Sustainable Engine Technologies: Hydrogen and Electric Cars Development and Future

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Introduction

Global warming has forced us to attempt to redesign our everyday sources of mobility. Majority of these climate warming pollutants come from the transportation industry, more specifically the auto industry. Many solutions have been proposed, but the two that are at the foremost are hydrogen and electric power, replacing our diesel and gasoline powered internal combustion engines that make up the brunt of the automotive workforce today. Hydrogen vehicles and their technology have many obstacles that need to overcome before it will be seen as a viable source, and in that time the shortcomings of electric cars will have improved due to advancements in technology. Sustainable vehicle technology has the potential to cut carbon emissions drastically, but this technology needs to be implemented quickly to avoid further depletion of the atmosphere. Hydrogen may have future applications, but that fate rests on whether hydrogen technology can keep up with the growing advancements of battery technology. At this point in time, there is no reason for battery technology to stop improving, as batteries are in virtually everything we own. The consistent marketing and development of new electric systems gives electric cars an edge.

Hydrogen Fuel

Hydrogen is the most common, lightest and smallest element on earth due to its unique chemical properties, having only one electron in its neutral state. Hydrogen can be synthesized in many ways, but the most environmentally friendly is electrolysis,(Jörg Adolf, 2017) which involves the separation of the hydrogen atoms from the oxygen atom. Much of the world's hydrogen is produced through the refining of hydrocarbons such as natural gas, petroleum products, or coal,(Dadashzadeh, M, 2016) but these processes are very inefficient and produce many harmful byproducts.

This table shows the primary sources of hydrogen, and what energy sector that the produced hydrogen is used in:

Hydrogen Production by Production Sector

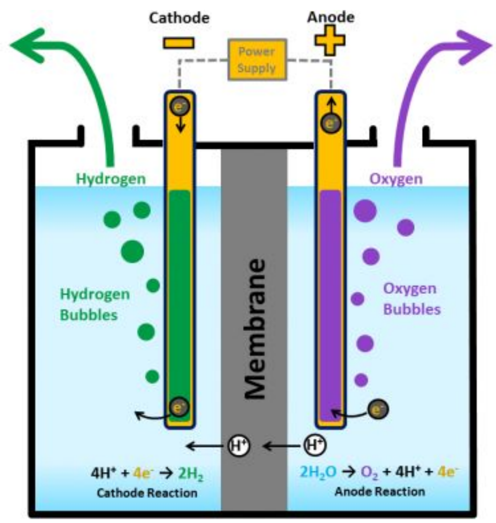
Production Source	*Percent (%)*
Natural Gas	48
Liquid Hydrocarbons	30
Coal	18
Electrolysis	4

Hydrogen Consumption by Consuming Sector

Consuming Sectors	*Percent (%)*
Ammonia	51
Refining	35
Methanol	8
Others	6

(Table 1) Dadashzadeh, M., Ahmad, A., & Khan, F. (2016)

As shown in the table, the majority of hydrogen is synthesized from natural gas and other fossil fuels. These methods are very wasteful and the by-products, mainly hydrocarbons, have more energy potential than the hydrogen extracted. By using these approaches to extract hydrogen for large scale production, is not reducing our reliance on fossil fuels, defeating the purpose of a green energy vehicle. Instead, of using fossil fuels, an environmentally friendly source is electrolysis, where hydrogen is separated from water. This is achieved by running an electric current through two plates, one positively charged and one negatively charged, sitting in an electrolytic solution separated by a membrane. This causes the water separate into hydrogen and oxygen given by the formula



