Proceedings of CONF-MCEE 2026 Symposium: Geomaterials and Environmental Engineering
DOI: 10.54254/2755-2721/2026.MH30525

Comparison Between Hydrogen Fuel Cell Vehicles and Internal Combustion Engine Vehicles

Xuan Wang

College of New Energy and Materials, China University of Petroleum (Beijing), Beijing, China
Wangxuan310@outlook.com

Abstract. Addressing vehicle emissions is a crucial issue in global air pollution control. Hydrogen-powered vehicles are considered the best form of pollution-free transportation. However, due to the development of hydrogen-powered cars not being perfect, the possibility of hydrogen-powered vehicles being widely used is being questioned. This article compares existing hydrogen-powered vehicles and internal combustion engine vehicles in terms of technological maturity, performance advantages of hydrogen fuel cells, pollution levels generated, and production difficulties. Besides, based on the analysis of hydrogen-powered vehicles on the market, this article found that Hydrogen Fuel Cell Vehicles (HFCVs) possess remarkable advantages such as zero pollution, high energy efficiency, and low noise. This represents an excellent solution to replace traditional internal combustion engine vehicles and reduce environmental pollution. Meanwhile, this article points out the disadvantages of HFCV, such as high cost, an undeveloped supply chain, and high safety risk, making them unsuitable for household use. But, as HFCV technology becomes well developed in the future and refueling stations become widespread in the future, HFCV will become the best choice to replace traditional internal combustion engine vehicles and help improve the environment.

Keywords: Hydrogen Fuel Cell Vehicle, Environmental Pollution, Energy Efficiency

1. Introduction

Vehicle pollution emissions are one of the primary sources of air pollution, and reducing them is a key challenge in environmental governance. Hydrogen Fuel Cell Vehicles (HFCVs), as a clean and efficient means of transportation, are regarded as one of the solutions to address vehicle pollution emissions. Currently, countries around the world have made plans for the development of HFCV. In 2020, the United States released the "Hydrogen Project Plan 2020", setting technical and economic targets for hydrogen energy development by 2030 [1]. In March 2022, the Medium and Long-term Plan for the Development of the Hydrogen Energy Industry (2021-2035), jointly issued by the National Development and Reform Commission and the National Energy Administration of China, set the development goal of "maintaining a fleet of approximately 50,000 fuel vehicles by 2025 and deploying a batch of hydrogen refueling stations" [1]. HFCV has become a global development goal with its advantages of no pollution and the ability to fast charge.

DOI: 10.54254/2755-2721/2026.MH30525

However, hydrogen energy still faces significant challenges in its application, that is because hydrogen energy is much more expensive in its production process compared to traditional energy sources. Meanwhile, the high cost incurred during long-distance transportation and storage of hydrogen energy, coupled with the low density of hydrogen refueling stations globally, makes the application of hydrogen energy more challenging.

Therefore, this article will compare the technical advantages and disadvantages of HFCV and traditional internal combustion engine vehicles. By combining the future development and outlook of hydrogen fuel cell technology to explore whether HFCV is capable of replacing traditional internal combustion engine vehicles as an environmentally friendly way of transportation.

2. Hydrogen fuel cell

Hydrogen fuel cells are able to turn chemical fuels into electrical energy. Hydrogen fuel cells can generate water and electric energy through the reaction of oxygen and hydrogen [2]. In practical applications, by oxidizing hydrogen, electrons can flow from the anode to the cathode through the current circuit, thereby generating electricity. This generated electricity can be used to power electrical appliances.

2.1. The structure of a hydrogen fuel cell

A hydrogen fuel cell stack is composed of multiple proton exchange membrane fuel cells (PEM fuel cells) connected in series. A complete hydrogen fuel cell stack is composed of a bipolar plate, membrane electrode assembly, sealing gasket, heat dissipation plate, current collector, insulating plate, end plate, and other components [3].

The fuel cell stack is composed of multiple single fuel cells stacked together, with the fuel cells connected by polar plates. Except for the plates at both ends of the fuel cell stack, the middle plates have one side as an anode and the other side as a cathode, hence they are called bipolar plates. The bipolar plate also serves as an isolator between batteries.

Located between the plates is the membrane electrode assembly, which is also the core part of a hydrogen fuel cell. A complete membrane electrode assembly integrates a proton exchange membrane, a catalytic layer, and a diffusion layer.

