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Comparing life cycle emission of Hydrogen cars to Combustion cars.

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Table of Contents

List of Abbreviations

Abbreviation	Explanation
GHG	Greenhouse gases
GWP	Global Warming Potential
LCE	Life Cycle Emissions
ICE	Internal Combustion Engine
H_2	Hydrogen gas
CO_2	Carbon dioxide gas
N_2O	Nitrous oxide
CH_4	Methane gas
$CO_{2eq.}$	Equivalence of carbon dioxide gas
ISO	International Organization for Standardization
SUV	Sport Utility Vehicle

List of Figures

List of Tables

List of Stacked column charts

Abstract

At present, all nations are mainly depending upon conventional fossil fuels like petrol & diesel for energy production, and on the other hand, fossil fuels are limited as well as a not sustainable choice for our nature. In recent decades, Nations have been emphasizing the climate impact of the transportation sector and minimizing fossil fuel dependency. The transportation framework gives a significant commitment to expanding ozone harming substances, and then again, this area will line up with endeavour to help the most obvious opportunity with regards to accomplishing the Paris agreement's objectives. Many new engines or fuel cells vehicles are coming to the market. Hydrogen cars or Hydrogen fuel cell cars will be the alternate source of our transport systems. Here we take greenhouse gas emissions of cars for two different years, 2021 and 2030 for three different car segments, compare the life cycle emissions of hydrogen cars and combustion cars and give a conclusion about relevant car systems which should use in the upcoming times or next decades to minimize greenhouse gases. We can get the appropriate result of greenhouse gases during the Cradle to Grave phase of the vehicles. After getting results, we will understand, which type of fuel technologies will be more relevant for pursuing and achieving the Paris Agreement goal, and we will make our earth emissions-free and help reduce the unwanted changes in our climate.

Keywords: *Hydrogen cars, combustion cars, Life cycle emissions, Greenhouse gases, well to tank, tank to wheel.*

1. Importance of life cycle emissions in our life:

Nowadays, due to the increasing population, the need for vehicles is also increasing with time. Especially cars are one of the common sources of our transportation in our routine life. The cars sold in 2021 are nearly around 66 million across worldwide [1]. GHG emissions produced by cars are approximately 12Gt of $CO_{2eq.}$ Into the air per year and due to increasing economic growth as well as vehicle demand 21Gt of $CO_{2eq.}$ Will produce by 2050 [26]. Due to globalization and technological advancements, there are many types of working fuel technologies available in markets like Electric cars, Hydrogen cars, Hydrogen fuel cell cars, Natural gas cars, and conventional combustion cars. Due to regular research and development, these technologies are available will also increase in upcoming decades. All motor innovations have their advantages and disadvantage. In the manufacturing process of cars and during the use of cars, there are several amounts of unwanted and hazardous gases released in our environment [6]. The average temperature of our earth is increasing by 0.15 to 0.20℃ per decade due to these greenhouse gases [2]. Because of this, our environment changes step by step.

The Paris Agreement defined a global framework to avoid unwanted climate change by minimizing global warming to well below 2℃ and achieving efforts to set this limit to 1.5℃. The second target is to strengthen countries' abilities to deal with the effects of climate change and encourage them in their works to achieve this goal by 2050 [3]. To achieve the Paris Agreement goal, GHG emissions should be reduced by 80% from today or approximately 2.6Gt every year [26]. A tremendous piece of this decrement should have to come from traveller vehicles. Including the estimated future progress of this sector, the change needed in working fuel technology of conventional vehicles will be more. To achieve this Paris agreement goal, a deep study of all readings of life cycle emissions is necessary [4].

Life cycle assessment is derived as the addition of the emissions produced from the different stages in a vehicle's raw materials extraction or production, components manufacturing, transport, store, & sale of the vehicle, fuel production, use of vehicle or life span, and dismantling or disposal of vehicles. In simple words, emissions are produced during cradle to grave vehicles [5].

2. Hydrogen fuel-based Cars:

Hydrogen becomes an alternate source of power in comparison with fossil fuels. Hydrogen is used in many power sectors as a power source. Isaac de Rivas made the first hydrogen internal combustion engine in 1807 [7]. Currently, there are two hydrogen vehicles available named Hydrogen internal combustion engine cars and Hydrogen fuel cell cars.

2.1 Hydrogen internal combustion engine cars:

The power generated by chemical energy to mechanical energy by burning hydrogen is the same as a conventional combustion engine. Hydrogen is a carbon-free and flammable gas. It has the potential to run engines without harmful emissions [8]. There are several techniques for improving engine efficiency.

2.1.1 **Pressure-boosted H2 ICE:** The pressurized hydrogen is obtained by adding a hydrogen gas chamber to increase air/hydrogen intake for getting maximum power output. This process is similar to supercharging, which is used in conventional vehicles [7].

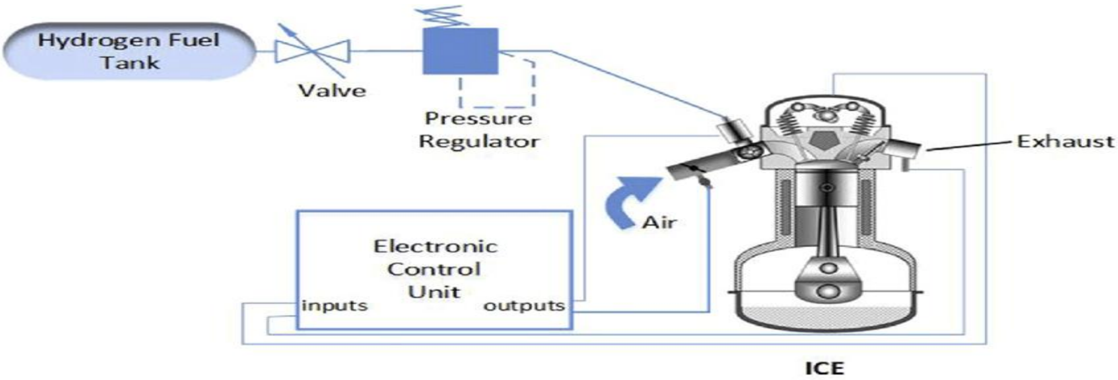


Figure 1 Pressure-boosted H2 ICE [9]

2.1.2 **Liquid Hydrogen-fuel ICE**: We can use liquid hydrogen in our conventional IC Engine without making significant changes. The basic design of LH_2 ICE is shown in the figure. Store the hydrogen in the form of gas is complicated because of its lower molecular mass and low density. So, hydrogen can be stored by converting its gaseous form to liquid form with the help of a cryogenic cylinder [7].

