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Hydrogen Fuel Cell AutoMobile: A Comprehensive Overview

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Abstract - *It is currently being thought about finding alternatives for obtaining energy by using technologies that give maximum efficiency and little pollution by harnessing the potential of renewable energy around the globe. New energy generation methods are required in this situation to both produce minimal carbon emissions and to fully utilize renewable energy sources. One of the other possibilities for upcoming sustainable energy systems is hydrogen fuel cell technology. This essay offers a thorough analysis of automobiles fueled by hydrogen fuel cells. It briefly explains the fuel cell theory, how current is generated in a fuel cell, the components of a fuel cell electric car, and overview of Hydrogen. The future scope of FCV are also covered, as well as the main advantages of FCV's are also discussed, along with the principal challenges to ACV adoption and Further challenges are also covered. The relationship between the fundamentals and applications of fuel cells has been examined using data from both industry and academics.*

Key Words: **Hydrogen fuel cells, Emission, Eco-friendly, Fuel cell, hydrogen refueling, Electrolyzer, Proton exchange membrane fuel cell (PEMFC), Fuel cell Electric vehicle(FCEV)**

1. INTRODUCTION

A hydrogen-containing fuel (water) reacts electrochemically with oxygen or another oxidizing agent to produce electricity in a fuel cell, which is an electrochemical device. Battery storage is used for produced energy. after which it is put to use outside of the company. They differ from batteries in that they need an ongoing supply of fuel and oxygen, typically from the air, to maintain the chemical reaction, whereas in a battery, the chemical energy comes from chemicals already existing in the cell. As long as fuel and oxygen are available, FCs can continually and uninterruptedly produce energy. In remote or difficult-to-access locations, they provide backup power for industrial, commercial, and residential buildings.

2. Working of a hydrogen fuel cell vehicles

Fuel cell electric vehicles (FCEVs) use energy to power an electric motor, much like fully electric cars do. Unlike other electric cars, FCEVs create their own electricity through the use of a fuel cell fuelled by hydrogen rather than relying only on a battery. The size of the electric motor(s) that get electric power from the suitably sized fuel cell and battery combination establishes the power of the vehicle during the vehicle design phase. Although automakers could design an FCEV with plug-in functionality to charge the battery, the majority of FCEVs today use the battery for energy recovery from braking, extra power during brief acceleration events, and to smooth out the power delivered from the fuel cell with the option to idle or turn off the fuel cell during low power needs. The size of the hydrogen fuel tank affects how much energy can be stored on board. An all-electric car, on the other hand, has a strong relationship between the amount of power and energy available and the size of the battery.[1]

