



University of Wales Trinity Saint David

School of Engineering

BEng Motorsport Engineering

<i>Title of Report</i>
Sustainability Challenges in Industry
<i>Module Name and Code</i>
Automotive Materials & Sustainability ACHA6012
<i>Student Name & Number</i>
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<i>Submission Date</i>
17/3/2024

University of Wales Trinity Saint David

2023-2024

BEng Motorsport Engineering

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Introduction

In this assignment, the environmental impact of current implemented fuels is going to be evaluated in terms of carbon footprint and general pollution. Furthermore, the effectiveness of sustainable practices involved in the automotive industry are also going to be discussed. Limitations for these aspects are also evaluated. Lastly, the challenges related to the use of synthetic fuels are also going to be discussed. The required developing factors to overcome these barriers are also critically assessed, along with the future outlook and impact of this technology in the automotive industry.

1- Environmental Impact of Fuels

1.1- Environmental Impact Overview

The current fuel technology used within road transport is based primarily on gasoline-ethanol and diesel blends, along with an increase in hybrid and fully electric vehicles. However, the current implementation of more severe regulations and decarbonisation of the industry is shown to be a high priority, due to pressure from various factors namely, governments, media, scientific research, etc to the respective leading manufacturers. This involves the search for alternative fuel propulsion propositions through carbon capture or the use of other leading technologies. “Fuels obtained from electrolytic hydrogen, or e-fuels, can play in reducing oil dependence and decarbonising the transport sector” (IEA, 2023). These regulations will result in an overall reduction of oil demand for transportation. As seen in figure 1, the oil demand growth for road transport is seen peaking at approximately 1mb/d (million barrels a day) in 2022, while the forecast for 2028 depicts a reduction in demand growth of nearly 1.25 mb/d. Other transport includes values indicated for the aviation industry along with maritime and rail. As depicted below, the growth for oil demand for other transport is peaking at 1.25mb/d, with a percentage decrease of 88% (1.1mb/d).

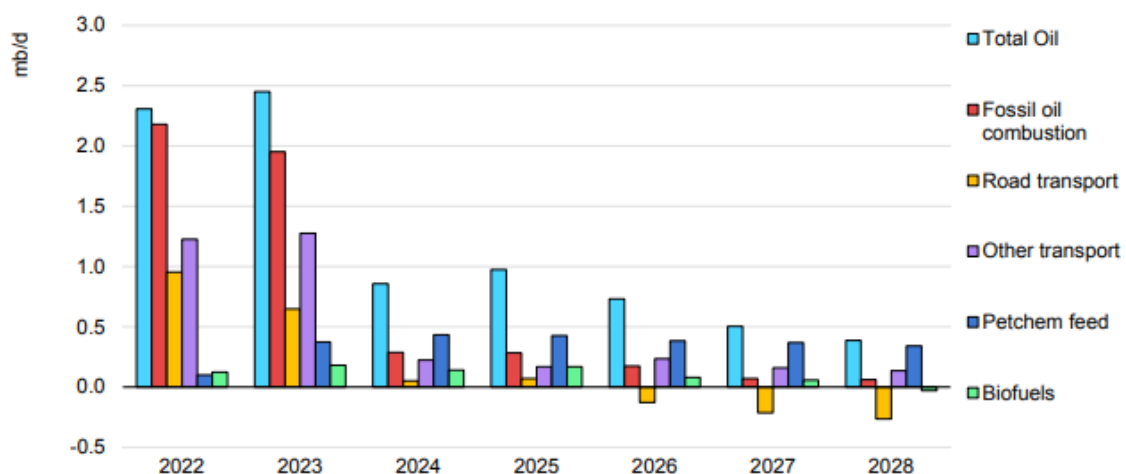


Figure 1- Annual Oil Demand Growth 2022-2028 (IEA, 2023)

On the other hand, when observing the global oil demand by product (table 1), the values outlined for aviation fuel (jet/kerosene) show a growth of 4.7% for 2028. IEA (2023, p.13) indicates that the growth on aviation jet fuel until 2024 is seen due to the travel rebound from the Covid lockdown, with a continued increase after 2024, from long-distance travel in middle-income countries, with higher GDP (Gross Domestic Product). Moreover, the difference in growth for the gasoline product sees a reduction of 0.2% (0.3mb/d), displaying a 2.3mb/d difference compared to the aviation industry. Additionally, fuel oil and gasoil/ diesel for maritime use see a growth of 0.4% for 2028. Due to the early stages of alternative fuel technology development, and a lower restriction in emission regulations present in

aviation and maritime, these values are maintained/ increased for the 2028 forecast, whereas the impact on restrictions in the automotive industry sees a decrease in oil demand.

