Development Status and Path Analysis of Fuel Cell Vehicles

Xingyue Xie, Chujian Guo*, Ruiyan Wang, Zifang Tang, Leyu Su
Wuhan Business University, Wuhan, Hubei, China

Abstract: This paper systematically studies the development status and future path of fuel cell vehicles (FCVs). Through literature analysis and data comparison, it sorts out the technological progress of proton exchange membrane fuel cells (PEMFCs) in key materials, system integration, and manufacturing processes, and constructs a three-level technical evaluation system from materials to systems. Research shows that the performance improvement of key components has driven a significant cost reduction: the service life of proton exchange membranes has increased from 2000 hours to 6000 hours, platinum loading has decreased by 70%, and the system cost has dropped substantially. Based on the industrial data of major global economies, an industrial development model of "policy-driven - technological breakthrough - scenario implementation" is summarized. It is predicted that by 2030, the market scale of commercial vehicles and passenger vehicles will reach 500,000 units/year and 300,000 units/year respectively. Addressing the current challenges such as technical bottlenecks, cost pressures, and backward infrastructure, countermeasures including strengthening technological research, expanding industrial scale, improving infrastructure, and optimizing the policy system are proposed to provide reference for the development of the fuel cell vehicle industry.

Keywords: Fuel Cell; Technological Progress; Automobile Industry; Carbon Neutrality; Large-Scale Promotion

1. Introduction

On September 22, 2020, President pointed out at the 75th Session of the United Nations General Assembly that the green and low-carbon transition is the general direction of global economic development. China will adopt more powerful policies and measures to strive for peak carbon dioxide emissions before 2030 and carbon neutrality before 2060. Against the backdrop of "carbon neutrality", the green and low-carbon transition in the transportation sector lies in vigorously developing new energy vehicles [1]. Compared with battery electric vehicles (BEVs), fuel cell vehicles have unique advantages such as fast hydrogen refueling, long driving range, and strong adaptability to low-temperature environments. They are irreplaceable especially for long-distance transportation scenarios and will become an important direction for the future development of new energy vehicles. At present, the development of fuel cell vehicles has achieved remarkable results but also faces certain challenges. This paper sorts out the current status and prospects of fuel cell vehicle development, and puts forward countermeasures and suggestions based on China's "dual carbon" goals and industrial development reality, so as to provide reference for industrial development and policy formulation.

2. Current Development Status of China's Fuel Cell Vehicle Industry in the Global Context

With the gradual maturity of fuel cell technology, the global fuel cell vehicle industry has entered a critical stage of commercial demonstration and large-scale promotion. Major economies have successively introduced industrial policies, increased R&D investment, and promoted the construction of hydrogen refueling infrastructure, forming a global industrial pattern centered on China, Japan, South Korea, the United States, and Europe.

2.1 Progress in Core Fuel Cell Technologies

The rapid development of the fuel cell vehicle industry is inseparable from the continuous breakthroughs in core technologies. In recent years, significant progress has been made in fuel cell technology in key materials, system integration, and manufacturing processes, laying a solid foundation for commercial promotion.

In the field of key materials that determine battery performance and cost, technological progress is particularly prominent. Proton exchange membranes have evolved from relying on imported perfluorosulfonic acid membranes in the early stage to a stage where modified perfluorinated membranes and new non-fluorinated membranes coexist. Their service life has increased significantly from about 2000 hours in 2015 to more than 6000 hours, with greatly improved high-temperature stability and localization level. Catalyst technology has focused on reducing dependence on the precious metal platinum. Through alloying and structural optimization, platinum loading has decreased from 0.4 mg/cm² to less than 0.12 mg/cm², a reduction of 70%, while important research progress has also been made in non-platinum catalysts. As the mainstream choice for automotive fuel cells, bipolar plates have continuously improved in surface coating technology and precision processing processes, resulting in significantly enhanced corrosion resistance and a cost reduction from 1500 yuan/m² to about 450 yuan/m².

