Future Acceptance for Hydrogen Fuel Cell in Vehicle & its Outcome on Indian Context

Author- Mr. Mallhar Maitra

Corresponding Author- Dr. Nitin Kumar Waghmare

Abstract

Hydrogen fuel cell is the future in automobile industry which will help the Indian society to move one place to another place with peaceful and more conveniently as, fuel cell cars are powered by compressed hydrogen gas that feeds into an onboard fuel cell stack that doesn't burn the gas, but instead transforms the fuel's chemical energy into electrical energy. This electricity then powers the car's electric motors. Tailpipe emissions are zero, and the only waste produced is pure water. The construction of the fuel cell is similar to a battery. Hydrogen enters the anode, where it comes in contact with a catalyst that promotes the separation of hydrogen atoms into an electron and proton. The electrons are gathered by the conductive current collector, which is connected to the car's high-voltage circuitry, feeding the onboard battery and/or the motors that turn the wheels. As per the need of Indian citizens need vehicle for daily use and need more mileage in less cost. Hydrogen fuel is not polluting the environment so, its eco friendly mode of power supply for the vehicle. Moreover, hydrogen fuel cell will be more successful source of power to the vehicle as per the electric vehicle power. Hence, Hydrogen fuel cell is the future in Indian automobile industry.

Key Words: Hydrogen Fuel Cell, Automobile Industry, Non-Polluting environment emission.

1. Introduction

Hydrogen is the simplest and most abundant element in the universe. Despite its simplicity and abundance, hydrogen rarely occurs naturally as a gas on Earth. It is almost always combined with other elements. It can be generated from oil, natural gas, and biomass or by splitting water using renewable solar or electrical energy. Once hydrogen is produced as molecular hydrogen, the energy present within the molecule can be released, by reacting with oxygen to produce water. This can be achieved by either traditional internal combustion engines, or by devices called fuel cells. In a fuel cell, hydrogen energy is converted directly into electricity with high efficiency and low power losses. Hydrogen, therefore, is an energy carrier, which is used to move, store, and deliver energy produced from other sources. **(Hosseini, S.E.et al,2013)[1]**

Hydrogen fuel cell will be the next generation for the required energy formation for the vehicle which help the vehicle run easily and complete the natural generational operation easily and successfully. The upcoming generation required **(Granovskii, M, et al, 2007)[2]**vehicle in daily use and there works, for the safety precautions in environment also required, hence the hydrogen fuel is the future in automobile industry.

Fuel cell electric cars are powered by the most abundant element in the universe: hydrogen. Although a fuel cell car runs on electricity, it does so differently than battery-powered or plug-in hybrid cars. In a fuel cell, hydrogen reacts electrochemically to produce electricity to power the car. Shown in Fig.1.1. Working of fuel cell process in vehicle:

1. Fuel Cell Stack – An aggregate of numerous fuel cells that combine oxygen and hydrogen to generate electricity and power the electric motor.
2. Fuel Tank – Hydrogen gas is stored in carbon-fiber reinforced tanks to provide fuel to the fuel-cell stack.
3. Electric Motor – Powers the car using energy produced in the fuel cell stack
4. Battery – Captures (Store or power backup) energy from regenerative braking and provides additional power to the electric motor.
5. Exhaust – The byproduct of the reaction occurring in the fuel cell stack is water vapor, which is emitted through the exhaust.

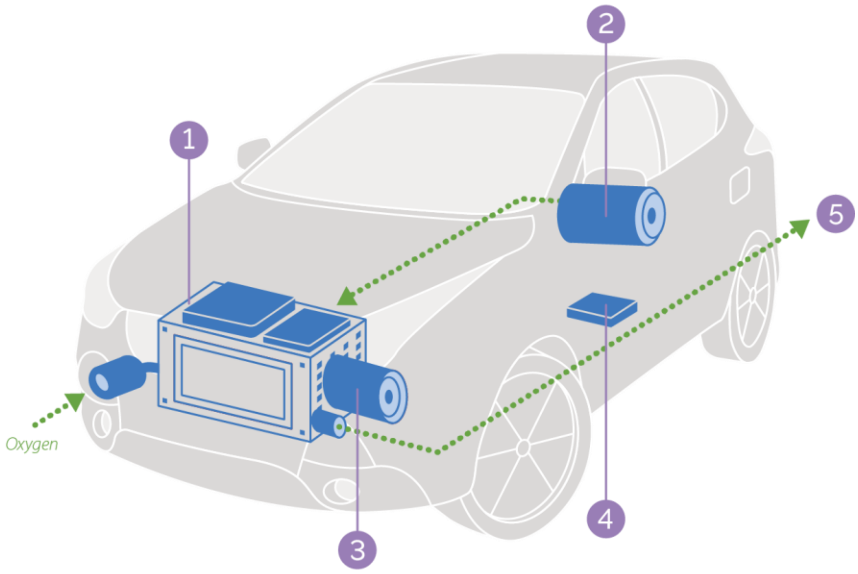

Fig.1.1. Fuel cell power process.

