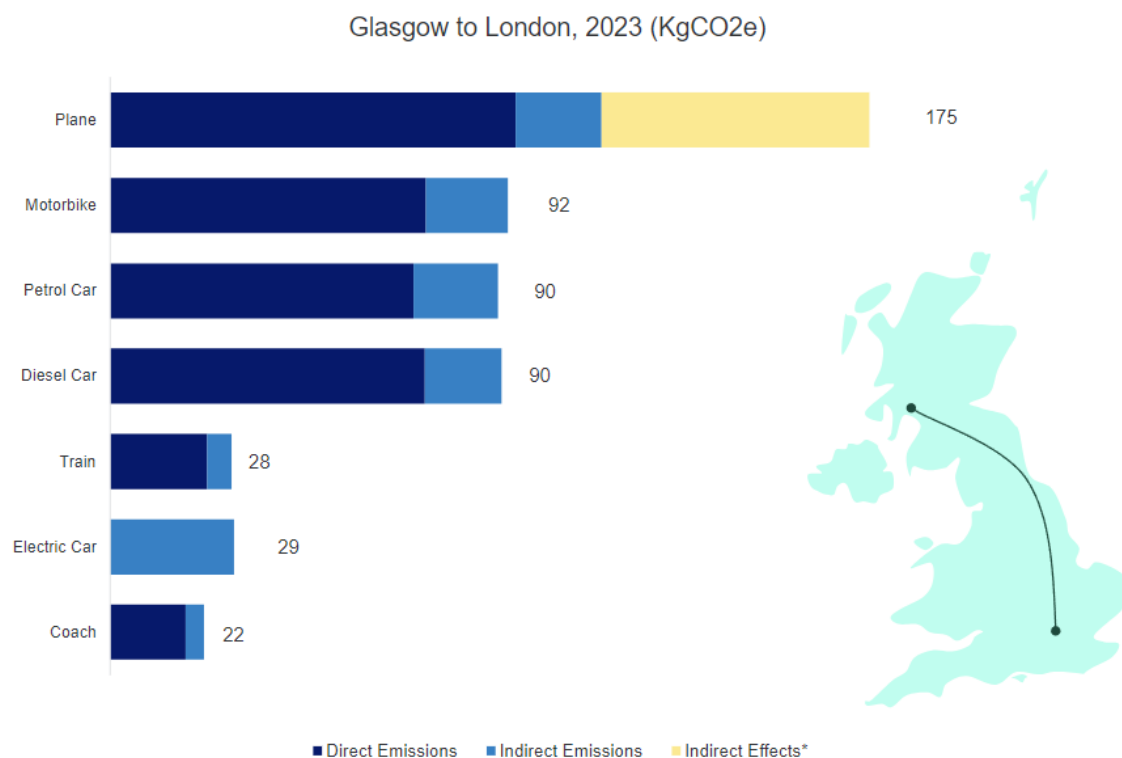
Once the drill has reached the target distance, the drill pipe is removed and steel pipe is pushed to the bottom. The well casing is cemented in place. Thorough testing is done to ensure that the pipe is impermeable before the extraction of natural gas or oil occurs.

Before drillers can tap the oil and natural gas, a perforating gun is typically lowered into the ground and fired into the rock layer in the deepest part of the well, creating holes that connect the rock holding the oil and natural gas and the wellhead, which completes the construction of the well.

Fracking

Once the first stage of the well is open, it's time to unlock the oil and natural gas that has been trapped in the rock. Using specialised instruments to monitor pressure and data from the well in real time. Fracking fluid, which is 97 - 99.5% water and sand and 3 - 0.5% chemicals. Many of which are found in everyday household products, is pumped at high pressure through the perforating holes to create paper-thin cracks in the shale rock, freeing the oil and natural gas trapped inside. After a few days, typically fracking is complete. Production can begin, oil and natural gas flows up from the well bored and the fracturing fluid is then recovered and recycled and used in other fracking operations. (Coloradans for Responsible Energy Development, n.d.)

The impact of oil rigs is not just an environmental impact of disturbing the land but of nearby areas, including roads needed to access areas due to the volume of vehicles transporting equipment and interruptions from additional traffic due to workers.



