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Hydrogen as an Alternative Fuel for Internal Combustion Engines

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Contents

1	Introduction	1
1.1	Justification	1
1.2	Aims.....	1
1.3	Objectives.....	1
2	Background	2
2.1	Hydrogen Production	2
2.2	Hydrogen Storage.....	3
2.3	Development of Hydrogen Cars	4
3	Discussion.....	6
3.1	Why hydrogen is a suitable fuel for ICE.....	6
3.2	Why using hydrogen for ICE vehicles is a bad idea.	6
4	Conclusion.....	6
5	References.....	7

1 Introduction

1.1 Justification

Currently, the government is trying to reduce emissions by introducing a law that prevents the sale of purely fossil fuelled vehicles by 2035. Yet this may not be an immediate solution to reduce emissions. As the emission from an EV's production is a large producer of both CO₂ and greenhouse gases, if there was to say a high demand for electric cars there would be a massive amount of CO₂ produced. Whereas hydrogen (H_2) is more environmentally friendly with the emissions from production being low, as well as tailpipe emissions being only water. If the use of hydrogen is developed further, then we may be able to implement it into current cars saving on the environmental cost of producing new vehicles. With brands like Toyota who have developed a hydrogen fuelled Internal Combustion Engine (ICE), significant advances have been made within recent years.

1.2 Aims

This paper aims to investigate whether hydrogen is a suitable fuel for a combustion engine, looking at environmental costs, use in ICE powered vehicles as well as the storage options for hydrogen.

1.3 Objectives

The goal in this paper is to find an alternative to fossil fuel and electric cars, such as hydrogen. This will try to deepen understanding as to whether hydrogen is a suitable alternative to fossil fuelled vehicles, while also looking into the disadvantages and the advantages of hydrogen's use in ICE powered vehicles.

2 Background

2.1 Hydrogen Production

Currently, more than 50% of hydrogen is produced through steam reforming, this is where the steam is created from an electric heating element, which according to the U.S department of energy 22.28% of electricity is still produced from coal. There are other materials that hydrogen can be obtained from: ammonia, biomass, coal, ethanol, methanol, water, with further options in Fig.1. Despite having many options, when you start to look at the costs, emissions and efficiency there aren't many that are fit for large scale production that could produce enough for every car on the road, whilst also maintaining those low emissions sweet spot. For example, coal requires extra measures to reduce emissions, where carbon capture and storage (CCS) needs to be implemented to meet greenhouse gas emissions targets.

(Dincer and Acar, 2017) (Velazquez Abad and Dodds, 2017)

