Study on the Evaluation of China's Fuel Cell Vehicle Commercialization Progress

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Abstract: An industrial progress evaluation mode is built, through which current commercialization progress of fuel cell vehicle industry in China is assessed. The research results indicate that China's fuel cell vehicle technology level and promotion scale have achieved significant progress, meeting the conditions for large-scale deployment. Typical application scenario characteristics are gradually becoming clearer. The overall industry development has entered the adjustment phase of the promotion period. It is imperative to promote the supply of hydrogen energy, increase wider and multi-regional scenario applications, further enhance product competitiveness and promote high-quality development of the industry.

1. Introduction

The development of hydrogen energy and fuel cell vehicles (FCVs) has become a strategic consensus among major global economies[1-3]. Over 40 countries and regions worldwide have introduced relevant strategic plans and specific initiatives to accelerate the construction of hydrogen energy application systems[4,5]. These efforts include reducing hydrogen costs, accelerating the development of hydrogen refueling infrastructure, and promoting the application of green hydrogen in transportation and other sectors[6,7].

China is firmly advancing the national strategy for new energy vehicles (NEVs), achieving historic milestones in industrial development. Through continuous support since the 10th Five-Year Plan, particularly following the initiation of the 'subsidy replacement by awards' demonstration program, China's fuel cell vehicle industry has experienced rapid development[8-10]. To summarize the key issues and valuable experiences in industrial development, consolidate the foundation, expand the market, and enhance quality and efficiency, it is necessary to conduct a comprehensive readiness evaluation of the development process of the hydrogen fuel cell vehicle industry. This involves an in-depth analysis of the industrial development stages, summarizing promotion experiences, and proposing development recommendations to support the accelerated commercialization of the industry.

The study proposes a scientific evaluation model for the commercial readiness of hydrogen FCVs based on research from over 90 upstream and downstream units and more than 130 industry experts in the industry chain. The evaluation is conducted from five dimensions - policy, technology, market, and others - reflecting the actual process of the industry and proposing reasonable development suggestions, providing guidance and support for the rapid development of the industry.

2. Commercialization Readiness Levels

The commercialization readiness status of hydrogen fuel cell vehicles can be specifically described as follows: the industrial chain and supply chain are fundamentally established; product performance satisfies multi-scenario requirements and achieves mass application; policy, infrastructure, and other support systems are well developed; the industry demonstrates a market-

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driven and rapid growth trend. Taking this as the development goal, and combining with the characteristics and laws of different stages of industrial development, the commercial readiness level of hydrogen fuel cell vehicles is divided into 10 periods, namely the incubation period, germination period, breeding period, start-up period, promotion period, sales lifting period, acceleration period, commercialization ready period, mature period, renewal period. The main characteristics of each development period are presented in Table 1.

Table 1 Commercialization readiness level of hydrogen fuel cell vehicles.

Development level	Key characteristics
Incubation period	Representative products pass pilot testing
Germination period	Representative products enter mass production and rollout
Breeding period	Demonstration applications of individual projects conducted; infrastructure construction progressing slowly
Start-up period	Demonstration applications conducted across multiple regions
Promotion period	Mass promotion and application; acceleration of infrastructure construction
Sales lifting period	Product optimization and iteration; mature business models begin to emerge; product advantages start to manifest
Acceleration period	Business models validated; widespread product application and accelerated promotion
Commercialization ready period	Market-driven, achieving large-scale deployment, well-established infrastructure layout, and high product growth
Mature period	Industry chain-driven, with increasing concentration and leading enterprises emerging
Renewal period	Market supply and demand approaching saturation, growth rate slowing, further increase in industry concentration, overall entering an adjustment and renewal phase

3. Readiness Evaluation System

Based on five comprehensive dimensions affecting commercialization readiness—policy, technology, industrial chain and supply chain, hydrogen energy supply, and market—a three-tier evaluation indicator system for the commercialization readiness of hydrogen fuel cell vehicles has been established, as detailed in Table 2.

A 3-level evaluation index system for the commercial readiness of hydrogen fuel cell vehicles is constructed based on five comprehensive dimensions that affect commercial readiness: policy, technology, industrial chain supply chain, hydrogen energy supply, and market. Please refer to Table 2 for details.

