Sweden-China Bridge

Collaborative Academic Platform for the
Electrification of Transportation Systems

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ELECTRIFICATION OF THE TRANSPORTATION SYSTEM IN CHINA

EXLOPRING HYDROGEN TECHNOLOGY FOR ELECTRIC VEHICLES IN CHINA 1.0

Title: Exploring Hydrogen Technology For Electric Vehicles In China 1.0.

Authors: Jasmine Lihua Liu[1, 2, 3], Xiang Cheng[2] & Mike Danilovic[1, 2, 4].

[1]Lund University, Sweden; [2]Shanghai Dianji University, China; [3]Jönköping University, Jönköping International Business School, Sweden; [4]Halmstad University, Sweden.

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In cooperation with Tomas Müllern [5], Arne Nåbo [6] & Philip Almestrand Linné [6].

[5]Jönköping University, Jönköping International Business School, Sweden.

[6]Swedish National Road and Transport Research Institute, Sweden.

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ABOUT THE SWEDEN-CHINA BRIDGE PROJECT

This project funded by The Swedish Trafikverket (TRV), formally started the 1st of September 2020, and will last until the end of 2022.

Exploratory approach

This project is exploratory in nature and includes a step-by-step approach to knowledge development in the Swedish and the Chinese context. The project spans different areas of knowledge in which we will highlight what technologies and systems are prioritized in China, Sweden and in Europe, what drivers and motives exists for them, what actors are involved in the transition to electrified, intelligent and integrated transport systems, and what conditions and business models look like to achieve this conversion to electrified and integrated transport systems in an intelligent and smart society.

The purposes of the Sweden-China Bridge Project

1. The project aims to establish and develop an academic knowledge-sharing and -transfer platform between Sweden and China for collaboration between universities and research institutes in the two countries, in order to contribute to increased understanding and information and knowledge sharing on the technical and commercial development of electrified vehicle systems, integrated transport system solutions, and energy supply infrastructure as a fully integrated system of intelligent and smart cities.

2. From this perspective, the project will explore the development and implementation of relevant technology for the electrification of vehicles, such as fuel cells, bio energy, battery storage, combinations of energy systems for hybrid vehicles, energy supply for integrated electrified vehicles, integrated electric road technology, associated charging infrastructure, and static and dynamic technology.

3. We also intend to explore the management of renewable energy supply systems, from the production of renewable electricity to its distribution to consumers of electrified transport systems, which is needed to ensure that electrified vehicles and transport systems.

Expected value creation

1. To create insights into the current and future status of electrification of transportation systems in Sweden and in China from technical, social, societal and economic perspectives.

2. To learn and mutually develop insights into how new knowledge, technology, system-based solutions, logistics and transportation systems can be developed, commercialized and operated according to a life cycle perspective in both Sweden and China.

3. To create a long-term learning context in which Sweden and China exchange experience for the benefit of both countries and their industries.

4. To develop a deeper understanding of how Sweden and China are managing the large-scale electrification of the road network using different technologies, including electric charging, energy production (fuel cells, hybrid vehicles, battery storage and electric roads): what do the short- and long-term potentials look like? How are they using long-term industry policy instruments to develop technology and implement it in society? How are they outlining business models for the large-scale roll-out of electrified transportation systems?

Research team

Mike Danilovic
Ph.D., Project leader, Professor, Halmstad University, Sweden & Distinguished Overseas Professor at Shanghai Dianji University Shanghai, China.
Affiliated researcher at Lund University, Sweden.

Tomas Müllern
Ph.D., Professor, Jönköping University, Jönköping International Business School, Sweden.

Jasmine Lihua Liu (刘莉华)
Ph.D., Senior researcher at CIRCLE, Lund University, Shanghai Dianji University, China. & Affiliated researcher at MMTC, Jönköping University, International Business School, Sweden.

Arne Nåbo
Tech. lic., Research director, Swedish National Road and Transport Research Institute (VTI), Sweden.

Jeanette Andersson
Ph.D., Researcher, Swedish National Road and Transport Research Institute (VTI), Sweden.

Philip Almestrand Linné
Ph.D., Researcher, Swedish National Road and Transport Research Institute (VTI), Sweden.

Wang Junhua
Ph.D., Professor, Tongji University, Shanghai, China.

Liu Shuo
Ph.D., Assistant Professor, Tongji University, Shanghai, China.

Qiu Xiaoping
Ph.D., Professor, Southwest Jiatong University, Chengdu, China.

Susan Lijiang Sun
Ph.D., Professor, Shanghai Dianji University, Shanghai, China.

Ma Hongwei
Ph.D., Associate Professor, Shanghai Dianji University, China.