The proton exchange membrane is a crucial component in fuel cells, situated in the electrolyte region depicted in Figure 1. It serves as both a separator and an electrolyte. Its diaphragm function is to prevent gas communication between the anode and cathode, thus preventing hydrogen and oxygen from mixing and causing an explosion. Its role as an electrolyte is to allow only protons to pass through while impeding electron transfer, forcing electrons to flow through the external circuit and output electrical energy. As shown in Picture 1, hydrogen ions generated through the anode reaction $H_2 \rightarrow 2H^+ + 2e^-$ enter the cathode region through the proton exchange membrane and react with oxygen in the reaction $2H^+ + 1/2O_2 + 2e^- \rightarrow H_2O$ to produce water. The electrons generated by the anodic reaction are isolated due to the presence of the proton exchange membrane, allowing them to enter the external circuit to supply power and generate electric energy to drive the car.

The catalytic layer is the reaction zone between the cathode, anode, and proton exchange membrane in Figure 1. In hydrogen fuel cells, the role of the catalyst is to facilitate the electrochemical reaction between hydrogen and the oxidant, thereby generating electrical energy. Currently, platinum is widely used as a catalyst due to its high electron transport ability, low overpotential, and suitable hydrogen atom adsorption free energy during water electrolysis. It can gently adsorb hydrogen atoms and desorb hydrogen gas from the surface.

DOI: 10.54254/2755-2721/2026.MH30525

The overall reaction of a hydrogen fuel cell is the reaction between hydrogen and oxygen to produce water. During the power generation process, no pollutants are produced, and as long as hydrogen and oxygen are continuously supplied, electric energy can be continuously provided [4].

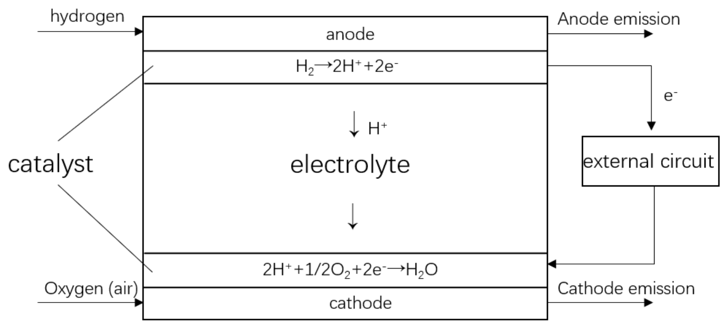

Figure 1. Structure and working principle of proton exchange membrane hydrogen fuel cell (original)

2.2. Operating characteristics of hydrogen fuel cells

Hydrogen fuel cells exhibit excellent operational efficiency. Since the chemical energy of hydrogen can be directly converted into electrical energy in fuel cells, they do not undergo heat engine conversion during this conversion process and are therefore not limited by the efficiency of the Carnot cycle. This working principle enables hydrogen fuel cells to achieve a theoretical electric energy conversion efficiency of over 90% [5]. However, various forms of energy losses occur during actual operation, making it impossible to achieve its theoretical value. Nevertheless, the actual power generation efficiency of fuel cells remains stable at 40% to 60% [5]. When combined with combined heat and power (CHP) technology, its overall efficiency can climb to over 80%, demonstrating extremely high energy utilization efficiency [5].

Hydrogen fuel cells are notably environmentally friendly. During their operation, hydrogen fuel cells produce almost no harmful emissions such as nitrogen oxides and sulfides. Especially when using green hydrogen as fuel, fuel cells can achieve zero emissions during their operational process.

Hydrogen fuel cells exhibit excellent applicability. Since fuel cells generate electricity and heat through electrochemical reactions, they do not require complex friction or rotating parts. This operating mode significantly reduces operational noise, making them highly suitable for household use. Meanwhile, its suitable operating temperature range is 60°C-80°C, and it can be quickly started at low temperatures. Its characteristic of functioning well at room temperature makes it particularly suitable for applications in the transportation sector, especially for power supply in public transportation and vehicles such as automobiles.