At the system integration level, the power density of fuel cell stacks has increased from 3 kW/L in 2015 to 6-8 kW/L at present, with some leading products exceeding 10 kW/L, and the low-temperature startup capability has been enhanced to -30℃ [2]. The optimization of the water-heat management system has also ensured the stable operation of fuel cell stacks under different operating conditions.

In addition, the automation and standardization of manufacturing processes have been greatly improved. For example, membrane electrode assemblies (MEAs) adopt roll-to-roll continuous production technology, which increases production efficiency by more than 10 times [3] and effectively controls product consistency. These collective breakthroughs in core technologies have directly driven a significant reduction in fuel cell system costs and an improvement in reliability, forming the key technical foundation for the fuel cell vehicle industry in China and even the world to move from demonstration operation to large-scale development.

2.2 Differences in Industrial Policies between China and Other Countries

Countries around the world have adopted differentiated fuel cell vehicle industrial policies based on their own energy structures and industrial systems, mainly focusing on technology development support, demonstration operation subsidies, hydrogen refueling station construction, and promotion and application subsidies.

As a pioneer in fuel cell technology, Japan formulated the "Next-Generation Vehicle Strategy" in 2009, identifying fuel cell vehicles as the primary development direction. In 2023, the "Green Growth Strategy" proposed to promote the construction of a low-carbon ecosystem with hydrogen energy as the core of the "Next-Generation Vehicle Strategy" [4], aiming to form a market scale of 200,000 fuel cell vehicles and 1000 hydrogen refueling stations by 2030. It provides subsidies of up to 2 million yen for fuel cell vehicle purchasers and 300-500 million yen per station for hydrogen refueling station construction. Currently, Japan has the densest hydrogen refueling station network in the world, and models such as the Toyota Mirai and Honda Clarity have achieved commercial sales.

South Korea has built a complete industrial chain system of "technology R&D - vehicle manufacturing - infrastructure" centered on Hyundai Motor, and issued the "Hydrogen Economy Development Roadmap". It aims to have 1.1 million fuel cell vehicles and 1200 hydrogen refueling stations by 2030, and provides substantial subsidies for fuel cell vehicles in the commercial vehicle sector, with a subsidy of about 100 million won per fuel cell bus. At present, South Korea ranks first in the world in the ownership of fuel cell commercial vehicles, and Hyundai XCIENT fuel cell heavy trucks have been exported to European and American markets.

China has included fuel cell vehicles in the "New Energy Vehicle Industry Development Plan (2021-2035)", targeting more than 100,000 vehicles in ownership and 1000 hydrogen refueling stations by 2025. Domestically, through the "Ten Cities, Thousand Vehicles" demonstration and promotion model, demonstration operations are mainly carried out in key regions such as Shanghai, Beijing, Guangdong, and Shandong. Special fund subsidies are provided for fuel cell vehicle purchases, hydrogen refueling station construction, and R&D of key materials for fuel cell vehicles. In addition, the National Hydrogen Energy Industry Innovation Center has been established to build a highland for industry-university-research collaborative innovation and accelerate the localization process of key technologies.

The United States provides tax credits for fuel cell vehicles through the Inflation Reduction Act and invests 3 billion US dollars in hydrogen refueling infrastructure construction. The European Union has released the "Hydrogen Strategy", proposing to have 400 hydrogen refueling stations and 1 million fuel cell vehicles in ownership by 2030, focusing on the application of fuel cell vehicles in commercial vehicles and public transportation.

2.3 China's Product Layout Based on the Global Market Scale

At present, the global fuel cell vehicle market is developing rapidly. In 2024, global fuel cell vehicle sales reached 38,000 units, a year-on-year growth rate of 65%, of which commercial vehicles accounted for more than 60%, becoming an important driving force for the industry's development.