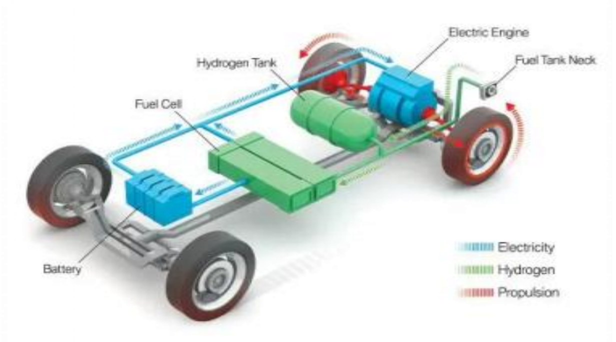


Fig - 1: Hydrogen fuel cell vehicle

3. Hydrogen Fuel cell

The chemical energy that hydrogen fuel stores is converted into electricity by a hydrogen fuel cell. A fuel cell with a supply of hydrogen and oxygen may be used to power electrically powered equipment, much like a battery. Fuel cells and batteries both transform chemical energy into electrical energy, but batteries store this chemical energy within the battery itself. This implies that a battery will become exhausted or need to be recharged when there is insufficient chemical energy in storage to provide enough electricity to operate the connected device. A hydrogen fuel cell gets its source of chemical energy from the outside rather than storing it within. The hydrogen that is given to the fuel cell's anode stores this chemical energy. In essence, hydrogen and oxygen are used by a hydrogen fuel cell. A fuel cell may produce electricity if it receives constant supplies of hydrogen and oxygen and is not exposed to water throughout the production process. Batteries and hydrogen fuel cells are both types of electrochemical cells. They each contain two electrodes in contact with an electrolyte, which is a substance that can conduct ions. The anode is one electrode, while the cathode is the other. In contrast to batteries, which release electrons from the substance inside the anode, hydrogen fuel cells release electrons from the hydrogen that is delivered to the anode. Battery electrodes actively contribute to the conversion of chemical energy into electrical energy, which over time may have a negative impact on the electrodes and, consequently, the battery's efficiency. Pure water and heat are the sole byproducts of the fuel cell when pure hydrogen is employed as the fuel. Since they have no effect on the environment, fuel cells have the potential to be incredibly efficient devices. Both of these by-products are frequently useful in some way. The heat, for instance, may be applied wherever heat is required. Since the Gemini programme in the 1960s, fuel cells have been utilized in NASA spacecraft, and they are still used today to power and hydrate personnel on Space Shuttle missions. Since hydrogen is not naturally present in the environment, hydrogen fuel must be produced from substances like methanol, gasoline, natural gas, and water that contain hydrogen. Today, natural gas is used to manufacture the majority of the hydrogen. The only result of producing hydrogen from water is clear water. There will be more byproducts, such carbon dioxide, if fossil fuels are the hydrogen's primary source. Electricity is used to divide the water molecule in order to make hydrogen from water. The generated hydrogen is a renewable, zero-emission fuel if the electricity originates from a renewable energy source, such wind or solar power. Although it may be given in pure form, oxygen is generally taken through the air.[3]

4. Working of hydrogen fuel cell

The anode of the fuel cell receives hydrogen gas. The anode is plated with platinum, which functions as a catalyst to break down hydrogen into protons and electrons. If a circuit is linked between the anode and cathode, electrons can move across the circuit and deliver power to any load that is connected as part of the circuit.

The anode’s response:

$2H_2 \rightarrow 4H^+ + 4e^-$

The electric current generated by the fuel cell is the flow of electrons through the load. The hydrogen ions (protons) generated from the hydrogen at the anode go from there to the cathode through the electrolyte of the fuel cell. These hydrogen ions and electrons from the external circuit combine with the oxygen delivered to the cathode to create water and heat, both of which are expelled from the fuel cell.

The cathode's response:

$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

Bipolar plates are positioned on the opposite side of the cell in a PEM fuel cell. They act as current collectors and aid in gas distribution. Between the anode and cathode, which are all sandwiched between the bipolar plates, is a membrane that houses the electrolyte. Proton exchange membranes, or PEMs, are membranes that only let protons flow through them. The membrane has to be wet in order to function correctly.

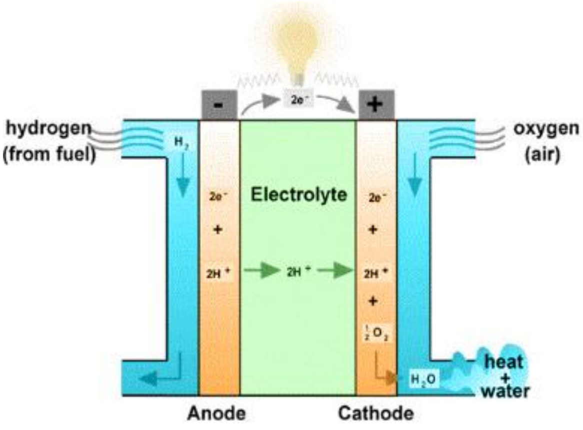


Fig-2: Parts and working of FC

The normal output of a hydrogen fuel cell is 0.5 to 0.8 volts per cell. Individual cells may be linked in series to raise the voltage. The structure in question is known as a fuel cell stack. The capacity of a fuel cell to generate current depends on its cross sectional area. More response sites may be created since a larger region has more of them. Power equals current times voltage. Therefore, it is feasible to create very huge amounts of electrical power—enough to power an entire neighborhood of homes, a hospital, or a vehicle like a car, bus, or even a submarine or spacecraft—by stacking cells in series to increase voltage and increasing cell area to enhance current.[3]