Table 2 Hydrogen fuel cell vehicle commercialization readiness indicator system.

<table>
<tr><th>Primary indicators</th><th>Secondary indicators</th><th>Tertiary indicators</th><th>Indicator definition</th></tr>
<tr><td rowspan="6">Policy</td><td rowspan="2">Strategic planning</td><td>Strategic planning</td><td rowspan="6">Status of national and local policy releases, related supporting measures and their implementation, continuity of policy improvements, and exploration of innovative policies, etc.</td></tr>
<tr><td>Industrial action plan</td></tr>
<tr><td rowspan="2">Support policies</td><td>Fiscal and tax</td></tr>
<tr><td>R&D</td></tr>
<tr><td rowspan="2">Management policies</td><td>Demonstration</td></tr>
<tr><td>Safety regulation</td></tr>
<tr><td rowspan="4">Technology</td><td rowspan="3">Vehicle technology</td><td>Driving range</td><td>Comparison of actual driving range between fuel cell vehicles and conventional vehicles of the same model.</td></tr>
<tr><td>Hydrogen consumption</td><td>Hydrogen consumption per 100 km for passenger cars/12-meter buses/49-ton trucks (kg/100 km).</td></tr>
<tr><td>Lifetime</td><td>Vehicle lifetime for passenger cars/commercial vehicles (10,000 km).</td></tr>
<tr><td>Fuel cell stack technology</td><td>Fuel cell stack lifetime</td><td>Fuel cell stack lifetime for passenger cars/commercial vehicles (hours).</td></tr>
</table>

Primary indicators	Secondary indicators	Tertiary indicators	Indicator definition
		Stack cost	Stack lifetime for passenger/commercial vehicles (yuan/kW).
	Core basic materials	Proton exchange membrane	According to the national standard "GB/T 22900-2022 General Principles for Evaluation of Scientific and Technological Research Projects" for rating[11].
		Catalyst	
		Gas diffusion layer	
		Bipolar plate	
	Onboard hydrogen storage system	Hydrogen storage cylinder	
		High-pressure valve assembly	
Industry chain	Industry chain level	Industry concentration	Production and sales enterprises of complete vehicles, systems, fuel cells, onboard hydrogen storage products, and other key components
		Industry chain completeness	Degree of autonomy and overall technological level of core links in the industrial chain
	Supply chain level	Supporting supply level	Overall scale and collaborative status of the supply chain
Hydrogen supply	Hydrogen refueling station	Number of hydrogen refueling stations	Number of hydrogen refueling stations, their layout, and alignment with hydrogen demand from concurrently promoted vehicles
		Hydrogen refueling station matching degree	
	Hydrogen supply	Green hydrogen supply	Proportion of green hydrogen in hydrogen refueled by in-use vehicles
		Hydrogen cost	Comparison of hydrogen cost with fuel cost of equivalent conventional vehicles
Market	Promotion and application	Market development potential	Demand space for this type of product in the target application market
		Application scenario matching	Maturity of application scenarios and product matching status
	Marketing capability	After-sales service	Scale, layout, and matching with vehicles of fixed service network
		Finance and insurance	Presence of dedicated insurance types and their alignment with vehicle operation risks, maintenance costs, vehicle value, and other factors
		Business model	Clarity of elements including customer base, cooperation channels, resource costs, operating income, business model cases, and replicability
	Product competitiveness	Vehicle cost	Comparison of average purchase cost with conventional fuel vehicles of the same model

4. Industrial Progress Evaluation

Over 90 organizations and more than 130 industry experts from the industrial chain have conducted comprehensive evaluation and scoring from five dimensions such as policy, technology and market. The results show that the overall fuel cell automobile industry is in the adjustment phase of promotion period. The details are as follows: 1) The top-level planning clearly leads the development direction, and some management policies still need to be improved; 2)Complete vehicle products are basically ready, while core materials and components still require intensified research and development; 3) The industrial chain is essentially complete, and the market structure and supply level are in the initial stage; 4) Significant progress has been made in hydrogen refueling station construction, yet supply stability and economic viability urgently require enhancement; 5)

Market development is in the initial stage, and business mode exploration and application measures shall be strengthened.

