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Comparing Efficiencies of Common Ways to Power a Car

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ABSTRACT

There are numerous ways of moving a car from point A to point B. The most common ways are, in no particular order; gasoline internal combustion engine (ICE), battery electric vehicle (BEV), hydrogen internal combustion engine (HICEV), fuel cell electric vehicles (FCEV) and diesel internal combustion engines. In gasoline cars, this is minimized as the fuel gets a chance to mix with air, resulting in less unburnt hydrocarbons. Gasoline cars are 25.5-21.25% efficient after factoring in the losses for deriving gasoline from oil. These values on efficiency gets noticeably better, 32% with a manual and 48% with a continuously variable transmission, when I start using hydrogen to power an internal combustion engine after factoring deriving hydrogen from electrolysis. There is another way of getting hydrogen, it is called methane reforming which is ~8% less efficient (72% compared to 80%). Another downside is that methane reforming results in carbon dioxide emissions. Surprisingly, these numbers do not change if I switch to a hydrogen fuel cell vehicle. These values skyrocket if I switch to a battery powered electric vehicle. 71% efficiency after considering charging efficiency, electricity transmission efficiency, electricity distribution efficiency and vehicle efficiency. This article will not include diesel as it creates more questions than answers due to the nature of the engine that they are in. Unburnt hydrocarbons are related to an increase in lung cancer.

Keywords: *Electricity, Hydrocarbons, Hydrogen, Losses*

1. Introduction

1.1. Why was this comparison necessary?

With a 45% increase in CO2 emissions from 2000 to 2019 (Tiseo & 5, Global historical CO2 emissions 1758-2020 2021), efficiency of cars which directly correlates with its emissions have started to become a major concern. Excluding diesel there are 4 common ways of powering a car so it moves from point A to point B. These are, in no particular order; gasoline internal combustion engine (ICE), battery electric vehicle (BEV), hydrogen internal combustion engine (HICEV) and fuel cell electric vehicles (FCEV)

1.2. Why am I not including diesel?

I am excluding diesel as it causes much bigger problems such as lung cancer due to unburnt hydrocarbons (Diesel Exhaust and Cancer 2020).These unburnt hydrocarbons could not combust due to the nature of diesel engines. This phenomenon is minimized in gasoline engines as the fuel

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gets the chance to mix in with the air. If there is excess fuel, it can be easily managed by the catalytic converter.

2. Details

2.1. Gasoline internal combustion engine

A typical gasoline engine is very inefficient, hovering around 25%-30% efficiency (Smartcitiesdive, Oil For Electricity is More Efficient than Oil for Gas 2017) in normal cars. Nowadays, internal combustion engines are using direct injection, where fuel is directly injected into the combustion chamber; port injection, where fuel is sprayed into the air before it gets into the cylinder or a combination of these two methods.

2.1.1. Injection methods and efficiency

Direct injection is more efficient than port injection (Staff et al., Direct Injection Engine vs. Port Fuel Injection 2019) as it gives the engineers the ability to change when the fuel gets into the combustion chamber and the freedom to alter the timings. Another advantage is that the fuel itself is much cooler this way which means lower cylinder temperatures which allows for engineers to change the ignition timings as well resulting in better fuel efficiency and lower emissions.

2.1.2. Getting gasoline and the process' effect on total efficiency

The efficiency of getting gasoline from crude oil is ~85% (Smartcitiesdive, Oil For Electricity is More Efficient than Oil for Gas 2017). This reduces the total efficiency of the gasoline engine to 21.5%-25.5% ((25*85)/10000, (30*85)/10000). As a result, I will be using 25.5% in the benchmarks.

2.2. Hydrogen internal combustion engine

The standard hydrogen ICE is 40% efficient if paired with a manual gearbox or 60% efficient once it is matched up with a CVT (continuously variable transmission) (Gillingham , Hydrogen Internal Combustion Engine Vehicles: A Prudent Intermediate Step or a Step in the Wrong Direction? 2007).

2.2.1. Why are they the least common?

Hydrogen ICE's are the least common of the bunch as they require tighter tolerances due to the fact that the hydrogen molecule is much smaller than a hydrocarbon chain. Not only this makes the production much more expensive, any mistake may result in blowby which would in turn decrease the pressure within the chamber resulting in loss of efficiency.

2.2.2. Getting hydrogen

There are 2 primary ways of getting hydrogen, methane reforming and electrolysis. There are upsides and downsides to both of these methods so neither is superior to the other. Methane reforming is easier to do at a large scale but is less efficient and it is not renewable. This method is ~74% efficient (Basile & Iulianelli, Methane Steam Reforming 2017). Another option, electrolysis, is 80% efficient (Goodall, Hydrogen made by the electrolysis of water is now cost-competitive and gives us another building block for the low-carbon economy 2017) however using sea water cannot be used for this process as it releases chlorine gas instead of hydrogen. With these considered, the total efficiency of hydrogen ICE's lowers to 32% and 48% respectively.

2.2.3. Storing hydrogen

Storing hydrogen is much harder than storing electricity in the form of chemical energy or having a tank of liquid gasoline. While hydrogen has lots of energy for a certain amount of mass, it takes up lots of space. In addition, a single hydrogen molecule is tiny compared to a molecule of gasoline thus it is really important to make sure that it is sealed properly. To make matters worse, hydrogen doesn't have a smell unlike gasoline. To combat its volumetric inefficiency, it gets compressed and there are numerous ways of compressing hydrogen.

