



Adoption of Hydrogen Fuel Cell Vehicles and Its Prospects for the Future (A Review)

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ABSTRACT

The consumption of massive quantities of these fossil resources leads to extreme warming, air pollution, and the depletion of the ozone layer. Hydrogen can be the most promising source of renewable energy. Hydrogen fuel cells can produce electricity by allowing chemical gases and oxidants as reactants. The entire technology is environmentally friendly and produces water as a byproduct. The benefits of hydrogen and fuel cells are numerous but will not be fully apparent until they are in widespread use. Hence the usage of hydrogen as fuel in the fleet of cars will boost energy efficiency and reduce greenhouse pollution. For using hydrogen fuel cells in the road transport sector, the viability of the hydrogen energy network needs to be evaluated appropriately, and its tools, manufacturing processes, storage, fuel transport, dispensing, and consumption should be analyzed. This research discusses the key issues of elevated rates of environmental pollution in numerous urban areas and transport fuels efficiency and explores their protection measures utilizing hydrogen energy technology. In this study, the fundamentals, recent development, and prospects have been reviewed to analyze the practicability of consuming hydrogen as the primary fuel in vehicles and Proton exchange membrane fuel cell (PEMFC) has been used as the main fuel cell technology.

Keywords: Hydrogen Fuel Cell, HFC vehicle, Cost, Demand forecast, PEMFC.

INTRODUCTION

The movement of citizens and goods as a socio-economic requirement has increased with modernization¹⁻³. The expansion of commercial development reflects the rise in transportation infrastructure, resulting in increased fuel usage. The transportation system is focused mainly on fossil fuels in modern days⁴⁻⁶. These transports end up with high environmental pollution, particularly unchecked carbon dioxide emissions. This carbon

dioxide continuously adds to the harmful greenhouse effects and ozone layer depletion^{4,7,8}. Consequently, producing fuel with cleaner, more reliable, more economical, and more environmentally sustainable characteristics has become an important issue to fulfill the demands of the modern world and save the environment simultaneously.

Because of its lightweight, exclusive abundance, and environmentally friendly oxidation component (water), hydrogen appears to be a



perfect, environment-friendly energy carrier^{2,9,10}. Hydrogen is a rising fuel technology with a sustainable outcome to meet the increasing energy demand^{2,11}. Almost every kind of existing energy source such as renewable energy (solar, wind, tidal, biogas, biomass), fossil fuel (petroleum, gas, coal) can be transformed into Hydrogen energy which can be used as universal fuel to energize transport vehicles and electricity supply without emission¹³. Global hydrogen demand in 2050 will be around 972 million tons; among this demand, Europe, the United States of America, China will consume almost 80% of the total demand¹². In the way of cost-effective hydrogen fuel vehicle hydrogen fuel generation, fuel storing, fuel supply, fuel refill station management pose great challenges^{14,15}. Currently, fossil fuel is the prime source of hydrogen generation^{16,17}. Around 96% of hydrogen fuel is generated from fossil fuel, and the rest of the hydrogen fuel source is water¹⁵. Fossil fuel-based hydrogen production meets the industrial hydrogen demand^{18,19}, but this way of hydrogen production has carbon emission issues^{8,20}. On the other hand, hydrogen generation from a renewable source is yet to be economically feasible^{16,21}.

Hydrogen Fuel Cell (HFC) Vehicle

A vehicle that is run by the energy of a fuel cell is known as a fuel cell vehicle. Fuel cell vehicles are emission-free, less knocking, trustworthy technology^{22,23}. For a sustainable world, there is a need to find new technology to get rid of fossil fuel burning pollution²⁴⁻²⁶. In comparison to the existing fossil fuel-based vehicles, hydrogen fuel cell (HFC) vehicles are yet to be cost-effective. Two possible ways the vehicles powered by emission-free hydrogen fuel or fossil fuel and hydrogen fuel, both technology hybrid-powered vehicles can be better options rather than fossil fuel-based vehicles²⁷⁻²⁹.

Hydrogen is the number one element in the periodic table with one electron and one proton. Colorless, odorless hydrogen fuel is a universal power source³⁰. This fuel is produced either from water split or oxygen and fossil fuel reaction. Hydrogen fuel can be used to run transports and can produce electricity or heat^{31,32}. A fuel cell is an electrochemical device with two electrode anode and cathode³³⁻³⁵. A proton exchange membrane separates two electrodes³⁶. The membrane allows

only hydrogen ions to pass through it. Two input gas, hydrogen in the anode and oxygen (from the air) in the cathode, create an electrochemical environment, and a direct current is produced in the external circuit^{37,38}. This electricity makes the vehicle operate.