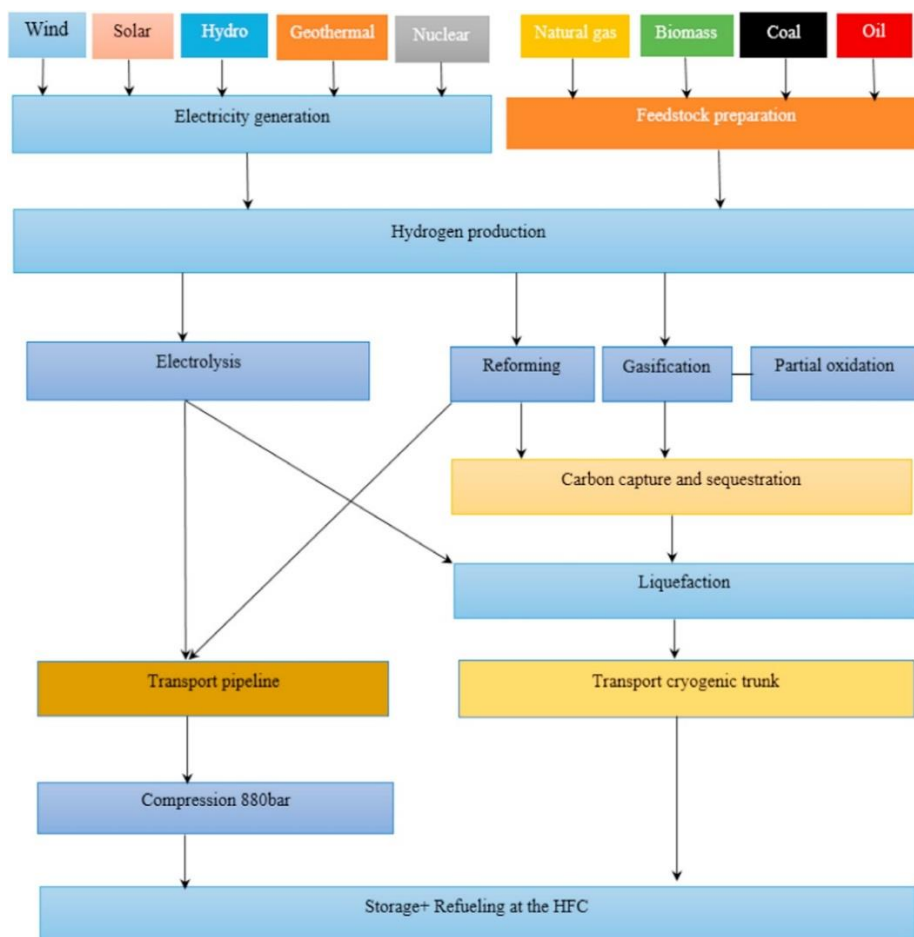


Figure 1 Table summaries production, storage and transportation of hydrogen

(Hosseini and Wahid, 2016)

2.2 Hydrogen Storage

When we find a sustainable way to produce hydrogen, storage and transportation are where the main problems with hydrogen lie, and this is what makes hydrogen expensive. The easiest way to store hydrogen is in gaseous form, where the hydrogen can be kept at room temperature in a high-pressure steel cylinder, at the standard pressure of up to 200 bar. Approximately 16kg of hydrogen will require a volume of 62L, if you were to replace this with petrol, (at atmospheric pressure), 50kg would fit in the same space. This is due to the density of hydrogen being 120mj/kg resulting in it being more than 4 times higher than that of Petrol which is 25MJ/kg, for example 1kg hydrogen is equal to 4.5kg of Petrol.



Figure 2 Cross section of liquid hydrogen fuel tank from BMW's Hydrogen 7

Hydrogen can also be stored in liquid form, allowing up to 75% more fuel to be stored in the same space, compared to gaseous hydrogen at 700 bar; which is the pressure that was used in Toyota's concept hydrogen fuelled car. This sounds promising as a lot less space is required to store hydrogen, but there is a major disadvantage. To stay in liquid form hydrogen is required to stay below -253 degrees Celsius, to keep the fuel at this temperature it requires at the very least a double skinned tank (refer to fig.2), with a vacuum to isolate the hydrogen from outside temperatures, keeping it cool. In a car the temperature is mostly down to the insulation as there wouldn't be much space for the occupants if it had its own cooling system, if the temperature inside the tank rises above this the hydrogen turns back into a gas and must be vented off resulting in fuel loss.

Results from a car made by BMW in 2008 indicate it would vent off the whole tank of fuel within 10-12 days, though this may sound like a hazard it is simply resolved by using a catalyst to introduce oxygen, therefore turning the hydrogen into water.

(The Unfortunate Truth About Toyota's Hydrogen V8 Engine - YouTube, no date; Toyota Developed a Liquid Hydrogen Combustion Engine! - YouTube, no date; BMW's Hydrogen V12 Engine Is a Hilarious Engineering Stunt - YouTube, no date; Bondarenko et al., 2022)

2.3 Development of Hydrogen Cars

In 2021 Toyota came out with a fully hydrogen powered vehicle based on a Corolla, they entered a 24-hour endurance race for testing and to see how well a hydrogen car could do. The engine functioned like a conventional direct injection petrol engine; they used gaseous hydrogen stored at 700 bar. During the race they spent about 8 hours in the pits for repairs and safety checks because of the high pressure in the fuel system. But Toyota isn't the only company that has successfully made hydrogen powered vehicle, BMW made a liquid hydrogen powered vehicle in 2008, as mentioned above, though there are some major disadvantages. The car produced almost half the amount of power compared to its production counterpart with it producing 260 hp where the purely petrol-powered car produced 438 hp from the same 6 litre V12, this was mainly due to the fact they used indirect injection which resulted in a less than ideal 30% hydrogen in the cylinder, because it's being drawn in at atmospheric pressure. When Toyota later developed their Hydrogen endurance car, they used direct injection which resulted in a much better fuel to air ratio, because they filled the cylinder with air on the induction stroke while later injecting the hydrogen to better the fuel air mix. Though this was the case BMW's system did not require a fuel pump which made the system more reliable as a result. However Toyota took a different approach with there liquid hydrogen endurance car in 2023 who's fuel pump failed twice throughout the race, caused by the extreme temperatures.