2. Literature review

Globally, the development of economic activities is associated with a great interest in energy-consuming services and the subsequent increase of fuel consumption. However, this fuel demand is commonly followed by high and unregulated carbon dioxide emission, which is the main source generator of the greenhouse gas (GHG) effect. **(Derbeli, M. et al, 2018)[3]** Fossil fuels (mainly in the forms of petroleum, natural gas and coal) are experiencing accelerated consumption and stock depletion, despite meeting today's global energy demand. Such combustion products are the main contributors to environmental problems and uncontrollable climate changes, thus threatening the global environmental safety and sustainability. Among feasible and realistic solutions to these global problems are those which have been proposed by engineers and scientists who agree to replace the existing fossil-fueled energy systems by the hydrogen energy system (HES). **(Hosseini, S.E., et al, 2013)[4]** Subsequently, hydrogen can be fed to fuel energy-consuming services in order to improve energy security and simultaneously control the GHG effect. A plausible hydrogen energy system, which includes its resources, production technologies, storage, fuel-tank, dispensing and utilization, can be primarily analyzed for urban services, but it remains underdeveloped or sparsely studied in alignment with the renewable energy sources (RES). Hydrogen can be characterized as an efficient and clean fuel. Technological advantages are that the hydrogen combustion is neither a GHG producer nor a generator of ozone-layer-depleting chemicals. **(Eriksson, E.L.V.,et al,2017)[5]** Moreover, hydrogen combustion does not generate acid rain ingredients or air pollution. It is also noteworthy that hydrogen produced from RES can develop a stable and permanent energy system that is never subject to future changes or modular modifications.

In the following sections of this literature review, a classification of HES-collected studies was developed into five fields, followed by a critical overview of the operation characteristics and the technological synergies developed between HES and RES. Moreover, the main key aspects, considerations and future prospects of HES and RES convergence are discussed in the Conclusions section. **(Heywood, J.B., et al, 2018)[6]**

"Hydrogen, in vast quantities, has been used safely in chemical and metallurgical applications, the food industry, and the space program for many years. In the not-sodistant future, hydrogen and fuel cells will play an even greater role in meeting the energy needs of our nation and the world."1 The use of hydrogen as an energy carrier and fuel cells as power producers is not new. Applications include stationary systems, portable products, and transportation-related vehicles. Stationary applications, which provide the oldest examples of the fuel cell industry, have been in development since the 1960s. Fuel Cell Today estimates that about 530 complete systems, each having electrical output over 10 kW, have been operated worldwide. While, in the past, Japan has been the leader in stationary fuel cell development, the United States has also supported development. **(Costilla-Reyes, A., et al, 2018)[7]** Most of these systems were fueled by natural gas. Portable applications of fuel cells have also been in use since the 1960s; Fuel Cell Today estimates that about 1,700 complete systems, with electrical power output between 1 W and 1.5 kW, have been operated worldwide. The United States is the primary region in which portable fuel cell development is on-going, although the primary applications are for military, not commercial, uses. Fuel cells have also been used in transportation-related applications. Fuel cell applications in buses began in 1993; by late September 2002, about 31 fuel cell buses had been built and operated worldwide. Research and development on fuel-cell-powered light-duty vehicles escalated in the mid-1990s.

3. Technical terms and condition (Remove Underline)

3.1. Hydrogen Fuel Basics

Hydrogen is a clean fuel that, when consumed in a fuel cell, produces only water. Hydrogen can be produced from a variety of domestic resources, such as natural gas, nuclear power, biomass, and renewable power like solar and wind. These qualities make it an attractive fuel option for transportation and electricity generation applications. It can be used in cars, in houses, for portable power, and in many more applications. Hydrogen is an energy carrier that can be used to store, move, and deliver energy produced from other sources. Today, hydrogen fuel can be produced through several methods. The most common methods today are natural gas reforming (a thermal process), and electrolysis. Other methods include solar-driven and biological processes.

I. THERMAL PROCESSES

Thermal processes for hydrogen production typically involve steam reforming, a high-temperature process in which steam reacts with a hydrocarbon fuel to produce hydrogen. Many hydrocarbon fuels can be reformed to produce hydrogen, including natural gas, diesel, renewable liquid fuels, gasified coal, or gasified biomass. Today, about 95% of all hydrogen is produced from steam reforming of natural gas.

Natural gas reforming

Coal gasification

Biomass gasification

Reforming of renewable liquid fuels.

II. ELECTROLYTIC PROCESSES

Water can be separated into oxygen and hydrogen through a process called electrolysis. Electrolytic processes take place in an electrolyzer, which functions much like a fuel cell in reverse—instead of using the energy of a hydrogen molecule, like a fuel cell does, an electrolyzer creates hydrogen from water molecules.

III. SOLAR-DRIVEN PROCESSES

Solar-driven processes use light as the agent for hydrogen production. There are a few solar-driven processes, including photobiological, photoelectrochemical, and solar thermochemical. Photobiological processes use the natural photosynthetic activity of bacteria and green algae to produce hydrogen. Photoelectrochemical processes use specialized semiconductors to separate water into hydrogen and oxygen. Solar thermochemical hydrogen production uses concentrated solar power to drive water splitting reactions often along with other species such as metal oxides.

IV. BIOLOGICAL PROCESSES

Biological processes use microbes such as bacteria and microalgae and can produce hydrogen through biological reactions. In microbial biomass conversion, the microbes break down organic matter like biomass or wastewater to produce hydrogen, while in photobiological processes the microbes use sunlight as the energy source.

3.2. Fuel cell basics

Fuel cells can provide heat and electricity for buildings and electrical power for vehicles and electronic devices.