Components of Hydrogen Fuel Cell Vehicle

At the early stage of the fuel cell, water has been used as the hydrogen source. Hydrogen and oxygen are the two components of water³⁹. The electrochemical reaction in the fuel cell is reversed to the electrolysis process of water. After feeding the fuel cell with hydrogen gas, the fuel cell will produce electricity, heat, and water due to an electrochemical reaction occurring between anode and cathode separated by a proton exchange membrane⁴⁰. After performing all the studies and findings from electric vehicles and hydrogen fuel cells, the fuel cell vehicle becomes a reality. The produced electricity from the fuel cell will run the wheel or be stored in a capacitor system called a hybrid fuel cell vehicle^{10,41}. If the higher acceleration load is applied in the fuel cell, the longevity of the membrane and fuel cell will decrease in a hybrid fuel cell vehicle^{35,42}. Fuel cell, hydrogen fuel source, air input, humidifier, cell heat realizing system, electricity containing system, direct current to alternative current conversion system, propelling motor, a total integrated operating system are all the significant fuel cell vehicle building components. All the components must be optimized with each other for better performance. The fuel cell produces direct current (DC) using hydrogen gas. The DC must be converted to an alternative current (AC) to propel a vehicle. A primary battery holds the energy from the fuel cell, and this energy is applied to rotate the vehicle wheel by a motor. Additionally, a secondary battery is used to initiate all the mechanisms in the vehicle. To supply input hydrogen gas to the fuel cell, there is a hydrogen storage tank. By a sophisticated nozzle, the storage tank is refilled from the hydrogen refueling station^{43,44}. A fuel cell vehicle is run by the electricity produced from fuel cells. By an integrated cooling system, the optimum thermal condition is maintained.

Table 1 shows the fuel cell types mostly used in fuel cell vehicles. In most of the vehicles in the market, proton exchange membrane fuel cells are being used as a powerhouse due to some particular criteria⁴⁵. Short initiation time,

operation feasibility at room temperature, collection capacity of reactant gas (oxygen) from the air, low operating temperature range from 50°C to 100°C make proton exchange

membrane more practicable to implement in fuel cell vehicles⁴⁷. In a large vehicle, the hydrogen fuel cell can energize the additional needs as the replacement of a battery.

Table 1: Most used fuel cell types in transportations

Cell variants	Working Temperature	Efficiency%	Catalyst	Pros	Cons	Application
Proton Exchange Membrane Fuel Cell	20 to 120°C	40 to 60	Pt	I. Instant initiation time II. Operates at room temperature III. Collects reactant gas (Oxygen) from air	High carbon-mono-oxide sensitivity Need humidification for input gas	Secondary energy source, Transportation Fuel cell vehicles ⁴⁷
Alkaline Fuel Cell	60 to 120°C	60	Ni/Ag	I. Instant initiation time II. Operates at room temperature	Reactant gas (Oxygen) must be pure	Airways or Defense ^{48,49}

There are other types of fuel cells that are fed with hydrocarbon, ethane-based alcohol, methane-based alcohol, gas from natural sources. The classification of fuel cells differs from the operating temperature⁵⁰. A higher operating temperature indicates the higher price of the fuel cell. Considering overall performance, Proton exchange membrane fuel cell (PEMFC) and Solid oxide fuel cell (SOFC) are in a favorable state to be utilized further. Less operation time, better performance, operating temperature range is below 100°C, easy mechanism and installation process make the perfluorosulfonic based proton exchange membrane feasible to introduce it in the fuel cell technology^{51,52}. Commercially this membrane is known as Nafion, and chemically it is made from perfluorosulfonic acid^{53,54}. In a fuel cell vehicle, the widely used membrane type is polymer electrolyte because the operating temperature range is within 100°C, fits in a small space, has better performance, and has multipurpose usability^{33,39,42,53,54}. Solid oxide fuel cell operates at a high-temperature range at 1000°C⁵⁵. This type of fuel cell is mainly used in static mode or as a backup electricity source⁷. Logistic supply, buses, trucks, forklifts, airways, marine, motorcycles, etc., are the main vehicles that can use hydrogen fuel cells^{1,15}.