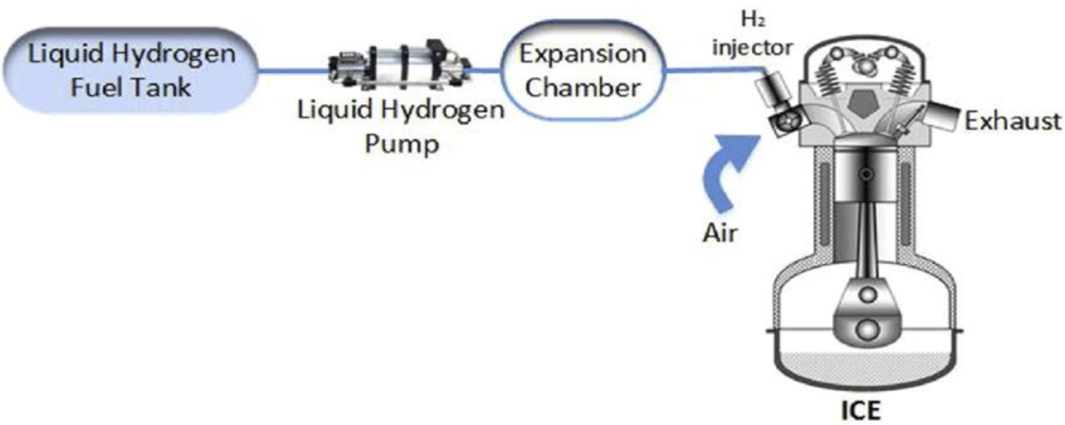


Figure 2 Liquid hydrogen-fuel ICE [10]

2.1.3 **Direct injection H2 ICE:** The output power is produced in a compressed ignition engine motor used with hydrogen injection is nearly double that of the same motor operating in the premixed mode. This technique is more complicated in comparison to two other techniques because of the design of the injection nozzle, which make controls how pressurized hydrogen is spread in the combustion chamber [7].

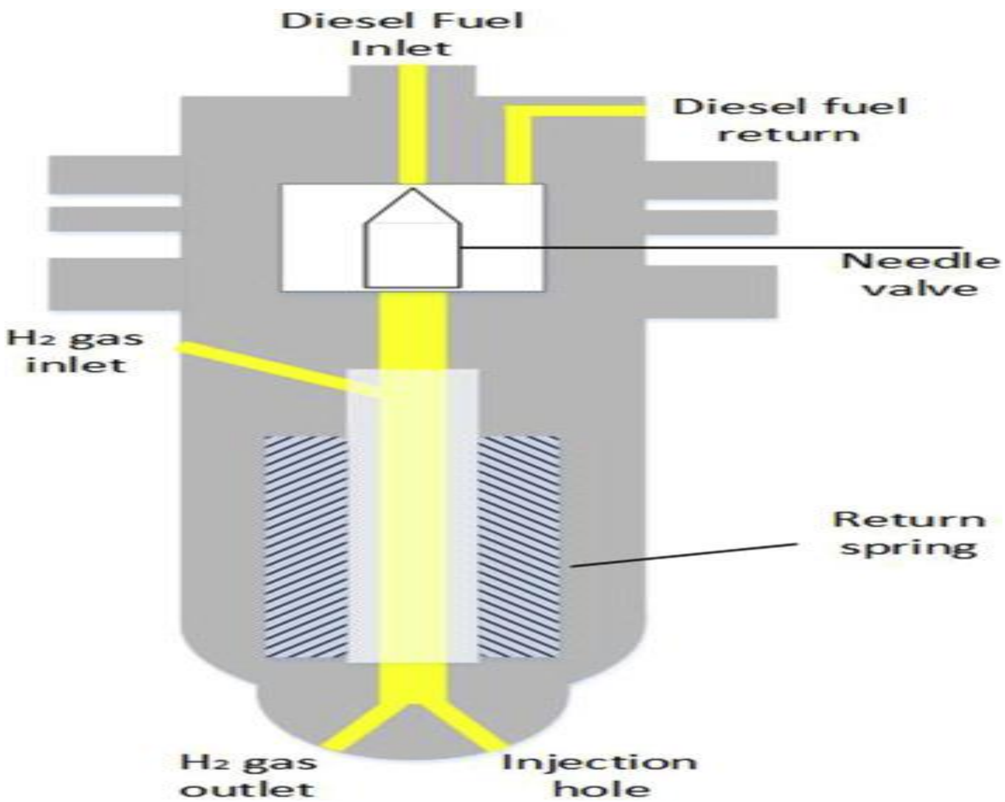


Figure 3 Direct injection H2 ICE [11]

2.1.4 Emission in Hydrogen ICE:

Water is produced in the combustion process of Hydrogen with Oxygen, but water is not the only final product in the emission stage.

$$2H_2 + O_2 = 2H_2O$$

[12]

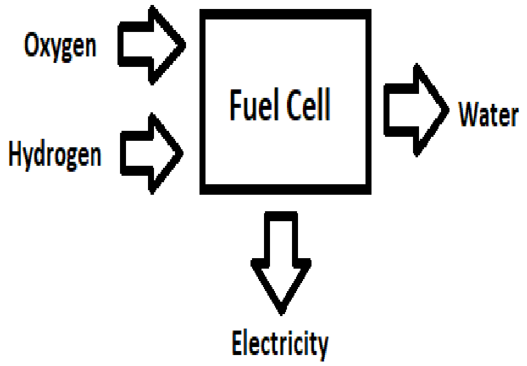
The chemical reaction of hydrogen with air can also generate different unwanted oxides of nitrogen. The amount of nitrogen oxides depends on the thermodynamic properties of hydrogen internal combustion engines like air/hydrogen ratio, the compression ratio of the engine, speed of the engine, and time of ignition. Further, due to fast oil burning in the combustion chamber, some traces of greenhouse gases carbon monoxide and carbon dioxide are delivered in the fumes gas with nitrogen oxides [12].

$$H_2 + O_2 + N_2 = H_2O + NO_x$$

[12]

2.2 Hydrogen fuel cell cars:

The first hydrogen-powered fuel cell automobile was developed by Roger Billings in 1991. A fuel cell is an electrochemical storage device that produces electric energy by adding hydrogen and oxygen. This fuel cell can produce a direct current or DC Current to run the electric car. In the current time, there are various types of fuel cell systems are available like solid oxide fuel cells, direct methanol fuel cells, phosphoric acid fuel cells, and polymer electrolyte fuel cells. But the principle of their function is similar in every type in a fuel cell system. There are two electrodes used for the reaction process, which take place in fuel cell Anode and Cathode. The anode is the negative post of the cell, which conducts electrons that are stripped from the electricity supplied to an external circuit. The cathode is a positive post of the fuel cell. It conducts the electrons from the external circuit to the catalyst. In the final stage, water vapour is generated as an emission [7].