2.3. Application examples of hydrogen fuel cell vehicles

Hydrogen fuel cell vehicles have achieved commercial application, covering both passenger cars and commercial vehicles. Representative passenger cars include the Toyota Mirai and the Hyundai NEXO. The NEXO boasts a long range of 720 kilometers, 255 horsepower, and a 0-100 km/h acceleration of only 7.8 seconds [6]. Additionally, it only takes 5 minutes to refuel, making it as fast as refueling a gasoline vehicle. Currently, it is used as a private car, taxi, or official car in Japan, the United States, Europe, and other places. Commercial vehicles are the core battlefield. Modern

DOI: 10.54254/2755-2721/2026.MH30525

XCIENT heavy-duty trucks, China Jiefang/Dongfeng hydrogen fuel cell heavy-duty trucks, and hydrogen-powered buses in multiple regions (such as Beijing and Foshan) have been scaled up and deployed in port transportation, steel logistics, urban bus transportation, and other scenarios, addressing the zero-emission challenge for heavy-load and long-distance needs. In the realm of hydrogen-powered heavy-duty trucks, the H49 hydrogen-powered heavy-duty truck developed by Hypertruck boasts a hydrogen consumption of just 7.8 kilograms per 100 kilometers and a range of over 1,000 kilometers. It is nearing mass production and will provide a novel solution for long-distance trunk logistics [7]. In addition, hydrogen fuel cell technology has been gradually promoted in special vehicles such as logistics vehicles and airport tractors, becoming an important practice in the decarbonization of transportation.

3. Traditional automobile engine

In 1885, German mechanical engineer Karl Benz designed and manufactured the world's first three-wheeled automobile equipped with a 0.85-horsepower single-cylinder gasoline engine [8]. Since then, internal combustion engine vehicles have gradually become the most important means of transportation in people's lives. However, due to the characteristic of internal combustion engines relying on combustion to generate energy, with the widespread use of internal combustion engine vehicles, the air pollution they cause cannot be ignored.

The engine is the power unit of a car; it generates kinetic energy by burning fossil fuels. Most automotive engines employ reciprocating piston internal combustion engines, primarily fueled by gasoline and diesel [8].

The core structure of an automobile engine is a sealed space containing a cylinder, piston, connecting rod, and crankshaft. The mixture of fuel and air is compressed within the cylinder and ignited by a spark plug, generating an explosion that propels the piston to move linearly. The piston transfers this force to the crankshaft via the connecting rod, thereby converting linear motion into rotational motion and generating the torque that drives the vehicle. The entire working cycle is precisely controlled by the valve train, including valves and camshafts, for precise intake and exhaust management. Typically, a turbocharger is used to forcefully inject more air to enhance efficiency. All these components, enclosed within the cylinder block and cylinder head, maintain stable operation through lubrication and cooling systems.

The most common automobile engines in daily life are primarily gasoline engines, and the current state-of-the-art gasoline engines can only achieve an efficiency of 40%. Meanwhile, diesel engines are used in large construction vehicles and some household cars. The typical diesel engine has an efficiency of 40% to 45%, and some top-tier diesel engines can reach an efficiency of 50%.

Traditional internal combustion engines have obvious drawbacks, such as incomplete combustion, low work efficiency, and the production of pollutant gases.

4. Comparison between hydrogen fuel cell vehicles and traditional vehicles

4.1. Performance comparison

Hydrogen-powered vehicles have numerous advantages over internal combustion engine vehicles in terms of performance, as illustrated in Table 1, which compares the performance data of hydrogen fuel cell vehicles and internal combustion engine vehicles. Since hydrogen fuel cells can directly convert hydrogen into electrical energy without the need for conversion between thermal energy and mechanical energy, the energy conversion efficiency of hydrogen fuel cell vehicles can reach 60%

DOI: 10.54254/2755-2721/2026.MH30525

[9]. Meanwhile, the refueling time and driving range of hydrogen-powered vehicles are basically on par with those of internal combustion engine vehicles. Furthermore, hydrogen-powered vehicles exhibit better acceleration smoothness, as motor drives do not suffer from jerky acceleration. Additionally, hydrogen-powered vehicles perform better in low-temperature environments.

Table 1. Performance comparison between electric vehicles and internal combustion engine vehicles (data from Mercedes-Benz and Hyundai brand official websites)

Performance indicators	Hydrogen fuel cell vehicles,	Internal combustion engine vehicles
Energy conversion rate	60%	40%
Endurance range	600-800km	500-700km
Recharging time	5 minutes	3-5 minutes
Acceleration	7.8 seconds (NEXO)	7.44 seconds (Mercedes-Benz C-Class)
Smoothness	No stuttering	With stuttering
Quietness	Silence without noise	Engine noise
Weight	1800kg(NEXO)	1550kg(Mercedes-Benz C-Class)

4.2. Comparison of pollution levels

Internal combustion engine vehicles produce a large amount of pollutants during combustion, mainly including carbon dioxide, which contributes to climate warming, and hydrocarbons, which contribute to the formation of smog. At the same time, under high temperature and pressure conditions, nitrogen oxides that can trigger acid rain and respiratory diseases are generated. Additionally, particulate matter from car emissions can cause asthma and cardiovascular and respiratory diseases, posing a threat to people's health [10]. These pollutants pose a major threat to the environment and human health. Taking China as an example, carbon emissions from transportation account for 10% of the country's total carbon emissions, with road transportation accounting for 74% of the total carbon emissions from transportation [11].