5.Key Components of a Hydrogen Fuel Cell Electric Car

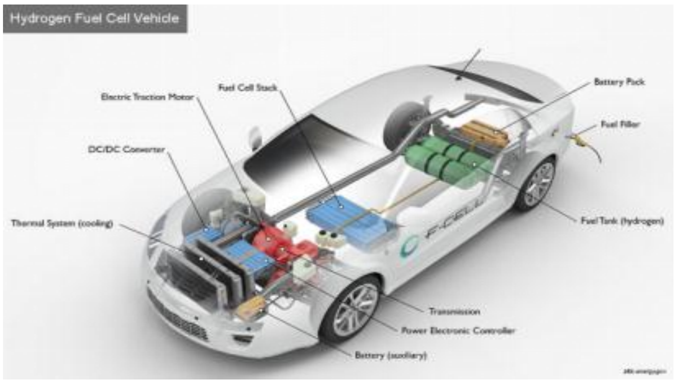


Fig-3: Key components of HFCV

Battery pack: In addition to supplying additional power to the electric traction motor, this high-voltage battery stores energy produced during regenerative braking.

DC/DC converter: The traction battery pack's higher-voltage DC power is converted by this device into the lower-voltage DC power required to operate the vehicle's accessories and replenish the auxiliary battery.

Electric traction motor (FCEV): This motor moves the wheels of the vehicle by drawing energy from the traction battery pack and fuel cell. Some automobiles employ motor generators that serve as both drives and regenerators.

Fuel cell stack: An arrangement of individual membrane electrodes that generate electricity from hydrogen and oxygen.

Fuel filler: To fill the tank, a gasoline dispenser's nozzle is connected to the vehicle's receptacle.

Power electronics controller (FCEV): This device controls the electric traction motor's speed and torque by managing the flow of electrical energy produced by the fuel cell and the traction battery.

Thermal system (cooling) - (FCEV): The fuel cell, electric motor, power electronics, and other parts of the system are all kept within a safe operating temperature range by this system.

Transmission (electric): To move the wheels, the transmission converts electrical traction motor output into mechanical power.[1]

5.1 Electric motor and battery

In hydrogen fuel cell automobiles, where the power is produced by the chemical reaction of hydrogen and oxygen, electric motors are introduced. The car moves along with minimum noise and vibration thanks to the electric motor. It can also gain energy by slowing down. The fuel cell and battery output and input are controlled by the power control unit depending on the driving situation.

The fuel cell's output of power Depending on the demands of the particular driving situation, a hydrogen engine can travel in one of two directions. It either goes to the electric motor and immediately drives the FCEV or it charges a battery that saves the energy until the engine needs it. Because the fuel cell frequently recharges this battery, which is referred to as a peak power battery, it is substantially smaller and lighter than the battery of a completely electric vehicle.[5]

5.2Hydrogen fuel tank

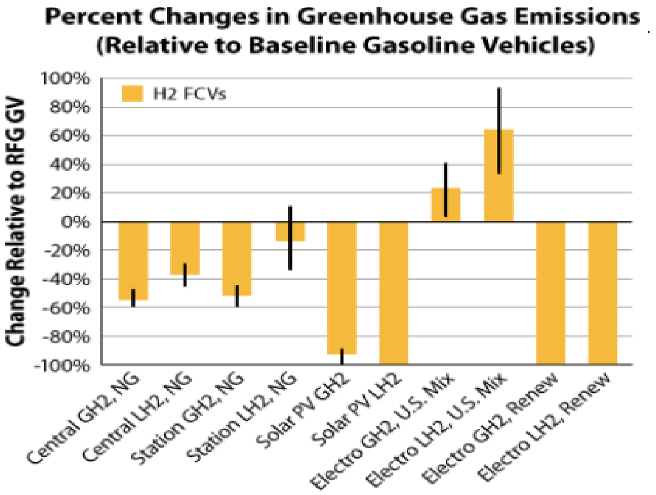
The hydrogen storage tank is the component of the HFCV that is the most dependable, secure, manageable, and economical. In comparison to other fuels, hydrogen has a low energy density that is sustainably lower. Its energy per volume is significantly lower than that of liquid fuels like gasoline. In the past, an HFCV could travel 300 miles on about 5 kg of hydrogen, but today, this requires a fuel tank that is 3–4 times larger than that of gasoline. The main challenge is figuring out how to store the hydrogen.To develop and validate the onboard automotive hydrogen system, which must meet consumer demands and expectations for range, passenger and cargo space, refueling time, and overall vehicle performance, several types of research and development are being conducted using fuel cell technology. Toyota has developed a tweak that allows for 1.7 times as much hydrogen to be stored in 350 bar tank