I. How Fuel Cells Work

Fuel cells work like batteries, but they do not run down or need recharging. They produce electricity and heat as long as fuel is supplied. A fuel cell consists of two electrodes—a negative electrode (or anode) and a positive electrode (or cathode)—sandwiched around an electrolyte. A fuel, such as hydrogen, is fed to the anode, and air is fed to the cathode. In a polymer electrolyte membrane fuel cell, a catalyst separates hydrogen atoms into protons and electrons, which take different paths to the cathode. The electrons go through an external circuit, creating a flow of electricity. The protons migrate through the electrolyte to the cathode, where they reunite with oxygen and the electrons to produce water and heat

II. Types of Fuel Cells

Although the basic operations of all fuel cells are the same, special varieties have been developed to take advantage of different electrolytes and serve different application needs. The fuel and the charged species migrating through the electrolyte may be different, but the principle is the same. An oxidation occurs at the anode, while a reduction occurs at the cathode. The two reactions are connected by a charged species that migrates through the electrolyte and electrons that flow through the external circuit.

III. POLYMER ELECTROLYTE MEMBRANE FUEL CELLS

Polymer electrolyte membrane (PEM) fuel cells, also called proton exchange membrane fuel cells, use a proton-conducting polymer membrane as the electrolyte. Hydrogen is typically used as the fuel. These cells operate at relatively low temperatures and can quickly vary their output to meet shifting power demands. PEM fuel cells are the best candidates for powering automobiles. They can also be used for stationary power production. However, due to their low operating temperature, they cannot directly use hydrocarbon fuels, such as natural gas, liquefied natural gas, or ethanol. These fuels must be converted to hydrogen in a fuel reformer to be able to be used by a PEM fuel cell.

IV. DIRECT-METHANOL FUEL CELLS

The direct-methanol fuel cell (DMFC) is similar to the PEM cell in that it uses a proton conducting polymer membrane as an electrolyte. However, DMFCs use methanol directly on the anode, which eliminates the need for a fuel reformer. DMFCs are of interest for powering portable electronic devices, such as laptop computers and battery rechargers. Methanol provides a higher energy density than hydrogen, which makes it an attractive fuel for portable devices.

V. ALKALINE FUEL CELLS

Alkaline fuel cells use an alkaline electrolyte such as potassium hydroxide or an alkaline membrane that conducts hydroxide ions rather than protons. Originally used by the National Aeronautics and Space Administration (NASA) on space missions, alkaline fuel cells are now finding new applications, such as in portable power.

VI. PHOSPHORIC ACID FUEL CELLS

Phosphoric acid fuel cells use a phosphoric acid electrolyte that conducts protons held inside a porous matrix, and operate at about 200°C. They are typically used in modules of 400 kW or greater and are being used for stationary power production in hotels, hospitals, grocery stores, and office buildings, where waste heat can also be used. Phosphoric acid can also be immobilized in polymer membranes, and fuel cells using these membranes are of interest for a variety of stationary power applications.

VII. MOLTEN CARBONATE FUEL CELLS

Molten carbonate fuel cells use a molten carbonate salt immobilized in a porous matrix that conducts carbonate ions as their electrolyte. They are already being used in a variety of medium-to-large-scale stationary applications, where their high efficiency produces net energy savings. Their high-temperature operation (approximately 600°C) enables them to internally reform fuels such as natural gas and biogas.

VIII. SOLID OXIDE FUEL CELLS

Solid oxide fuel cells use a thin layer of ceramic as a solid electrolyte that conducts oxide ions. They are being developed for use in a variety of stationary power applications, as well as in auxiliary power devices for heavy-duty trucks. Operating at 700°C–1,000°C with zirconia-based electrolytes, and as low as 500°C with ceria-based electrolytes, these fuel cells can internally reform natural gas and biogas and can be combined with a gas turbine to produce electrical efficiencies as high as 75%.

IX. COMBINED HEAT AND POWER FUEL CELLS

In addition to electricity, fuel cells produce heat. This heat can be used to fulfill heating needs, including hot water and space heating. Combined heat and power fuel cells are of interest for powering houses and buildings, where total efficiency as high as 90% is achievable. This high-efficiency operation saves money, saves energy, and reduces greenhouse gas emissions.

X. REGENERATIVE OR REVERSIBLE FUEL CELLS

This special class of fuel cells produces electricity from hydrogen and oxygen but can be reversed and powered with electricity to produce hydrogen and oxygen. This emerging technology could provide storage of excess energy produced by intermittent renewable energy sources, such as wind and solar power stations, releasing this energy during times of low power production.

4. Hydrogen fuel cell application in Automobile industry in India

The need for Green Hydrogen is rapidly increasing due to its potential to decarbonize several sectors, including transportation, shipping, and steel among others. Green hydrogen can replace traditional fossil fuels in transportation, which contributes significantly to greenhouse gas emissions. It can also be used in industry for the production of ammonia, methanol, and steel, which are currently heavily reliant on fossil fuels. Additionally, Green Hydrogen can be used as a backup energy source for renewable energy plants, providing a constant and reliable source of energy.

Green hydrogen has numerous applications and can be used in fuel cells to power vehicles and provide electricity. It can also be used in heating systems and in the production of chemicals and fertilizers. Hydrogen fuel cells have a high energy density and are more efficient than traditional combustion engines, making them an attractive option for powering vehicles. Furthermore, Green Hydrogen can be used in microgrids, providing electricity to remote areas and enabling energy independence.

The importance of Green Hydrogen in achieving energy independence for India cannot be overstated. The production of Green Hydrogen using renewable energy sources like solar, wind, and hydropower can provide energy security, reducing dependence on fossil fuels and ensuring a stable and reliable source of energy. Green hydrogen can also be produced locally, reducing the need for costly and environmentally damaging imports. Furthermore, Green Hydrogen produced using waste biomass provides an additional revenue stream for farmers and local communities.

