# Hydrogen as A Fuel in Modern Automotive Industry

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***Abstract*—Hydrogen gas is the simplest molecule in the universe composed of two hydrogen atoms, the lightest element in the periodic table. In terrestrial conditions of temperature and pressure, it exists in gaseous state and to turn it into liquid, it must be cooled to -253 deg. Celsius, very close to absolute zero. But for its use as an energy source, its most interesting feature is its ability to combine with oxygen and release energy.**

**Although the market for hydrogen as a transportation fuel is in its infancy, various governments and industries are working toward clean, economical, and safe hydrogen production and distribution for widespread use in fuel cell electric vehicles (FCEVs). Light-duty FCEVs are now available in limited quantities to the consumer market in localized regions domestically and around the world.**

**This paper discusses the various beneficial properties of hydrogen, its use as a fuel in internal combustion engines, fuel cells, its performance and compares FCEVs with electrical vehicles and the challenges faced in making hydrogen-based vehicles available for the masses thereby giving the reader a thorough idea about the scope of hydrogen-based vehicles.**

***Keywords—Hydrogen, fuel cell, FCEV***

## I. INTRODUCTION

Hydrogen, a simple, colorless, odorless, but highly flammable gas consists of molecules made up of two atoms of the simplest element in the universe – Hydrogen – one proton, one electron. The earliest known chemical property of hydrogen is that it can burn with oxygen to form water, giving correct justification to its name, Hydrogen – derived from the Greek words 'Hydro' and 'Genes' meaning water and creator respectively. Thus, "maker of water".

Although, hydrogen is the most abundant element in the universe, the stuff that makes up stars, its availability here on Earth in its pure form is rather limited. It makes up only 0.14% of the Earth's crust by weight. However, in the vast quantities of water that exist on the planet, it is abundant. It also occurs in innumerable carbon compounds like all animaland vegetable oils and even in petroleum.

## II. HYDROGEN ECONOMY

The concept of 'Hydrogen Economy' dates back to the 1960s. It's the vision of developing a world that relies on hydrogen as a low-carbon, clean energy source, replacing thetraditional carbon-based fuels. Hydrogen is attractive because, whether it is burned to produce heat or reacted to with air to produce electricity in afuel cell, the only by-product is water.

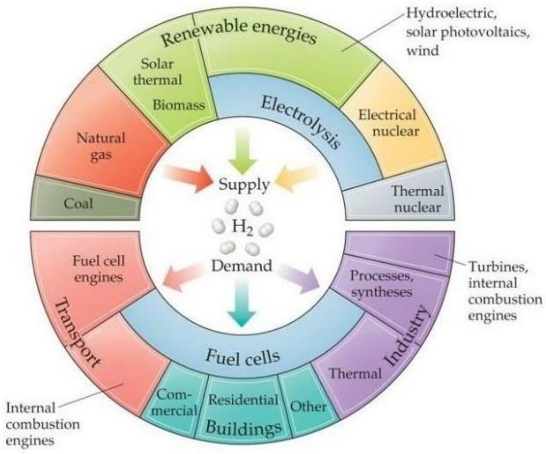


Figure 1: Hydrogen Economy

In the early stages, hydrogen was thought of as an intensive energy-carrier capable of transmitting energy more cost efficiently by pipeline than electricity by copper wires. Later, due to the serious air pollution and CO2 emission problems posed by fuel combustion, hydrogen was thought of as an ideal form of clean fuel from which the by-product is only water.

## III. HYDROGEN PRODUCTION

In order for hydrogen to efficiently help reduce CO2 emissions, it is necessary that no CO2 is generated during its production. The majority of hydrogen found on Earth is in the form of water or other carbon compounds. Hence, it has to be extracted to be used as an energy source. One of the main reasons that hydrogen is so expensive is the extraction process. Hydrogen can be produced from fossil fuels, biomass, and from water electrolysis with electricity. The environmental impact and energy efficiency of hydrogen depends on the method used for its production. Generating hydrogen from water electrolysis is very expensive, so the majority of hydrogen generated world-wide is produced via steam reforming. Steam reforming is currently the cheapest and most efficient way to produce hydrogen on a large scale. However, the hydrogen obtained from steam reforming is less energy dense than the natural gas it was extracted from and also produces CO2 as a by-product. Several studies are being conducted to decrease the costs associated with hydrogen production and making them more efficient for large scale production.