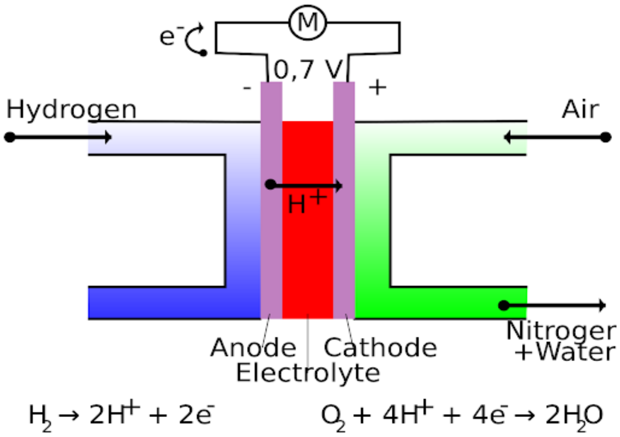


Figure 4 Hydrogen fuel cell block diagram [7]   Figure 5 Hydrogen fuel cell block diagram [13]

There are some barriers in Hydrogen fuel cell cars, which are low power output during low speed, slow response in need of power supply, long initial time, and excessive power output in high acceleration. To overcome these barriers, hydrogen fuel cell cars are used as hybridized fuel cell cars which are, Fuel cell electric and Plug-in extended range fuel cell electric cars [7].

2.2.1 Hydrogen fuel cell electric car:

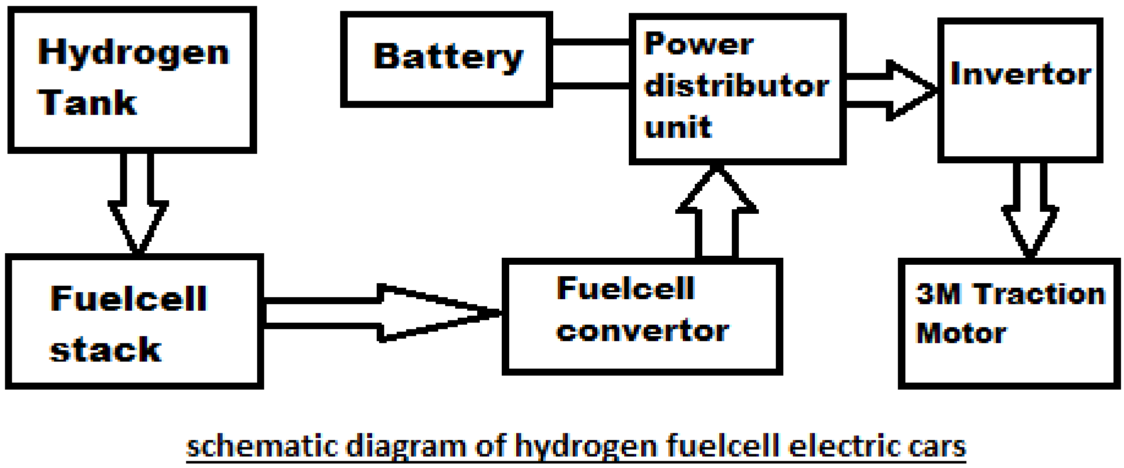


Figure 4 Schematic diagram of hydrogen fuel cell electric cars [7]

2.2.2 Plug-in extended range fuel cell electric cars:

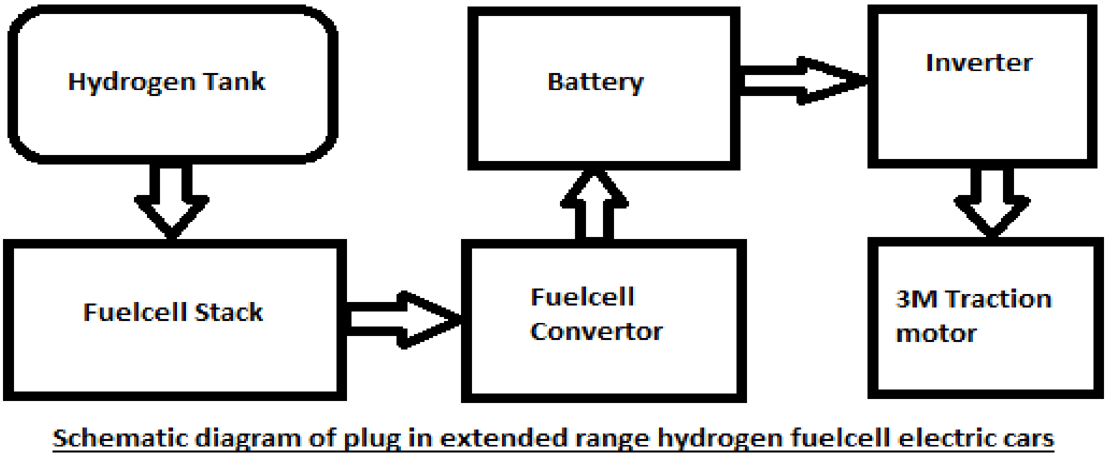


Figure 5 Schematic diagram of plug-in extended range hydrogen fuel cell electric cars [7]

2.2.3 Emission in hydrogen fuel cell cars:

The final product from the hydrogen fuel cell cars is only water (H_2O). No hazardous gases are released in the emission phase [7].

3. Conventional combustion fuel-based cars:

Fossil fuels are the main source for combustion cars. There are two types of combustion cars, spark-ignition engine cars, and compression-ignition engine cars. There is main four strokes name as Suction stroke, Compression stroke, Power stroke, and exhaust Stroke in combustion petrol and diesel engine cars, but both these engines have their working principle [14].

3.1 **Spark ignition engine cars**: In 1876, Nikolaus August Otto developed the first petrol engine. The SI engine can also run on other fuels like compressed natural gas (CNG), methanol, liquefied natural gas (LNG), compressed hydrogen, and bioethanol. In an SI engine, fuel burns after spark entry inside the combustion chamber. SI engine is also known as petrol and gasoline engine, and it works on the Otto cycle principle [14].

3.2 **Compression-Ignition engine:** Rudolph Diesel invented the world's first diesel engine in 1893. In this engine, diesel is ignited by high compression of air into the combustion chamber. CI engine is otherwise called the diesel engine, and it deals with the diesel cycle rule [14].

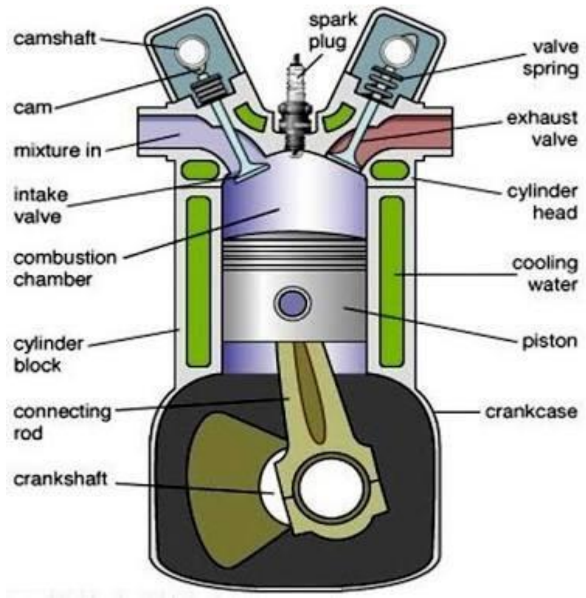


Figure 7 Petrol Engine [15]

