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The Green Cars of the Future

FUTURE RESEARCHERS PROGRAMME

Fad or the future: Hydrogen vs Electric –

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Abstract

Climate change, while a natural phenomenon, is being accelerated by mankind. Carbon dioxide levels are 40% higher than they were before the industrial revolution. One large contributor to these emissions is the transportation industry, specifically commercial vehicles. Scientists have spent a considerable amount of time researching alternatives solutions to internal combustion engines. While this research is very valuable and useful, it loses its purpose when no firm conclusions are made. There is currently no universal scale of how to assess the pros and cons of replacements for internal combustion engines. Hence, in this paper rationale is used to create a system to weight the factors of the two fuel types with the most potential to replace internal combustion engines: hydrogen and electric.

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Contents

Introduction

For a long time now, there has been a consensus that, as a global population, we need to move away from using fossil fuels and find more sustainable sources of energy. According to MAHB Admin at Stanford (2019), Oil will run out by 2052, gas will run out by 2060 and coal stores will have diminished by 2090. Approximately 84% of energy consumption on earth comes from fossil fuels (Kumar, 2021). The reliance of the automotive sector on fossil fuels is a huge contributor to climate change. In 2021, fossil fuels accounted for around 90% of the total U.S. transportation sector energy use. In addition, around 27% of greenhouse gas emissions come from transportation (Eastman & Buttigieg, 2022).

The positive correlation between a reduction in petrol car ownership and a reduction in carbon dioxide emissions is a major contributing factor to the overall goal of governments and scientists to reduce fossil fuel emissions (Ashik, et al, 2022). Though it varies by country, transportation typically makes up at least one third of total carbon emissions (O'Callahan and Kim, 2022). Therefore, to mitigate climate change, the commercial car industry needs to move away from internal combustion engines.

Research in this domain is vital. Without significantly reducing carbon emissions, models predict that the earth's average global temperature will rise by 4°C by the end of the century, global average precipitation will increase by up to 12% and sea levels will increase by 30-100cm (*Predictions of Future Global Climate | Center for Science Education*, 2022). These consequences are life threatening, irreversible and have devastating effects on society and the environment.

Possible Fuel Types

"Green cars" have the potential to significantly reduce carbon emissions. It is important to consider how internal combustion engines will be replaced.

Natural gas vehicles emit oxides of nitrogen, carbon monoxide and carbon dioxide. Although natural gas is considered a low carbon fuel (due to reduced emissions of around 15%), the overall life cycle emissions are too significant for natural gas to be a suitable substitute for petrol. (*Alternative Fuels Data Center: Natural Gas Vehicle Emissions*, n.d.). Biogas engines use vegetable oils, animal fats or recycled restaurant grease as fuel. Carbon dioxide is still emitted from biogas combustion, however most of this is counteracted by the carbon dioxide that is absorbed by the plants that make up the fuel. However, only the net emissions of carbon dioxide have been reduced and biogas is an extremely expensive fuel to manufacture, making it unsuitable for use on a large scale. In theory, solar panels could be installed on the roof of cars to provide electricity. However in reality, to reach average speeds in a car, 30 square metres of solar panels are needed on a car roof which is usually around 3-5 square metres. Therefore solar panels at the current average efficiency (around 15%) will not provide enough energy to cars (Tom Murphy, 2011).

There have been suggestions over the years that nuclear power could be the way forward. In theory, small nuclear reactors could be stored in cars to provide vast amounts of energy. However, in order to keep this reactor safe, at least a metre of concrete needs to surround the reactor to prevent radiation leaks. This will therefore make the engine extremely heavy and practically immobile (Tai Thomas, 2016).

Although all these fuel types will move the automotive industry away from fossil fuels, the benefits are quickly outweighed by the risks or issues.