Table 1- Global Oil Demand by Product 2022-2028 (IEA, 2023)

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2022-28 Growth Rate	2022-28 Growth
LPG/Ethane	13.2	13.2	13.8	14.2	14.4	14.6	14.8	15.1	15.5	15.9	1.9%	1.7
Naphtha	6.6	6.4	6.9	6.8	7.0	7.4	7.8	8.0	8.2	8.3	3.4%	1.5
Gasoline	26.7	23.7	25.6	26.0	26.6	26.6	26.6	26.4	26.1	25.8	-0.2%	-0.3
Jet/Kerosene	8.0	4.7	5.2	6.2	7.3	7.5	7.6	7.9	8.0	8.2	4.7%	2.0
Gasoil/Diesel	28.3	26.1	27.5	28.3	28.4	28.5	28.7	28.7	28.8	28.9	0.4%	0.6
Residual fuel oil	6.2	5.6	6.2	6.5	6.7	6.7	6.7	6.7	6.7	6.7	0.4%	0.2
Other products	11.8	11.9	12.2	11.8	11.8	11.9	11.9	12.0	12.0	12.0	0.3%	0.2
Total products	100.7	91.7	97.5	99.8	102.3	103.1	104.1	104.8	105.3	105.7	1.0%	5.9
<i>Annual change</i>	0.6	-9.0	5.8	2.3	2.4	0.9	1.0	0.7	0.5	0.4		

1.2- Environmental Impact Analysis

One of the leading issues with fuels in the automotive industry is the overall CO₂ emissions. These emissions are mainly produced from passenger vehicles, with an example, seen at a total of 61% in the EU road transport (European Parliament, 2019). The main associated fuels (petrol and diesel) contain properties which are favourable to the automotive industry. On the other hand, the overall efficiency and energy required to complete the distillation process along with the general transportation and usage can be assessed. These can be split into well to wheel testing, which is measured from the crude oil extraction to the usage of fuel by the respective vehicle, thus evaluating the overall efficiency of the process. In addition, tank to wheel can also be used in order to only measure the actual vehicle efficiency and pollution magnitude.

The well to tank efficiency seen for petrol (figure 2) is higher using petrol propulsion (81%), whereas the values depicted by hydrogen fuel cell (H₂ FCV) and hybrid hydrogen fuel cell (H₂ FCV HEV) example are considerably lower at 56%. However, if assessing a tank to wheel efficiency, the values depicted for petrol are reduced by 68%, where efficiency is contrasted by the H₂ FCV and H₂ FCV HEV, which are only reduced by 9% and 5% respectively (Evans, 2007).

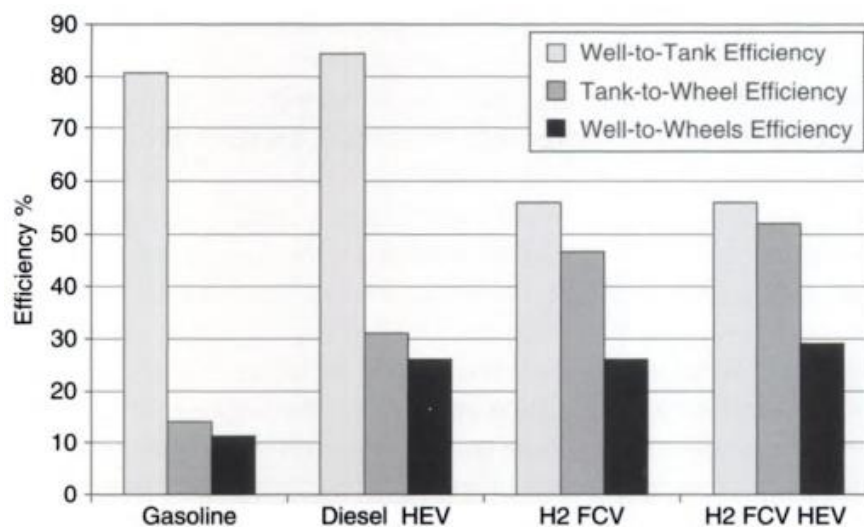


Figure 2- Well to Wheels Efficiency Comparison (Evans, 2007), (SAE, 2003)

1.2.1- Petrol

The demand for petrol powered vehicles is still widely required in global transport applications. “Petroleum-based liquid fuels account for around 95% of global transport energy” (Kalghati, et al., 2022). With the primary fuel used in the UK being E10 (10% Ethanol and 90% Gasoline), the overall environmental impact of the respective fuels can be measured in factors such as carbon footprint, pollution, etc. Pure gasoline contains a majority of isoalkanes at 25-40%, alkanes (2-5%) along with aromatics seen at 20-50%, etc (ATDSR, 1995). This will contain a higher negative environmental impact than respective ethanol-based blends such as E10 and E85 (15% Ethanol and 85% Gasoline). With pure gasoline the overall carbon footprint is indicated by the refinement process, which also must include the energy and pollution generated by the transport of this fuel to distribution. The expansion on conventional fuels ignores the leading resource depletion present with the automotive industry (Mackenzie, 1999). In addition, the global oil production measurement concludes that future supply can result in depletion risk, however, difficulties when evaluating overall resource usage can provide an accurate estimate total depletion risk, therefore, the prevention required can be implemented according to the respective risk generated. In contrast, research and policy communities recommend a more focused approach to the risks presented by global oil depletion. (Sorrell, et al., 2009).