In conclusion, Green Hydrogen has enormous potential to decarbonize several sectors, reduce carbon emissions and achieve energy independence. The production of Green Hydrogen using renewable energy sources like solar, wind, and hydropower is sustainable and environmentally friendly, making it an attractive option for the transition to a low-carbon future. Green hydrogen can replace traditional fossil fuels in transportation and industry, providing a constant and reliable source of energy. Its importance in energy independence cannot be overstated, as it can reduce dependence on fossil fuels and provide a stable and reliable source of energy.

4.1. Initial research

India's foray into hydrogen-powered vehicles began with experimental projects and prototypes in the early 2000s. The Tata Group and Mahindra & Mahindra were among the first Indian companies to explore hydrogen fuel cell technology. While these early initiatives were limited in scope, they laid the groundwork for future developments.

4.2. Government Initiatives to develop Hydrogen cars in India

Recognising the potential of hydrogen as a clean energy source, the Indian government has taken several steps to promote hydrogen-based transportation. The National Hydrogen Energy Mission (NHEM), launched in 2021, aims to facilitate the development and deployment of hydrogen technologies across various sectors, including transportation. The government is conducting feasibility studies to check the potential of fuel-cell electric vehicles (FCEVs) in India. The current transport minister of India, Mr. Nitin Gadkari, has been actively advocating for hydrogen fuel cell electric vehicles (FCEVs). He has even adopted a Toyota Mirai pilot study car as his daily mode of transportation.

4.3. Current Status

Hydrogen fuel cell technology for vehicles is still in its early stages in India. It still requires a lot of research and development before it becomes a preferred car by users. Hydrogen fuel cell technology is emerging as a significant alternative to electric vehicles. In India, it is now being given serious consideration as a green mobility solution, particularly for larger vehicles designed for extended journeys. Several Indian and international automotive companies have shown interest in hydrogen cars. Tata Motors, Mahindra & Mahindra, and Ashok Leyland have announced plans to develop hydrogen fuel cell vehicles. Additionally, collaborations with foreign manufacturers, such as Toyota and Hyundai, have paved the way for the introduction of hydrogen-powered cars in the Indian market.

4.4. Upcoming Hydrogen cars in India

Currently, there are no hydrogen cars for sale in the Indian car market. However, several car manufacturers have expressed their plans to bring such vehicles to the Indian market. It will be intriguing to observe how hydrogen car prices in India stack up against those of electric cars. The most talked about hydrogen car in India Toyota Mirai, is expected to cost INR 60 Lacks. The International Centre for Automotive Technology (iCAT), an Indian governmental automotive testing agency, has recently forged a memorandum of understanding with Toyota. Their collaboration aims to conduct a comprehensive assessment of the second-generation Mirai, a fuel-cell electric vehicle (FCEV). This initiative entails thorough testing of the Mirai to ascertain its performance under Indian conditions, encompassing climate and road conditions.

Hydrogen cars have a lot of promise in India for cleaner and more eco-friendly transportation. India has lots of clean energy like solar and wind power, and people are worried about pollution. So, India can use hydrogen cars which are good for the environment.

But, there are some problems like not enough places to fill up with hydrogen, the cars cost a lot, and safety worries. If the government helps, companies invest, and other countries work together, hydrogen cars can make India's cars better for the planet. It's not going to be easy, but using hydrogen for clean and efficient cars is a great idea that we shouldn't ignore. Last but not least, irrespective of the fuel type, every motor vehicle in India needs to have a third-party bike or car insurance to abide by the law of the land.

5. Advantage & Disadvantage

5.1. Disadvantages

I. Infrastructure Development:

Hydrogen fuel technology is still in its early stages. Establishing a network of hydrogen refuelling stations is a significant challenge. Currently, India has only a handful of such stations, primarily located in a few cities. Expanding this infrastructure to cover the entire country is essential for the widespread adoption of hydrogen cars.

II. Reduced Cabin Space:

Hydrogen fuel cars often sacrifice cabin space to accommodate the hydrogen fuel tank. It reduces the car space and is especially noticeable in smaller car models.

III. High Production and Car Costs:

Hydrogen fuel cell technology is expensive to produce and maintain. This makes Hydrogen cars in India more expensive than electric vehicles. The high initial costs of manufacturing hydrogen fuel cell vehicles pose a barrier to their mass-market adoption. Reducing production costs through innovation and economies of scale is a critical challenge we face today.

IV. Carbon Footprints in Hydrogen Production:

The process of producing, storing, and transporting hydrogen involves energy at various stages. This reduces hydrogen cars' green benefits. Hydrogen cars must address these energy challenges to compete with electric vehicles, which are steadily improving in terms of energy efficiency.

V. Safety Concerns:

Hydrogen is highly flammable and requires special safety precautions in production, storage, and transportation. Addressing safety concerns and building public confidence in hydrogen technology is vital for its acceptance in India.

VI. Higher Operating Costs:

Running a hydrogen-powered car tends to be more expensive than operating an electric vehicle because hydrogen fuel typically costs more than electricity. However, this cost dynamic may change as hydrogen demand increases and production scales up.

5.2. Advantages

I. Zero Emissions:

One of the most significant advantages of hydrogen cars is their minimal environmental impact. With zero tailpipe emissions, hydrogen cars contribute to improving air quality and reducing India's carbon footprint, especially in congested urban areas.

II. Longer Range:

Hydrogen cars typically offer longer driving ranges on a single full talk compared to electric vehicles (EVs). This feature is crucial in a country as vast as India, where long-distance travel is common, and charging infrastructure is still developing.