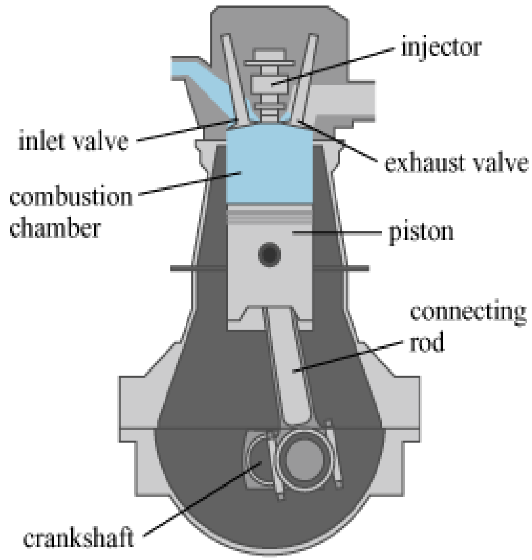


Figure 6 Diesel Engine [16]

4. Comparing properties of hydrogen and combustion cars:

Flammability: Hydrogen in IC Engine cars can run on an extremely lean mixture up to 180:1; because of this hydrogen has a high flammability range [17]. In addition, due to higher lean mixture fuel economy is greater and final combustion temperature is lower so, pollutant amount is low such as nitrogen oxides [8]. On the other hand, petrol and diesel engine cars have lower diffusivity than the H_2 ICE cars because of air/fuel ratio lies in a range of 14:1 to 17:1, and combustion temperature is also higher than H_2 ICE [17].

Ignition Energy: Ignition energy means the amount of energy needed to ignite the fuel in the combustion chamber. Hydrogen has lower ignition energy than petrol and diesel because hydrogen engines ignite on a very lean mixture. On the contrary, due to low ignition energy, premature ignition and flashback create in hydrogen [8].

Quenching Distance: Flames in hydrogen engines travel closer to the cylinder wall than petrol and diesel. So that hydrogen has a very small quenching distance. The smaller quenching distance may increase the backfire tendency [18]

Auto Ignition Temperature: Hydrogen has a high ignition temperature (500℃) [17]. The compression ratio of an engine depends on the autoignition temperature of any fuel. Petrol and diesel have a low autoignition temperature of 230℃ [17]. Almost half to hydrogen. So the compression ratio of a hydrogen engine is higher than a petrol and diesel engine.

Flam Velocity: Flam velocity of a hydrogen engine is higher than the petrol and diesel engine. High flam velocity may create a better stoichiometric ratio which burns quicker [18].

Diffusivity: Diffusivity means how fuels can spread in the combustion chamber. The diffusivity of hydrogen is more than petrol and diesel engine. High diffusivity may help to create a uniform air/fuel mixture and make the combustion process more efficient. Hydrogen has more efficiency than petrol/diesel engines [18].

Density: Mass of a unit volume of any substance is known as density. The molecular weight of hydrogen is low due to this the density of hydrogen is also low 0.08375 kg/m^3 [19]. A huge fuel tank is required to store enough hydrogen in IC Engine for an adequate driving range. So approximate 200liter tank is required to store 5kg of hydrogen [20]. Petrol and diesel have a density of 0.70Kg/L and 0.85kg/L, respectively [21]. The fuel tank capacity lies between 45liter to 65liter in petrol and diesel engine cars [22].

5. Life cycle emissions:

Life cycle emissions or life cycle assessments are defined as the sum of all emissions associated with the production and use of a specific car product from cradle to grave stage. Including emissions produce by different stages like raw materials manufacturing, car manufacturing, working fuel manufacturing or extraction, use of a car, maintenance, and last recycling, dismantling or disposal of that car [5]. Life cycle assessments of Hydrogen cars and combustion cars are performed according to the ISO Standards 14040 [23].

Here we consider three different main stages of life cycle emissions [5].

1) The production stage of cars.
2) Fuel manufacturing or extraction (well to tank)
3) The working period of cars (tank to wheel)

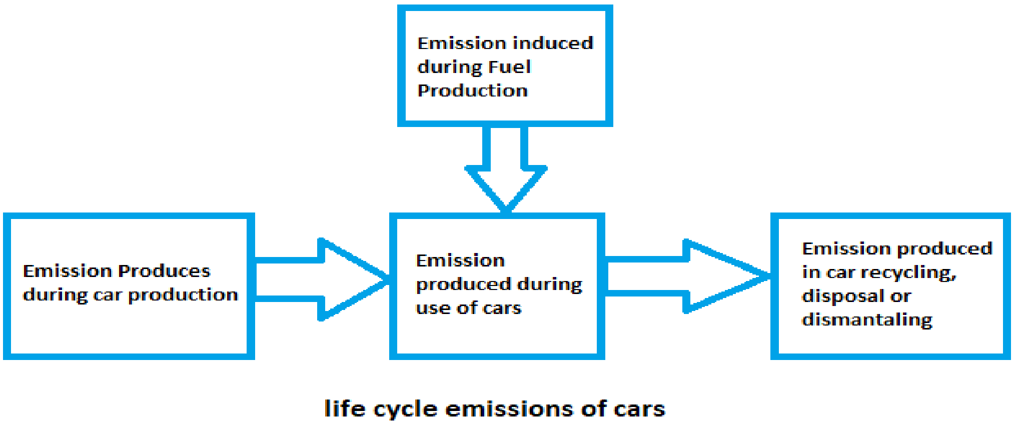


Figure 8 Life cycle emissions of the car [24]

6. Data and Assumptions:

Here we consider different types of emissions produced during the different processes like vehicle manufacturing, battery manufacturing, hydrogen tank manufacturing, maintenance of vehicle, fuel consumption of vehicle, fuel and electricity production, and years GWP for methane (CH_4). We take petrol + biofuel cars and diesel + biofuel cars in the conventional combustion engine, and additionally, we consider a plug-in hybrid electric vehicle, which depends on both IC Engine and battery. On the other hand, we add two different hydrogen fuel cell cars. These hydrogen fuel cell cars are classified according to the manufacturing process of hydrogens like natural gas hydrogen and renewable hydrogen. Here we count all emissions in $CO_{2eq.}$[25] Furthermore, transfer different emissions like Methane (CH_4) and Nitrous Oxides (N_2O) in $CO_{2eq.}$ [26].

1) Convert Methane and Nitrous Oxide emissions into the equivalent of CO_2 ($CO_{2eq.}$) based on 100years GWP [26].

$1gCH_4 = 30g\ CO_{2eq.}$

$1gN_2O = 265g\ CO_{2eq.}$

2) Convert emissions of Methane and Nitrous Oxide into the equivalent of $CO_{2eq.}$ Based on 20years of GWP [26].

$1gCH_4 = 85g\ CO_{2eq.}$

$1gN_2O = 264g\ CO_{2eq.}$

We consider three different car segments small, lower-medium and SUV. The emissions readings taken during car life cycles differ for all segments [26].