There are two more fuel types that present the greatest reduction of carbon emissions and the fewest side effects: hydrogen and electric.. Due to the abundance of hydrogen in our atmosphere, and the possibility of significant reductions in fossil fuel usage, hydrogen fuel serves as a viable alternative. Electric vehicles have the potential to reduce life cycle emissions by up to 89% (Buberger et al, 2022) The energy efficiency and environmental benefits of electric cars makes it a suitable contender to be "the green car of the future".

Factors Involved in Determining the Appropriate Fuel Type

In order to determine the most suitable replacement for combustion engines four key factors must be considered.

The first is safety. If a fuel type is highly efficient and cost effective but the dangers of the fuel upon impact or certain exposure are unknown or possibly harmful, the fuel should no longer be considered suitable for use in commercial vehicles. User safety is paramount and people need to believe that the fuel that they are using is safe, otherwise they will be hesitant to make the transition away from petrol.

Another determining factor is cost. From the cost to extract the raw materials to manufacturing of the engine, to refilling or recharging, money is at the forefront of this switch to renewable energy. It is in the best interest of governments and society to keep costs low where possible.

The total life cycle emissions also need to be taken into account as many will think that because hydrogen fuel cells and batteries don't directly emit carbon dioxide, that these fuel types are completely carbon neutral. This however, is not the case, because the fossil fuels are used during the extraction process, manufacturing process and shipment of the fuel or battery. Potentially, this could outweigh the use of these cars on the roads.

Lastly, practicality for customers' needs to be considered. Generally, consumers have relatively easy access to fossil fuels. This has set a level of expectation that a replacement fuel type must seek to match. One cannot expect a consumer to drive a great distance just to refill or recharge their car or start paying significantly more to do so. This green fuel of the future needs to minimise any change to an average person's daily routine and usual car maintenance.

The Framework Behind Establishing the Green Car of the Future

In order to evaluate the suitability of hydrogen fuel cell cars and electric vehicles, the aforementioned factors require investigation, but it is inappropriate to give each factor an equal weighting. Some factors are more important than others. Instead, a weighted scoring system will be used so that the more crucial a factor is, the greater the impact it will have on the final score. To determine how crucial a factor is, rationale rather than statistical data will be used to reach a conclusion as there is no existing universally accepted scale in this realm of research. In the opinion of the authors, safety is the most important factor so will therefore account for 40% of the points. Emissions will account for 25% of the overall score as this is the primary driver behind changing from fossil fuels. Cost will make up 20% of the overall scoring given the current economic pressures that are being experienced around the world following the coronavirus pandemic. Practicality will have a weighting of 15%. The total score per fuel type will be out of 100, so safety will be scored out of 40, emissions out of 25, cost out of 20 and practicality out of 15 points. Points will be given based on the available data that exists in the public domain.

Hydrogen Fuel Cell Cars

The use of hydrogen fuel cells in cars has the potential to significantly reduce carbon emissions. In order to run the car by this fuel cell, hydrogen enters through one tube to the positive anode and oxygen enters the other tube to the negative cathode. At the anode the hydrogen atoms are ionised resulting in free electrons and protons. The protons cross the electrolyte towards the cathode. The free electrons, unable to cross the electrolyte, flow up the wire creating a flow of charge, inducing a current and generating electricity. As the protons flow to the cathode, they react with the oxygen forming H_2O, which then leaves the cell as pure water. Therefore, the only direct emissions from a hydrogen fuel cell is water vapour.