1.2.2- Biofuels

Although the leading use of biofuels within the automotive industry can be considered a sustainable approach, the application is not recent, thus being assessed as regular fuel. These fuels are extensively based on the similar utility when compared to gasoline properties. These can also be implemented in gasoline powered vehicles in which require almost, or no change in combustion generated power principles. The classification of biofuels considers the local fuel origin for production. A widely utilised fuel in the industry is corn-based ethanol, blended with gasoline. “Currently, in the European Union, the share of bio-based components is up to 10% for petrol and 7% for diesel” (Furch, et al., 2022). The rate of usage and production of bioethanol fuels was increased extensively since the implementation of the regulations by the European Union.

As mentioned before, when assessing the effect on the environmental impact of these, a contrast is shown in pollution values by fuel production and usage. As seen in table 2, the values depicted for E10 and E85 are reflected on pure gasoline emissions (Kim & Dale, 2006). The deviation displayed shows a 71.52% (161.5 g/km⁻¹) of CO₂ content in E85 compared to pure gasoline. The ethanol blended examples see an inverse proportionality of CO₂ g/km⁻¹ as the alcohol content is increased. On the other hand a directly proportional relationship is shown in NO_x (Nitrogen Oxides). Lastly, the environmental impact related to production on the fuels mentioned above, presents a positive resource depletion and waste generation reduction in terms of crude oil extraction and non-renewable energy. Kim and Dale

(2006, p.119) contrast that the usage of ethanol content in gasoline will register an increase on fuel acidification and eutrophication, due to phosphorus and nitrogen soil emissions from corn cultivation.

Table 2- Air Emissions Comparison after 80000Km of Usage (Kim & Dale, 2006), (Wang, 2000), (EPA, 2003)

Air emissions	Unit	Gasoline fueled	E10 fueled	E85 fueled
CO ₂ ^a	g km ⁻¹	229.6	214.0	65.4
CO	mg km ⁻¹	468.9	227.8	248.5
HCHO	mg km ⁻¹	0.70	0.62	0.62
Non-methane organic gases	mg km ⁻¹	27.3	27.3	27.3
NO _x	mg km ⁻¹	62.1	93.2	124.3
SO _x ^b	mg km ⁻¹	48.8	45.5	13.9

^a Carbon dioxide emission in driving a gasoline fueled vehicle is obtained from the GREET model [6]

^b Sulfur content in gasoline is obtained from the GREET model [6]

2- Sustainable Practices and Legislations of Fuels

2.1- Sustainable Practices and Legislations Overview

With the growth in oil demand involved in the automotive industry, leading to the mandatory changes involving more sustainable approach to fuel production technology and usage. Previous practices implemented in order to present conformance in emission regulations, consist of catalytic converters, EGR (exhaust gas recirculation), particulate filter, etc. These contain measures in which gases are filtered or recirculated back to the combustion chamber to reduce key harmful emissions such as CO₂ and NO_x. SAE (2016, p.690) state that fuel tank ventilation is a supplemental system used to prevent vapours from being transferred to the atmosphere.

Current sustainable approaches include the wide investment and commercialization of hybrid vehicles along with fully electric examples. In addition further regulation with current technology is being implemented in order to manage the emissions output from regular petrol and diesel vehicles. Alternative fuels are also widely researched within the transport industry, including road vehicles, motorsport and motorcycle exemplars.

2.2- Emission Regulations

The leading imposed emission regulations look to control the air pollution in road vehicles. The primary example of emissions regulation control are the Euro standards, which are proposed to manufacturers. Euro 1 have been applied since 1992 which consider pollutants such as CO (carbon monoxide), No_x , HC (Hydrocarbons residue from incomplete combustion), etc. “The G-20 countries account for 90 percent of global vehicle sales, and 17 out of the 20 members have chosen to follow the European regulatory pathway for vehicle emissions control” (Williams & Minjares, 2016). Furthermore, with regulations such as the recent EURO 7 proposal, further controls the limits of pollutant controls with more developed vehicle testing prior to commercialization. Driving conditions in these test are considered at more extreme situations such as a higher temperature range. Additionally, Euro 7 also regulates brake and tyre emissions (European Commission, 2022).