Advantages of Hydrogen Fuel Cell Vehicle

The transportation sector is one of the major contributors to greenhouse gas emissions⁵⁶. Fuel demand is rising day after day. With the depleting of fossil fuels, the globe is heading towards an energy crisis^{57,58}. If we don't find any

alternative energy source, the demand would be grave. After burning all fossil fuels, the world is unstable to live in with all the greenhouse effects due to pollution. Transport vehicles are one of the main contributors to greenhouse gas emitter, which is around 30% of the total global emission. The vehicles run on the road contribute 70% emission among the total 30% transport emission³⁹. Road transport vehicles consume 27% of fossil fuel among the total fuel consumption globally. Consequently, this conventional fossil fuel-based vehicle is 25% responsible for global carbon emissions. Among all the transport pollution, 70% of carbon emission is due to the vehicles run on the road, and 61% emission is due to the car. The emission has been curtailed in almost all the power consumption systems except the transportation⁸. In Europe, fossil fuel cars will be reduced to 50% within 2030, and by 2050 fossil fuel car use will be zero. Fossil fuel car registration has been restricted in a few countries⁶⁰.

In addition to this, the geopolitical crisis for fossil fuel will brew in the future. All over the world, every nation is seeking a self-sufficient dependency for energy with renewable and emission-free criteria⁶¹. Electric vehicles and hydrogen fuel cell vehicles can be an eligible way out of the issue. The electric power use in vehicles is very minimal. During the decreased load of electricity use from renewable energy sources such as solar, wind, geothermal, etc., the unused electricity can be converted to hydrogen fuel for further use^{62,63}. All the leading fuel cell vehicle manufacturer has prospects of next-generation fuel cell vehicle production, and

the vehicle will be more sophisticated than before with a lower price range^{31,51}.

Emission due to fossil fuel burning has enormous environmental and health issues^{64,65}. Every year around five hundred thousand people die because of air pollution-borne diseases²⁹. Agricultural damage, medical cost for pollution-related disease, decreased production, global warming, and natural disaster due to pollution needs to be considered in the responsibility list of fossil fuels. Every year this pollution-related cost is 24 billion euros in Europe and globally the cost is thousand billion euro⁶⁶.

The fuel value of hydrogen is 140kj/g. The energy value of conventional fossil fuel is three times less than the fuel value of hydrogen³⁰. Total hydrogen fuel weighs relative to fossil fuel much less. As a result, the vehicle net weight will be less after refill, and the fuel loss will be less. Hydrogen refill time in fuel cell vehicles is quicker than in an electric vehicle. In a study, 78% of vehicle expert believes that this fact will make hydrogen fuel cell vehicle more achievable in the vehicle market²⁹.

Prerequisites of using HFC Vehicles

It is very important users switch from fossil fuel vehicles to hydrogen fuel cell vehicles⁶⁸. User motivation will accelerate the viability of the fuel cell vehicle. With safety assurance, the consumer will buy fuel cell cars to achieve carbon-free, pollution-free, noise-free and healthy environments. Initially, fuel cell integration in heavy load applications such as public vehicles, supply vehicles, etc., will grow

faith and initial infrastructure. A risk-free public and private investment will improve a wide range of fuel cell incorporation.

A study shows that 54 fuel cell vehicle drivers run their vehicle around 124,290 km with a hydrogen fueling of 1370 kg. Among the drivers, 80% were satisfied with the performance of the fuel cell vehicles, 98% think that hydrogen fuel cell vehicle is more reliable than conventional fossil fuel and 75% find that the vehicle cost needs to be at the limit of 40 thousand USD⁶⁷.

Hydrogen is odorless, colorless, flammable gas. Hydrogen gas is stored in a tank with 700 bar pressure. Therefore, any accidental tank leakage will be dangerous³⁹. Hydrogen gas tank architecture is very significant in terms of safety measures. So, there must be a hydrogen or leakage sensing system in a fuel cell vehicle²⁹. Hydrogen is a flammable gas, but there will be less damage because of the localized behavior of hydrogen gas.