Academic partners in China

China Electric Power Research Institute (CEPRI), Beijing, China.

Zhejiang University, Deqing Research Center, Institute of Artificial Intelligence, Hangzhou, China.

Urban and Rural Construction and Transportation Development Research Institute, China.

Industrial partners in China

Beijing
Scania China Innovation Center, Beijing, China.

Shanghai
Shanghai Power Keeper, Shanghai, China.
Shanghai Jiulong Power, Shanghai, China.
Zhejiang VIE-Evatran Electronic Technologies Co., Ltd., Shanghai, China.
BYD, Shanghai, China.

Shenzhen
DST, Shenzhen, China.
Xieli innovation Center, Shenzhen, China.
Shenzhen Bus Group, Shenzhen, China.
Shenzhen Electric Vehicle Application and Promotion Center, Shenzhen, China.
Potevio New Energy, Shenzhen, China.
Haylion, Shenzhen, China.
Guangzhou Bus Group, Guangzhou, China.

Contact

Mike Danilovic, Ph.D.
Professor of Industrial Management Innovation and Technology Management.

Halmstad University
P O Box 823
SE18 301 HALMSTAD
SWEDEN

Phone:
+46708157588 (Sweden) I +8613761129945 (China)

E-mail:
mike.danilovic@hh.se

Visiting professor:
Distinguished Overseas Professor at Shanghai Dianji University Shanghai, China.
Affiliated researcher at Lund University, Sweden.

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As project leader, I am grateful to my research fellows and colleagues in this project: Dr. Jasmine Lihua Liu, Professor Tomas Müllern, Tech.lic. Arne Nåbo, and Dr. Philip Almestrand-Linné.

I thank you all from the bottom of my heart.

Professor Mike Danilovic, on the behalf of the entire research team

ABSTRACT

With the development of human society, the total demand for energy is rising. However, due to the limited fossil energy stock and the threat of the greenhouse effect, adjusting the energy structure is crucially important for the sustainable development of all countries in the world.

Hydrogen energy has received great attention as one technology that can provide society with clean energy, support decarbonization, and be one key technology in the electrification of transport.

In 2018, China's hydrogen production was 21 million tons, accounting for 2.7% of the total energy according to the calorific value of energy management. According to the prediction of China hydrogen energy alliance, hydrogen energy will account for 5% of total energy consumption in 2030 and 10% in China's thermal energy by 2050. According to the market forecast, China's hydrogen production will exceed 20 million tons in 2020. China hydrogen energy alliance predicts that China's hydrogen demand will reach 35 million tons by 2030, with a compound annual growth rate of 5.76%.

In 2050, China's hydrogen demand will be close to 60 million tons. Hydrogen energy is increasingly more widely used in China, and the market development speed is growing rapidly.

This report focuses on the development of hydrogen technology in China where the Chinese central government has put hydrogen technology on the strategic listing, repeatedly issued relevant policies to support the development of hydrogen technology and the industry, upgraded the fuel cell development to the level of strategic development, and guides and encourages the development of the fuel cell vehicle industry.

Hydrogen based vehicles have been launched mainly in Japan, USA and South Korea. Compared with the relatively mature fuel cell vehicle market in Japan and South Korea, the customers of domestic hydrogen refueling stations in China are mainly buses and official vehicles. However, there are several Chinese enterprises manufacturing passenger cars to run on hydrogen fuel, such as Chery, Changan, Hongqi, GAC, FAW and others. As illustration, the GAC's self-developed hydrogen fuel cell-based passenger vehicle has an operational range of 650 km.

Compared with the more mature pure electric vehicle, based on batteries as energy source, the hydrogen fuel vehicle is still in a very early but rapidly maturing stage.

The data show that in 2018, China's input of hydrogen energy vehicles reached 1,527, including 1,418 buses and 109 logistic trucks. In 2019, the production and sales of fuel cell vehicles in China was 2,833 and 2,737, respectively, with a year-on-year growth of 85.5% and 79.2%, respectively. By the end of 2019, the cumulative number of fuel cell vehicles in China was 6,000.

In 2020, the policy for fuel cells became favorable. From the development of China, there is still a lot of room for growth.

Hydrogen technology requires refueling stations, and in China, several traditional oil suppliers are building hydrogen refueling stations.

On 1 July 1 2019, Sinopec built the first domestic oil and hydrogen combined station in Foshan, Guangdong Province. Since then, Sinopec has built the first batch of comprehensive energy supply stations in Zhejiang, Shanghai and other places, which integrate refueling, hydrogenation and other functions. As a strategic partner of the 2022 Beijing Winter Olympic Games, Sinopec will provide hydrogen supply, vehicle hydrogenation, and operation support of hydrogenation stations for hydrogen fuel cell vehicles in the Beijing and Zhangjiakou Winter Olympic Games.