When analysing the exhaust emissions considered for passenger vehicles containing an internal combustion engine within the Euro 7 proposal (table 3), the allowable CO emissions are considered as 0.5g/km, where the Euro 6 consider these emissions as 1g/km and 0.5g/km for diesel. This decision pressures manufacturers into developing more efficient powertrains to be conformed with emission control. Euro 7 focuses on key values for CO and NO_x . CO_2 emissions are not primarily mentioned, which depicts a general limitation. However, the agreed aim of transferring to carbon neutral emissions are still considered by the Euro 7 proposal. Additional restrictions evaluated for effectiveness of the suggestion includes a 1.2 scale factor for the vehicle lifetime relation with pollutant emissions. Requisite for the principal durability of vehicles is doubled, in comparison to the Euro 6 regulations (European Commission, 2022). Other foremost limitations, contain the unestablished lack of more restrictive control on fuels with higher levels of gaseous pollutants such as diesel.

Table 3- Euro 7 Exhaust Emissions Containing a Combustion Engine (European Comission, 2022)

Pollutant emissions	M_1, N_1 vehicles	Only for N_1 vehicles with power to mass ratio ¹ less than 35 kW/t	Emission budget for all trips less than 10 km for M_1, N_1 vehicles	Emission budget for all trips less than 10 km only for N_1 vehicles with power to mass ratio less than 35 kW/t
	<i>per km</i>	<i>per km</i>	<i>per trip</i>	<i>per trip</i>
NO_x in mg	60	75	600	750
PM in mg	4.5	4.5	45	45
PN_{10} in #	6×10^{11}	6×10^{11}	6×10^{12}	6×10^{12}
CO in mg	500	630	5000	6300
THC in mg	100	130	1000	1300
NMHC in mg	68	90	680	900
NH_3 in mg	20	20	200	200

2.3- Hybrid and Electric Powertrains

2.3.1- Hybrid Powertrains

Hybrid vehicle implementation is commonly seen within the automotive industry. These vehicles combine both combustion and electric power as the main propulsion method. This allows for the usage of smaller capacity ICEs (Internal Combustion Engines). The leading advantages of hybrid technology involve an improvement on exhaust emissions and fuel consumption (Furch, et al., 2022). The advantageous reduction in exhaust emissions can be employed, where emission charges in congested areas is applied, therefore cost-free trips in these locations are attributed. There are several examples of hybrid technology developed for the automotive market with two ruling examples namely, MHEV (Mild Hybrid Electric Vehicle) and PHEV (Plug-in Hybrid Electric Vehicle). A MHEV is a system which contains a hybrid module positioned between the transmission and the engine. This module allows for fully electrical driving at a low acceleration rate and energy recuperation (Graf, et al., 2016). Another advantage presented is the electrical power aided usage during regular driving conditions with help on acceleration and coasting speed reduction. Moreover, PHEVs possess a larger capacity battery, enabling full electric drive for longer distances, therefore, reducing pollutants.

When evaluating the limitations with the hybrid technology include a highlighted increased vehicle and maintenance cost. Energy production, storage and usage in well to wheel efficiency with hybrid vehicles has a lower figure in comparison to alternative technologies such as BEV (Battery Electric Vehicles). A 62.7% efficiency deviation is seen between hybrid and electric vehicle technology. (Pollet, et al., 2012). The investment in hybrid technology can be considered has a successful sub-counter measure towards carbon neutral emissions in the automotive industry.

2.3.2- Electric Powertrains

The identifiable BEV investment and commercialization shows another successful counter measure for the proposed CO₂ emission ban from 2035. BEVs provide no driving emissions, which is the key contrast with regular ICEs and hybrid technology. As mentioned above, these ruling harmful emissions can be reduced and more accurately controlled in areas with higher congestion rates. On the other hand, lithium-ion battery production sees a high impact in CO₂ emissions. “Given that the carbon intensity of battery production is known to be a primary source of the production CO₂ emissions for the green electricity case leaves BEVs looking not so good” (Senecal & Leach, 2021). The comparison between BEVs and ICEs is widely evaluated as the clear difference in energy intensive processes is needed for battery production, allowing an ICE vehicle to perform various driving cycles through a dependant range of time until it meets the break even point with BEVs. These values are often ignored, being one of the main limitations with the propulsion technology. Another clear limitation with BEVs with the reduced driving range along with the overall vehicle weight (Newton & Cantarello, 2014). These factors

will also generate a higher brake wear and tyre degradation through time, increasing the costs of maintenance. The lifespan of batteries as well as the insufficiency of recharging and powering infrastructure is also an additional limitation component.