Safety

Hydrogen stored within a vehicle does pose some safety concerns. Within the fuel cell the hydrogen and oxygen are only separated by a thin polymer membrane around 20-30 micrometres. If this membrane was to break hydrogen and oxygen would combine. However, the danger will be minimal because if the membrane were to rupture the potential difference across the cell would drop which could be detected by a spark free optical-based hydrogen sensor (Alan Fury, 2021) and the supply lines can be disconnected. If the supply lines weren't disconnected the risk of thermal ignition is still very low due to the small amount of hydrogen present in the fuel cell. However, if hydrogen manages to escape the cell and ignite, the risks associated with this accident are even lower. This is due to the inherent property of hydrogen. It can diffuse at around 20 miles per hour (Jacob Leachman, 2017), so the hydrogen flame will burn up and away from the vehicle. In a study by Directed Technologies Inc. (1996), it was concluded that in open air, hydrogen fuel cell cars pose less of a hazard than vehicles powered by gasoline and in tunnels, this risk only reaches around the same as a gasoline powered vehicle. The greatest risk is noticed when hydrogen fuel slowly leaks in a closed environment such as a home garage. This could lead to fires or an explosion in the absence of detectors and risk mitigation techniques like active ventilation. Therefore, with adequate detectors and battery bank disconnectors that new technologies can easily provide, the risks associated with hydrogen fuel cells can be minimised to the same level as gasoline vehicles (Barbir, 1999).

Once again due to the inert properties of hydrogen, storing it outside of the fuel cell in the car poses risks, but these risks are no greater than those associated with gasoline.

Hydrogen can be explosive with oxygen concentrations around 18 to 59 percent but gasoline can be explosive at oxygen concentrations between 1 and 3 percent (Tae, 2021). Therefore, gasoline has greater risk for explosion than hydrogen for any given environment with oxygen. In addition, for over 40 years, hydrogen has been used in rocket fuel, oil refineries, and the production of fertiliser (Tae, 2021). Therefore, there is already existing evidence base for its safe usage and procedures have long since been in place to securely store hydrogen on an industrial level.

In conclusion, hydrogen scores 30/40 on safety based on the safety procedures in place. It was not possible to give a score greater than 30 due to the possibility of severe accidents.

Cost

The use of hydrogen fuel cars includes both private and external costs. A private cost is incurred by an individual or a firm as a part of its production or other economic activities, whereas the external cost is incurred by an individual or a firm as a result of production or other economic activities they were not involved in.

The main private costs that could arise on the consumers is the currently expensive cost of hydrogen powered cars. An average hydrogen fuel car will cost up to $80,000 (Arnold, 2019). For example, Toyota and Hyundai's hydrogen fuel cell cars are approximately $60,000, which is almost twice as much as the starting cost of an electric vehicle and triple the cost for a petrol vehicle (Carlier, 2022; Eastman & Buttigieg, 2022). One of the reasons why these cars are so expensive is due to the use of expensive metals such as platinum, which is used in the car during the power generation. The precious metal acts as a catalyst to speed up the chemical reaction. However, in the long run, companies like BMW are planning to reduce the amount of platinum used in their hydrogen cell cars (Rücker, 2019), which will bring down the costs and in turn, make these cars more affordable.

The external costs of producing hydrogen cell cars, mainly comes for the extraction of the platinum that is later used as catalyst. The negative externalities that arise from this are mainly environmental impacts. This includes high electricity consumption which is on average about 175 GJ/kg of platinum group metals (Glaister and Mudd, 2010). Also there is high water usage, on average 400 m^3/kg (Glaister and Mudd, 2010). Due to this high water usage, overconsumption of water could occur, resulting in reduced water security in certain areas. Additionally, mining platinum brings very high carbon dioxide emissions which average around 40 tonnes of CO2 per kg of platinum (Glaister and Mudd, 2010), this could result in an increased amount of greenhouse gases in the atmosphere, which could lead to a rise in average global temperatures, as well as increased levels of air pollution (Glaister and Mudd, 2010).

In conclusion, hydrogen fuel cells currently score 13/20 on cost. A score higher than 13 could not be given as upfront costs of fuel cell cars are high and the materials used to manufacture the fuel cells are precious metals which limit the possibility of price reductions upon mass production.