On 28 May 2020, Sinopec Guangdong Petroleum Branch, together with Huangpu District and Guangzhou Development Zone, built the infrastructure for the application and development of hydrogen energy vehicles. It was planned to build more than 20 integrated energy sales stations in the area, integrating hydrogenation, refueling, charging, non-oil and photovoltaic power generation. It is estimated that the revenue of a series of projects will exceed 10 billion yuan/RMB (1,6 billion USD).

The Foshan area in the south of China has rapidly become a center of hydrogen development. Foshan municipal government has successively issued development planning and supporting subsidy policies.

The hydrogen energy industry development plan (2018-2030) includes building 57 hydrogen stations in 2030, which will develop the Foshan area into a leading national hydrogen energy industry demonstration city and agglomeration highland.

Finally, hydrogen energy in China is facing a trend of rapid speed and scale of development. Clean energy hydrogen production and energy utilization are still in the early but rapidly growing stage of development. Soon, hydrogen energy will see immense development prospects in the field of transportation, heavy freight transportation and electric energy storage.

We have reasons to believe that hydrogen will be one of the strategic technologies and practices in China in the development of a green society, decarbonization and the electrification of transport.

Key words: energy structure, hydrogen energy industry, standards and policies, fuel cell vehicle.

OUTLINE OF THE PAPER

This paper comprises six main parts:

Part one
Introduction to hydrogen energy and charging systems in China

In this part we introduce hydrogen technology development within the Chinese context and show the speed at which hydrogen technology is being developed, even though it started late.

Part two
Standards and policies for hydrogen in China

Here we illustrate the most important policies, regulations and standards for the development of hydrogen energy in China.

Part three
Application and development status

In this part we identify the most important university-based R&D teams, industrial-based R&D, show the most advanced Chinese vehicle manufacturers developing and producing hydrogen-based vehicles and discuss the required infrastructure for hydrogen refueling stations.

Part four
TRL analysis of hydrogen energy development in China

In this section we analyze hydrogen technology development using the Technology Readiness Level (TRL) approach, showing the speed of development of key technologies needed for the hydrogen energy commercialization and practices.

Part five
Analysis and challenges

Here we analyze hydrogen technology development and identify major challenges that hydrogen technology faces in China.

Part six
Conclusions

In the final part we draw major conclusions of the research on hydrogen development in China and the diffusion of technology in the electrification of transport.

RESEARCH METHODOLOGY

The research for the Sweden-China Bridge project is based on primary data from company visits, observations, and interviews, and through the collection of secondary data in English and in Chinese. One senior research team member, Dr. Jasmine Lihua Liu, is of Chinese origin and thus we were able to cover this area from Chinese perspectives, both in respect of a literature search and from the point of view of a deeper understanding of the societal, cultural, and contextual environment as it pertains to the process of electrification of transportation in China. To deepen our understanding further still, we followed a variety of discussions in different webinars, conferences, and among experts.

Dr. Liu is an experienced researcher in both the Swedish and Chinese contexts of transformation towards renewable energy. She received her PhD in Innovation Sciences from Halmstad University in 2019 and is thus well oriented in the Swedish context. Mr. Xiang Chen is a researcher at Shanghai Dianji University and member of a local research team consisting of Mr. Ran Dong, Mr. Xiang Chen, and Mr. Shengdong Zu, under the lead of Professor Susan Lijiang Sun. In the Chinese context, the research underling this report was undertaken in 2020 as desktop-based research. Mr. Xiang Chen was the main data collector and the main co-author of this report.

In October-December 2020, some of the research team travelled to China where they visited corporate organizations, leading institutions, and leading academic institutes in Beijing, Shanghai and Shenzhen, and carried out observations and personal interviews with people in the research area of the electrification of transportation systems in China.

During December 2020, in one intensive week, we conducted company visits, discussions, and formal interviews with key players in the electrification of Shenzhen city in southern China. This working week was a joint collaborative venture with the Scania China Innovation team in Beijing. The information collected during this intensive period in China will be elaborated on in forthcoming papers on electrification technology development and research into the electrification of Shenzhen as the only city in the world to have achieved 100% electric taxis, buses and most of its intra-city-based logistics and working vehicles.

In May 2021, we collaborated with the Scania China Innovation team through corporate visits to several Chinese battery-swapping developers and operators in order to jointly explore the role of battery-swapping for heavy vehicles, such as trucks.

In April-June 2021, we conducted several seminars in Sweden with participants from academia and industry to share our observations and listen to questions on electrification of transportation in China in general, and on battery-swapping in particular. This dynamics in our research creates awareness and mutual learning based on our ongoing research on electrification of transportation in the Chinese context.