Car segments	Annual average	Life
Small cars	11000 km/a	198000km
Lower-Medium cars	13500 km/a	243000km
SUV cars	15000 km/a	270000km

Table 1 Specifications of cars [26]

In small segment cars, there are no types of hydrogen and hybrid cars available in 2021. Here we consider standard routine cars for all segments cars in petrol and diesel engine. For a plug-in hybrid internal combustion engine, we consider two different cars, BMW 225Xe and Mitsubishi Outlander. For hydrogen fuel cell cars, we consider Toyota Mirai for lower-medium cars and Hyundai Nexo for the SUV segment [26].

6.1 Scope of GHG emissions considered with fuel cycle:

Here we consider life cycle emissions for two different years in Europe. First, we take a reading of 2021 cars life-cycle emission for three different segments small cars, lower-medium cars, and SUV cars [26].

Types of fuel	Process	Emissions
Fossil fuels	Crude oil and natural gas extraction processing, transport, fuel refining, distribution	Biofuels
Biofuels	Plant cultivation, waste collection, processing, transport, fuel production and distribution	CH_4, N_2O
Hydrogen	1) Electrolysis based hydrogen: GHG emission of electrolysis emission, energy loss during electrolysis, hydrogen compressing. 2) Natural gas and coal-based hydrogen: extraction, processing transport. 3) Steam reforming and gas gasification: Hydrogen extraction, processing and compression.	CH_4

Table 2 Emissions produced in the fuel cycle [26].

7. Life cycle GHG emissions of combustion cars and hydrogen cars registered in 2021 (Europe) [26]:

7.1 Life cycle emissions of small cars in 2021 (Europe) [26]:

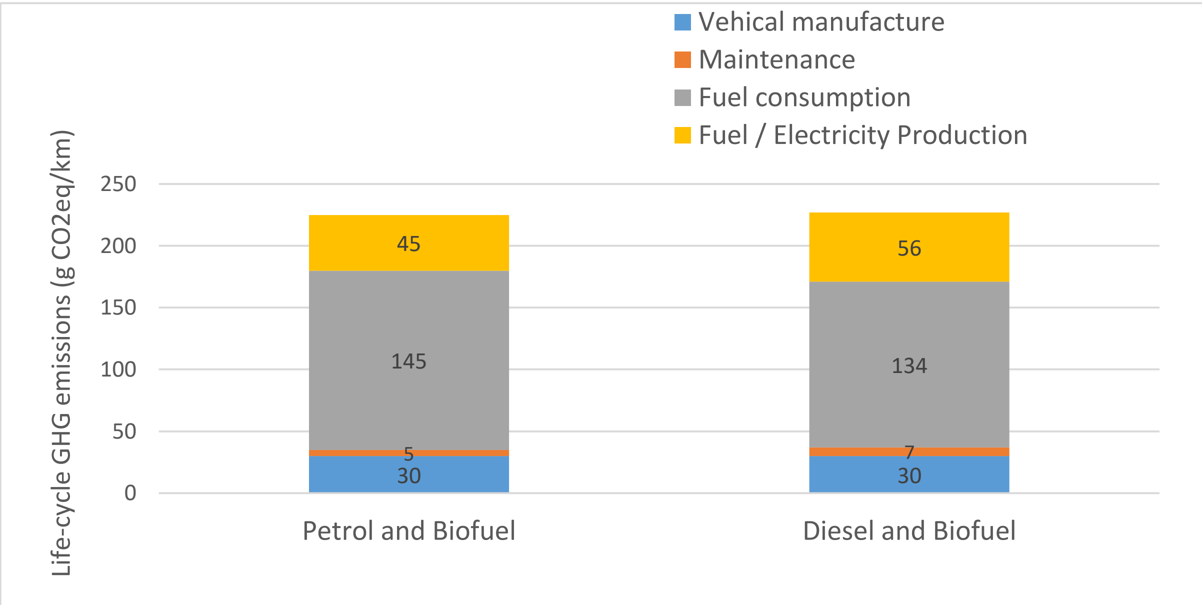


Chart 1 Life cycle emissions for small cars in 2021 (Europe) [26]

7.2 Life cycle emissions of lower-medium cars in 2021 (Europe) [26]:

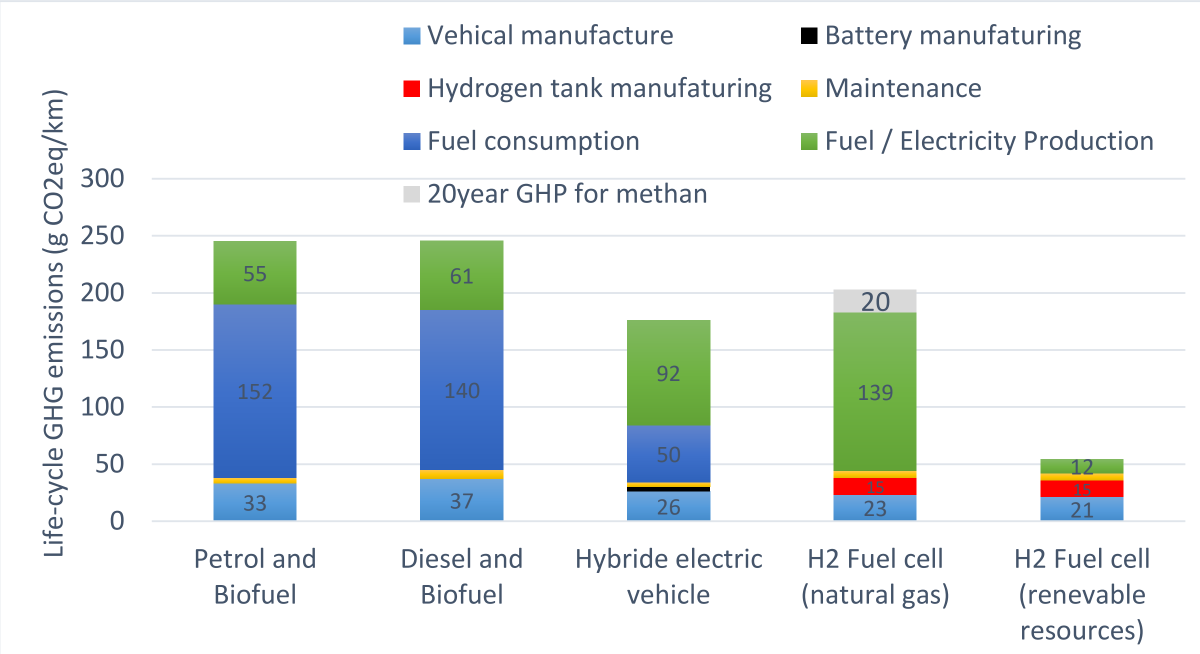


Chart 2 Life cycle emissions for lower-medium cars in 2021 (Europe) [26]