Emissions

Hydrogen fuel cell cars produce zero harmful tailpipe emissions, however this does not necessarily give the full picture. To see the actual amount of harmful gases released into the atmosphere as a result of these cars, you must look at the gases released during their full life cycle, particularly emissions made from producing the hydrogen. (Union of Concerned Scientists, 2014)

There are several different ways of producing the hydrogen needed for these cars. Currently, the most common way is by using natural gases, and converting them into hydrogen and carbon dioxide. While this obviously poses a problem, as it is releasing greenhouse gases into the atmosphere, the amount of said gases is still much less than what would be produced by a gasoline powered car on the road. Even when using natural gas produced hydrogen, hydrogen fuel cell cars reduce emissions by over 30% (Union of Concerned Scientists, 2014). In terms of emissions, a comparable example of hydrogen fuel cell cars vs gasoline cars would be the Hyundai Tucson. When fuelled by hydrogen from natural gases, the car produces 286 g CO2 eq/mile (grams of carbon dioxide equivalent per mile drive). The most efficient gasoline equivalent of the Tucson produces 436 g CO2 eq /mile which is over 1.5 times more in terms of emissions. (Union of Concerned Scientists, 2014)

It shouldn't be forgotten that this is all from using hydrogen from natural gases, one of the less green ways of producing it. There are other, much cleaner alternatives, such as using electrolysis to split water into hydrogen and oxygen. This process can be powered using renewable sources such as solar power or wind turbines, producing far fewer greenhouse gases into the atmosphere (Nunez, 2019).

Other alternatives include using hydrogen from methane gas which produces relatively little carbon (Union of Concerned Scientists, 2014). When using sources of hydrogen that fall under California's renewable hydrogen requirements (Achtelik, 2009), the reduction of emissions goes from about 30 to over 50% (Union of Concerned Scientists, 2014). As technology advances and more efficient methods for extracting and producing hydrogen are designed, this number is likely to rise, making hydrogen fuel cells even cleaner.

Hence, hydrogen fuel cells score 20/25 for emissions. The emissions in the life cycle of these fuel cells are not zero, but they significantly reduce the amount of carbon dioxide being released into the atmosphere.

Practicality

As of June 2022, there are only 45 hydrogen fuelling stations in the United States, and 43 of those stations are in California (Eastman & Buttigieg, 2022). This is a tiny fraction of the total petrol stations in the United States which as of 2021 was around 115,000 (Sallee, 2021). In order for hydrogen fuel cells to be a sufficient replacement for combustion engine cars, more refuelling stations need to be built. The problem isn't constructing the hydrogen fuel stations, it is instead the lack of confidence of petrol stations to invest in a hydrogen pump for the fear that profit won't be generated. However, this then contributes to a cycle of customer reluctance to buy a hydrogen fuel cell car, as there aren't enough refilling stations for it to be convenient, which in turn, causes petrol stations to refrain from installing pumps due to the lack of perceived consumer demand based on the scarcity of hydrogen cars on the road. This cyclical pattern will be very hard to break.

Hydrogen fuel cells have a driving range of more than 300 miles and can be refuelled in less than 10 minutes (Manoharan et al., 2019). This is very comparable to current gasoline fuelled vehicles, therefore if there were more hydrogen pumps internationally, the process of refuelling a hydrogen fuel cell car is not demanding any lifestyle changes to customers.

In conclusion, hydrogen fuel cells currently score 7/15 for practicality. The refuelling time is very attractive but the sheer lack of places to refuel outweighs that benefit at the moment.

Electric Cars

The use of batteries in cars has the potential to significantly reduce carbon emissions. In order to run electric vehicles, the battery inside consists of multiple cells. When cells are immersed into the electrolyte, oxidation occurs at the negative electrode, and this causes a flow of electrons to the positive electrode where reduction occurs. This discharge reaction at the positive electrode induces a potential difference, generating electricity.

Safety

There are different risks associated with batteries inside of electric vehicles when compared to hydrogen powered cars as there is no fuel involved. The biggest risk posed is caused by the large voltages in fully electric cars. Batteries have high energy and power density, therefore an uncontrolled release of this electrical energy due to high temperatures or physical accident, could cause very high temperatures around 800°C which could lead to an explosion or fire (Shantelle Nembhard, 2019, 14). There are also chemical risks due to the electrolyte which is corrosive and toxic. Therefore, venting is a vital safety feature that creates an anaerobic atmosphere so the gases produced from reactions (e.g. hydrofluoric acid) with the electrolyte and any moisture, cannot ignite. (Shantelle Nembhard, 2019, 15).