*A. Steam Reforming:*

This method is popular because of the ease with which it can produce hydrogen from natural gas i.e., methane (contains 4 hydrogen atoms for every carbon atom). Methane reactswith steam under a pressure of 3-25 bar in presence of a catalyst to produce hydrogen, carbon monoxide, and a small amount of carbon dioxide.

$CH_4 + H_2O$ (+ heat) → $CO + 3H_2$

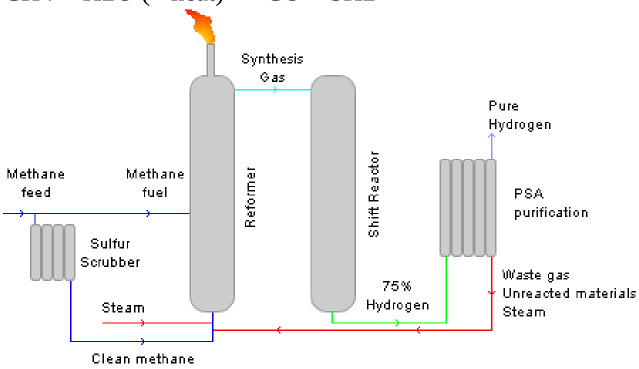


Figure 2: Steam Reforming

*B. Water electrolysis:*

The splitting of water into hydrogen and oxygen using electricity is known as electrolysis. Theoretically, this is the easiest method for producing hydrogen. However, it suffers from a major disadvantage of raw energy requirement which must be supplied as a high-quality energy, in this case, electricity.

Generating hydrogen via electricity doesn't necessarily mean no CO2 is produced. If the electricity supplied for hydrogen production is not of 100% renewable origin, then there is CO2 emission at some point in the process.

*B. Renewable liquid reforming:*

Fuels such as ethanol are reacted with high-temperature steam to produce hydrogen.

*C. Fermentation:*

Biomass can be converted into sugar-rich feedstocks that can be fermented to produce hydrogen.

A number of other hydrogen production methods that are in development,

*D. High temperature water splitting:*

In this process, high temperatures generated by solar concentrators or nuclear reactors drive chemical reactions that split water to produce hydrogen.

*E. Photobiological water splitting:*

This process makes use of microbes such as green algae that consume water in the presence of sunlight, producing hydrogen as a by-product.

## IV. HYDROGEN ENGINES

Although hydrogen engines, at first, may seem like a radical idea, but it's one that has been studied since the 1800s. The combustion characteristics of a hydrogen engine are quite different from those of conventional fuel internal combustion engines. This makes it necessary to make some changes in the engine design. In general, hydrogen engines tend to exhibit pre-ignition, knock and backfire, attributed to the low ignition energy and high flame speed of hydrogen compared to petrol.

The hydrogen engine is capable of operating over a wide range of air-fuel ratio: from ultra-lean, to stoichiometric conditions. An SI engine can use neat hydrogen as fuel and also adopt hydrogen supplementation along with gasoline. But diesel engines cannot be converted to complete hydrogen operation because of the high auto- ignition temperature of hydrogen, about 576 degrees Celsius. Instead, diesel engines can be run on a dual-fuel mode using both diesel and hydrogen.

A hydrogen-based engine also has a few other added advantages. Radiation hazards from hydrogen-air fire are relatively much less compared to traditional petroleum fire because of the low emissivity of the hydrogen flame. Additionally, radiation from hydrogen fire is at a wavelength that is readily absorbed by the atmosphere.

Another advantage is that hydrogen is very light. In the event of leakage, it rises rapidly through the air, limiting the risk of explosion to space immediately above the leakage. On the other hand, spilled gasoline spreads over the ground, thereby endangering a larger area around the spill. In the event of an accident involving a gasoline-operated vehicle, splashed gasoline would present a danger for hours, while hydrogen would disperse to incombustible proportions in moments.