4.1. Policy Readiness Evaluation

Firstly, in terms of strategic planning. The national top-level plan for new energy vehicles and hydrogen energy has played a good guiding and supporting role in the development of the industry. more than 20 provinces or municipalities directly under the central government, and over 50 cities across the country have released regional hydrogen and fuel cell vehicle development plans and supporting plans, proposing clear development goals and paths, and implementing and promoting national strategies. Secondly, in terms of supporting policies. Strong support from national fiscal and taxation policies, as well as demonstration measures, has resulted in significant progress in industrialization. The national new energy vehicle purchase tax reduction policy and national key research and development plan will continue to support the research and development of hydrogen fuel cell vehicle technology and vehicle promotion, especially under the encouragement and promotion of the national fuel cell vehicle demonstration city cluster policy and local supporting policies, the promotion effect of industrial commercialization development is significant. Thirdly, in terms of management policies. Local governments are actively exploring innovation in hydrogen energy management, and relevant management policies at the national level still need to be improved. Local governments actively explore and innovate in hydrogen refueling station management, hydrogen energy safety supervision, and renewable energy hydrogen production management. The specific policy information has been summarized in Table 3.

Table 3 Key policies for the hydrogen fuel cell vehicle industry.

Category	Main content
Strategic planning	'New Energy Vehicle Industry Development Plan (2021–2035)', 'Hydrogen Energy Industry Medium- and Long-term Development Plan (2021–2035)', 'Industrial Structure Adjustment Guidance Catalogue (2024 Edition)'
National support policies	'Announcement on the Continuation and Optimization of the New Energy Vehicle Purchase Tax Exemption Policy', 'Announcement on Adjusting the Technical Requirements for New Energy Vehicle Products Exempt from Vehicle Purchase Tax', 'National Key R&D Program Key Projects on New Energy Vehicles and Hydrogen Energy Technology', 'Notice on the Demonstration Application of Fuel Cell Vehicles'
Local support policies	Approvals have been granted for demonstration applications in city clusters and approximately 40 cities, with over 200 industrial policies issued in total, effectively driving policy innovation, technological breakthroughs, vehicle deployment, and the enhancement of infrastructure construction.
Relevant management policies	More than 10 provinces and cities have issued specialized hydrogen energy safety policies, and approximately 40 cities have promulgated construction and operation management measures for hydrogen refueling stations. Cities from Hebei, Tangshan, Zhangjiakou, and Inner Mongolia are actively exploring permitting green hydrogen production projects and integrated hydrogen production and refueling stations outside chemical industrial parks. However, national-level hydrogen energy policies regarding the construction and operation of hydrogen refueling stations remain absent or require further improvement.

4.2. Technical Readiness Evaluation

Table 4 Current status of core material technology level.

Core Materials	Type and Parameters	Domestic	International
Catalyst	Mass activity (A/mg Pt@0.9V)	0.2	0.5
	Durability (h)	15000	20000
Gas diffusion layer	Gas permeability @0.1 bar $m^3/(m^2 \cdot h)$	> 1100	> 1500
	Bulk pesistance @1 mpa ($m\Omega \cdot cm^2$)	7±1	8±1
	Tensile strength (mpa)	12±2	22±2
Proton exchange membrane	Thickness (μm)	12	8.5
	Tensile strength (transverse/longitudinal) (mpa)	≥32/32	96/91

The technological level of fuel cell vehicles and stack products basically meets the conditions for large-scale promotion. Nearly 60% of heavy-duty commercial vehicles have a range of over 500 km, and 49-ton fuel cell tractors have a hydrogen consumption of 10.5 kilograms per 100 km. The lifespan of commercial vehicle fuel cells has reached 16,500 hours, and the cost has been reduced to 1000 yuan/kW. The 35 MPa III type hydrogen storage cylinder technology is mature, with a mass hydrogen storage density of 5%, and has achieved large-scale production and application. The IV type vehicle mounted hydrogen storage cylinder is still in the early stages of research and development, trial production, and industrial application. Some of the IV bottle products with performance advantages have passed type tests and vehicle validation. There is a significant gap in the technical performance of key core materials compared to the international leading level. Proton exchange membranes and catalysts for domestic fuel cells have been widely promoted and applied on a small scale, and domestically produced gas diffusion layer products have been validated for use in vehicles. The performance of core material products is shown in Table 4.