In terms of enterprise layout, Japanese and South Korean enterprises such as Toyota, Hyundai, and Honda are among the top in passenger vehicles. The second-generation Toyota Mirai has a driving range of up to 650 kilometers, takes only 3 minutes to refuel with hydrogen, and has accumulated sales of 20,000 units. Hyundai Motor focuses on commercial vehicle scenarios, such as the XCIENT fuel cell heavy truck, which has sold nearly 10,000 units and holds a market share of more than 50% in Europe.

Chinese enterprises have performed prominently in the fuel cell commercial vehicle sector. Enterprises such as Yutong Bus, Sinohytec, and Weichai Power have formed a complete industrial chain layout. Yutong fuel cell buses have been put into demonstration operation in more than 20 cities nationwide, with a cumulative operating mileage exceeding 100 million kilometers. In the passenger vehicle sector, enterprises such as SAIC Maxus and GAC Aion have launched fuel cell passenger vehicle products with a driving range exceeding 600 kilometers, gradually entering the stage of commercial promotion.

In addition, as mainstream global automakers accelerate their layout in the fuel cell vehicle industry, Mercedes-Benz and Volvo have jointly developed fuel cell commercial vehicles, BMW and Toyota are co-developing fuel cell passenger vehicles, and General Motors and Honda are carrying out joint development of fuel cell systems. Various forms of competition and cooperation coexist, promoting the rapid development of the fuel cell vehicle industry.

2.4 Difficulties in Hydrogen Refueling Infrastructure Construction from the Perspective of China and Global Status

Hydrogen refueling infrastructure is an indispensable condition for the large-scale commercialization of fuel cell vehicles. According to current data, nearly 1000 hydrogen refueling stations have been built worldwide, showing an overall trend of "regional concentration and gradual expansion". By the end of 2024, the total number of global hydrogen refueling stations was 1000, including 420 in Europe, 400 in Asia, and 150 in North America, mainly concentrated in these three regions.

Japan has the highest density of hydrogen refueling stations, with about 2.7 stations per 10,000 square kilometers, mainly concentrated in Tokyo, Osaka, and other places. South Korea's hydrogen refueling stations are mostly used for commercial vehicles, and currently about 60% of them are located in ports, logistics parks, and other areas. China has the fastest construction speed of hydrogen refueling stations. In 2024, 200 new hydrogen refueling stations will be added, bringing the cumulative number to 350 [5], mainly centered on demonstration regions such as Guangdong, Shandong, and Shanghai. However, the average utilization rate of hydrogen refueling stations is about 30%, resulting in a situation of "few vehicles and idle stations". Europe mainly has public hydrogen refueling stations, serving passenger and commercial vehicles, with Germany, France, Norway, and other European countries having a large number of hydrogen refueling stations.

The main difficulties include three aspects: first, high construction costs, with the cost of building a single hydrogen refueling station ranging from 20 to 30 million yuan; second, high hydrogen storage and transportation costs; third, differences in hydrogen refueling station construction standards. To reduce the construction and operation and maintenance costs of hydrogen refueling stations, it is necessary to further use new technologies to reduce costs and increase efficiency, and achieve internationalization of hydrogen refueling standards through international cooperation.

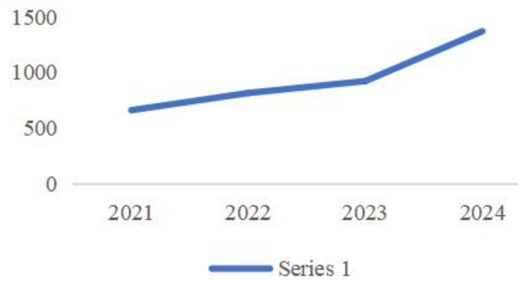

Figure 1. Growth Trend of Global Hydrogen Refueling Station Quantity (2020-2024) (Unit: Station)