The hydrogen fueling station has to be sophisticated with higher thermal condition and storage capacity maintenance^{30,62}. Initially, about 60 hydrogen fuel refill stations will be adequate to feed fuel cell vehicles in the UK^{9,68}. Fuel cell vehicle-friendly infrastructure is also significant, along with hydrogen fuel generation, fuel supply, fuel station^{12,39}. Table 2 shows the estimated expansion of HFC vehicles throughout the world by 2050.

Table 2: Expansion estimation of HFC vehicles throughout the world by 2050

Country	Currently	2025	2030	2050
Republic of Korea [80]	100 ⁶⁹	210 ⁶⁹	520 ⁶⁹	
Japan[82]	160 ⁶⁹	320	900	
China[39,83-90]	100 ⁶⁹	300 ⁶⁹	500	
California, USA [86]				10000
All over USA [68]	80 ⁶⁹	100 ⁶⁹	7100	21000 ⁴⁷
Netherlands	100 ⁶⁹	400 ⁶⁹	1000 ⁶⁹	
Europe[73]	152		3700	4600
Germany		400 by 2023 ⁶⁹	1000 ⁶⁹	
France		100 by 2023	400 to 1000 by 2028 ⁶⁹	

Fuel cell vehicle Demand Forecast

From 1999, California state of USA has the hardest regulation to emphasize emission-free vehicle operation and favorable infrastructure. All

over the USA, the total number of hydrogen fuel cell vehicles was near 2700 in the year 2017. Fuel demand currently in California is 2 ton per day, and within 2023, the fuel demand will be 26 ton per

day⁷⁰. A town in Japan named Kitakyushu is based on Hydrogen energy and application. Among all the applications of hydrogen fuel, hydrogen-based fuel

stations for fuel cell vehicles were demonstrated in this city in 2004. Table 3 shows the Fuel cell vehicle target in number by 2030.

Table 3: Fuel cell vehicle target (in number) by 2030 (Adapted from APERC Asia-Pacific Economic & Cooperation, 2018)

Countries	2020	2023	2025	2030
Europe	100042 ⁴⁷			3700000 ³⁴
USA	13400		40000	
Japan	40000 ⁷¹		200000 ⁷¹	800000 ²⁴⁷¹
China	5000 ⁶⁹		50000 ⁶⁹	1000000 ³⁶
France		5000 ⁶⁹	5200 ⁷¹	20,800-52000 ⁶⁹
Korea	10000 ⁶⁹		100000 ⁶⁹	1,800,000 ^{69,71}

In Asia-pacific economic cooperation (APEC) region, there is a goal to replace conventional fossil fuel vehicles with hydrogen fuel cell vehicles or hybrid vehicles. It has been anticipated that the purchase of fuel cell vehicles will rise from 2031, and after that, in 2040, the rise will be 15%, and in 2050 the rise be 30% more than the previous periods. In this region, there will be a need for 32691 kiloton hydrogen fuel in 2040, and this need will go up to 130277 kiloton ten years later in 2050⁷⁰.

In the APEC region, all the countries will try to reduce their fossil fuel intake and will introduce hydrogen fuel energy within 2040. At the amount of 131 million tons of fossil fuel use have been reduced in APEC countries. With the increasing integration of hydrogen fuel, the dependency on fossil fuel will be reduced by 4.5% in the APEC region⁷⁰. Consistent performance over time is a vital issue in fuel cell vehicles [22]³⁹. Table 4 shows present and future changes in characteristics of HFC vehicles.

Table 4: Present and Future change in characteristics of HFC vehicles (Adapted from Whiston 2019)

Parameters	Current	Future
Cost	USD 75/kW	USD 35/kW within 2050
Fuel cell lifetime	4000 hour	8000hour within 2050
Density of power	2.50kW/L	3kW/L within 2035

Prospects of Different types of Fuel Cell Vehicles

Fuel cell train

The locomotive engine will be knocking free, vibration-free and the train can be accelerated without any gear shifting mechanism²⁹. Now trains are being operated with electricity rather than fossil fuel³⁰. But the electricity is produced with fossil fuel or unsustainable ways. Hydrogen fuel cell train is

a better option for remote areas where the electric facility is more costly or in urban areas where enough space is a shortage for train electrification. A fuel cell train is now in operation in Germany, and 40 fuel cell trains will operate within 2020²⁹. The hydrogen fuel tank will be on the roof of the train, and the millage will be around 800 km. In the UK, the fossil-fuel train will be banned within 2040. To achieve this target, the UK has already started the conversion of train technology from fossil fuel train to fuel cell train³. Trams are in operation in China⁴⁴. The fuel cell of a bus or truck can be used in light train operations. There is no need for train base fuel cell production, and the production cost will be reduced. Hydrogen fuel cell trains will be 50 percent costly than fossil fuel trains. If hydrogen fuel production cost is reduced, then the fuel cell train will be more competitive and viable¹³. It has been found that the fuel cell train is already feasible to operate⁷³.