Compared to internal combustion engine vehicles, hydrogen fuel cell vehicles produce only water, which is environmentally friendly and a very clean energy source. If hydrogen fuel cell vehicles use green hydrogen, they can achieve zero carbon emissions throughout their entire lifecycle. At the same time, because hydrogen is non-toxic, even if an accidental leak occurs, there is no risk of environmental pollution [9].

4.3. Comparison of production difficulty

Table 2 compares the production difficulty data of hydrogen fuel cell vehicles and internal combustion engine vehicles. y comparing four aspects, it can be concluded that hydrogen-powered vehicles have production disadvantages.

DOI: 10.54254/2755-2721/2026.MH30525

Table 2. Comparison of production difficulty between hydrogen energy vehicles and internal combustion engine vehicles

Comparative dimension	Hydrogen fuel cell vehicle	Internal combustion engine vehicle
Manufacturing technology	The production of fuel cells involves complex processes such as catalyst coating, proton exchange membrane processing, and precision lamination, which require extremely high consistency.	With a century of technology, our casting, machining, and assembly processes are highly mature and feature a high degree of automation.
Supply chain maturity	There are a few suppliers for core components (fuel cells, air compressors, hydrogen storage tanks), leading to high costs, and most of them operate in small batches.	All components have a large number of tier 1/2 suppliers, resulting in low costs, stable quality, and significant economies of scale.
Production cost control	Due to low production volume, an immature supply chain, and the use of precious metals, the current manufacturing cost is much higher than that of internal combustion engine vehicles.	After a century of optimization and large-scale production, costs have been reduced to an extremely low level, and profit margins are transparent.
Infrastructure dependency	Production and sales are heavily reliant on the construction of hydrogen refueling stations and cannot achieve widespread adoption.	The world boasts a comprehensive and dense network of gas stations, which operate independently from automobile production, leaving no worries behind.

By the end of June 2024, China had built 426 hydrogen refueling stations, with 19 new stations added in the first half of 2024 alone [12]. However, compared to the over 110,000 gas stations that had been built by the end of 2023, the number of hydrogen refueling stations is far from sufficient to support the use and popularization of hydrogen fuel cell vehicles. It is not difficult to see through comparison that more hydrogen refueling stations need to be built for hydrogen fuel cell vehicles to achieve comprehensive popularization.

4.4. Future development prospects of hydrogen fuel cell technology

China's hydrogen-powered vehicles have experienced rapid development in recent years. By the end of 2023, the number of such vehicles in operation had reached 13,000, primarily targeting commercial applications such as buses, refrigerated trucks, delivery vehicles, and heavy-duty mining trucks [13]. However, commercial operation in China has just begun, mainly due to three reasons. Firstly, China's fuel cell technology is not mature enough, and its response speed and durability are insufficient to meet the usage demands of passenger vehicles. Secondly, compared to fuel-powered vehicles, hydrogen-powered cars are expensive and have a low cost-performance ratio, making them an unattractive choice for citizens. Lastly, the insufficient number of hydrogen refueling stations cannot support the daily use of hydrogen passenger vehicles.

In the current application of hydrogen energy, China has adopted a hybrid technology approach, with mainstream hydrogen fuel cell vehicles in China utilizing a combination of large fuel cell stacks and large batteries [14]. This design pattern can reduce the power demand on fuel cells and minimize the wear and tear on their lifespan, potentially doubling the lifespan of city buses. China's hydrogen energy vehicle research and development will continue to uphold this excellent and efficient design philosophy and further refine battery technology. Under this design model, which is

DOI: 10.54254/2755-2721/2026.MH30525

more tailored to the needs of China's hydrogen energy vehicles, production will be increased, enabling hydrogen energy vehicles to be more widely used in urban transportation.