3. Development Prospects and Countermeasures of Fuel Cell Vehicles

3.1 Development Prospects

3.1.1 Continuous expansion of application scenarios

Fuel cell vehicles will be applied more and more widely, especially heavy trucks, buses, and logistics vehicles, whose requirements for driving distance and refueling time are highly consistent with the characteristics of fuel cell vehicles. According to statistics and predictions, by 2030, global sales of fuel cell commercial vehicles are expected to reach about 500,000 units, accounting for more than 5% of the market. In the passenger vehicle sector, due to technological progress and cost reduction, fuel cell passenger vehicles will become a strong supplement to battery electric vehicles in the future, occupying a certain market share in long-distance driving or cold regions. It is expected that global sales of fuel cell passenger vehicles will reach 300,000 units by 2030. In addition, fuel cell vehicles are being applied in more new scenarios such as ships, rail transit, and construction machinery. For example, Hyundai Motor has launched fuel cell ships, and CRRC has developed fuel cell rail transit vehicles. The application scenarios of the fuel cell industry have expanded from road transportation to multiple fields, and the market space continues to expand [6].

3.1.2 Continuous optimization of technical routes

Fuel cell technology will develop towards the direction of "high power density, long service life, and low cost". It is expected that by 2030, the power density of fuel cell stacks can exceed 15 kW/L, the service life can exceed 10,000 hours, the platinum loading can be lower than 0.1 mg/cm^2, and the cost of fuel cell systems can be reduced to 5000 yuan/kW, which can be comparable to the cost of traditional internal combustion engine power systems [7]. At the same time, against the background of the gradual integration of fuel cells with battery electric and hybrid technologies, the hybrid combination of "fuel cell + power battery" will become the mainstream configuration. It can not only meet the demand for long driving range but also effectively improve the vehicle's braking energy recovery rate, thereby achieving the effect of saving operating costs.

3.1.3 Gradual formation of industrial pattern

The global fuel cell vehicle industry may present a development pattern of "Asia-led, Europe-US coordinated". China, Japan, and South Korea have achieved world-leading advantages in technology R&D, vehicle manufacturing, and key materials respectively, while Europe and the United States give full play to their own advantages and maintain leadership in hydrogen refueling infrastructure construction and business model innovation. Benefiting from the complete industrial chain, huge market demand, and policy support, China's fuel cell vehicle market is likely to grow into the world's largest fuel cell vehicle market. It is expected that by 2030, the ownership of fuel cell vehicles in China may reach 500,000 units, accounting for more than 50% of the global total. At the same time, domestic enterprises will accelerate their internationalization pace, and speed up the R&D process of fuel cell stacks and core materials, automotive fuel cell engines, and hydrogen fuel vehicles overseas [8].

3.2 Faced Challenges

3.2.1 Unresolved technical bottlenecks

Although great progress has been made in fuel cell technology, there are still some intractable key technical issues: the long-term stability of proton exchange membranes under high-temperature and high-humidity conditions is poor, the long-term durability and anti-poisoning ability of catalysts are insufficient, and the corrosion of bipolar plates has not been fully solved. In addition, the fuel cell system has low integration and reliability and is not adaptable to harsh operating conditions [9].

3.2.2 Persistently high costs

The cost of fuel cell vehicles is still much higher than that of traditional fuel vehicles and battery electric vehicles. Currently, the price of domestic fuel cell commercial vehicles is about 3-4 times that of equivalent fuel vehicles, and the price of passenger vehicles is about twice that of battery electric vehicles [10]. The main reasons for the high cost are the high cost of key materials, small production scale, and complex manufacturing processes. There is significant pressure to reduce costs in the short term.

3.2.3 Backward hydrogen refueling infrastructure

The backward construction of hydrogen refueling infrastructure is the core bottleneck restricting the large-scale promotion of fuel cell vehicles. The number of global hydrogen refueling stations is still unable to meet market demand. Moreover, hydrogen refueling stations have high construction costs and low operating efficiency. Hydrogen storage and transportation are mainly based on high-pressure gaseous storage and transportation, which are costly and energy-intensive. New technologies such as liquid hydrogen storage and solid hydrogen storage are not yet mature. The lack of unified hydrogen refueling standards also affects the convenience of cross-regional driving.