4.3. Industrial Chain Readiness Evaluation

On one hand, a relatively complete industrial chain system for fuel cell vehicles has been initially established. The number of hydrogen energy and fuel cell vehicle enterprises exceeds 2,000, covering the entire industrial chain, including hydrogen supply, core raw materials, components, systems, and complete vehicles. On the other hand, market promotion is primarily driven by demonstration application projects, with industrial concentration and market-level supply requiring further enhancement. Products from more than 50 complete vehicle manufacturers and over 60 system manufacturers have been promoted and applied. Among them, the top 5 complete vehicle manufacturers hold a 44% market share; the top 5 system manufacturers account for approximately 53% of the market share. Key enterprises of industry chain are show in Table 5.

Table 5 Key Enterprises in the Hydrogen Fuel Cell Vehicle Industry Chain.

Industry Chain	Main Enterprises
Complete Vehicle	Commercial vehicles: Foton, Yutong, King Long, Feichi, SAIC, FAW, Dongfeng, Shaanxi Auto, Sany, Sinotruk, etc; Passenger vehicles: FAW, Changan, SAIC, Dongfeng, GAC, etc.
System	Yihua Tong Technology, Re-Forge Energy, Guohong Hydrogen Energy, Grohem Technology, Sinohydrogen Technology, Weishi Energy, Hydro-Power, Xiongchuan Hydrogen Energy, Aidaman, Dongfang Electric Corporation, Hydrogen Morning, New Hydrogen Power, Shenli, Sinopower, Weichai Power, Tomorrow Hydrogen Energy, etc.
Membrane Electrode	Tangfeng Energy, SinoHykey, WUT HyPower, Qingdong Technology, Sinohydrogen Technology, etc.
Bipolar plate	Hongfeng Industrial, Hongjun New Energy, Huarong Technology, Guohong Hydrogen Energy, Jiayu Carbon, Duko New Materials, Shanghai Zhizhen, Edelman, Shenli Technology, Xinyan Hydrogen Energy, Nowogen, etc.
Proton Exchange Membrane	Dongyue Hydrogen Energy, Wuhan Ludong, Kerun New Materials, Hancheng Technology, Dongcai Technology, Pan-Asia Micropermeation, etc.
Catalyst	Jiping New Energy, Qingdong Technology, Zhongzi Environmental Protection Technology, Guiyan Platinum Industry, Wuhan Himalaya, General Hydrogen Energy, etc.
Gas Diffusion Layer	General Hydrogen Energy, Shanghai Tanji, WUT HyPower, Jiazi New Materials, Hesen Electric, Qingneng New Energy, Tanneng Technology, etc.
On-board hydrogen storage system	Shanghai Sunwise, Guofu Hydrogen Energy, Lantian Da, Tianhai Industry, CIMC Enric, Kotec, etc.
Hydrogen storage cylinder	Faurecia Sinda, Sinoma, Guofu Hydrogen Energy, Tianhai, Kotec, Aoyang New Energy, CIMC Enric, etc.
Hydrogen circulation system	Dongde Industry, Wise Drive Technology, .Scrolltec, Cisco Scroll, Snowman, etc.
Carbon fiber	Zhongfu Shenying, Jilin Chemical Fiber, Guangwei Composites, Shanghai Petrochemical, Sinofibers Technology, etc.

4.4. Hydrogen Energy Supply Readiness Evaluation

First, the construction progress of hydrogenation stations is obvious, and more than 400 hydrogenation stations have been built. Hydrogenation stations are generally arranged regionally and mainly distributed near urban transportation stations. Multi-regional network has not been formed, so it is difficult to support inter-city and long-distance scenarios. Secondly, hydrogen supply prices vary widely (ranging from 20 to 80 RMB/kg, see in Table 6) and remain high. The economic competitiveness of hydrogen for vehicles in many key promotion areas is still lacking. Differential subsidy policies for vehicle hydrogen consumption in different cities further restrict inter-city operation of vehicles. Furthermore, hydrogen used for vehicles is primarily sourced from industrial by-product hydrogen. The low-carbon performance of the entire industrial chain remains to be improved. Regions such as Beijing, Hebei, Shanghai, and Guangdong are actively exploring and deploying renewable energy-based hydrogen production. Demonstration experience with green hydrogen has been continuously accumulated through events and projects such as 2022 Winter Olympics Games.