Fig-4: Hydrogen Tank

As opposed to 700 bar tanks, giving vehicles a driving range of more than 310 miles.[5]

6. FCV Emissions

The only pollutants produced by fuel cell electric cars are water vapor and warm air, with no tailpipe emissions. Hydrogen, like electricity, is an energy carrier that may be created from a variety of feedstocks. When calculating hydrogen emissions, these feedstocks and manufacturing processes must be taken into account.[1]

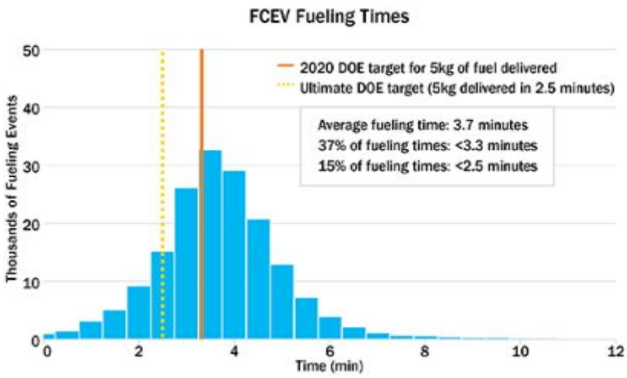


Graph-1: Gas Emission graph

7. Overview of Hydrogen

Hydrogen, when used in a fuel cell to generate electricity, is a zero-emission alternative fuel derived from a variety of energy sources. Drivers of light-duty fuel cell electric cars (FCEVs) can already fill up in less than 5 minutes and have a driving range of more than 300 miles. There are currently research and commercial activities underway to extend the limited hydrogen fuelling infrastructure and increase FCEV manufacturing.

The Energy Policy Act of 1992 defines hydrogen as an alternative fuel. The ability of hydrogen to power fuel cells in zero-emission cars, the possibility for domestic production, and the fuel cell's rapid filling time and high efficiency all contribute to the interest in hydrogen as an alternative transportation fuel. In fact, a fuel cell paired with an electric motor is two to three times more efficient than a gasoline-powered internal combustion engine. Hydrogen may also be used to power internal combustion engines. These, however, create exhaust emissions and are less efficient than FCEVs. Find out more about fuel cells. The energy content of 2.2 pounds (1 kilogramme) of hydrogen gas is about equivalent to the energy content of 1 gallon (6.2 pounds, 2.8 kilogrammes) of gasoline. Because hydrogen has a low volumetric energy density, it is stored as a compressed gas onboard a vehicle to provide the driving range of conventional automobiles. The majority of modern applications make use of high-pressure tanks capable of holding hydrogen at 5,000 or 10,000 pounds per square inch (psi). For example, the FCEVs now in production and available at dealerships have 10,000 psi tanks. Retail dispensers, which are often found near petrol stations, can fill these tanks in around 5 minutes. Currently, fuel cell electric buses have 5,000 psi tanks that take 10-15 minutes to fill.[1]



Graph-2: Fueling time graph

8. Types of hydrogen

The three most common types of hydrogen are gray, blue, and green hydrogen.