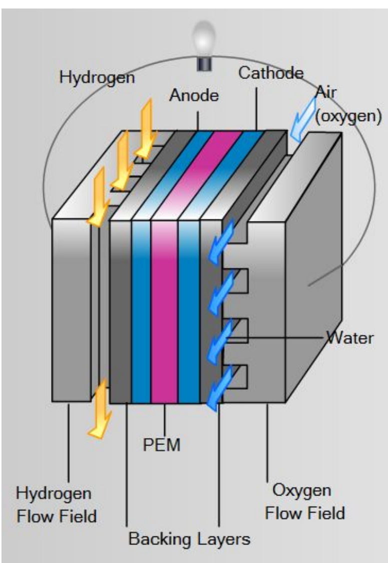
$$2H_20 + 2e^- \rightarrow H_2 + 2OH^-$$
$$2OH^- \rightarrow H_2O + \tfrac{1}{2}O_2 + 2e^-$$

(U.S Department of Energy, 2018)

The polymer membrane of a Polymer Electrode Membrane (PEM) Electrolyzer prevents gaseous H_2 and O_2 from passing through but allows OH^- ions to pass through. There are multiple different types of electrolyzers, all with different efficiencies, but this method is the most environmentally friendly and has an efficiency from 80% to 60%. Currently, this accounts for about 4% of global hydrogen production. As technology improves, so will electrolysis efficiency.

Fuel Cells

In addition to utilizing hydrogen and a battery, hydrogen vehicles need fuel cells to convert the potential energy stored in hydrogen to electrical energy. This is accomplished with a fuel cell. Fuel cells hold a major advantage over traditional combustion engines, as they can convert chemical energy to electrical energy without the large thermal losses of a combustion engine. (Jörg Adolf, 2017). A single mol of hydrogen contains 286 kilojoules of energy, and in theory, this energy in fuel cells can reach 80% efficiency, but realistically are around 50-60%, (Jörg Adolf, 2017), which is still a significant improvement over combustion engines, which fare normally under 30%. The fuel cell works in reverse of the electrolysis process, turning the hydrogen and oxygen back into water as an emission, or byproduct. This is given by the formula:



Cathode: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$
Anode: $2H_2 \rightarrow 4H^+ + 4e^-$
Net: $2H_2 + O_2 \rightarrow 2H_2O$
(Hydrogenics Fuel Cell, 2018)

Once again, there are many different types of fuel cells but since there is PEM electrolyzer in the previous example, there is a PEM fuel cell in this example. PEM stands for Proton Exchange Membrane. PEM only allows protons to pass through the membrane. This funnels the electrons through the electric circuit, powering the car.(IEA 2015) The fuel cell is not completely heat free, but it still produces thermal energy at a much lower rates than a combustion engine.

Electric Car Fuel

Electric cars are powered by a battery and an electric current, powering an electric motor that drives the car. Most electric cars have a range of about 80-500 kilometers, depending on the manufacture and size of the battery. Many early version were hybrids, which use a combination gasoline-electric motor to reduce emissions and increase fuel economy. The Chevrolet Bolt, for example, has 383 kilometers of range on one charge.(Chevrolet Motors,2018), where the Tesla Model 3 has 354 km on the smaller, short range battery, or 539 on the long range battery. Electric cars are powered by either lithium ion batteries or nickel metal hydride. Both metals have their advantages and disadvantages, but they both are very viable power sources. Using Tesla's batteries for example, the company guarantees that the batteries will retain 70% battery capacity after 193,000 kilometers on the 75 kWh battery and 160,000 kilometers on the short range, 62 kWh battery. A survey done by Tesla Motors found that these numbers were low, and that the batteries typically hold around 90% at 300,000 kilometers throughout the different battery sizes.

Problems With Hydrogen

Safety

Hydrogen safety concerns arise when it comes to the transportation industry. Highly publicized incidents such as the Hindenburg disaster have shown past issues with using a highly flammable gas in the transportation industry (Airships.net, 2017), and the automotive industry is not immune to accidents. Hydrogen has a very low ignition point, making it vulnerable to fire, and because the hydrogen is stored in a pressurized container it draws much concern about explosions in the event of an accident.