2.4- Hydrogen

The use of hydrogen within vehicle propulsion can be done either by injection in an ICE or by the use of a fuel cell, which uses additional oxygen for chemical reaction in order to transfer power to an electric motor. Either method is effective, as carbon-neutral properties can be achieved through sustainable sources. The general driving range using hydrogen power is also similar to conventional ICEs. The limitations involved with hydrogen vehicles present a high infrastructure requirement and current research of hydrogen technology is also not fully sufficient (Newton & Cantarello, 2014). Another key disadvantage present is the requirement of near absolute zero temperature for efficient hydrogen storage along the higher capacity tanks in vehicles due to the lower density of hydrogen. The volume mass ratio of hydrogen necessary for complete combustion can be seen contrasted to other leading fuel/ fuel blends in figure 3:

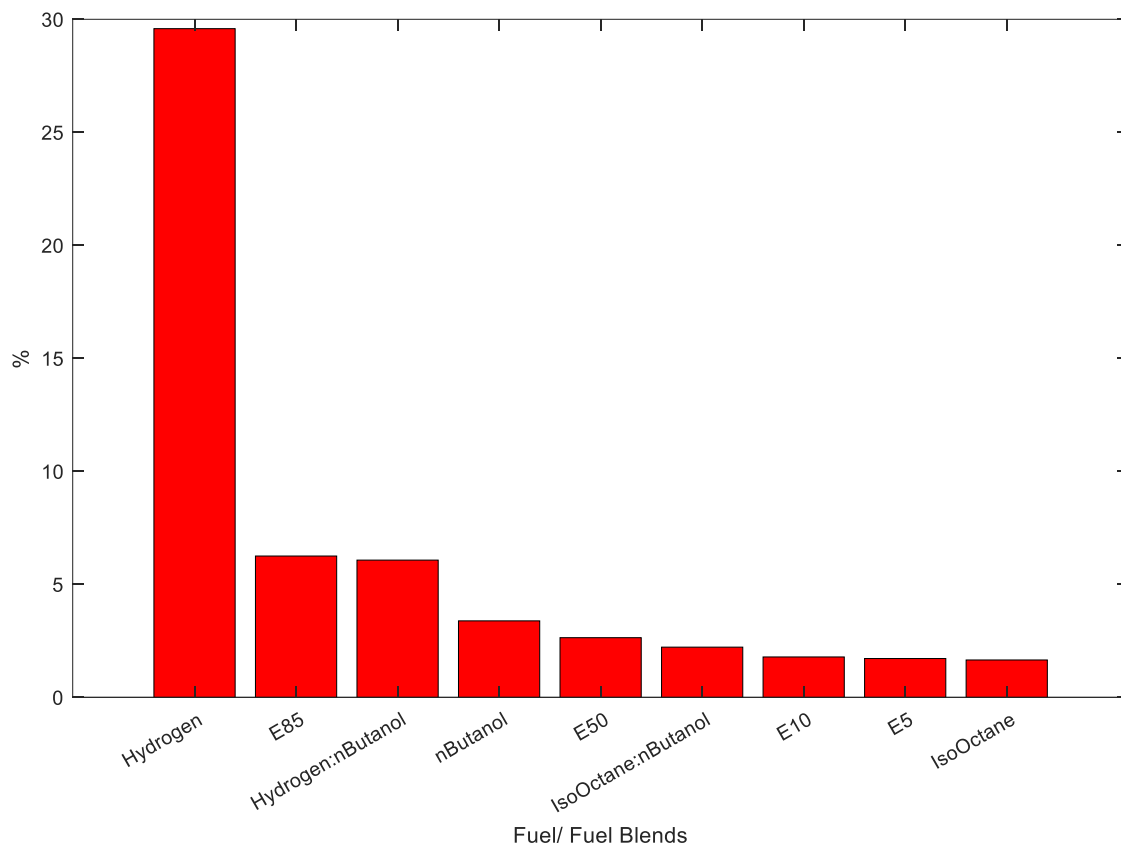


Figure 3- Fuel Volume:Mass Required in the Cylinder (%)

Task 2.5- Other Alternative Fuels

Other leading sustainable practices within fuels is the research for alternative sources of combustion power without the need of petrol or diesel. Biofuels such as corn-ethanol based mixtures and biodiesel are currently part of fuel blends necessary to be in conformance with the Euro standards. However, the stricter control of emissions in the automotive industry influences manufacturers into the application of different combustible fuels. Synthetic fuels is another possible technology which brings a wide positive range of aspects. This includes equivalent physicochemical properties as petrol and diesel and only demands raw sustainable materials for production (Repsol, nd.). This technology is currently widely researched by companies namely, Mazda and Porsche. With the only use of water and CO₂, the process can be repeated indefinitely with the recycling of the leading pollutant (CO₂). The only present limitation is the low availability present in the market. From 2022 on, Porsche will produce an estimate of 130000 litres of the developed carbon captured synthetic fuel (Porsche, 2023). Although the value demonstrates a positive development, the demand present is not able to be fulfilled.