III. Better Performance:

Hydrogen fuel cell cars offer excellent performance, providing full power even at low speeds.

IV. Quiet Operation:

Unlike traditional cars with internal combustion engines, Fuel Cell Electric Vehicles (FCEVs) operate quietly, similar to electric cars. So green hydrogen cars are not only good for reducing environmental pollution but also noise pollution.

V. Fast Refuelling:

Hydrogen refuelling stations can fill a hydrogen tank in a matter of minutes, similar to the time it takes to refuel a gasoline or diesel vehicle. This quick refuelling time addresses one of the key concerns associated with EVs – lengthy charging periods.

VI. Consistent Range:

Unlike Electric Vehicles, the driving efficiency of hydrogen cars remains consistent regardless of the outside temperature. In an electric car, the efficiency drastically falls when it's used in cold weather conditions.

VII. Versatility:

Hydrogen can be used in various modes of transportation, from cars and buses to trucks and trains. This versatility makes hydrogen an attractive option for India's diverse transportation needs. The Fig.5.1. shown as Hydrogen power train.

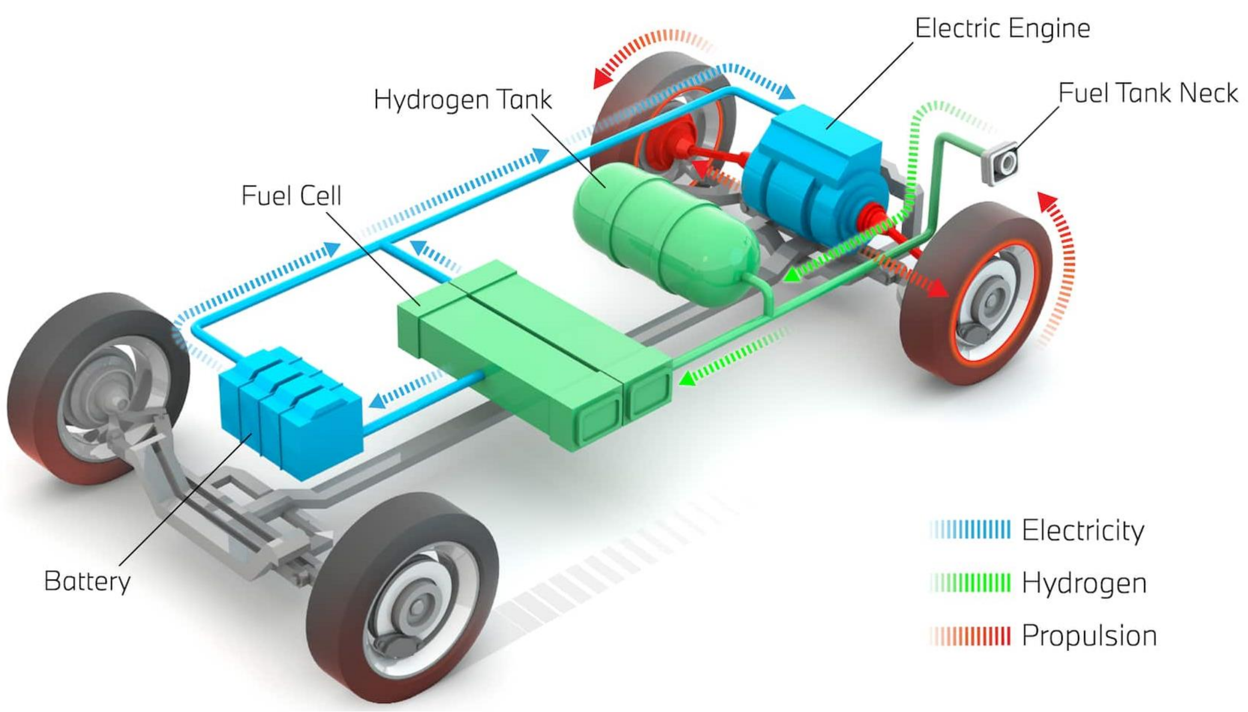

Fig.5.1. Hydrogen power tarin in the vehicle.

6. Real time driving range

HFCVs can be refuelled in about 6 minutes, vs. 20 mins to 8 hours for EVs. The former also offers greater driving range per tank of hydrogen. These differences are some of the attributes that Toyota premised the Mirai around, which is a fuel-cell passenger car that was introduced in 2015 and has so far sold 21,475 units globally. It can drive for around 647 km on a full tank of hydrogen and has a refuelling time of just around 5 minutes. A certain Mirai was even hypermiled to 845 miles (1,352 km) on a single tank of hydrogen in 2021. one of the most popular EVs on sale today, goes for between 290 - 595 km on a single charge (depending upon which battery pack it's using) and takes around 15 minutes to charge at a Supercharger (which is not recommended for repeated use). Granted, there has been tremendous progress on increasing the range of EV batteries and Samsung has even revealed a solid-state battery with 500 miles of driving range. But for now, HFCs have the advantage in this aspect.

Hydrogen fuel cell cars and electric cars are two distinct types of zero-emission vehicles. Here's a comparison of hydrogen fuel cell cars and electric cars:

I. **Fuel Type:** As the name suggests, Hydrogen fuel cell cars use hydrogen gas as their fuel source, while Electric cars run on electricity stored in batteries.

II. **Power Source:** Hydrogen cars generate electricity by combining hydrogen with oxygen in a fuel cell. While an EV needs to be charged by plugging into electrical outlets or charging stations.

III. **Refueling:** Hydrogen is refilled within a few minutes, which is way lower compared to recharging electric vehicle (EV) batteries which can take hours.