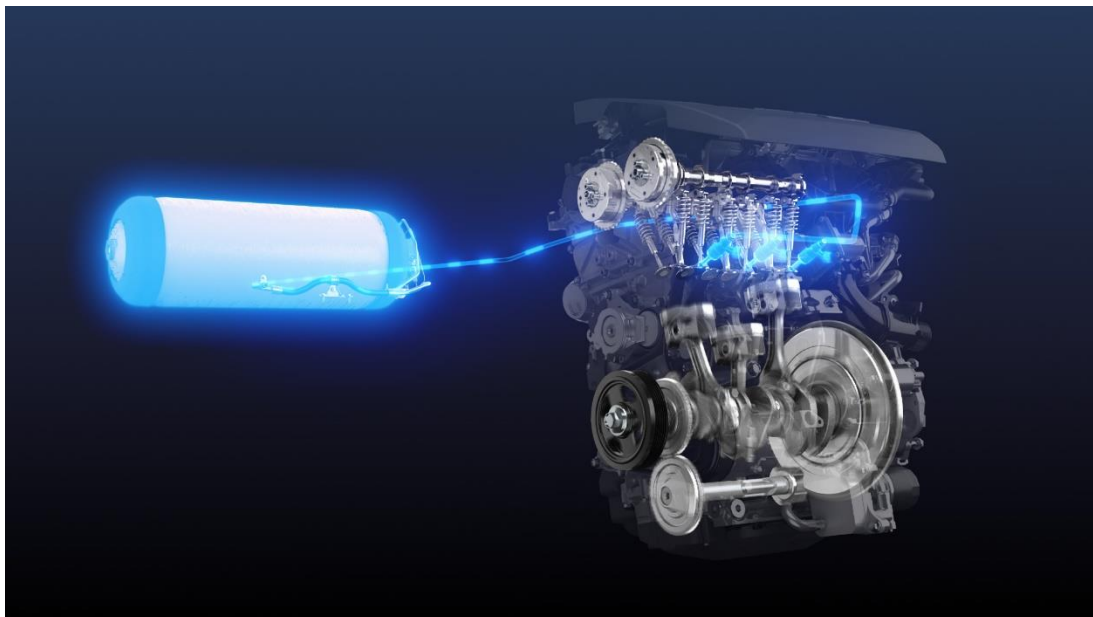


Figure 3 Toyota's hydrogen engine with gas tank

(The 24-Hour Challenge of the Hydrogen-Powered Engine, no date; (BMW's Hydrogen V12 Engine Is A Hilarious Engineering Stunt - YouTube, no date; (Toyota Developed A Liquid Hydrogen Combustion Engine! - YouTube, no date)

3 Discussion

3.1 Why hydrogen is a suitable fuel for ICE.

Hydrogen presents itself as a very usable fuel for current on the road cars, as demonstrated by Toyota developing an endurance car that has competed in an endurance race with promising results. Hydrogen has a very high energy density near enough matching that of petrol, where 1 gallon of petrol is equal to 1 kg of liquid hydrogen. From this research it's shown that hydrogen has been proven to work as a fuel for ICE powered vehicles, with companies like Toyota developing new hydrogen powered vehicles, it seems as though we aren't very far away from hydrogen powered road cars. Hydrogen is also in abundance with it mainly existing in water it can be found in many different resources, so there's not a limited supply.

3.2 Why using hydrogen for ICE vehicles is a bad idea.

Even though there have been many things that make hydrogen suitable for existing cars, many downsides outweigh some of the positives. For example, storage is the biggest flaw in hydrogen powered vehicles, with it requiring so much space a family car will have barely any room in the back due to the size of the fuel tank as shown in Fig.2. This along with a fuel pump issue found by Toyota, that because of the extreme temperature of liquid hydrogen of -253 Celsius, Toyota had to replace it twice throughout the endurance race, shows that further development is required.

4 Conclusion

In conclusion hydrogen has a promising future with the likes of Toyota developing hydrogen for ICE powered vehicles. Hydrogen also has lots of potential, with some current disadvantages that impair the use in an everyday vehicle, like the fact of how much space a liquid hydrogen tank takes up, or the extreme pressure that gaseous hydrogen must be stored at to obtain an almost acceptable range before refilling.

Hydrogen does have many advantages in terms of emissions being very clean. Current ICE vehicles could be converted to run on hydrogen with Toyota's development, though this is not currently possible. We still can't achieve the efficiency of a conventionally powered fossil fuelled vehicle. Saying that, with further research hydrogen may still be the solution to a cleaner fuel for ICE vehicles.

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