Methanol in petrol blends is a possible option within transportation. “Its ease of synthesis and broad range of source feedstocks makes it a strong candidate for a sustainable fuel with the potential to significantly reduce the fossil carbon footprint of transportation” (Verhelst , et al., 2019). The effectiveness of this fuel provide properties, such as the maintained liquid state when in transportation, low air to fuel ratio, and relative low CO₂ in comparison to petrol. On the other hand, one main limitation involved with methanol is the possible engine modification required prior to usage of this fuel. This may have an effect on overall vehicles sales.

3- Sustainability and Technological Challenges of Alternative Fuels

3.1- Sustainability and Technological Challenges Overview

While alternative fuels (efuels) display a key benefits to the automotive along with motorsport and motorcycle industry. The sustainable measure also depicts ruling challenges which may affect different perspectives. These can be evaluated and split into a PEST (Political, Economic, Social and Technological) analysis.

3.2- Political Factors

The key political factors present with synthetic fuels involve the control of remaining conventional and electric vehicles on the road after mass implementation of efuels. The mean vehicle age during the scrapping a material recycling process in 2015 was 13.9 years (SMMT, 2023). The pollutant emissions emitted can possibly contribute for a negative impact in carbon neutral regulations, therefore these regulations to control older vehicles can be implemented. The resulted incentive of purchase of an efuel powered vehicle can see an increase, relating to the social challenges. Another leading risk depicted is the missing regulatory framework in the synthetic fuel transition. (European Commission, 2021).

3.3- Economic Factors

Possible economic challenges seen with the production and use of synthetic fuels, contain factors such the concern of leading superior fuel prices due to the technological barriers in current times. “The current cost of efuels is estimated to be around €4.50/litre for diesel equivalent” (German Energy Agency, 2017). This barrier is also connected to general political factors such as support to companies in order achieve advanced technological development.

3.4- Social Factors

With the potential fuel price increase within synthetic fuels, the use of these would be limited in low GDP countries, therefore a social barrier is faced. “This will lead to a “transport underclass” in which only high-income groups own private vehicles” (PIN, 2022).

3.5- Technological Factors

Leading technological barriers which are faced with efuels involve the expenses within the carbon capture process. Due to the only recent development, this process still maintains a high cost, therefore, research would result in a price reduction, with a possible decrease in future fuel prices. “Key research challenges identified include improving the fundamental understanding of catalysis” (The Royal Society, nd.). The gap in development predicts a low competitiveness in fuel marketing.

Lastly, projected resolutions for these faced barriers include the incentive to the consumer in order to reduce the number of ICE and electric vehicles on the road. As mentioned before, a wider investment in research with an additional encouragement from governments would result in a less expensive catalysis production method, with a subsequent decrease in fuel prices. Further regulations can also be implemented, in order to control and standardize the leading remaining emitted pollutants present in synthetic fuels such as NO_x .

4- Future Outlook of Alternative Fuels

With a continued investment present on synthetic fuels, aspects such as fuel costs, which can be reduced as development is achieved. This will have a significant impact in the transportation industry. As seen in figure 4, the leading efuel cost range is proportionately reduced as the 2050 net zero proposed aim is reached. “Drop-in replacement fuels from renewable sources seems a sensible and economically sound approach, making the best use of legacy assets” (House of Commons, 2023). Furthermore, with the wide implementation of efuels, the net zero aim can be achieved, maintaining a complete carbon neutral transportation industry. Another aspect of the future outlook of synthetic fuels is the possible modification of current infrastructure in order to produce efuels, reducing the gap with technological development.