Outside of the car, batteries need to be carefully recycled or disposed of. There are hundreds of lithium-ion cells within an electric vehicle which need to be disassembled carefully (Woollacott, 2021). At the Department of Energy's Oak Ridge National Laboratory, a robotic system has been developed to disassemble dead electric vehicle batteries safely and efficiently (Manners, 2021). This automated process not only reduces exposure of humans to toxic chemicals, but it also makes part of the battery recyclable and reusable, reducing waste (Manners, 2021). Although there are risks associated with the end of the life cycle of batteries, there are methods to safely dispose of the batteries.

In conclusion, electric cars score 32/40 for safety. Due to the wider knowledge of how batteries work and the absence of any gas leaks, electric vehicles can be given a higher score than hydrogen. Any risks associated with electric vehicles have already been accounted for and pose less risk to everyday usage.

Cost

As has been mentioned previously, there are two types of costs, private cost and external cost. The private cost of owning an electric vehicle is often lower compared to hydrogen. For a typical electric car with a 60kWh battery, it will cost on average around £15.10 to charge a full battery, which can have a range of 200 miles (Pod point, 2022). In addition, charging power locations in public places like supermarkets or car parks are usually free of charge. (Roberts, 2019). Whereas the current price of unleaded petrol , in the UK, today is 190.22 pence per litre (23/06/2022) and with an average full tank size of 68 litres, every full petrol refill will cost ~£130. However, even if the running cost of an electric car is cheaper, on average the initial cost you will have to pay for an electric car is almost double the price of a normal petrol car. This should not be seen as totally negative because over time, the additional upfront costs associated with buying an electric car will be made up for by the savings Made by recharging instead of refilling.

With regard to manufacturing, these costs are decreasing as the need for lithium ion batteries increases. Since 1991, when lithium-ion batteries were first commercially introduced, the cost has dropped significantly; by 97% no less (Chandler, 2021).

The external costs of the electric vehicle, mainly arise in the form of negative externality from the extraction of the lithium that is used in the production of the batteries. Similarly to obtaining hydrogen, mining lithium demands a very large quantity of water around 500,000 gallons of water per ton of lithium (Ahmad, 2020). As with hydrogen, this can also create water security issues and negatively affect the surrounding environment.

In conclusion, an electric car scores 17/20 for cost. Unlike hydrogen fuel cells, the metals required for manufacturing are not precious, so the price reduction upon mass production isn't as limited. In addition, the upfront costs are quickly made up for by weekly savings on fuel.

Emissions

It is important to take into account the amount of CO2 emitted when electricity is produced or fuel is burnt, as well as the carbon impact of resource extraction for batteries or of building a power plant. It can be concluded from those criteria that electric cars in Europe emit, on average, more than 3 times less CO2 than equivalent petrol cars. (Yoann Gimbert, 2022)

Data shows that at the least efficient electric cars still produce 37% less carbon dioxide emissions than the average petrol car, and at their most efficient they can emit over 80% less emissions than petrol cars (Yoann Gimbert, 2022). In addition, as the EU grid starts to rely more on renewable methods of producing energy, this number is likely to increase even further. (Yoann Gimbert, 2022)

However, the emissions caused by the use of electric vehicles are not limited to the gases admitted via their exhaust pipes. The production of batteries for the vehicles is shown to produce 56 to 494 kilograms of carbon dioxide per kilowatt-hour of battery capacity (kgco2/kWh) (Dale Hall and Nic Lutsey, 2018). For comparison, on average electric vehicles produce 1-2 grams of CO_2 per kilometre driven (Dale Hall and Nic Lutsey, 2018). The lithium ion batteries used to power electric vehicles require a lot of energy to make, as the process involves extracting and refining earth metals at high temperatures. In 2016, 25% – 40% was produced by burning coal. (Dale Hall and Nic Lutsey, 2018)

However, even when including the production of the batteries, the total amount of emissions produced by electric vehicles is still less than that of traditional cars. The emissions of an average European electric vehicle is 28% to 72% less than a gasoline equivalent. (Dale Hall and Nic Lutsey, 2018)

In conclusion, the emission of electric vehicles will be scored 22/25. There is great scope with electric vehicles to reduce carbon emissions. However, while it is not as significant, the emissions released during the production of batteries cannot be ignored, therefore limiting the score to 22.