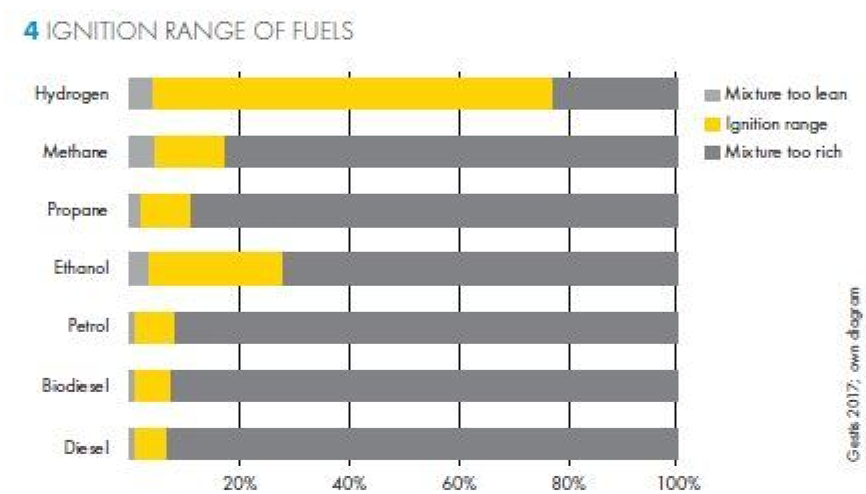


Figure 3

Figure 3 shows the ignition range of several different fuels when the have different densities. Hydrogen has the furthest range, shown in yellow at the top.

Current production vehicles such as the Toyota Mirai use valves that safely relieve pressure in the event of a collision or an over-pressured situation. Toyota went even as to shoot their hydrogen tank with a .50 caliber bullet. Fortunately, the tank didn't explode and the only reaction was a small, bullet-sized hole which allowed the gas to escape to atmospheric equilibrium. This means the gas wouldn't pool around the car as a liquid such as gasoline or diesel would, rendering a rupture to be safe with adequate ventilation. Hydrogen is an odorless and colorless gas, making leaks difficult to detect. A Computational Fluid Dynamics (CFD) model was constructed to get the most accurate picture of the situation, and found that the car needs proper ventilation to keep the gas from remaining trapped around the car. (Dadashzadeh, M, et al 2016). The lack of ways to vent dangerous build up of gas shows a need for sensors and for

Infrastructure

The main advantage electric cars have over hydrogen cars is that the electric power grid is used everyday for all sorts of charging purposes. Urban planning and effective strategies for power management should allow for proper use of electric grid capabilities. This is discussed more under *Interactions with the Electric Grid* section. Setting up a charger for personal use or in a commercial setting is as simple as installing some wiring and connecting the system to the local power grid.(Tesla Motors) These chargers can be small, and run off of 120 volt outlets with recharge times of around 11-16 hours for a completely electric car. (BC Hydro, 2018). If a faster charge is needed, then a home station can also have a 240 volt charger, give a recharge time of 6-8 hours for full electric vehicles. (BC Hydro, 2018). Hydrogen filling sites are much more complex than electric car charging.   Hydrogen infrastructure is very poorly developed in North America, and there are only a few centralized long term storage facilities. The United States only has 61 filling stations, 30 of which are in the state of California.(CaFCP, 2017). That leaves the option of storing it in one location and shipping it to another, but hydrogen presents some challenges. To transport both long and short distances, hydrogen needs to be either compressed into a tank, or cryogenically turned into a liquid to achieve necessary energy density.(Jörg Adolf, 2017) Due to the low starting density, this would require a compression to 790 ATMs, which requires approximately 13% of the energy supplied by the hydrogen. The other option is to make the hydrogen a liquid, which is accomplished by freezing it to -252.9 degrees Celsius. This again take more energy, approximately 40%.To further complicate the process, the location of productions station have a huge impact on cost due to transport.