## V. WHY HYDROGEN ENGINES ARE A BAD IDEA?

Hydrogen powered engines might seem like the ultimate solution to environment problems while still using the IC engine that many people have come to love, after all, the only emission hydrogen would produce on combustion would be water. But this is not the case in real life, how hydrogen powers the vehicle makes all the difference.

The biggest reason hydrogen combustion engines are not good is that on combustion, they attain temperatures that are high enough to produce NOx. The second reason is that hydrogen engines are not as efficient as hydrogen fuel cells. By the time hydrogen makes its way to the wheels, almost 75% of its potential energy is lost while current technology fuel cells are capable of transmitting up to 50% energy to the wheels. This is a lot higher than both hydrogen and gasoline-based engines. Also, hydrogen takes up a lot of space, hydrogen fuel cell vehicles can have smaller fuel tanks compared to their hydrogen combustion engine counterparts.

## VI. FUEL CELLS

Fuel cells are key to the development of a hydrogen economy, particularly for electric vehicle propulsion, and are therefore being investigated and studied in various countries around the world. The fuel cell is an electrochemical device used to convert chemical energy into direct current electricity. The fuel gas is oxidized at the negative electrode with a release of electrons that pass through the external circuit and reduce oxygen at the positive electrode. The general construction of a fuel cell consists of two plates between which a membrane layer and catalyst are compressed. The plates have channels etchedin their material which let the reactants uniformly make contact with the catalyst.

Similar to batteries, many individual fuel cells are connected in series/parallel to form a fuel cell stack to achieve the desired voltage, current and power ratings for a particular application.

The fuel cell vehicle operating on hydrogen is seen by many as the ultimate solution to the increasing energy security and environmental problems that are confronting the road transport sector. These vehicles are effectively hybrids in which the internal combustion engine is replaced by a fuel cell to provide the continuous source of energy. This must be coupled with a secondary battery if regenerative braking is to be used. The hydrogen fuel could, in theory, be derived from a hydrocarbon storage tank and processed in a 'reformer' aboard the vehicle. However, it is more practical to supply hydrogen from an outside source to a pressurized storage tank mounted on the vehicle. Such vehicles can be refueled with compressed gas at a rate of 2 kg of hydrogen per minute, but the provision of an infrastructure necessary to supply hydrogen conveniently, i.e., from stations as widely distributed as petrol stations today, remains a significant issue.

## VII. PEMFC

The PEMFC, also known as the 'polymer-electrolyte-membrane fuel cell' and also as 'solid-polymer-electrolyte fuel cell', SPEFC, is an acid-electrolyte fuel cell, widely considered to be the best fuel cell for automotive applications due to its high power-density, high energy conversion efficiency, compactness, lightweight, and low operating temperature. It consists of a cathode, an anode, and an electrolyte membrane. Hydrogen is oxidized at anode while oxygen is reduced at cathode. Protons are transferred from the anode to the cathode through the electrolyte membrane.

PEMFCs are built out of Membrane Electrode Assemblies (MEA) which include the electrodes, electrolyte, catalyst, and gas diffusion layers. An ink of catalyst, carbon, and electrode are sprayed onto the solid electrolyte. They contain a special proton-conducting polymer electrolyte membrane. The membrane only conducts hydrogen ions (protons) but not electrons as this would short circuit the fuel cell. The membrane must also not allow either gas to pass tothe other side of the cell. Efforts have been focused on the development of thinner membranes that would offer the added performance benefits of lower electrical resistance, and hence higher power-density.