Gray: Grey hydrogen generation is now the most popular and least expensive method. Although it doesn't produce greenhouse gas emissions on its own, the process of making it does. It is used as a fuel. Steam reforming, which separates the hydrogen from the natural gas, is used to produce gray hydrogen from natural gas. The carbon emissions produced during the process are not, however, captured by the technologies utilized and are instead discharged into the atmosphere.

Blue: The steam reforming method is used to extract blue hydrogen, but it varies from gray hydrogen in that the emitted carbon emissions are caught and stored, reducing but not completely eliminating the emissions in the atmosphere. Due to the fact that the production technique just stores greenhouse gasses rather than preventing their generation, blue hydrogen is frequently referred to as "low-carbon hydrogen."

Green: Green hydrogen is a real source of clean energy since it is produced from renewable resources, which results in zero emissions throughout its entire life cycle. It is produced by electrolyzing water with clean electricity produced from extra sustainable wind and solar energy. The procedure results in a reaction that separates water into its hydrogen and oxygen components (the H and O in H2O). As a consequence, there are no carbon emissions produced during the process. Although it's a fantastic replacement for gray and blue, the key obstacle right now is lowering the price of green hydrogen generation in order to make it a really affordable renewable energy source.

Black and Brown: Using any kind of coal in the extraction process results in the production of black and brown hydrogen. The electrolysis of green hydrogen is one end of a spectrum, while this process, called gasification, is the other. It is a well-known method that is employed in several sectors to transform materials rich in carbon into hydrogen and carbon dioxide. The emissions are subsequently discharged into the atmosphere, where they cause pollution and turn into the most environmentally hazardous form of hydrogen.

Pink: Nuclear energy is used for the electrolysis process that extracts pink hydrogen. Pink hydrogen is sometimes referred to as purple hydrogen or red hydrogen.

Turquoise: Turquoise hydrogen is still being researched to see if it can be effectively employed on a broad basis. It is produced by a procedure known as "methane pyrolysis," which uses heat to decompose a substance's chemical structure to yield hydrogen and solid carbon. Instead of being released into the atmosphere, carbon is kept in the solid carbon that is produced. If turquoise is shown to be successful and the carbon can be permanently stored in an environmentally safe manner, it may join blue as a "low-carbon hydrogen."

Yellow: Yellow hydrogen is produced by electrolysis particularly using solar energy, much to the method used to produce green hydrogen but with a cheerier moniker.

White: Underground geological hydrogen deposits contain naturally occurring white hydrogen. By drilling into the ground and injecting a highly pressurized solution of water, sand, and chemicals at the rock to liberate the gas inside, the procedure is known as fracking. There are no plans to utilize this kind of hydrogen as a source of energy at the time.[2]

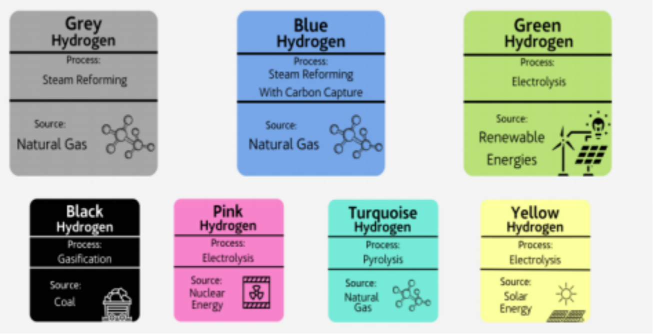
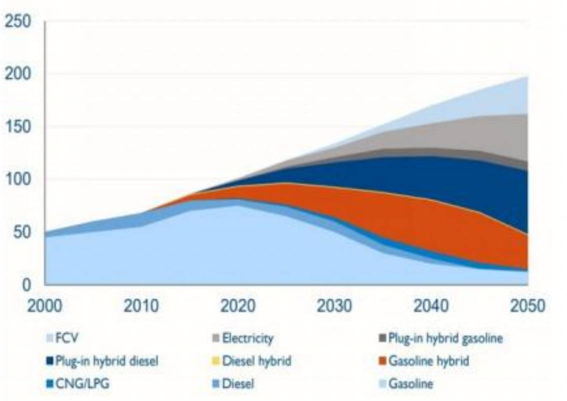


Fig-5: Types of hydrogen [2]

9. Future scope of FCV

Despite a positive outlook for climate legislation, considerable FCV sales volumes are only anticipated over the long run. Following the approval of the Paris Agreement, hopes for the future FCV market are increasing due to a recognised lack of CO2 emissions during vehicle operation.