Fuel cell bus

In the USA, they fix a fuel cell vehicle manufacturing roadmap in which the longevity of a hydrogen fuel cell bus will be 25 thousand hours, and for a car, it will be 8 thousand hours²⁹. In heavy vehicles such as buses or trucks, it is very feasible to operate with fuel cells because the heavy vehicle needs longer operation with less refueling time. Where hydrogen fuel cell fits in reliably, heavy fuel cell vehicle technology has already advanced a lot⁷⁴. The hydrogen fuel capacity of a bus is about 40 kilograms with 350 bar pressure in a storage tank. In Europe, a fuel cell bus successfully traveled about 4 million miles⁷⁵. Within 2030 the fuel cell bus price will be 10 to 20 percent costly than fossil fuel vehicles⁵. The bus operation lifetime reached 18

thousand hours in the United Kingdom, 25 thousand hours in California⁷⁶. In Europe, the affordability of the fuel cell bus crossed 90 percent than before,

and hydrogen fuel refill stations rose around 96% than before⁷⁷. Table 5 presents the Fuel cell bus operation, count.

Table 5: Fuel cell bus operation count

Region	Current	Fuel cell bus count of 2020	2030
Europe	76 ^{42,73,86}	83	45,000
USA	74	-	5,300,000 ^{3,37,47}
North America[87,88]		44	-
Japan[89]	18	100 ⁴⁷	1200
China[90]	2000 ^{64,83,84,85}	11600 ⁸⁷	-

Fuel cell Truck

For heavy transport vehicles such as trucks need high-performance propulsion. Here hydrogen fuel cell is a good choice because of short refueling time and high operation time with a single refill of fuel. For the heavy requirement of performance, the fuel cell truck longevity goal has been fixed to 50 thousand hours. High performance using reduced fuel price is also required. Truck manufacturer companies around the world are about to launch fuel cell trucks. The hydrogen fuel cell truck will be more feasible if there are enough hydrogen refueling facilities.

Fuel cell ships

Hydrogen fuel cell technology has already been introduced in the marine sector. Ships, ferries are operating with fuel cells on a trial basis, and the number of the fuel cell will rise within 2030. There is a pollution control water zone where hydrogen fuel cell integration is the perfect option. Initially, hydrogen fuel cells can be used for backup electricity supply in marine requirements such as cooling systems, light, heating, ignition, etc., particularly in small electrical loads. If hydrogen fuel cost drops to 7 dollars per kg, then fuel cells could be widely used in full electricity and propulsion applications in marine demand^{7,48}. Hydrogen fuel cell marine integration will improve air quality and reduce pollution in the marine region.

Hydrogen fuel cell-powered airways

Research is ongoing to curtail pollution from aviation, but fruitful progress is yet to be found. The target of the International Civil Aviation Organization is emission-free aviation. Hybrid aviation operation does not show much reduction of emission. To meet the propulsion demand in aviation, compressed liquid hydrogen is needed, which is more costly.

Initially, hydrogen fuel cells can be applied in light flying requirements rather than a heavy application. It is an expectation that within 2050 hydrogen energy will be introduced in aviation significantly²⁹.

Fuel cell motorcycle

To reduce the carbon footprint from the globe motorcycle pollution, need to be addressed²⁹. Already Suzuki introduced a 4-kilowatt fuel cell motorcycle, and 48 motorcycles are being studied in the UK⁷⁴.