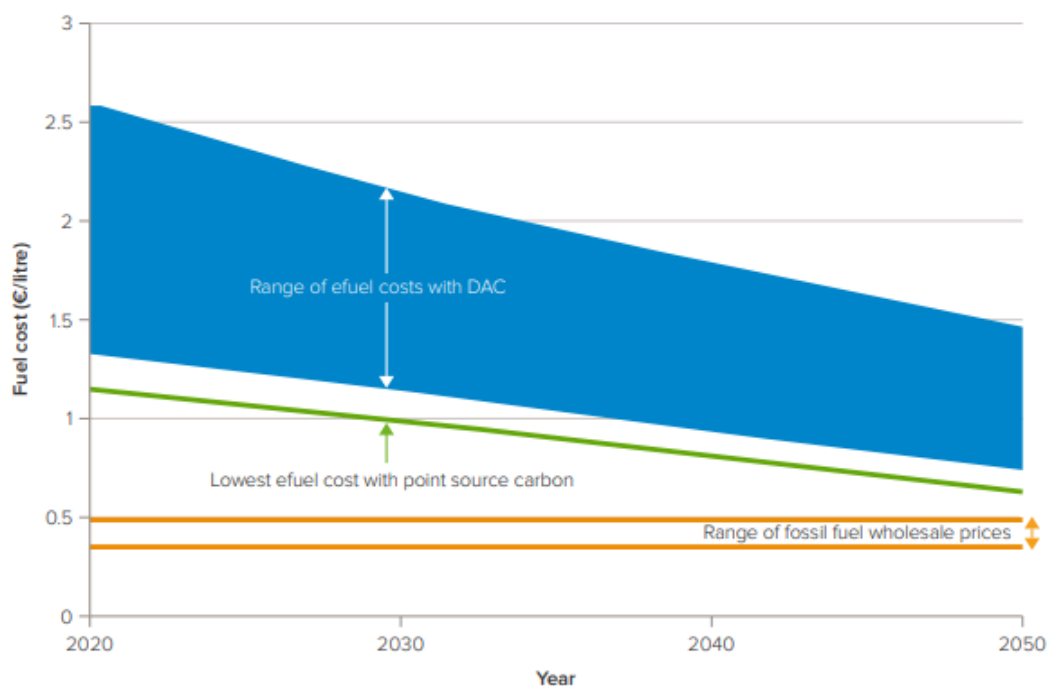


Figure 4- eFuel Cost Forecast 2020-2050 (The Royal Society, nd.), (AG, et al., 2018), (Verkehrswende & Energiewende, 2018), (Schmidt, et al., 2016)

The impact seen with the developed synthetic fuels in the automotive industry, will provide effective low-cost fuels within consumers. Manufacturers will also lead future sustainable technologies for other industries such as aviation and maritime. Lastly, governments will see a conformance with emissions regulations from the public, therefore, reducing the possible chance of anti-pollution protests and petitions

Conclusion

To conclude, current fuels in uses already contain present sustainable measures implemented. However, the stricter emission regulations and the aimed net zero emissions by 2050 requires manufacturers to develop alternative sources of propulsion such as synthetic fuels. These contain current technological barriers due to carbon capturing processes and lack of infrastructure. Future development will reduce these faced challenges and will positively impact manufacturers, governments along with the leading consumer.

References

- AG, P., UMSICHT & DBFZ, 2018. *Status and Perspectives of Liquid Energy Sources in the Energy Transition*, Berlin: Prognos.
- ATDSR, 1995. *Toxicological Profile for Automotive Gasoline*. [Online] Available at: <https://www.atsdr.cdc.gov/ToxProfiles/tp72.pdf> [Accessed 15th March 2024].
- EPA, 2003. *Annual certification test results & data*, Washington DC: EPA (United States Environmental Protection Agency).
- European Commission, 2021. *Synthetic fuels offer great opportunities for the sustainability transition of the European energy system and the decarbonisation of the transport sector*. [Online] Available at: <https://monitor-industrial-ecosystems.ec.europa.eu/reports/other-reports/synthetic-fuels> [Accessed 17th March 2024].
- European Commission, 2022. *Proposal for a Regulation of the European Parliament and the Council*, Brussels: European Commission.
- European Commission, 2022. *Commission proposes new Euro 7 standards to reduce pollutant emissions from vehicles and improve air quality*, Brussels: European Commission.
- European Parliament, 2019. *CO₂ emissions from cars: facts and figures (infographics)*, ns.: European Parliament.
- Evans, R. L., 2007. *Fueling Our Future: An Introduction to Sustainable Energy*. 1st ed. Cambridge: Cambridge University Press.
- Furch, J., Krobot, Z., Konečný, V. & Stodola, J., 2022. Advantages and Disadvantages of Common used Fuels for Passenger Cars. *International Conference on Electrical, Computer, Communications and Mechatronics Engineering, ICECCME 2022*, ns.(ns.), pp. 1-6.
- Genta, G. & Morello, L., 2020. *The Automotive Chassis- Volume 2: System Design*. 2nd ed. Turin: Springer.
- German Energy Agency, 2017. *The potential of electricity-based fuels for based fuels for low-emission transport emission transport in the EU*. [Online] Available at: <https://www.vda.de/en/services/Publications/%C2%Abe-fuels%C2%BB-study---thepotential-of-electricity-based-fuels-for-low-emission-transport-in-the-eu.html> [Accessed 17th March 2024].
- Graf, F., Nuss, M. & Eckenfels, A., 2016. *Drivability and 48 Volt Hybrids- Opportunities beyond CO₂-Reduction*, Berlin: Springer.

House of Commons, 2023. *Fuelling the future: motive power and connectivity*, London: House of Commons.

IEA, 2023. *Oil 2023*, Paris: IEA.

IEA, 2023. *The Role of E-fuels in Decarbonising Transport*, Paris: IEA.