3.2.4 Strong policy dependence

The development of the fuel cell vehicle industry currently relies on government subsidies. With the gradual withdrawal of subsidies globally, there will be significant market competition pressure. Industrial policies and technical standards vary from country to country, affecting the globalization process of the fuel cell vehicle industrial chain. It is necessary to coordinate policies and standards to create a favorable competitive environment.

3.3 Development Countermeasures

Fuel cell technology is an efficient and clean new energy technology that can be used in the transportation sector. It has broad prospects in transportation and is also an important path to achieve "carbon neutrality" [11]. To address the problems in the development process, the following countermeasures are proposed:

3.3.1 Strengthen core technology research and enhance independent innovation capabilities

Core measure: Establish a public testing and certification platform for key materials and components oriented towards engineering applications. The technical goals in the current countermeasures require specific carriers for implementation. It is recommended that the national government take the lead, jointly with leading enterprises, universities, and research institutes, to establish a national-level testing and certification center for key fuel cell materials and components. Instead of conducting basic research, this center will focus on providing unified durability testing (such as formulating an accelerated stress test standard of >30,000 hours), process scaling pilot tests (from gram-level to kilogram-level), and third-party certification services for laboratory results, aiming to solve the "valley of death" problem from "paper" to "product". This initiative can avoid the redundant construction of high-cost test lines by various enterprises, accelerate the screening and industrialization of optimal technical routes, and provide solid support for achieving specific goals such as "increasing the service life of commercial vehicle stacks to more than 30,000 hours".

Simultaneous promotion: Continue to increase R&D investment, focus on tackling "bottleneck" technologies such as low-platinum/non-platinum catalysts and long-life proton exchange membranes, and improve the technical standard system for the entire industrial chain to enhance international discourse power.

3.3.2 Expand industrial scale and reduce comprehensive costs

Core measure: Driven by scenario innovation, implement "10,000-unit level" centralized procurement of key models in demonstration city clusters. Simply calling for large-scale development is insufficient to quickly reduce costs. It is recommended that under the framework of the "Ten Cities, Thousand Vehicles" demonstration city clusters, for commercial vehicle models with clear demand and high standardization such as sanitation vehicles, intercity logistics vehicles, and buses on specific routes, the competent authorities coordinate to launch an annual "10,000-unit level" joint centralized procurement by the government and enterprises. This deterministic order of "trading volume for price" will greatly encourage upstream component enterprises such as membrane electrode assemblies and bipolar plates to invest in automated production lines, enabling a rapid reduction in fuel cell system costs within 2-3 years. This will open up a key path to achieve the goals of "reducing the system cost to below 1000 yuan/kW" and "reducing the price of hydrogen fuel heavy trucks to within 800,000 yuan".

Simultaneous promotion: Continue to promote the mass production of key materials and industrial chain collaboration, and establish an integrated development model of the entire industrial chain covering "hydrogen production - storage - transportation - refueling - application".

3.3.3 Improve infrastructure network and enhance hydrogen refueling convenience

Core measure: Prioritize the layout of "oil-hydrogen-electricity" integrated energy stations along national trunk highways and at logistics hubs. The construction of hydrogen refueling stations should not be scattered. The most urgent task at present is to open up cross-regional trunk transportation channels for commercial vehicles such as fuel cell heavy trucks. Therefore, the layout of infrastructure should be strategically targeted. Priority should be given to building integrated energy stations with refueling, hydrogen refueling, and charging functions at key service areas of national trunk highways. This can not only quickly improve network coverage efficiency and solve users' "range anxiety" but also significantly reduce the construction and operation costs of individual stations by sharing land, power supply, and other facilities, directly addressing the challenge of "backward hydrogen refueling infrastructure". As shown in Figure 1, the number of global hydrogen refueling stations continues to grow, but networked layout is crucial.