PART ONE
INTRODUCTION TO HYDROGEN ENERGY AND CHARGING SYSTEMS IN CHINA

Why hydrogen energy?

With the continuous progress and development of society, the energy problem has become a common one, faced by all countries in the world. The reason is that the energy we use in large quantities, such as oil, natural gas and coal, are non-renewable resources. The earth's supply of petroleum gas is limited, and human survival is always inseparable from energy, so we must find new sources. As a recognized clean energy, hydrogen has the characteristics of good combustion performance, high calorific value, independent of fossil fuel, non-toxic and harmless. It stands out among many new energy sources and is favored by various countries. It is considered as the energy answer for the future development of society.

At the same time, with the transformation of energy structure and the enhancement of social awareness of environmental protection, more attention has been paid to the energy attributes of hydrogen all over the world. As a clean and efficient energy, hydrogen has become a current research hot spot. At the same time, the progress of downstream technologies, such as electric vehicles and fuel cells, has also led to the rapid development of the hydrogen energy industry.

In June 2019, the International Energy Agency (IEA) released an industry report entitled "The future of hydrogen energy: seize today's opportunity", which calls the current period the key opportunity period for hydrogen energy development.

China's government work report in 2019 also suggested, for the first time, to promote the construction of hydrogenation facilities. Therefore, the hydrogen industry will usher in a sustained and rapid development in China, and the role of hydrogen energy in promoting economic and social development will be more obvious.[1]

Hydrogen takes off

In the past two years, with the advancement of technology and the promotion of relevant policies, such as banning the sale of fuel vehicles, pure electric has become the focus of research and development of major automobile enterprises. As the impact on the environment is relatively small compared with traditional cars, the prospects for pure electricity are widely optimistic. But from the perspective of environmental protection, the fuel cell vehicle is the future development direction for automobiles. In recent years, China has actively promoted fuel cell vehicles.

The data show that in 2018, China's introduction of hydrogen energy vehicles reached 1,527, including 1,418 buses and 109 logistic trucks. In 2019, the production and sales of fuel cell vehicles in China was 2,833 and 2,737, respectively, with a year-on-year growth of 85.5% and 79.2%, respectively. By the end of 2019, the number of fuel cell vehicles in China reached 6,000.

In 2020, the policy for fuel cells become favorable, and with the country's development in China, there is still much room for growth.

PART TWO
STANDARDS AND POLICIES FOR HYDROGEN IN CHINA

China's standards for hydrogen

The system table for fuel cell electric vehicles gives the specification for standard formulation. The system table not only reflects the product structure, technical connotations and development direction, but also plays an important guiding role in the establishment of scientific and technological development and the standard formulation plan. Therefore, the compilation principles of the standard system table for fuel cell electric vehicles are as follows:

1. Determine the position of fuel cell electric vehicles in the vehicle standard system. The fuel cell electric vehicle itself is a type of vehicle and cannot be independent of traditional vehicles. Therefore, it must meet the relevant standard requirements of traditional vehicles, but also meet the unique standard requirements of fuel cell electric vehicles.

2. Determine the unique structure and system of the fuel cell electric vehicle, to identify the items in the standard system.

3. Determine the commonalities and characteristics of pure electric vehicles, hybrid electric vehicles and fuel cell electric vehicles. For those with common requirements, a common standard can be considered; for those with unique characteristics, standard items shall be listed separately in the system table. In this way, we not only ensure the completeness of standard items, but also reduce the waste of manpower and financial resources in the process of standard formulation.

4. Referring to the existing foreign standard projects of fuel cell electric vehicles and combining these with the actual needs of the development of fuel cell electric vehicles in China, the standard projects should be as complete as possible. Some items in the system table consider the supporting standards matching with China's fuel cell electric vehicle industrialization development policies, and China's unique standards, such as fuel cell electric vehicle type test procedures.

5. The standard system table is dynamic, and the current system considers the urgent and long-term standard needs. With the continuous development of technology, the standard items should be adjusted accordingly.

6. The standard system table of fuel cell electric vehicles is compatible with the development goal of China's fuel cell electric vehicle products.

Standard number	The content of the standard
GB/T 37244-2018	Fuel specification for proton exchange membrane fuel cell vehicles—Hydrogen.
GB/T 37154-2018	Fuel cell electric vehicles—Test methods of hydrogen emission.
GB/T 38914-2020	Evaluation method for lifetime of proton exchange membrane fuel cell stack in vehicle application.
GB/T 24549-2020	Fuel cell electric vehicles—Safety requirements.