7.3 Life cycle emissions of SUV cars in 2021 (Europe) [26]:

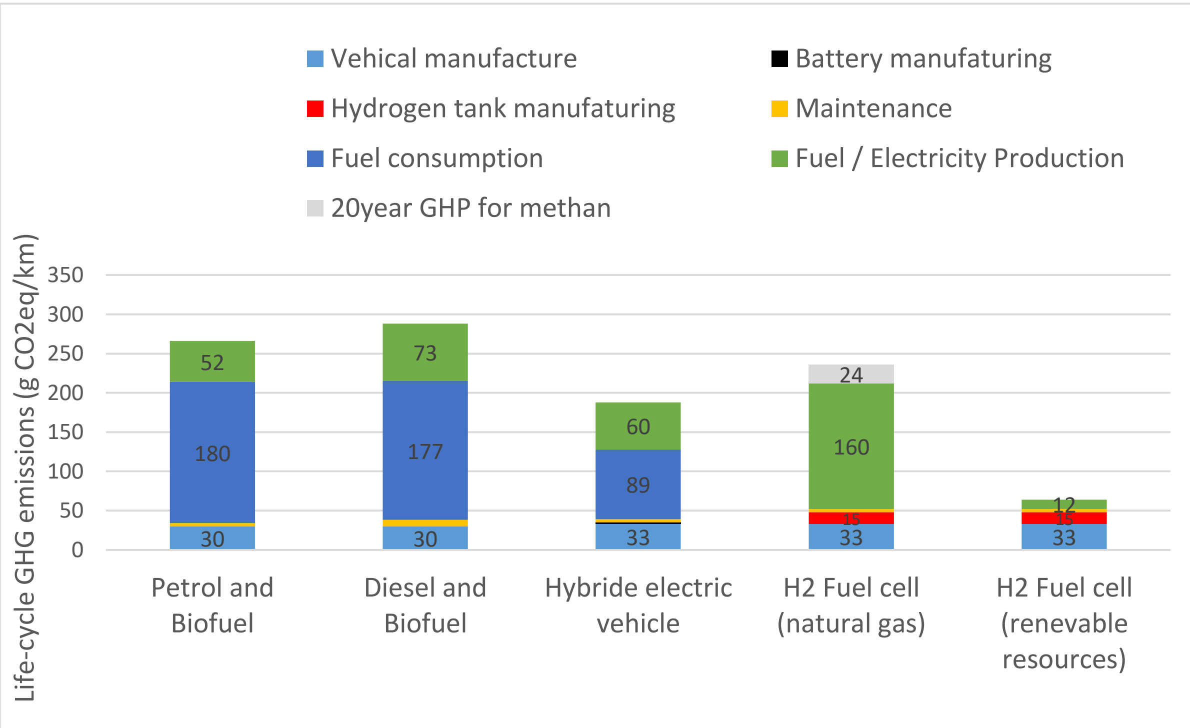


Chart 3 Life cycle emissions for SUV cars in 2021 (Europe) [26]

8. Life cycle GHG emissions of combustion cars and hydrogen cars projected to be registered in Europe in 2030 [26]:

8.1 Life cycle emission of small cars in 2030 (Europe) [26]:

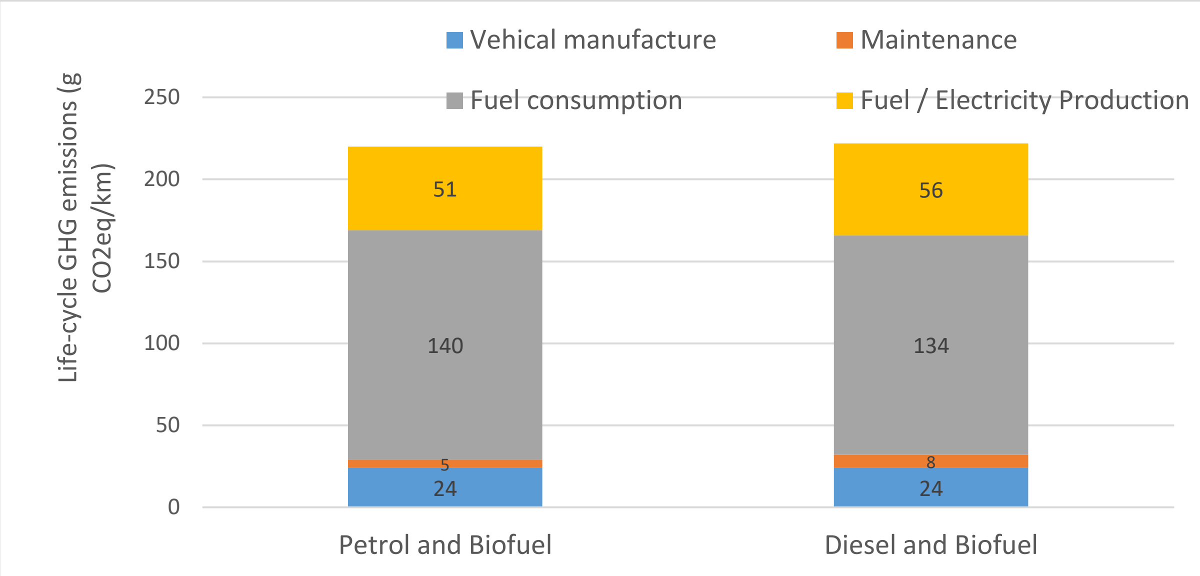


Chart 4 Life-cycle emissions of small cars in 2030 (Europe) [26]

8.2 Life cycle emission of lower-medium cars in 2030 (Europe) [26]:

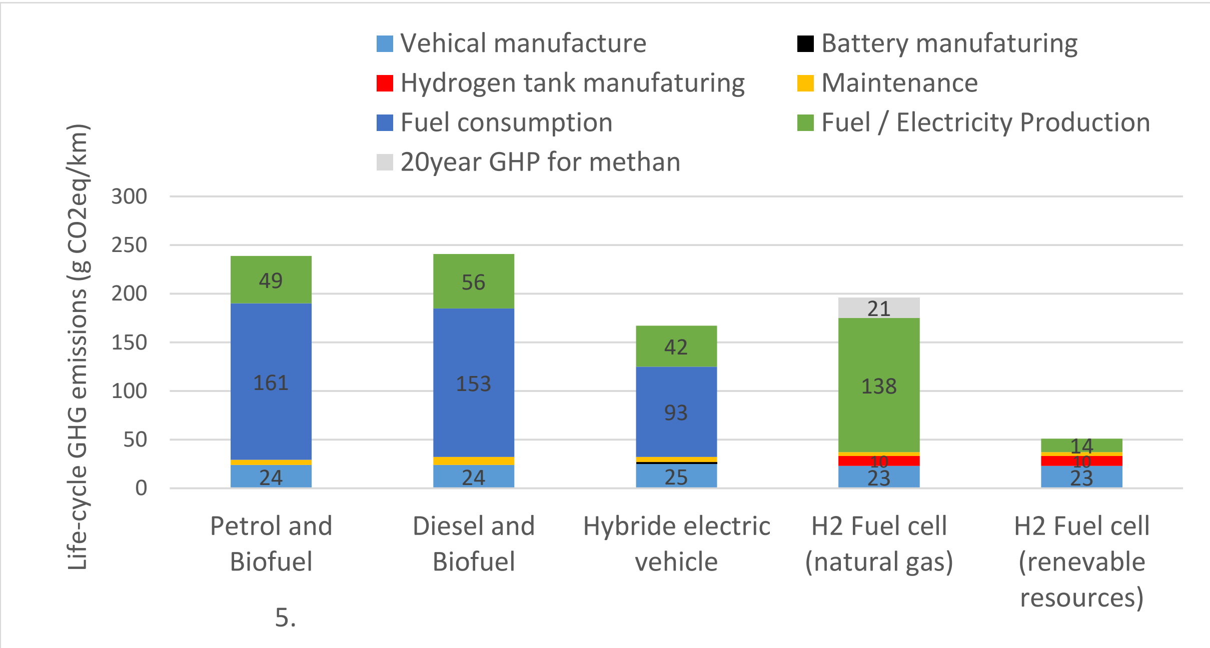


Chart 5 Life-cycle emissions of lower-medium cars in 2030 (Europe) [26]