Description: this is a bar chart which shows an estimate of emissions in kilograms of CO₂e from an example journey, Glasgow to London, in 2023. Plane: 175; Motorbike: 92; Petrol car: 90; Diesel car: 90; Train: 28; Electric car: 29; Coach: 22

Figure 2 - GHG emissions for a single passenger on an example journey

Figure 2 shows an estimate for emissions produced by each type of transport on a predetermined route, as an example, to allow for a direct comparison between each mode of transport.

Sustainable Practices and Legislation

Current regulations are based around euro 6 with euro 7 coming in the near future. Its aim is to support the transition towards clean mobility and keep the prices of private and commercial vehicles affordable to citizens and businesses.

As of the 12th December 2023, parliament and council reached a provisional agreement on new rules to reduce road transport emissions for passenger cars, vans, buses, trucks and trailers.

The number of exhaust particles will be measuring particles that are as small as 10 nanometres (nm) instead of the current 23 nm in order to reduce the particulate number (PN) released into the environment. Due to testing a larger number of particles due to testing for smaller particulates, total emissions released from cars should be reduced as the same emission targets will have to be achieved, therefore lowering the overall emissions released from cars with ICEs. Research has shown that implementing low-emission zones (LEZs) can effectively reduce pollutants such as PN10 mentioned above. (Zhai, M., & Wolff, H. 2021)

Regulations and best practices for onshore oil and gas exploration in the UK are heavily regulated and require an application after an approval's checklist has been completed. Contained with the checklist are such things as Obtaining a petroleum exploration and development licence (PEDL) from OGA or petroleum licence (PL) from DETI. (Department of Energy & Climate Change, 2024)

Offshore oil rigs also need to follow strict regulations in order to protect the environment. Guidance is given on offshore oil and gas exploration, production and offshore gas unloading and storage alongside offshore carbon dioxide storage activities. The contents also include the Energy Savings Opportunity Scheme Regulations (ESOS) 2014, which is a mandatory energy assessment and energy saving identification scheme applicable to offshore oil and gas sector which was introduced to implement Article 8 of the Energy Efficiency Directive 2012/27/EU (EU Parliament and Council, 2012)

Road transport contributes a significant portion to greenhouse gas (GHG) emissions, and in order to reduce these emissions it is important to address how they can be reduced to comply with the Paris Agreement and Euro 7 is being designed to address this issue. (UK Government, 2021)

Within the UK, strict legislation must be followed in the production of fuels, as they are classed as hazardous as defined by the Hazardous Waste (England and Wales) Regulations 2005 under Regulation 3 H3 noting that a liquid substance and preparations having a flash point below 21°C is listed as highly flammable.

Sustainability And Technological Challenges

There are technological challenges with hydrogen, and it currently being too costly due to the efficiency of electrolysis. The creation of hydrogen by electrolysis is commonly referred to as green hydrogen. Electrolysis uses electricity to split water molecule (H_2O) into hydrogen (H_2) and oxygen (O_2). Electrolysers are to help balance the electricity grid by rapidly increasing or decreasing demand to ensure supply and demand are equal. (Hydrogen UK, n.d)

In the UK, hydrogen is generally created by steam-methane-reforming, known as carbon capture usage and storage (CCUS), or as blue hydrogen, which involves high temperature steam being produced from a methane source such as natural gas. The issue is that it is only 65-75% efficient, leading to a large waste of energy and therefore being relatively expensive compared to fossil fuels using this method in its current form. Alongside this issue, is the issue of transporting and storing hydrogen, as the current fuel stations are unlikely to have an ability to readily store and dispense hydrogen. (Terlouw, T., Bauer, C., McKenna, R., & Mazzotti, M. 2022)

In order to meet to reach net zero emissions by 2050, 300 million electric vehicles will be required by 2030 according to the International Energy Agency (IEA, 2021). Based on calculations using an average battery size of 71 Kw/h (Electric Vehicle Database, n.d.), a total of 18 million megawatt hours (18 Terra-watt hours) will be required to power those EVs by 2050. This would equate to using roughly 10% of total known global lithium resources. Environmental and social impacts will be large due to the mining of the lithium required alongside developing a way to more efficiently recycle lithium which yields around 5% of the total used. An enormous demand is likely to be placed on the electricity grids to power electric vehicles. The quantity of electric required can solved by nuclear power, with government plans calling for up to 24 Giga watt (GW) of new nuclear power. Most existing capacity is to be retired by the end of the decade.

Total electricity generation in 2022 was 323.9 TWh with a total consumption of 273 TWh meaning a consumption of around 4100 kWh per capita.