Graph-3: FCV sales predictions

Source: International Energy Agency 2012 (IEA) According to a comparable scenario, the international energy agency (IEA) forecasts a 35 million unit annual sales FCV market share of roughly 17% by 2050.[4]

10. Principal challenges to FCV adoption

Three primary issues, including the cost of cars, distribution infrastructure, and hydrogen generation, are impeding the potential adoption of FCVs.

Cost of vehicles: The usage of costly catalysts and other materials in the fuel cell "stack" is the major cause of the high cost of FCVs (e.g. platinum).

Distribution infrastructure: Important and costly investment choices are necessary for the growth of infrastructure, and they must be backed by ongoing FCV market demand.

Hydrogen production: Similar to how electricity is produced, hydrogen may be produced using a variety of basic energy sources, each of which has a varied effect on the GHG footprint.

The hydrogen can be classified as "green" or "gray" depending on the main energy source from which the energy is generated. Producing hydrogen from renewable primary energy sources (often referred to as "green") as opposed to "gray" resources is more advantageous in terms of GHG impact.[4]

11. Main advantages of FCVs

FCVs promise advantages across a range of parameters in addition to the absence of CO2 emissions during vehicle operation:

Refueling time: To fill the tank, it will take a few minutes (as for ICE engines), as opposed to the lengthier time anticipated for battery-electric cars to recharge (BEVs).

Driving range: With a driving range of more than 450 km, FCVs are already competitive on the market and, on average, have longer ranges than BEVs.

Fuel efficiency: FCVs utilize roughly 40 to 60 percent of the energy included in hydrogen, compared to about 20 percent in ICE cars, making them more energy efficient than gasoline-powered vehicles. It's vital to note that EVs use around 75% of the energy from the batteries, which makes them more efficient than FCVs.

Scalability: It is simple to increase the power of FCVs: to create a fuel cell stack, which can generate enough electricity to power a vehicle, separate fuel cells are connected in series. This feature of the technology makes it possible to employ it in heavy-duty vehicles as well.

Weight and volume of energy storage: A lithium-ion battery system requires around six times more weight and twice the space to permit comparable driving ranges (for example, 500 km), whereas H2 requires less weight and volume for energy storage to provide the same distance range.

Sustainability: In addition to producing no greenhouse gasses while the vehicle is in motion, FCV drive batteries are smaller than those of BEVs, resulting in a reduced environmental effect from the use of heavy metals in the production of Li-ion battery packs. However, pollution from power plants should be contrasted with pollution from the H2 generation process (which depends on the primary energy source used to create it) when comparing FCVs with BEVs.[4]

12. Further challenges

Durability and reliability: It will be necessary for FCV lives to be equivalent to those of traditional passenger cars (e.g. approximately 14 years)

Safety and public acceptance: The pressurized storage of hydrogen on-board vehicles is one area of concern. H2 is invisible to the human eye, nose, and tongue since it has no taste, smell, or color.

Onboard hydrogen storage: In order to store enough H2 to create a long-range vehicle, a very big tank or extremely highly pressured tanks are required.[4]

13. CONCLUSIONS

Since the only byproducts of hydrogen fuel gas powered cars are water and heat, they are an excellent solution for reducing pollution and greenhouse gas emissions. Because hydrogen has a higher energy storage capacity, it takes less time to recharge the car and has a longer driving range. The only challenge is obtaining hydrogen. The conventional technologies for obtaining hydrogen have the drawbacks of significant energy loss, limited efficiency, and environmental degradation. However, other techniques of creating hydrogen are being developed, such as the proton exchange membrane, which experts believe has an 86% efficiency. Using the extra energy source for hydrogen production and developing a hybrid version of hydrogen-lithium-ion automobiles may potentially be something

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