Interactions with the Electric Grid

Electric cars need suitable locations to recharge, both at home and in places around common areas, without overloading the power grid at peak load times. There have been several solutions proposed, one of which is power sharing . Power sharing uses the capability of one system and utilizes it to charge multiple electric vehicles (Biondi, et al. 2016). Each cable can be adjusted to meet the current flow of the situation, such as lower flow for a peak load time or to favor a certain vehicle. This is also referred to a Multiple Outputs Multiple Cable (MOMC) system. (Biondi, et al. 2016). This model shows that most stations only require a small station, around 4 spots or less, but a large area would need a large station, which would be 15 spots or more. This would only be for locations with large turnaround areas. Power sharing would help improve the load distribution on both large and small scale power grids. The impact on electricity demand during peak times can be reduced further by urban planning, involving planning these types of station based on demand and location geography.

Electrical Efficiency

Hydrogen cars suffer from many efficiency losses before the fuel even reaches the fuel cell. Electrical efficiencies are restricted to the power grid, transmission losses and the car's internal systems. Currently, the United States power grid loses 6% of the original transmission from production to filling station, and globally the number is somewhere between 4-8%. (Rostamian, A. 2012). The power grid supplies alternating current (AC) to the car, but the batteries store the current in direct current (DC) form. The switch between AC and DC requires the use of an inverter, accounting for more energy losses depending on the efficiency of the inverter. This also changes on the type of electric motor used by the car brand, which varies by brand. Cars such as the Tesla Roadster and the Toyota Prius use induction, or AC drive motors or inverter motors, while the Chevrolet Bolt uses Permanent Magnet (PM) DC motor.(Tesla Motors), (Chevrolet Canada). AC drive motors use an inverter to create the electric field, instead of using bulky magnets. Permanent Magnet DC motors don't require an extra inverter from the batteries and have much better starting torque under load, a real problem for electric motors. (Bitar, 2012) They are also quite heavy and require the use of heavy magnets, which are quite expensive. Inverter motors have a lower cost and are now able to adjust their torque to fit the situation, giving them an advantage over DC motors. This includes accelerating and braking.

Figure 4

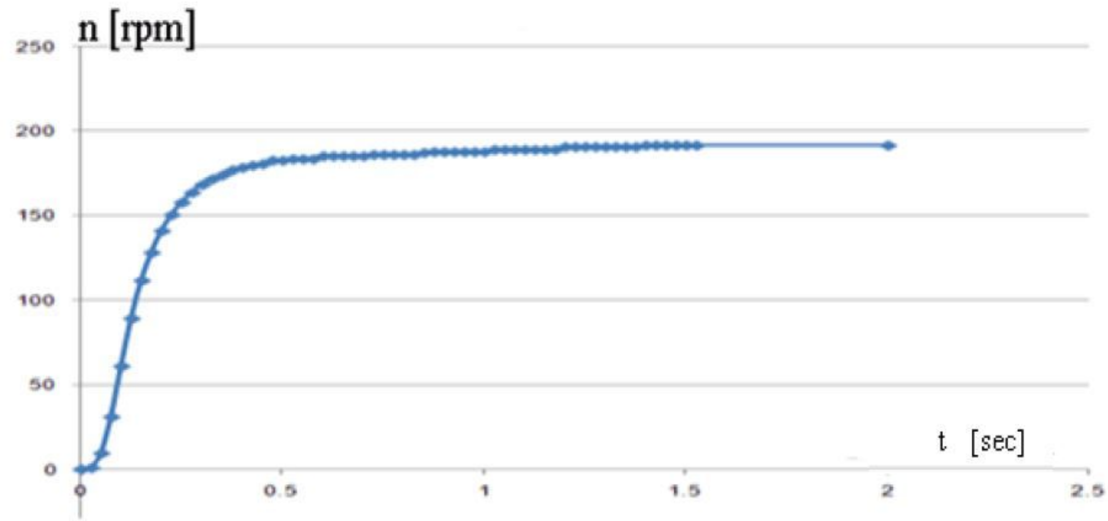


Figure 4 shows the rotation speed of an inverter motor when 34.4 Newton meters are applied.Y axis shows rotation speed in revolutions per minute, and the x axis shows time (Bitar, 2012). The steep acceleration curve shows that the rpms level out consistently, giving the motor a steady rotation speed.