Table 1: Progress of China's fuel cell standards
Source: China Standardization Administration /www.sac.gov.cn/ [2-5]

The standard system includes the terms, test methods and technical conditions of fuel cell electric vehicles, as well as the relevant standards of infrastructure to ensure the normal, convenient and safe operation of fuel cell electric vehicles, such as on-board hydrogen system, hydrogen fuel, hydrogenation station, hydrogenation machine, fuel cell system, etc. At the same time, the standard system of fuel cell electric vehicles also involves the management standard, product certification, enterprise certification, employee qualifications, and many other aspects related to the fuel cell electric vehicle.

Policy development to support hydrogen energy

At the end of 2008, the Ministry of Science and Technology and the Ministry of Finance launched the demonstration project of energy-saving and new energy vehicles in 10 Chinese cities. Since the subsidy amount given to fuel cell vehicles is far less than the difference between the cost of the fuel cell electric vehicle and the cost of traditional vehicles of the same type, the demonstration of fuel cell vehicles has made little progress in the first year of the implementation of the “1,000 vehicles in 10 cities” program.

In 2010, the new energy Chamber of Commerce of the All-China Federation of Industry and Commerce submitted a proposal to the third session of the 11th CPPCC National Committee of the Chinese people’s Political Consultative Conference that the subsidy for fuel cell cars should be increased to 600,000 yuan, that the subsidy for public buses should be increased to 1.6 million yuan, and that the construction of hydrogen refueling stations should be directly funded or subsidized and supported by policies.

At that time, China’s domestic capital market pursued too many short-term returns, and enterprises and investors lacked long-term planning for pillar industries. Due to the immaturity of the domestic capital market, short-sightedness, lack of vision, and lack of foresight in the flow of market funds, it was difficult for hydrogen fuel cell technology to get the support of market funds, which became the biggest obstacle to the development of China’s new energy vehicle industry. Since then, central and local finance has provided long-term support, directly funded the construction of hydrogenation stations or provided subsidies and policy support for their construction, and increased the number of subsidies for fuel cell vehicles in operational commercial demonstration, so that hydrogen fuel cell vehicles can effectively participate in the demonstration project.

The following is a list of China’s policies on hydrogen energy industry in recent years:

Year	Name and main contents of the policy
2019	"Promoting the construction of charging and hydro-filling facilities" was included in the Government Work Report.
2019	The Directory of Green Industry Guidance (2019 edition) encourages the development of renewable energy use facilities for construction and operation of fuel cell equipment, as well as new energy steam applications on cars and ships.
2019	The action plan for tackling pollution from diesel trucks proposes to encourage all countries. The local government organized the operational demonstration of fuel cell trucks and built a batch of hydrogenation vehicle fan stations.
2018	Adjusting and improving the fiscal subsidy policies for the promotion and application of new energy vehicles. The circular sets standards for fuel cell vehicle subsidies.
2017	The special plan for Scientific and Technological Innovation in the transportation sector during the 13th Five-Year Plan period was proposed to be deepened. Research and development to be carried out on the core technology for fuel cell vehicles, promotion of the development of additional basic equipment implementation, and demonstration of assessment technology development.
2017	The medium- and long-term development plan for the automobile industry proposes to gradually expand the fuel cell electricity Carpool Pilot Demonstration Area.
2016	The 13th Five-Year Plan for the Development of National Strategic Emerging Industries puts forward "Promoting the R&D and Industrialization of Fuel Cell Vehicles".
2016	"Energy-saving and New Energy Vehicle Technology Road map" released hydrogen fuel cell vehicles Technology Road map
2016	Energy Technology Revolution and Innovation Action Plan (2016-2030) "Hydrogen energy and fuel cell technology innovation" is one of the key tasks.
2015	"Made in China 2025" proposes continued support for the development of fuel cell vehicles.
2015	National Key Research and Development Program New Energy Vehicle Key Special Implementation (draft) proposed that "fuel cell vehicle technology has made a breakthrough, up to industrialization requirements".
2015	Accelerating the application of new energy vehicles in the transportation industry.

Table 2: Policies on hydrogen development in China 2015-2019

Source: Current situation and prospect analysis of hydrogen energy industry chain[6]

PART THREE
APPLICATION AND DEVELOPMENT STATUS

Chinese universities

Hydrogen fuel cell research started late in China and did not get much attention during its early stages; the early research on fuel cell technology focused mainly on catalyst, bipolar plate and other manufacturing materials. More than 10 years later, the status of hydrogen fuel cell technology in China has been greatly improved, and now there has been a break-through in the research of materials. However, there is still a long way to go for the application and the overall manufacturing of hydrogen fuel vehicles.