Kalghati, G., Agarwall, A. K., Senecal, K. & Leach, F., 2022. Introduction to Engines and Fuels for Future Transport. In: G. Kalghati, A. K. Agarwall, K. Senecal & F. Leach, eds. *Engines and Fuels for Future Transport*. Gateway East: Springer, pp. 1-6.

Kim, S. & Dale, B. E., 2006. LCA Case Studies Ethanol Fuels 117 LCA Case Studies Ethanol Fuels: E10 or E85-Life Cycle Perspectives. *Int J LCA*, 11(2), pp. 117-121.

Liu, X. et al., 2023. Emission characteristics and light absorption apportionment of carbonaceous aerosols: A tunnel test conducted in an urban with fully enclosed use of E10 petrol. *Environmental Research*, 216(ns.), pp. 1-11.

Mackenzie, J. J., 1999. Sustainable Transportation in the 21st Century. In: V. Sinha & B. K. Karmakar, eds. *Proceedings of the International Symposium and Exposition on Automotive Electronics and Alternate Energy Vehicles*. New Delhi: Allied Publishers, pp. 39-48.

Newton, A. C. & Cantarello, E., 2014. *An Introduction to the Green Economy: Science, Systems and Sustainability*. 1st ed. Abingdon: Routledge/ Taylor & Francis Group.

PIN, 2022. *What Are the Disadvantages of Synthetic Fuel?*. [Online] Available at: <https://www.petro-online.com/news/synthetic-fuels/180/breaking-news/what-are-the-disadvantages-of-synthetic-fuel/59303> [Accessed 17th March 2024].

Pollet, B. G., Staffel, I. & Shang, J. L., 2012. Current Status of hybrid, battery and fuel cell electric vehicles: From electrochemistry to market prospects. *Electrochim Acta*, 84(ns.), pp. 235-249.

Porsche, 2023. *eFuels to supplement electric mobility on the road to becoming CO2 neutral*. [Online] Available at: <https://media.porsche.com/mediakit/innovation-sustainability-performance/en/innovation-sustainability-performance/synthetic-fuels> [Accessed 17th March 2024].

Repsol, nd.. *Synthetic fuels: An alternative for decarbonizing mobility*. [Online] Available at: <https://www.repsol.com/en/technology-and-digitalization/technology-lab/sustainable-mobility/synthetic-fuels/index.cshtml> [Accessed 17th March 2024].

- Rosenfeld, J. et al., 2018. *A Life-Cycle Analysis of the Greenhouse Gas Emissions from Corn-Based Ethanol*. [Online]
Available at: https://www.usda.gov/sites/default/files/documents/LCA_of_Corn_Ethanol_2018_Report.pdf
[Accessed 16th March 2024].
- SAE, 2003. *Well-to-wheels analysis of advanced SUV fuel cell vehicles*, Detroit: SAE.
- SAE, 2016. *Internal Combustion Engine Handbook*. 2nd ed. ns.: SAE.
- Schmidt, P., Zittel, W., Weindorf, W. & T, R., 2016. *6 Renewables in Transport 2050: Empowering a sustainable mobility future with zero emission fuels from renewable electricity*, 2016: ns..
- Senecal, K. & Leach, F., 2021. *Racing Toward Zero: The Untold Story of Driving Green*. 1st ed. Warrendale: SAE International.
- SMMT, 2023. *2023 Automotive Sustainability Report: Average Vehicle Age*. [Online]
Available at: <https://www.smmt.co.uk/industry-topics/sustainability/average-vehicle-age/>
[Accessed 17th March 2024].
- Sorrell, S. et al., 2009. *Global Oil Depletion*, London: UKERC.
- Styring, P., Duckworth, E. L. & Platt, E. G., 2021. Synthetic Fuels in a Transport Transition: Fuels to Prevent a Transport Underclass. *Front. Energy Res.*, 9(ns.), pp. 1-7.
- The Royal Society, nd.. *Sustainable synthetic carbon based fuels for transport*. [Online]
Available at: <https://royalsociety.org/news-resources/projects/low-carbon-energy-programme/sustainable-synthetic-carbon-based-fuels-for-transport/>
[Accessed 17th March 2024].
- Verhelst, S., Turner, J. W., Sileghem, L. & Vancoillie, J., 2019. Methanol as a fuel for internal combustion engines. *Progress in Energy and Combustion Science*, 70(ns.), pp. 43-88.
- Verkehrswende, A. & Energiewende, A., 2018. *The Future Cost of Electricity-Based Synthetic Fuels*, ns.: Frontier Economics.
- Wang, M., 2000. *Transportation fuel-cycle model*, Illinois: Argonne National Laboratory.
- Williams, M. & Minjares, R., 2016. *A technical summary of Euro 6/VI vehicle emission standards*. [Online]
Available at: https://theicct.org/sites/default/files/publications/ICCT_Euro6-VI_briefing_jun2016.pdf
[Accessed 16th March 2024].