IV. **Energy Storage:** Hydrogen cars have a fuel tank, while electric car uses batteries.

V. **Range:** Hydrogen fuel cell vehicles are known to offer longer driving ranges than most battery-electric vehicles.

VI. **Cost of the vehicle:** Hydrogen fuel cell vehicles are more expensive to manufacture and purchase than electric cars.

VII. **Energy Efficiency:** The process of production, transportation, and conversion into electricity in a hydrogen car uses a lot of energy, compared to direct electricity generation in electric vehicles

VIII. **Limited Infrastructure and refusing stations:** Hydrogen refuelling infrastructure is not as widespread as electric charging stations, making it challenging to find refuelling stations in many areas.

7. Customer acceptability of hydrogen fuel cell in India

In India, the hydrogen fuel cell vehicle (HFCV) is in its infancy, and the future for HFCV looks promising. Several automakers have shown keen interest in launching such cars in India. The Indian government wants to increase the use of electric and fuel-cell vehicles to reduce pollution and annual petroleum imports (Sahoo et al., 2022). Observing the government's policy measures to make HFCVs cost-competitive with conventional vehicles and electric vehicles (EVs) would be fascinating. HFCVs are sold worldwide by manufacturers like Hyundai, Toyota, and Honda. The present study empirically tests the adoption of hydrogen fuel cell vehicles (HFCV) through the role of attitudes, perceptions, environmental concerns, and the effect of policy implications. An online survey was conducted among Indians who are knowledgeable and aware of HFCV developments in the country. A multi-stage stratified sampling technique was used to acquire the data. The paper examined a postulated model using structural equation modelling. The findings of this research confirms that motivation and knowledge sharing had a significant effect on attitude toward HFCV adoption. Potential adopters perceived that risk, cost, and infrastructure significantly impact HFCV adoption. In addition, the research indicates that stakeholders may influence buyer attitudes through suitable government policy and coordinated affirmative actions, including incentives for HFCV manufacturers, refuelling stations, HFCV buyers, and infrastructure developers. The infrastructure developers need viability gap funding to address the financial constraints and create enabling eco-system for a higher HFCV adoption.

8. Discussion & Conclusion

Hydrogen fuel cell vehicles do not emit greenhouse gases. This helps to fight climate change. As many countries are opting for energy transition, clean hydrogen fuel vehicles along with other alternative fuel vehicles can pave the way to sustainable transportation. As these vehicles do not emit greenhouse gases such as Carbon dioxide, they can cut air pollution to a great extent. Hydrogen vehicles are much quieter than fossil fuel-based vehicles. So, they can reduce noise pollution too. The prices of fossil fuels are increasing continuously. So, if more hydrogen vehicles come into the market, the price of fossil fuels may reduce. Hydrogen vehicles have fast charging times when compared with electric vehicles. Hence the Hydrogen Fuel Cell is the future of Automobile industry & future growth.

9. Reference

1) Hosseini, S.E.; Andwari, A.M.; Wahid, M.A.; Bagheri, G. A review on green energy potentials in Iran. Renew. Sustain. Energy Rev. 2013, 27, 533–545. [CrossRef]
2) Granovskii, M.; Dincer, I.; Rosen, M.A. Greenhouse gas emissions reduction by use of wind and solar energies for hydrogen and electricity production: Economic factors. Int. J. Hydrogen Energy 2007, 32, 927–931. [CrossRef]
3) Derbeli, M.; Barambones, O.; Sbita, L.; Derbeli, M.; Barambones, O.; Sbita, L. A Robust Maximum Power Point Tracking Control Method for a PEM Fuel Cell Power System. Appl. Sci. 2018, 8, 2449. [CrossRef]
4) Hosseini, S.E.; Wahid, M.A.; Aghili, N. The scenario of greenhouse gases reduction in Malaysia. Renew. Sustain. Energy Rev. 2013, 28, 400–409. [CrossRef]
5) Eriksson, E.L.V.; Gray, E.M.A. Optimization and integration of hybrid renewable energy hydrogen fuel cell energy systems—A critical review. Appl. Energy 2017, 202, 348–364. [CrossRef]
6) Heywood, J.B. Internal Combustion Engine Fundamentals; McGraw-Hill Education: New York, NY, USA, 1988. Costilla-Reyes, A.; Erbay, C.; Carreon-Bautista, S.; Han, A.; Sánchez-Sinencio, E. A Time Interleave-Based Power Management System with Maximum Power Extraction and Health Protection Algorithm for Multiple Microbial Fuel Cells for Internet of Things Smart Nodes. Appl. Sci. 2018, 8, 2404. [CrossRef]
7) Kerviel, A.; Pesyridis, A.; Mohammed, A.; Chalet, D.; Kerviel, A.; Pesyridis, A.; Mohammed, A.; Chalet, D.An Evaluation of Turbocharging and Supercharging Options for High-Efficiency Fuel Cell Electric Vehicles. Appl. Sci. 2018, 8, 2474. [CrossRef]
8) Wang, C.; Nehrir, M.H.; Gao, H. Control of PEM Fuel Cell Distributed Generation Systems. IEEE Trans. Energy Convers. 2006, 21, 586–595. [CrossRef]
9) Somekawa, T.; Nakamura, K.; Kushi, T.; Kume, T.; Fujita, K.; Yakabe, H. Examination of a high-efficiency solid oxide fuel cell system that reuses exhaust gas. Appl. Therm. Eng. 2017, 114, 1387–1392. [CrossRef]
10) Ayad, M.Y.; Becherif, M.; Henni, A. Vehicle hybridization with fuel cell, supercapacitors and batteries by sliding mode control. Renew. Energy 2011, 36, 2627–2634. [CrossRef]
11) Chakraborty, U.K. A New Model for Constant Fuel Utilization and Constant Fuel Flow in Fuel Cells. Appl. Sci. 2019, 9, 1066. [CrossRef]
12) Giorgi, L.; Leccese, F. Fuel Cells: Technologies and Applications. Open Fuel Cells J. 2013, 6, 1 20. [CrossRef]
13) Offer, G.J.; Howey, D.; Contestabile, M.; Clague, R.; Brandon, N.P. Comparative analysis of battery electric, hydrogen fuel cell and hybrid vehicles in a future sustainable road transport system. Energy Policy 2010, 38, 24–29. [CrossRef]