The future development of hydrogen fuel cell vehicles in China will primarily focus on commercial vehicles, with passenger vehicles as a secondary focus. In the future, the number of commercial vehicles will further increase, with cleaner hydrogen-powered commercial vehicles replacing traditional diesel vehicles to reduce environmental pollution. In the field of passenger vehicles, by further enhancing battery power density, increasing on-board hydrogen storage capacity, and boosting the construction of hydrogen refueling stations, the daily use of hydrogen-powered vehicles can be turned from a vision into a reality. The development of hydrogen-powered vehicles is highly dependent on the reduction of green hydrogen costs, the popularization of hydrogen refueling networks, and breakthroughs in core technologies. It is a vast, systematic project involving energy, transportation, and infrastructure. It will take a long time for the comprehensive popularization of hydrogen-powered vehicles to be achieved, as it requires substantial infrastructure development and technological breakthroughs. In the future, hydrogen passenger vehicles will be first introduced for household use in large cities with more comprehensive hydrogen refueling station infrastructure. Subsequently, with the widespread availability of hydrogen refueling stations, hydrogen vehicles will be widely adopted for household use nationwide.

5. Conclusion

Compared to traditional internal combustion engines, hydrogen-powered vehicles have significant advantages, such as high energy efficiency, low noise, and zero pollution, making them the cleanest means of transportation. They are also a powerful way to mitigate global pollution and achieve carbon neutrality. Despite the obvious advantages of hydrogen-powered vehicles, there are still many difficulties to overcome before they can fully replace internal combustion engine vehicles. Firstly, although hydrogen is widely available, the cost of the hydrogen supply chain remains high, and the construction of the relevant industrial chain is still imperfect. Hydrogen-powered vehicles are also unable to achieve large-scale production due to high production costs, and the risk of explosion associated with compressed hydrogen makes them even more dangerous to use. Currently, hydrogen fuel cell vehicles have begun to be applied in practice with the support of national policies and the efforts of enterprises. Vehicles such as hydrogen-powered buses have been put into daily use.

In general, hydrogen fuel cell vehicles cannot replace internal combustion engine vehicles in the short term, but they are currently mainly applied in work vehicles and have achieved remarkable results. With the improvement of the industrial chain and the breakthrough in hydrogen storage technology, hydrogen fuel cell vehicles are expected to replace internal combustion engine vehicles as a clean and efficient means of transportation and become a solution to environmental pollution.

References

[1] Li, K., Yao, Z., Wang, J., Wu, Z., & Ding, Z. (2024). Prospects for the development of fuel cell vehicle policies at home and abroad.
[2] Li, Y. (2024). Current status and trends of hydrogen fuel cell vehicles development in China. Light Vehicle Technology, 9, 52–55.
[3] Hydrogen fuel cell stack and system. (n.d.). Pengfan Technology.
[4] Chen, H. (2005). Hydrogen energy and proton exchange membrane fuel cells. Ordnance Automation, 24(1), 3.
[5] Gao, X., Li, Z., Wang, L., Chai, Q., Xiao, K., & Yin, J. (2025). Fuel cell technology and its application in new energy systems. Southern Energy Construction.
[6] Hyundai Motor Company. (n.d.). Official website. https: //www.hyundai.com

DOI: 10.54254/2755-2721/2026.MH30525

[7] Hydrogen-powered heavy-duty trucks: A new “zero-carbon” force that disrupts trunk logistics. (n.d.). Longxiang Zhilian.
[8] Peng, R., & Liu, X. (n.d.). Automobile Engine Structure and Maintenance. Publishing House of Electronics Industry.
[9] Advances in Transportation and Health: Tools, Technologies, Policies, and Developments. (2020). pp. 59–104.
[10] Zhuo, G., Zhou, J., Wang, Y., et al. (2024). Research on strategies for reducing traffic emissions under the carbon neutrality goal. Auto Weekly, 2024(2), 55–57.
[11] Hosseini, S. E., & Butler, B. (2019). An overview of development and challenges in hydrogen powered vehicles. International Journal of Green Energy, 17(1), 13–37.
[12] SINOCHEM New Network. (2024). China ranks first in the world in the number of hydrogen refueling stations. Modern Chemical Industry, 2024(7).
[13] Chai, M. (2024). Current development status and future outlook of hydrogen energy vehicles. China Petrochemical, 2024(5), 37–40.
[14] Peng, Y. (2025). The significant role of hydrogen energy in the energy revolution. Energy and Energy Conservation, 2, 13–17.