Fuel Cell Cost Management for Expanded Use

Almost all the leading vehicle manufacturers are trying to introduce fuel cell vehicles more reliably. One of the significant steps to be achieved to make fuel cell vehicles more viable is low-cost hydrogen fuel supply to the fuel cell³⁹. Ford car manufacturing company first introduced vehicles that will run not by the fossil fuel-based machine but with the electric powered technology⁴⁴. The hydrogen fuel cell vehicle will run 360 miles with a refueling period of 3 to 5 minutes⁷⁸. A 60W fuel cell is required to run a car in Europe⁴⁴. But the high price range is an obstacle to replacing conventional fossil fuel-based vehicles with electric or hydrogen fuel cell vehicles. The fuel cell architecture, hydrogen fuel recharge station, longevity, required hydrogen production needs to be assessed and optimized to meet the feasible price limit. Currently, the hydrogen fuel cell vehicle cost range is 55 to 65 thousand USD. Fuel cell production cost is high, and the number of productions is less^{35,73}.

The fuel cell vehicles are available in the market with a high price range due to their requirements of pure hydrogen at a value of 99%⁵⁰. The refueling system of hydrogen fuel, fuel preservation, fuel manufacture, and fuel supply is

the driving criteria of the high price of fuel cell-based vehicles. Methanol could be an Alternative fuel carrier due to the liquid form at room temperature. So, the preservation, manufacture, supply cost will be less than that with hydrogen⁸. Sophisticated upgrades in size, operation reliability can make fuel cell vehicles more feasible to be commercialized.

The cost of liquid hydrogen will be more feasible within 2050 rather than the recent gasification technology. A common hub of hydrogen supply can make fuel cell vehicles more comfortable for the users⁷⁹. A summary of a technological study in Germany highlighted that there is no need for a big investment in infrastructure development in hydrogen fuel cell vehicle prospects. This study also indicates that around 2050, the fuel cell vehicle price will decrease to 22 USD per kW³⁹. In a finding of the Motor Manufacturers and Traders Society, from 2017, the use of hydrogen fuel cell vehicles increased 280 percent than that of the previous four years^{80,81}.

The fuel cell vehicle producer reckoned that the decreased price in the recent period would be 32 to 34 thousand USD which is 24 percent lower than before 2020^{47,60}. Acknowledging this study International Energy Agency reported that the new cost of fuel cell vehicles will be 33.6 thousand USD and 33.4 thousand USD in 2030 and 2050, respectively^{9,72}. According to the recent hydrogen fuel cell vehicle sale and production, within 2050, there will be four hundred million fuel cell vehicles in use. Hydrogen fuel cell integration in locomotive and airways will rise 5 percent within 2050^{47,82}. Norway and the UK will forbid fossil fuel vehicles and will fully depend on carbon-free vehicles within 2025 and 2040, respectively⁷¹. There will be an 80 percent reduction of carbon emission within 2050 in Europe^{69,83}. If the hydrogen fuel comes from renewable energy sources, then the hydrogen fuel cell vehicles will be more environmentally friendly with zero pollution.

Alternative to the precious metal and more active catalyst integration could be a solution for cost-effective fuel cells. If a single manufacturing

station produces a large amount of fuel cell spars, then the overall cost will be reduced. About 50% cost of the fuel cell is consists of proton exchange membrane, bipolar components, catalytic metal, and gas diffusion components⁸⁴. In upcoming days combined metal elements and carbon tubes with nanotechnology will improve the hydrogen storage issues³⁹. Optimum use of the platinum catalyst can move the cost from 0.6 g/kW to 0.2g/kW^{61,82}. On the other hand, palladium will be an alternative for catalyst cost reduction¹².

Fuel cells would have to lower their costs significantly without compromising on performance to become successful in the business. By 2025, the cost of bulk fuel cell vehicles should be comparable to the cost of hybrid vehicles. Unlike batteries, where the majority of the cost is derived from the raw materials required to manufacture them, the most expensive aspect of a fuel cell is the construction of the fuel cell system itself—not the substances used to manufacture the vehicle.

CONCLUSION

The detrimental effects of pollutants from conventional fuel vehicles have led to the need for environmentally friendly energy sources. For the industry to embrace a hydrogen economy, the cost of building and maintaining hydrogen stations must also shrink. Plans and projections for the future of hydrogen and fuel cells should be developed in the user counties. Research for hydrogen fuel cell electric vehicles is important to develop technologies that advance fuel cell systems, subsystems, and components. Recent advances in the manufacture of hydrogen fuel, potential applications, and preservation, along with the environmental impacts of hydrogen as an energy carrier, are highlighted in this paper. This paper can serve as a direction for using hydrogen fuel cell vehicle in developing countries through cost reduction.

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