14) Choi, H.; Shin, J.; Woo, J. Effect of electricity generation mix on battery electric vehicle adoption and its environmental impact. Energy Policy 2018, 121, 13–24. [CrossRef]
15) Aceves, S.M.; Berry, G.D.; Weisberg, A.H.; Espinosa-Loza, F.; Perfect, S.A. Advanced concepts for vehicular containment of compressed and cryogenic hydrogen. In Proceedings of the 16th World Hydrogen Energy Conference 2006 (WHEC 2006), Lyon, France, 13–16 June 2006.
16) Michel, F.; Fieseler, H.; Allidiers, L. Liquid Hydrogen Technologies for Mobile Use. In Proceedings of the 16th World Hydrogen Energy Conference 2006 (WHEC 2006), Lyon, France, 13–16 June 2006.
17) Paggiaro, R.; Michl, F.; Bénard, P.; Polifke, W. Cryo-adsorptive hydrogen storage on activated carbon. II: Investigation of the thermal effects during filling at cryogenic temperatures. Int. J. Hydrogen Energy 2010, 35, 648–659. [CrossRef]
18) Hosseini, S.E.; Wahid, M.A. Hydrogen production from renewable and sustainable energy resources:Promising green energy carrier for clean development. Renew. Sustain. Energy Rev. 2016, 57. [CrossRef]
19) Boretti, A. Novel dual fuel diesel-ammonia combustion system in advanced TDI engines. Int. J. Hydrogen Energy 2017, 42, 7071–7076. [CrossRef]
20) Veziroglu, A.; MacArio, R. Fuel cell vehicles: State of the art with economic and environmental concerns. Int. J. Hydrogen Energy 2011, 36, 25–43. [CrossRef]
21) Hosseini, S.E.; Wahid, M.A.; Ganjehkaviri, A. An overview of renewable hydrogen production from thermochemical process of oil palm solid waste in Malaysia. Energy Convers. Manag. 2015, 94, 415–429. [CrossRef]
22) Hosseini, S.E.; Abdul Wahid, M.; Jamil, M.; Azli, A.A.M.; Mohamad, F.M. A review on biomass-based hydrogen production for renewable energy supply. Int. J. Energy Res. 2015, 39, 1597–1615. [CrossRef]
23) Hibino, T.; Kobayashi, K.; Ito, M.; Ma, Q.; Nagao, M.; Fukui, M.; Teranishi, S. Efficient Hydrogen Production by Direct Electrolysis of Waste Biomass at Intermediate Temperatures. ACS Sustain. Chem. Eng. 2018, 6, 9360–9368. [CrossRef]
24) Hibino, T.; Kobayashi, K.; Lv, P.; Nagao, M.; Teranishi, S.; Mori, T. An Intermediate-Temperature Biomass Fuel Cell Using Wood Sawdust and Pulp Directly as Fuel. J. Electrochem. Soc. 2017, 164, F557–F563. [CrossRef]
25) Hibino, T.; Kobayashi, K.; Ito, M.; Nagao, M.; Fukui, M. Applied Catalysis B: Environmental Direct electrolysis of waste newspaper for sustainable hydrogen production: An oxygen-functionalized porous carbon anode. Appl. Catal. B Environ. 2018, 231, 191–199. [CrossRef]
26) Hibino, T.; Kobayashi, K.; Nagao, M.; Teranishi, S. Hydrogen Production by Direct Lignin Electrolysis at Intermediate Temperatures. ChemElectroChem 2017, 4, 3032–3036. [CrossRef]
27) Hori, T.; Ma, Q.; Kobayashi, K.; Nagao, M. Electrolysis of humidified methane to hydrogen and carbon dioxide at low temperatures and voltages. Int. J. Hydrogen Energy 2019, 44, 2454–2460. [CrossRef]