Simultaneous promotion: Continue to optimize the hydrogen energy supply system, make full use of industrial by-product hydrogen, develop renewable energy-based hydrogen production, and improve the operating efficiency of hydrogen refueling stations.

3.3.4 Optimize policy support system and create a favorable development environment

Core measure: Design a long-term policy tool that smoothly transitions from "vehicle purchase subsidies" to "carbon emission reduction benefit incentives". The long-term development of the industry cannot rely on one-time subsidies. It is recommended to study and formulate a "carbon emission reduction credit" trading or incentive policy based on the actual operation data of vehicles. Vehicles record driving mileage and emission reductions through a data platform, and the government or a third party provides incentives based on the value of the credits. This policy can shift the focus of support from pre-purchase to low-carbon operation throughout the entire life cycle, encouraging technological progress to reduce hydrogen consumption [12]. Even after the withdrawal of purchase subsidies in the future, the industry can achieve self-sustainability through environmental value, forming a virtuous development cycle and effectively reducing dependence on subsidies.

Simultaneous promotion: Continue to improve fiscal and financial support policies, strengthen the construction of talent teams, and provide sustained momentum for industrial development.

Through the systematic promotion of the above measures, it is expected that by 2030, China's fuel cell vehicle industry will achieve large-scale development, key core technologies will reach the international advanced level, the independent controllability of the industrial chain will be significantly enhanced, and strong support will be provided for the green and low-carbon transition of the transportation sector.

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References

[1] Liu K G, Li Q Q, Guo T, et al. Green Development of Rail Transit under the "Dual Carbon" Goals. Municipal Engineering Technology, 2026, 44(01): 278-285.

[2] Teng Z Y, Han M F. Analysis of Technical Hotspots Related to Ammonia as an Alternative Fuel Under the Carbon Neutrality Vision. Sino-Global Energy, 2022, 27(09): 16-22.

[3] Wang Y. Consolidating the Foundation for the Healthy Development of the New Energy Vehicle Industry. Guizhou Political Consultative Conference News, 2026-01-22(003).

[4] Huang L, Xie S J, Guo Y F, et al. Integration of Carbon Peaking and Carbon Neutrality into Courses Related to Environmental Pollution Control. Guangdong Chemical Industry, 2024, 51(19): 242-244.

[5] Wei H Q. Insights into Four Key Trends of China's Automobile Industry in 2026. Nanfang Daily, 2026-01-23(B02).

[6] Hu W W. Application Scenario Analysis, Challenges and Prospect Outlook of Hydrogen Fuel Cell Vehicles. Automobile Knowledge, 2026, 26(02): 17-19.

[7] Zhao S J, Zhang Z M, Wang J B, et al. Development Trends and Bottleneck Issues of Key Technologies for Fuel Cell Vehicles. Journal of Tongji University (Natural

Science Edition), 2025, 53(S1): 438-443.

[8] Shen Y H, Liu X H, Fang Y H. Research on the Collaborative Development Mechanism of the Hydrogen Fuel Cell Industry Chain. Industrial Innovation Research, 2025, (22): 31-33.

[9] Li R. Key Technical Bottlenecks and Industrialization Promotion Strategies of Hydrogen Fuel Cell Vehicles. Automobile Knowledge, 2026, 26(02): 1-4.

[10]Liu S. Carbon Emission Reduction Technology Paths for the Integration of Natural Gas Power Generation and New Energy under the "Dual Carbon" Goals. Oil & Gas and New Energy, 2025, 37(04): 83-88.

[11]Lu P. Efficiency Improvement Strategies and Control Methods of New Energy Vehicle Drive Motors. Automobile Knowledge, 2026, 26(02): 20-22.

[12]Tian P. Carbon Sink Turned into "Gold" to Cultivate Green Development. Securities Daily, 2026-01-22(A01).