8.3 Life cycle emission of SUV cars in 2030 (Europe) [26]:

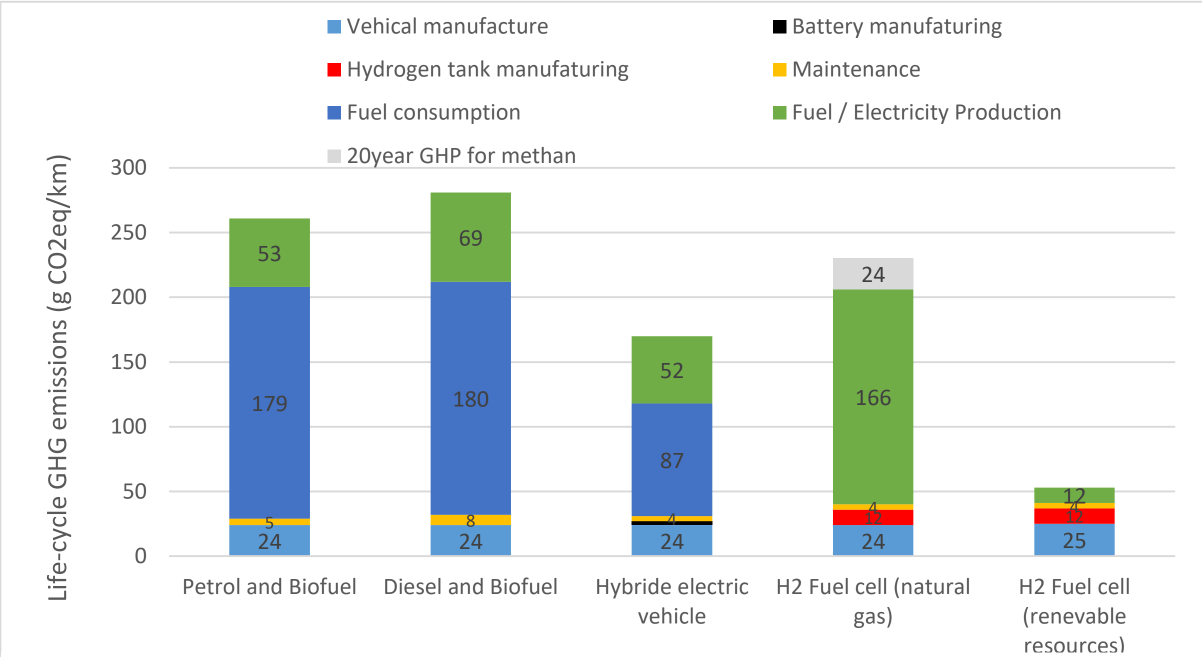


Chart 6 Life cycle emission for SUV Cars in 2030 (Europe) [26]

9. Comparing life-cycle GHG emissions between ignition cars and hydrogen cars in the years 2021 and 2030 in Europe [26]:

In small cars life-cycle, GHG emissions produced in petrol and diesel engine cars for 2021 and 2030 are 226-227 $CO_{2eq.}$/km and 220-222 $CO_{2eq.}$/km respectively. In the lower-medium car segment life-cycle, GHG emissions produced in petrol and diesel engine cars for 2021 and 2030 are 245-246 $CO_{2eq.}$/km and 239-241 $CO_{2eq.}$/km respectively. For SUV vehicles, life-cycle GHG discharges delivered in petroleum and diesel motors in 2021 and 2030 are 266-288 $CO_{2eq.}$/km and 261-281 $CO_{2eq.}$/km. In lower-medium segment cars for plug-in hybrid electric vehicle life-cycle, GHG emission in 2021 and 2030 are 176 $CO_{2eq.}$/km and 167 $CO_{2eq.}$/km respectively and last for SUV segment hybrid cars for 2021, and 2030 life-cycle GHG emissions are 188 $CO_{2eq.}$/km and 170 $CO_{2eq.}$/km respectively. Here we can easily understand that emissions produced in 2021 are almost the same for 2030 in petrol, diesel, and hybrid cars are almost identical, but we see that GHG emissions produced by hybrid cars are lower than petrol, diesel and biofuel cars for lower-medium and SUV segment both [26].

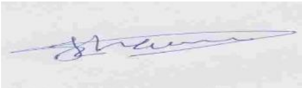
In consideration of life-cycle GHG emissions of hydrogen fuel cell cars based on natural gases for lower-medium car segments in 2021 and 2030 are 203 $CO_{2eq.}$/km and 196 $CO_{2eq.}$/km, respectively. For SUV segments lifecycle GHG emissions in 2021 and 2030 are 236 $CO_{2eq.}$/km and 230 $CO_{2eq.}$/km respectively. In the last life-cycle, GHG emissions produced by lower-medium hydrogen fuel cells based on renewable resources cars for 2021 and 2030 are 54 $CO_{2eq.}$/km and 51 $CO_{2eq.}$/km, respectively. For SUV segments these readings are 64 $CO_{2eq.}$/km and 53 $CO_{2eq.}$/km respectively [26].

10.Conclusion:

After comparing readings of life cycle emissions of hydrogen cars and combustion cars in the years 2021 and 2030, we clearly say that hydrogen fuel cell cars based on renewable resources have the lowest GHG emissions. Hydrogen fuel cell cars based on natural gas also have low life-cycle GHG emissions compared to petrol, diesel, and biofuels. Now we do not have any alternate methods that can reduce GHG emissions produced by the combustion engine, and this fossil fuel will not help us achieve the Paris agreement goal for 2050. To wrap things up, as I would like to think, the government of every country should stop fossil fuel-based vehicle production as soon as possible and may switch to an alternate option like hydrogen fuel cell vehicles and electric vehicles. We do not have to find another earth in Milky Way because we can also save our beautiful planet from unwanted climate changes.

Declaration of Independence

I, the undersigned, hereby declare that this assignment is my original work, gathered and utilized specially to fulfil the purpose and objectives of this study, and has not been previously submitted to any other course or university. I also declare that the publication and archival material cited in this work have been personally consulted.