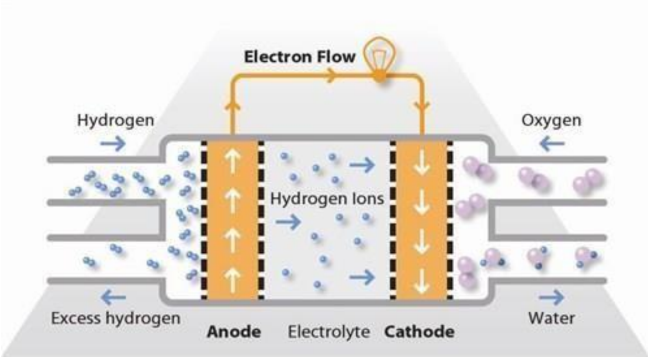


Figure 3: PEMFC

For PEMFCs to achieve widespread commercial success, membranes should also have greater durability, better water management and the ability to function at higher temperatures – all at reduced cost. Operation at higher temperatures would yield significant energy benefits. For example, heat rejection would be easier and would warrant the use of smaller heat exchangers in fuel cell systems.

## VIII. FUEL CELL EFFICIENCY

The efficiency of the fuel cell, i.e., the fraction of the energy in the fuel that is converted into useful output, is a critical issue. Much is made of the fact that fuel cells are not heat engines, so their efficiency is not limited by the Carnot cycle and therefore should be high. This reasoning has driven much of the interest and investment in the technology. The thermodynamic 'theoretical' efficiency, defined as the ratio of electrical energy output to the enthalpy of the fuel combustion reaction, can be above 80% for low temperature fuel cells. Nevertheless, electrochemical kinetic theory says that this ratio is an upper limit that is only reached at equilibrium when the current is zero. In practice, the efficiency is lower, particularly at high power outputs. However, this performance is still better in comparison to that of the internal combustion engine but is nowhere near the theoretical 80%.

## IX. CHALLENGES IN MAKING FCEVS AVAILABLE TO THE MASSES

Several car manufacturers made FCEV prototypes as long as the late 1990s and it was predicted that FCEVs would be seen in common use 10-15 years later. But here we are, 21 years later and we still don't have widespread use of FCEVs. However, in the meantime, BEV or Battery Electric Vehicles have become the main alternative for zero-emission road transports. Only a decade ago, people didn't really believe in the capability of the BEV for anything other than short distance, inter-city travel. But now, BEVs are becoming more and more common. For the BEV, the power comes from a storage battery while the FCEVs generate the needed power in fuel cells. BEVs are good enough for anything under 300 miles while FCEVs are better for more than 300 miles travelling range. The basic principles of FCEVs have been practical for a long time and development has been mostly about reducing the cost, both of the stack and the storage tanks. The main issue is that the cost per vehicle can drop only when production numbers rise. Unfortunately, there is no demand for FCEVs currently. This is because nowhere in the world can you find a sufficient hydrogen fueling infrastructure. However, this problem does not occur in the case of heavy-duty vehicles such as trucks and busses. For these, the potential advantages of FCEV over BEV are clear. The stack and tanks together weigh much less than a battery, so they payload is correspondingly greater. For commercial vehicle drivers, it is difficult to justify buying an FCEV until more hydrogen stations are established. Fuel companies will not build those stations until they can be sure of business. This is a major deadlock but South Korea has found a way around it by joining a partnership with the state. The government has announced plans for a network of 310 stations by 310 hydrogen stations by 2022.

## X. FUTURE SCOPE & CONCLUSION

It is evident from the current emerging trends that diesel and gasoline powered transportation will be history in the near future. However, instead of waiting till we finally run out of oil, the time to make the transition from an oil-based economy is now. Electric vehicles and FCEVs are brilliant solutions that are helping to slowly undo the damage and in making the transition to cleaner transportation. Electric vehicles are gaining popularity rapidly because of the biggest name in the industry, Tesla Motors' Elon Musk. With the current investment and development in battery technology, the rapidly expanding electric charging infrastructure, as well as the high hydrogen costs it is difficult to justify how successful hydrogen powered vehicles will be. But the limited supply of lithium ores and large battery degradation, and how much quicker it is to refuel hydrogen compared to charging batteries, it is possible that FCEVs might become the dominant transportation vehicles on the planet if the production of hydrogen becomes a 100% clean and affordable. Investing in the hydrogen economy would also open many new industries, thereby developing and implementing renewable energy technologies and manufacturing capabilities, that would build a sustainable energy economy that will carry us into the coming millennia.

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