Practicality

There are three main ways to charge electric vehicles. The first being AC (alternating current) level 1 charging which only provides around 4 to 5 additional miles per hour of charging (Winn, 2019). However, this charger can be installed at any 120 volt (V) electricity outlet (Winn, 2019). There is also AC level 2 charging which provides around 11 to 22 additional miles per hour of charge (Winn, 2019). The faster charging is made possible by the charger's higher power of 240 volts, but also makes this charger more expensive than the AC level 1 charger. The last type of charging is DC (direct current) fast charging which comes at the most expensive but efficient option. It has the capability to charge a car to up to 80% in 30 minutes (Winn, 2019). A fully charged electric vehicle has a range of around 100 miles (Verma & Kumar, 2021). Whereas a gasoline powered vehicle has an average range of around 250 miles that can be refuelled in under a minute (Sallee, 2021).

However, there is significant research currently being conducted into wireless charging of electric vehicles (Munson & Nutt, 2021; Gruzen, 2021;Mitchell, 2021). This could introduce the potential to install continuous charging points within the road surface itself. As a driver, one could switch into a lane on a road that's embedded with special charging strips, enabling the car to keep driving while recharging (Munson & Nutt, 2021). This technology could even be installed at traffic lights and stop signs, completely eliminating any time that is spent waiting for an electric vehicle to charge.

In conclusion, currently electric vehicles require extra planning and consideration by the owner in terms of charging, making long haul trips stressful. Detours to electric charging stations, home instalment of chargers and time need to be considered when owning an electric vehicle. Once the switch is made to an electric vehicle, charging the car at home or work becomes quite convenient.

Therefore, electric vehicles score 7/15 for practicality. This score is limited by the two major drawbacks associated with electric vehicles, the driving range and charging time. The limited driving range will worry those among society with range anxiety and the long charging times will discourage many from purchasing an electric vehicle.

Conclusion and Discussion

In conclusion, hydrogen fuel cell cars score 70/100 and electric vehicles score 78/100. Overall, electric vehicles score 8 points higher than hydrogen fuel cell vehicles, so, based on the rationale scale presented in this paper, will be a more suitable replacement for internal combustion engines.

Due to the scoring system being based on rational rather than statistical data, this will limit the reliability and validity of the conclusion to a certain extent. There is no universal weighted scale when considering the suitability of fuel types that is widely accepted by the scientific community. However, statistical data has been used to outline and evaluate each factor that was considered, somewhat strengthening the reliability and validity of the conclusion.

In the opinion of the authors, the task of getting people to truly believe that having hydrogen gas within their car is safe and won't spontaneously combust is a huge task. The situation in a few years may be different, so it is worth reflecting on this point again in the future, but currently electric vehicles have been introduced and been seen on roads for a longer period of time and the investment has already been made. Therefore, based on recent history, it may become an easier option to follow through on electric cars as "the green car of the future" rather than because it is definitively the better alternative to internal combustion engines.

If hydrogen fuel cell cars and electric vehicles were introduced to society at the same time, hydrogen powered cars may have stood a better chance at being considered "the green car of the future".

It is advisable that the scientific community focus research on greener alternatives to isolating the hydrogen for fuel cell cars and establish ways of making the battery production process more sustainable. In addition, it is important that scientists do not abandon research on either of the two alternatives, based on the findings of this paper. They could both be part of the overall goal to reduce carbon emissions and decrease the number of internal combustion engines on roads.

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