2.2.4. Reciprocating compressors

This is what first comes to my mind when I hear compressors. It is a piston squeezing the fuel to make it smaller. Often used for applications that require high compression ratios. In addition, this is the most common type of compressors. Last but not least their efficiency is 92% (Gardiner, Energy requirements for hydrogen gas compression and liquefaction as related to vehicle storage needs 2009)

2.2.5. Rotary compressors

This type of compressors are akin to superchargers found on gasoline engines. However it is extremely hard for these kinds of compressors to be used for hydrogen due to tight tolerances that hydrogen requires (Office of Energy Efficiency & Renewable Energy, Gaseous Hydrogen Compression).

2.2.6. Ionic compressors

Ionic compressors are similar to the reciprocating compressors but they use liquids instead of a piston and they do not require bearings or seals to function. As a result they are extremely efficient to the point where the losses are negligible. Linde is claiming 100% efficiency (Linde, Hydrogen technologies. The ionic compressor 50. https://www.linde-engineering.com/en/images/DS_IC%2050_tcm19-523715.pdf). As a result, I will be using 100% as the efficiency of compressors for the rest of the paper.

2.2.7. Centrifugal compressors

Centrifugal compressors work by spinning a centrifuge up to high speeds and letting the centrifugal force squeeze the gas into a smaller volume. Because hydrogen is such a small molecule, it requires the centrifuge to go faster to achieve the same amount of compression, which results in this method not being particularly efficient.

2.3. Hydrogen fuel-cell

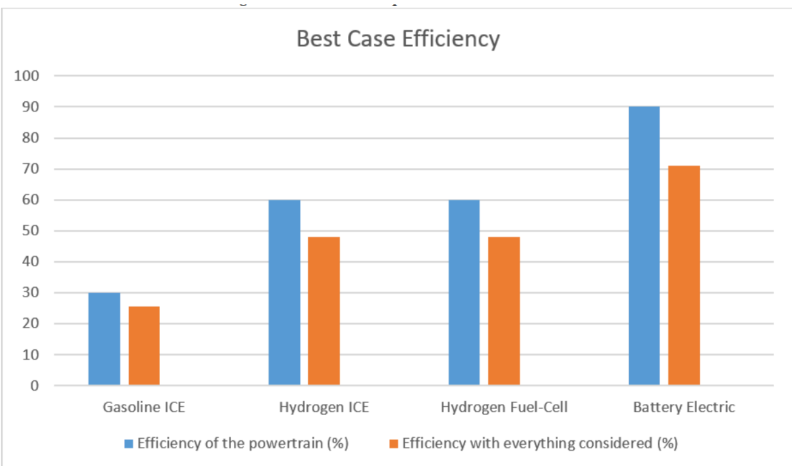
Fuel cell vehicles use a catalyst to take an electron from the fuel, in this case, hydrogen that is stored in the fuel tank, and use it to power electric motors. The hydrogen creates water vapour with the oxygen from the air. Unlike hydrogen ICE's fuel cell vehicles do not get hot enough to create nitrogen oxide. This powertrain's efficiency is around 60% (US Department of Efficiency, Fuel Cells 2015) which is the same as the best case scenario for the hydrogen ICE's. In 2.2.2 , I mentioned that the efficiency of electrolysis is 80% and the efficiency of the compressor is 100% in 2.2.6. We can use that figure to find the total efficiency of this powertrain. As a result, I will be using 48% ((80*60)/(100*100)) as the efficiency figure for benchmarking.

2.4 Battery electric vehicles

In battery electric vehicles, the energy is stored as chemical energy within the battery. Although the battery at hand is inefficient spatially and mass wise, it is ridiculously efficient at storing and releasing the energy. The efficiency of a battery electric vehicle with both the battery and the motor combined can reach over 90% (Energuide, How much power does an electric car use? 2015). Even after I consider the charging efficiency, distribution and transmission efficiency; which are 85.7% (Sears et al., A comparison of electric vehicle Level 1 and Level 2 charging efficiency 2015), 96% and 94-98% (Wirfs-Brock, Lost In Transmission: How Much Electricity Disappears Between A Power Plant And Your Plug? 2017) in that order and I will be using 96% for the transmission efficiency as it is the middle ground. In the end, the efficiency from the powerplant to the motors driving the wheel is a tiny bit over 71%. I reckon that number is way higher as I have used the smallest number for the car's efficiency and the middle ground for the transmission.

3. Discussion

Figure 1. A chart to help visualise the numbers



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In this article, I have specifically compared the efficiency of energy in versus energy out. However, with differing sizes different types of efficiency become important. On a smaller device, such as your phone, prioritizes energy efficiency while on a ship you would want to use the most spatially efficient fuel possible which happens to be fossil fuels. In addition, there are some cases where mass is the most important factor so you use hydrogen, for example, rockets. Cars, or autos as they are called now, happen to have all three of priorities or restrictions. They are in this "no man's land" where nothing is an obviously superior alternative. Just by looking at the chart you can say "Using a battery is the most efficient so it must be the best" but in batteries you are sacrificing mass just like how you will be sacrificing space if you decide to use hydrogen.

4. Conclusion

10-15 years ago, the future was thought to be powered by hydrogen and now its aiming directly at using batteries. Some people, younger me included, need to see the sheer difference in efficiency of gasoline versus battery electric vehicles while exploring other viable alternatives. With greenhouse gas emissions increasing, the efficiency of the vehicles that we use every day became a topic for some serious debate, rightfully so might I add. If batteries were not as efficient, they wouldn't have been considered as a solution to greenhouse gas problems as they produce much more CO2 than a typical ICE to get produced because of lithium and cobalt mining. The entire purpose of this was to get everything into a relatively short article that is easy to understand and easy to see which is more efficient. Every time I saw someone argue about this topic I would always ask myself "is it really that efficient after the losses from transmission and stuff along those lines" and never found a source compared any of these like I did.

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