28) Alternative Fuels Data Center: How Do Fuel Cell Electric Vehicles Work Using Hydrogen? Available online:https://afdc.energy.gov/vehicles/how-do-fuel-cell-electric-cars-work (accessed on 21 May 2019).
29) Devrim, Y.; Devrim, H.; Eroglu, I. Development of 500 W PEM fuel cell stack for portable power generators.Int. J. Hydrogen Energy 2015, 40, 7707–7719. [CrossRef]
30) Davis, C.; Edelstein, B.; Evenson, B.; Brecher, A.; Cox, D. Hydrogen Fuel Cell Vehicle Study. Presented at the Panel on Public Affairs (POPA), American Physical Society, 12 June 2003.
31) Atkinson, K.; Roth, S.; Hirscher, M.; Grünwald, W. Carbon nanostructures: An efficient hydrogen storage medium for fuel cells. Fuel Cells Bull. 2001, 4, 9–12. [CrossRef]
32) Das, L.M. Hydrogen-fueled internal combustion engines. Compend. Hydrog. Energy 2016, 177 217. [CrossRef]
33) Chen, P.; Xiong, Z.; Luo, J.; Lin, J.; Tan, K.L. Interaction of hydrogen with metal nitrides and imides. Nature 2002, 420, 302–304. [CrossRef]
34) Ehsani, M.; Gao, Y.; Longo, S.; Ebrahimi, K. Modern Electric, Hybrid Electric, and Fuel Cell Vehicles, Third Edition; CRC Press: Boca Raton, FL, USA, 2018; ISBN 9780429504884.
35) Jorgensen, S.W. Hydrogen storage tanks for vehicles: Recent progress and current status. Curr. Opin. Solid State Mater. Sci. 2011, 15, 39–43. [CrossRef]
36) Greene, D.L.; Leiby, P.N.; James, B.D.; Perez, J.; Melandez, M.; Milbrandt, A.; Unnasch, S.; Rutherford, D. Analysis of the Transition to Hydrogen Fuel Cell Vehicles and the Potential Hydrogen Energy Infrastructure Requirements; Oak Ridge National Lab. (ORNL): Oak Ridge, TN, USA, 2008.
37) Kirubakaran, A.; Jain, S.; and Nema, R.K. The PEM Fuel Cell System with DC / DC Boost Converter: Design, Modeling and Simulation. Int. J. Recent Trends Eng. 2009, 1, 157.
38) O'Hayre, R.P.; Cha, S.-W.; Colella, W.G.; Prinz, F.B. Fuel Cell Fundamentals; John Wiley & Sons: Hoboken, NJ, USA, 2016; ISBN 9781119113805.
39) Reschiotto, D. Effects of Anode Fuel Recirculation on SOFCs Fuelled with Biogas. Master's Thesis, Politecnicodi Torino, Torino, Italy, 2018.
40) Yang, G.; Jung, W.; Ahn, S.-J.; Lee, D.; Yang, G.; Jung, W.; Ahn, S.-J.; Lee, D. Controlling the Oxygen Electrocatalysis on Perovskite and Layered Oxide Thin Films for Solid Oxide Fuel Cell Cathodes. Appl. Sci.2019, 9, 1030. [CrossRef]
41) NFCRC Tutorial: Solid Oxide Fuel Cell (SOFC). Available online: http://www.nfcrc.uci.edu/3/TUTORIALS/ EnergyTutorial/sofc.html (accessed on 16 October 2018).
42) Barbir, F. PEM Fuel Cells: Theory and Practice, 2nd ed.; Academic Press: Cambridge, MA, USA, 2013; ISBN 9780123877109.
43) Yamarone, R. The Trader's Guide to Key Economic Indicators; Bloomberg Press: Hoboken, NJ, USA, 2004;ISBN 1576601390.

44) Srinivasan, S. Fuel cells: From fundamentals to applications. In Fuel Cells; Springer Science & Business Media: Boston, MA, USA, 2006; pp. 3–25.
45) Wilberforce, T.; El-Hassan, Z.; Khatib, F.N.; Al Makky, A.; Baroutaji, A.; Carton, J.G.; Olabi, A.G. Developments of electric cars and fuel cell hydrogen electric cars. Int. J. Hydrogen Energy 2017, 42, 25695–25734. [CrossRef]
46) Briguglio, N.; Andaloro, L.; Ferraro, M.; Antonucci, V. Fuel Cell Hybrid Electric Vehicles. In Electric Vehicles, The Benefits and Barriers; InTech: London, UK, 2011.
47) Garche, J.; Jörissen, L. Applications of Fuel Cell Technology: Status and Perspectives. Electrochem. Soc. Interface 2015, 24, 39–43. [CrossRef]
48) Bhosale, A.C.; Mane, S.R.; Singdeo, D.; Ghosh, P.C. Modeling and experimental validation of a unitized regenerative fuel cell in electrolysis mode of operation. Energy 2017, 121, 256–263. [CrossRef]
49) Zhang, Y.; Zhang, H.; Ma, Y.; Cheng, J.; Zhong, H.; Song, S.; Ma, H. A novel bifunctional electrocatalyst for unitized regenerative fuel cell. J. Power Sources 2010, 195, 142–145. [CrossRef]
50) Ito, H.; Miyazaki, N.; Ishida, M.; Nakano, A. ScienceDirect Efficiency of unitized reversible fuel cell systems. Int. J. Hydrogen Energy 2016, 41, 5803–5815. [CrossRef]
51) Shukla, A.K.; Jackson, C.L.; Scott, K. The Promise of Fuel Cell-Based Automobiles. Bull. Mater. Sci. 2003, 26, 207–214. [CrossRef]
52) Stefan, J.; Minott, S.J.; Norman, R.; Scott, N.R. Feasibility of Fuel Cells for Energy Conversion on Dairy Farms. In Proceedings of the ASABE Annual Meeting, Sacramento, CA, USA, July 29–August 1 2001.
53) Chu, S.; Majumdar, A. Opportunities and challenges for a sustainable energy future. Nature 2012, 488, 294–303. [CrossRef]
54) Mahmoud, M.; Garnett, R.; Ferguson, M.; Kanaroglou, P. Electric buses: A review of alternative powertrains. Renew. Sustain. Energy Rev. 2016, 62, 673–684. [CrossRef]
55) Hardman, S.; Tal, G. Who are the early adopters of fuel cell vehicles? Int. J. Hydrogen Energy 2018, 43, 17857–17866. [CrossRef]