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11. References:

[1] Statista Research Department, “Number of cars sold worldwide between 2010 and 2021 (In million unit)”, 15 November 2021. [Online]. Available: https://www.statista.com/statistics/200002/international-car-sales-since-1990/#statisticContainer [Accessed 31 December 2021].

[2] R. Lindsey, L. Duhlman, “Climate Change: Global Temperature”, Climate.gov, 12 08 2021. [Online]. Available: https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature [Accessed 31 December 2021].

[3] “Paris Agreement”, European Commission, 5 October 2016. [Online]. Available: https://ec.europa.eu/clima/eu-action/international-action-climate-change/climate-negotiations/paris-agreement_en [Accessed 31 December 2021].

[4] I. Diego, D. Javier, v. Antonio and C. Daniele, “Comparative life cycle assessment of hydrogen-fuelled passenger cars”, Science Direct. [Online] https://www.sciencedirect.com/science/article/pii/S0360319921000926 6 February 2021, p. 13, [Accessed 31 December 2021].

[5] "Greenhouse Gas Protocol”, World Resource Institute, [Online]. Available: https://ghgprotocol.org/sites/default/files/standards_supporting/FAQ.pdf [Accessed 31 December 2021].

[6] S. S. Ioan, B. Nicu, T. Phatiphat, V. Mihai, Elena Carcadea, C. Mihai, I. Mariana and R. Mircea, "Fuel Cell Electric Vehicles—A Brief Review of Current Topologies and Energy Management Strategies”, MDPI, 5 January 2021. [Online]. Available: file:///C:/Users/asus/Downloads/energies-14-00252-v2.pdf [Accessed 31 12 2021].

[7] G. Mehmet, B. Ertugrul, H. Yakup and Kemal Kaya, "The meeting of hydrogen and automotive: A review," ScienceDirect. 16 February 2017 [Online]. Available: https://www.researchgate.net/publication/314486970_The_meeting_of_hydrogen_and_automotive_A_review [Accessed 1 January 2022].

[8] G. Kenneth, "Hydrogen Internal Combustion Engine Vehicles", Stanford University. [Online]. January 2017 Available: https://resources.environment.yale.edu/gillingham/hydrogenICE.pdf [Accessed 1 January 2022].

[9] "ScienceDirect", [Online]. Available: https://www.google.com/search?q=The+meeting+of+hydrogen+and+automotive:+A+review&sxsrf=AOaemvJW9txQdHT34IeQVlk9k3BMgczo9g:1641290960816&source=lnms&tbm=isch&sa=X&ved=2ahUKEwjrz8Sl7Zf1AhXJ-KQKHV9UDKsQ_AUoA3oECAEQBQ&biw=1242&bih=597&dpr=1.1#imgrc=T_Za3cLsIe [Accessed 1 January 2022].

[10] "ScienceDirect," [Online]. Available: https://www.google.com/search?q=The+meeting+of+hydrogen+and+automotive:+A+review&sxsrf=AOaemvJW9txQdHT34IeQVlk9k3BMgczo9g:1641290960816&source=lnms&tbm=isch&sa=X&ved=2ahUKEwjrz8Sl7Zf1AhXJ-KQKHV9UDKsQ_AUoA3oECAEQBQ&biw=1242&bih=597&dpr=1.1#imgrc=T_Za3cLsIe [Accessed 1 January 2022].

[11] "ScienceDirect," [Online]. Available: https://www.google.com/search?q=The+meeting+of+hydrogen+and+automotive:+A+review&sxsrf=AOaemvJW9txQdHT34IeQVlk9k3BMgczo9g:1641290960816&source=ln

ms&tbm=isch&sa=X&ved=2ahUKEwjrz8Sl7Zf1AhXJ-KQKHV9UDKsQ_AUoA3oECAEQBQ&biw=1242&bih=597&dpr=1.1#imgrc=O9kMWDr3tf [Accessed 2 January 2022].

[12] "Hydrogen Used in Internal Combustion Engines," College of the Desert, January 2001, [Online] Available: https://www1.eere.energy.gov/hydrogenandfuelcells/tech_validation/pdfs/fcm03r0.pdf [Accessed 2 January 2022].

[13] [Online]. Available: http://large.stanford.edu/courses/2018/ph240/mangram2/images/f1big.png [Accessed 2 January 2022].

[14] R. K. "Rajput, Internal Combustion Engine", Laxmi Publications P LTD, 2007. [Online] Available: http://www.mediafire.com/file/dyqe8lvs5f2p08x/Internal-Combustion-Engines_by_Rajput_-_BY_Civildatas.com.pdf/file [Accessed 3 January 2022].

[15] "Wordpress.com," [Online]. Available: https://danishahmedhome.files.wordpress.com/2019/02/main-qimg-6301bca47a1ec48bda6c1b333405361d.jpg?w=640 [Accessed 3 January 2022].

[16] [Online]. Available: https://1.bp.blogspot.com/-Z5n66aeSwNw/YHJfdMqhzeI/AAAAAAAACNA/VhPQeBNri4gUE3GgInML-MeKknn_h5m6gCLcBGAsYHQ/w349-h349/diesel_engine.gif [Accessed 4 January 2022].

[17] S. Szymkowski, "The 8 differences between gasoline and hydrogen engines", Motor authority," 26 January 2020, [Online]. Available: https://www.motorauthority.com/news/1123676_the-8-differences-between-gasoline-and-hydrogen-engines [Accessed 4 January 2022].

[18] K. Gillingham, "The meeting of hydrogen and automotive: A review," ScienceDirect, no. 16 February, p. 13, 2017. [Accessed 4 January 2022].

[19] "Concoa," [Online]. Available: https://www.concoa.com/hydrogen_properties.html [Accessed 4 January 2022].

[20] "Hydrogen Storage," Energy Efficiency & Renewable Energy, March 2017. [Online]. Available: https://www.energy.gov/sites/prod/files/2017/03/f34/fcto-h2-storage-fact-sheet.pdf [Accessed 4 January 2022].

[21] "ScienceDirecrt," 7 2 2022. [Online]. Available: https://www.sciencedirect.com/topics/engineering/diesel-fuel. [Accessed 4 January 2022].

[22] T. Azuma, "Car from Japan", 25 December 2020, [Online]. Available: https://carfromjapan.com/article/car-maintenance/everything-drivers-need-know-fuel-tank-capacity/ [Accessed 5 January 2022].

[23] "ISO14040", ISO, July 2006, [Online]. Available: https://www.iso.org/standard/37456.html [Accessed 6 January 2022].

[24] "Vehicle life cycle," [Online]. Available: https://ahssinsights.org/wp-content/uploads/2018/09/Vol16_Fig1.png [Accessed 6 January 2022].

[25] "Carbon dioxide equivalent", Eurostat, [Online]. Available: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Carbon_dioxide_equivalent [Accessed 6 January 2022].

[26] B. Georg, "A global comparison of the life-cycle greenhouse gas emissions of combustion engine and electric passenger cars", ICCT, July 2021. [Online]. Available: https://theicct.org/wp-content/uploads/2021/12/Global-LCA-passenger-cars-jul2021_0.pdf [Accessed 6 January 2022].