Table 6 Hydrogen refueling prices in major demonstration region.

Demonstration region	Hydrogen Terminal Price (CNY/kg)
Beijing-Tianjin-Hebei city cluster	30-40
Shanghai city cluster	40-70
Guangdong city cluster	50-60
Hebei city cluster	≤35
Zhengzhou city cluster	≤35
Shandong	35-70
Jiangsu	55-76
Wuhan	35

4.5. Market Readiness Evaluation

First of all, the overall cost of fuel cell vehicles remains high, lacking economic competitiveness. The selling price of fuel cell vehicles is higher to varying degrees compared to similar internal combustion engine or pure electric vehicles, particularly several times higher than internal combustion engine models, which constitutes a key factor restricting large-scale adoption (see in Table 7). Secondly, application scenarios are primarily focused on medium and short distance operations, with long-distance scenarios not yet scaled up. Current scenarios are concentrated within urban areas or short intercity routes, with daily operating mileage within 300 km. Due to limitations in vehicle technology and hydrogen supply capacity, large-scale multi-regional long-distance applications have not yet been developed. Thirdly, the sales and after-sales support system for fuel cell vehicles remains in the early stages of development. After-sales services lack unified standards and regulations, and there is a significant shortage of service networks and skilled personnel. Financial insurance premium price is high, reference data is less, and targeted premium accounting and insurance types are absent.

Table 7 Comparison of purchase costs for FCVs, CVs, and EVs (unit: 10,000 CNY).

Vehicle Type	Fuel Cell Vehicle	Diesel Vehicle	Pure Electric Vehicle
49-ton Heavy Truck	130-180	30-60	/
31-ton Dump Truck	80-150	25-50	/
18-ton compressed garbage truck	80-160	20-50	30-80
4.5-ton van truck	60	8-20	15-30
Bus	110-200	/	90-160
Large passenger bus	140-200	/	100-160

5. Conclusions And Suggestions

In general, the technical level and promotion scale of fuel cell vehicles have achieved remarkable results, the conditions for large-scale promotion have been provided, and the characteristics of typical application scenarios have gradually become clear. The overall development of the industry enters the adjustment phase of the promotion period. It is imperative to focus on enhancing hydrogen energy supply capacity and market scale, integrate advantageous resources, increase support efforts, promote broader and cross-regional scenario applications, accelerate the improvement of product competitiveness, and facilitate the industry's overall progression into a sales lifting period. Looking ahead, the development suggestions are as follows:

1) Speed up addressing technical shortcomings and promote comprehensive development and improvement across the entire supply chain. The R&D institutions should focus on key material technology R&D, policy and project support for the application of domestically produced materials in vehicles, and accelerate breakthroughs in domestic high-performance materials and components technology along with their mass application in vehicle assembly. The innovation management departments should speed up the improvement of aftermarket standards, regulations, and policy requirements encourage innovation in business models, enhance service quality; and promote the healthy development of the entire industry chain.

2) Ensure the stable supply of hydrogen energy and improve the economical efficiency of vehicle use. The energy supply-related units should strengthen hydrogen supply by providing fiscal policy support targeting the upstream segments of the hydrogen energy value chain, and accelerate the construction of a large-scale and low-cost automobile hydrogen supply system.

3) Consolidate consensus on advantageous scenarios and concentrate resources to improve application scale. The authorities should develop and implement continuous demonstration application incentive policies to ensure industrial progression. The whole industry should focus on the advantageous scenarios, launch special support policies such as fuel cell vehicle toll reduction and exemption, traffic privileges, etc., drive the development of industry cost reduction and efficiency improvement.

4) Strengthen the popularization of hydrogen energy science. On one hand, the social organizations should strengthen the publicity and implementation of hydrogen energy safety regulations and safety standards, enhance the safety awareness of employees, and build a solid foundation for the safe utilization of hydrogen energy for vehicles. On the other hand, by carrying out extensive cooperation, academic exchanges, industry activities, etc., the relevant institutions should strengthen the public's awareness of hydrogen energy and fuel cell vehicles, eliminate development concerns and promote development consensus.

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