The following is the research status on the fuel cell by the Chinese university research teams:

Number	Research universities and research teams	Research content and development	Time
1	Professor Wang Heng Xiu, Tsinghua University	Two kinds of self-made PEMFC electrocatalysts.	2001
2	Professor Jiang Jin Guo, Wuhan University of Technology	Research on the cathode material for fuel cells.	2002
3	Professor Cao Guang Yi, Shanghai Jiao Tong University	Application status of various fuel cells in distributed generation market.	2005
4	Professor Zhang Na, Harbin Institute of Technology	Application of metal oxides to low temperature fuel cell catalysts.	2011
5	Professor Bao Peng Long, Tong ji University	Air compressors for fuel cell vehicles.	2016

Table 3: Research on the fuel cell technology by Chinese university teams
Source: China National Knowledge Infrastructure (www.cnki.net)

Hydrogen fuel cell car companies

Due to the late uptake of domestic automobile enterprises for the development of hydrogen fuel vehicles, there is a certain gap in terms of civil passenger vehicles compared with several foreign automobile enterprises, such as Toyota of Japan and Hyundai of South Korea. China mainly focuses on logistics vehicles, buses, and other similar types of vehicles.

Foreign car companies take the lead

Several international vehicle companies have, for quite some time, been conducting research and have developed demonstration projects based on hydrogen technology.

General Motors (GM) in USA is one example of the early pioneers.

"Floyd Wyczalek, 91, was project manager of Electrovan fuel cell development and recalls the 200-person team working on the first technology transfer of fuel cells from President John F. Kennedy's 1962 challenge to NASA to safely land a man on the moon before the end of the decade.

"We had three shifts of people on this project starting in January 1966 and finishing 10 months later," Wyczalek said. "We had one running demo for the Progress of Power press conference in October that year."

Source: https://www.gmhydrotec.com/product/public/us/en/hydrotec/Home.detail.html/content/Pages/news/us/en/2016/oct/1005-hydrogen.html

The German company, BMW, was another hydrogen technology pioneer that developed fully operational vehicles based on hydrogen energy in the 1980s-1990s.

In the recent times, Toyota has become one of the largest vehicle enterprises in the world, founded for more than 80 years of operation. It has assembly plants in more than 50 countries around the world. It is the first vehicle enterprise with an annual sales volume of more than 10 million vehicles. Toyota announced the goal of "Toyota environmental challenge 2050" on 14 October 2015, which proposed to achieve "zero" sales of vehicles driven only by engines by 2050. Toyota was the inventor of the world's first hybrid vehicle, Prius, that become the legendary breakthrough in the green vehicle development. Today, almost all vehicle manufacturers have hybrid technology in their fleet.

In recent years, Toyota has invested large R&D funds into new energy vehicles, especially fuel cell vehicles. Due to the limitation of traditional battery technology, Toyota executives believe that fuel cell vehicle is the ultimate environmental protection vehicle. In recent years, Toyota has gradually shifted its future research and development focus from mature hybrid electric vehicles to fuel cell vehicles.

Toyota began to develop fuel cell vehicles in 1992 and released its first model in October 1996. In the following 10 years, Toyota successively launched FCHV-3, FCHV-4, FCHV-5, Toyota FCHV, Toyota, etc. However, due to the high unit price and insufficient infrastructure for hydrogen refueling, the fuel cell vehicles at this stage did not have mass production and commercialization.

To put more hydrogen fuel cell vehicles on the road, Toyota has disclosed about 5,680 fuel cell-related patents free of charge, hoping to encourage other automobile manufacturers to launch fuel cell vehicles and reduce the construction and use costs of infrastructure, such as hydrogenation stations.

Let's take Toyota Mirai as an example. Since the launch of this model in Japan in 2014, only seven vehicles were sold in the first year. With the construction of hydrogen stations and the promotion in the overseas markets, the sales have gradually increased.

- In 2016, overseas sales of Toyota's hydrogen vehicles reached 1,096.
- In 2019, the total Toyota's annual sales of hydrogen vehicles reached 2,494 vehicles.
- In September 2020, total sales of this model reached 11,154 vehicles, with its main market is the United States, followed by sales of more than 100 vehicles to Europe every year.[7]

Different from Toyota, in the field of hydrogen fuel cell vehicles, Hyundai NEXO pays more attention to its local market. By the end of October 2020, the sales volume of NEXO in South Korea had exceeded 10,000 vehicles. With the excellent performance of NEXO and its vigorous promotion by the South Korean government, Hyundai has changed from a challenger to Toyota to an industry leader of hydrogen-based vehicles.