Alternative fuels and electric

Hydrogen

Compared to fossil fuels, when burnt hydrogen only has the by products of water (H₂O) and oxygen. Making it a zero or very low emission alternative. It can also be used in fuel cells, not just injected into an engine like a conventional ICE would require. There are ways to produce hydrogen that solely rely on renewable sources of energy like wind energy for the electrolysis. However, hydrogen is currently expensive to produce even with new methods of production. Without VAT and transportation of the hydrogen, it is still around the same price per litre compared to the price of fossil fuels at the pump in the UK.

Synthetic fuel

Synthetic fuels or efuels, had a \$75 million investment into a startup plant in Chile from Siemens Energy and Porsche. Carbon dioxide is captured from the air passing through various filters. Hydrogen is extracted from water by electrolysis and in both scenarios, oxygen is the byproduct. Due to the carbon dioxide being removed from the air, the fuel is virtually CO₂ free. The plant is located in Magallanes Province of southern Chile, due to the region's ideal conditions for generating wind energy, which will be the sustainable source of electricity in the process. Enel, ExxonMobil and the Chilean energy companies Gasco, ENAP and AME are working as partners alongside Siemens and Porsche to get a jump start on the production of efuels. Porsche plans on using eFuels for racing to reach the goal of the FIA to become net neutral. (ExxonMobil, 2021) AME is the main developed and owner of Highly innovative Fuels (HIF) which is the company running the project. (Porsche, 2023)

Electric

Electric Vehicles (EVs) are deemed as no emissions, however that does not take into account the emissions released from the construction of batteries, where a vast majority of the pollution is from. Emissions comparison between Fossil Fuel Vehicles (FFVs) and EVs can be done with a comparison of emissions released throughout the life cycle of comparable vehicle. Lifecycle includes: manufacturing, operation and end of life.

First the composition of EVs batteries is important. A battery is made up of lots of battery cells, most modern EVs use lithium-ion batteries (Barman, P., Dutta, L., & Azzopardi, B. 2023). Materials used within EV Batteries include essential materials such as aluminium, copper and iron alongside precious metals such as cobalt, nickel, manganese along with elements such as graphite and lithium form the core of EV batteries. Lithium is mined in countries such as Australia, Chile, Argentina. Then is transported on huge cargo ships to be

manufactured into batteries. The majority of the pollution in the life cycle EVs is down to the extraction and transportation of materials used to make the batteries. There is no correct solution to fix however, switching the equipment and cargo ships over to a renewable or alternative fuel source but there are problems as the equipment and ships consume an enormous quantity of fuel, generally diesel, and using an alternative such as ethanol would require a lot more fuel to be used and a larger storage capacity and potentially components such as seals to be replaced to allow it to handle the corrosiveness of the ethanol. Overall, EVs do produce less emissions over a life cycle in comparison to FFVs according to Chen Yang and Hong-Juan Shi in International Journal of Low-Carbon Technologies (Yang C, Shi H J. 2023)

Future Outlook

Future of ICE, will they continue to be used, limits and restrictions?

In the future, there is an expectation for ICE to be still be used, potentially using eFuels or hydrogen. It may be a blend of eFuels / hydrogen as a blend with fossil fuels, in order to continue reducing emissions. Likely, electric or hydrogen will be the main source of energy for cars within cities due to harmful emissions and trying to stop those harmful emissions from being breathed in. With LEZs being introduced more often throughout the UK, it will become more common for electric or no harmful emission vehicles to be allowed into certain areas, more than likely to urban areas such as large cities.

Hydrogen will likely be the alternative for ICE as fossil fuels are phased out of usage. With eFuels and Electric being an intermediary step. Due to eFuels still producing some emissions and electric having the current issue of what happens at end of life as they are difficult to recycle and put into landfill generally.

Conclusion

Overall, it is time to seriously fund development of alternative propulsion systems, not relying on fossil fuels forever as oil continues to deplete with enormous usage worldwide. Alternative fuels are currently being developed and tested by companies worldwide to discover the best solution in terms of cost, sustainability and environmental factors. Worldwide contribution of the 196 countries to agree to the Paris Agreement is moving the development forward to help achieve net carbon zero by 2050. Setting such a tough target is necessary to make everyone work hard to help achieve the goal and if it is missed a lot of progress will be made.

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