Figure 5

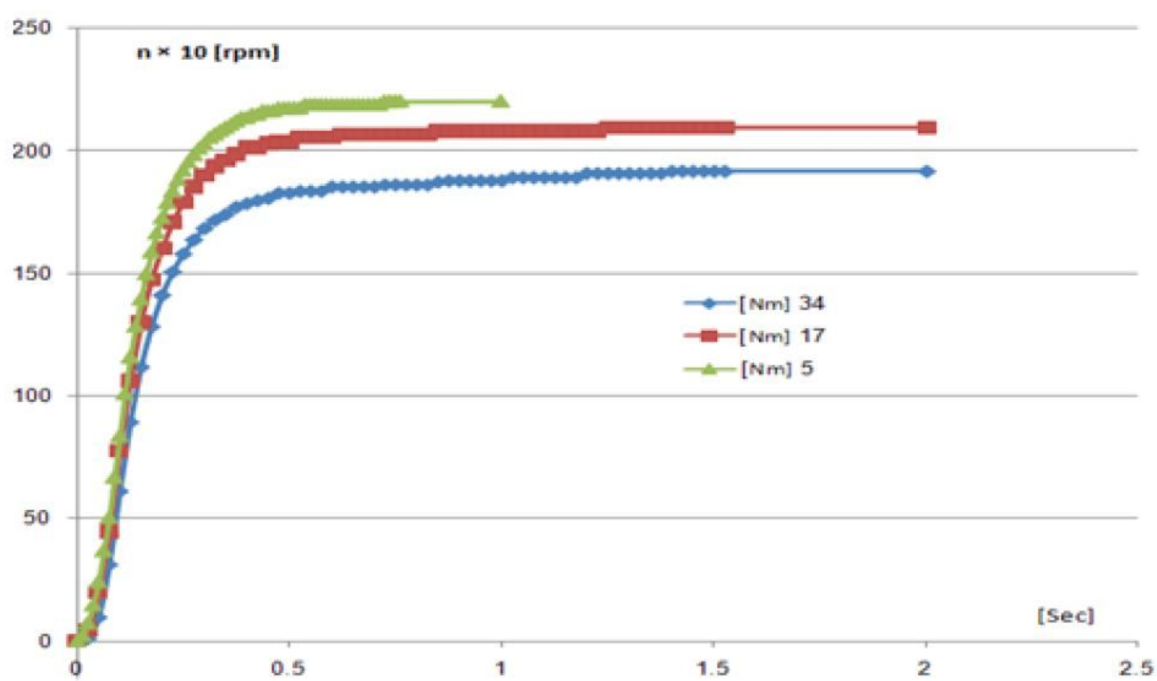


Figure 4 shows consistent results over different loads the ability to accelerate to a constant rpm. This makes the inverter motor a much more viable option in electric cars instead of heavy permanent magnet motors, allowing for a lightweight motor to be installed into electric cars.

Conclusion

Hydrogen and electric cars both have the potential of carbon neutral transportation, but electric cars are much further developed than hydrogen. Hydrogen technology is not ready to be used on a global scale to replace combustion engines, which will continue to be manufactured until sustainable engine technology becomes more readily available. Safety and infrastructure will continue to be major obstacles as well as accessibility and cost. The importance of getting these vehicles to the market and to the street can not be stressed enough, and hydrogen does not have that capability right now. Improvements in technology will help develop hydrogen more, but battery technology will likely continue to grow due to high demand in the sector itself.

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