In 2019, the sales volume of Hyundai NEXO was twice the number of Toyota Mirai. In 2020, due to the poor sales of Mirai in the overseas market, the sales volume of Hyundai NEXO was more than five times that of Mirai.

Figure 1: Toyota Mirai
Source: www.autohome.com.cn

Figure 2: Hyundai NEXO
Source: www.autohome.com.cn

Chinese domestic car companies

Compared with the relatively mature fuel cell vehicle market in Japan and South Korea, the customers of domestic hydrogen refueling stations in China are mainly buses and official vehicles.

However, there are several Chinese enterprises manufacturing passenger cars to run on hydrogen fuel, such as Chery, Changan, Hongqi, GAC, FAW, among others.

Taking GAC as an example, on 28 July 2020, the first hydrogen fuel cell vehicle, Aionlx fuel cell, was launched. According to a spokesperson at the press conference, it is a self-developed hydrogen fuel cell vehicle based on GAC's gep 2.0 platform. When filled with hydrogen, the vehicle's operational range can reach 650 km.

In Guangzhou, a small number of buses and heavy trucks have used hydrogen fuel cells as power and have been running on the road for a considerable time. There are more than five hydrogen refueling stations in Guangzhou that have already provided hydrogenation service, providing the necessary conditions for the use of hydrogen fuel vehicles in the region.

At present, hydrogen fuel buses and trucks are being developed rapidly in China. The current manufacturing cost of hydrogen fuel cell vehicles is higher than for the internal combustion engine (ICE), and the supplementary fuel is not as convenient as petrol-fueled vehicles and pure electric vehicles, so most users of hydrogen vehicles are governments or large enterprises.

As a manufacturer of hydrogen fuel buses, Foshan Feichi has successfully developed and successfully produced 7 m, 8.5 m, 11 m, 12 m-long hydrogen fuel cell and other new energy city buses and fuel cell commercial type vans. The products are listed in the Chinese government's recommended model catalog of energy saving and new energy vehicle demonstration and application projects.

At present, Foshan Feichi produces four models of hydrogen energy buses with passenger capacity ranging from 16 to 33 people. These have been put into operation in many regions of Guangdong Province and the company is in lead position in China.

Figure 3: GAC
Source: www.autohome.com.cn

Figure 3: FEICHI Bus
Source: www.fsfeichi.com.cn

Equipment manufacture

With the gradual introduction of hydrogen energy into the public domain, increasingly more people recognize and accept the technology. The government's policy support and encouragement for the development of hydrogen energy, including subsidies for fuel vehicles, have given hydrogen energy-related industries a new outlet. Many domestic enterprises have joined the research and development and production of fuel cell related equipment, which has laid a foundation for building a future hydrogen energy society. **Figure 5** shows an electric fuel composition diagram of the fuel cell system:

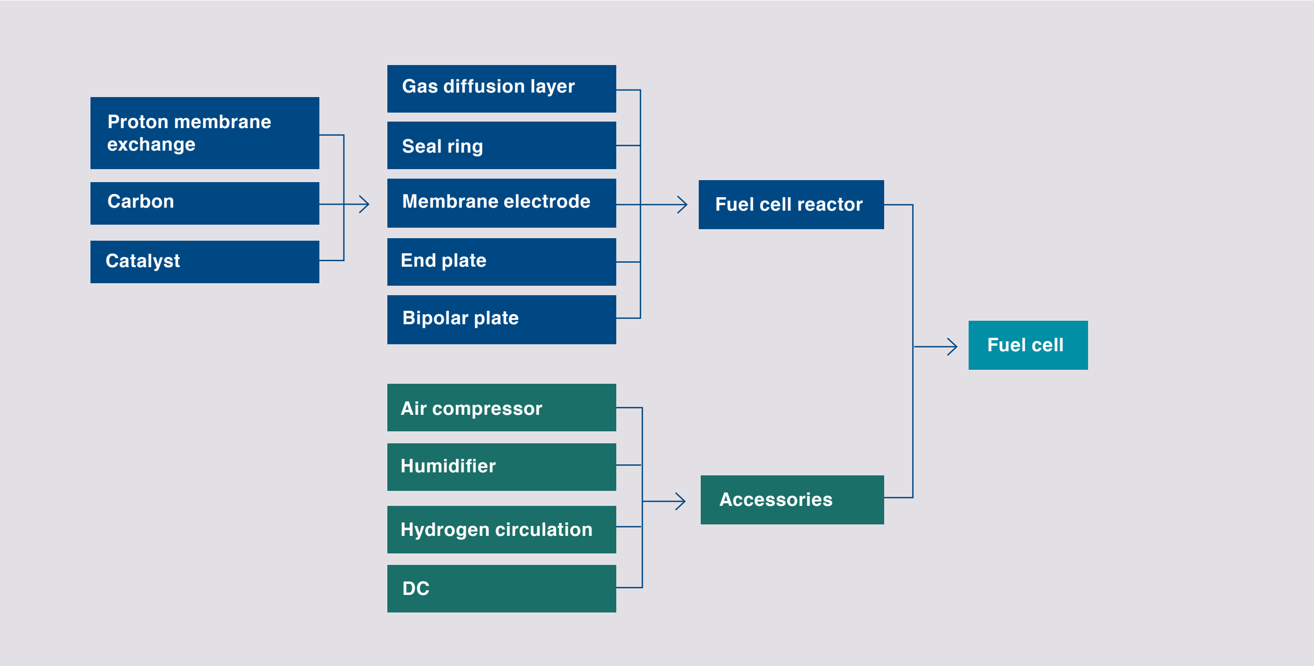

Figure 5: The composition of fuel cells
Source: Current situation and prospect analysis of hydrogen energy industry chain [6]

As the pioneer of China's hydrogen energy industry, Yihuatong focuses on the R&D and industrialization of hydrogen fuel cell engine systems and is committed to creating better and more efficient hydrogen total energy solutions. At present, Yihuatong has formed a vertically integrated product and service system with an independent hydrogen fuel cell engine as the core, including bipolar plate, stack, vehicle controller, intelligent DC/DC, hydrogen system, test equipment, full set of solutions for fuel cell laboratory, etc. A new generation of hydrogen fuel cell engine based on the core independent intellectual property rights has completed the national fuel cell system technical objectives ahead of schedule and reached the international advanced level. The self-developed full series test service system provides a complete set of solutions for fuel cell laboratories of many mainstream commercial vehicle enterprises.

Its hydrogen fuel cell engines Yhtg40, Yhts60, Yhtg60ss, and Yhtg80 are the company's signature products. It has realized the localization of core components can start at -30 °C at low temperature, and the protection level has reached IP67. Their fuel cell engines have the characteristics of high energy utilization, zero pollution, short hydrogen refueling time, long operational range, low noise and overall high performance. The brand's fuel cell voltage converters are 30 kW and 60 kW, the key component of a hydrogen fuel cell power system through the precise control of engine output power; they realize the decoupling between fuel cell and vehicle high pressure, and the power distribution and optimal control between vehicle power system; stabilize the working state of the engine and extend engine life; its boost variable ratio is as high as 1:12 and 1:7; and the operation efficiency reaches 95%.

Hydrogen energy-related infrastructure development

Currently, a total of 40 regions in China have issued relevant hydrogen energy plans. The tentacles of hydrogen energy development have extended from the Pearl River Delta to the Yangtze River Delta, Bohai Bay, and even to inland Shanxi, Inner Mongolia and other areas.

Sinopec Group, which has rich experience in gasoline station construction, also has significantly hydrogen production capacity, mature energy security management experience and a comprehensive network site system, with an annual hydrogen production capacity of more than 3 million tons and is one of the largest hydrogen energy suppliers in China.

On 1 July 1 2019, Sinopec built the first domestic oil and hydrogen combined station in Foshan, Guangdong Province. Since then, Sinopec has built the first batch of comprehensive energy supply stations in Zhejiang, Shanghai and other areas, which integrate refueling, hydrogenation and other functions. As a strategic partner of the 2022 Beijing Winter Olympic Games, Sinopec will provide hydrogen supply, vehicle hydrogenation, and operation support of hydrogenation stations for hydrogen fuel cell vehicles in the Beijing and Zhangjiakou Winter Olympic Games.

On 28 May 2020, Sinopec Guangdong Petroleum Branch, together with Huangpu District and Guangzhou Development Zone, built the infrastructure for the application and development of hydrogen energy vehicles. The plan is to build more than 20 integrated energy sales stations in the area, integrating hydrogenation, refueling, charging, non-oil and photovoltaic power generation. It is estimated that the revenue of a series of projects will exceed 10 billion yuan.

Foshan municipal government has successively issued development planning and supporting subsidy policies. In the hydrogen energy industry development plan (2018-2030), 57 hydrogen stations will be built in 2030, which will develop the Foshan area into a national leading hydrogen energy industry demonstration city and agglomeration highland.

PART FOUR
TRL ANALYSIS OF HYDROGEN ENERGY DEVELOPMENT IN CHINA

Different from fossil fuels, hydrogen energy has a long industrial chain, which generally includes hydrogen production, storage, transportation, hydrogenation and terminal application, and involves multiple fields such as the chemical, electric power, transportation and automobile industries.

The main structure of its industrial chain is shown in the figure below:

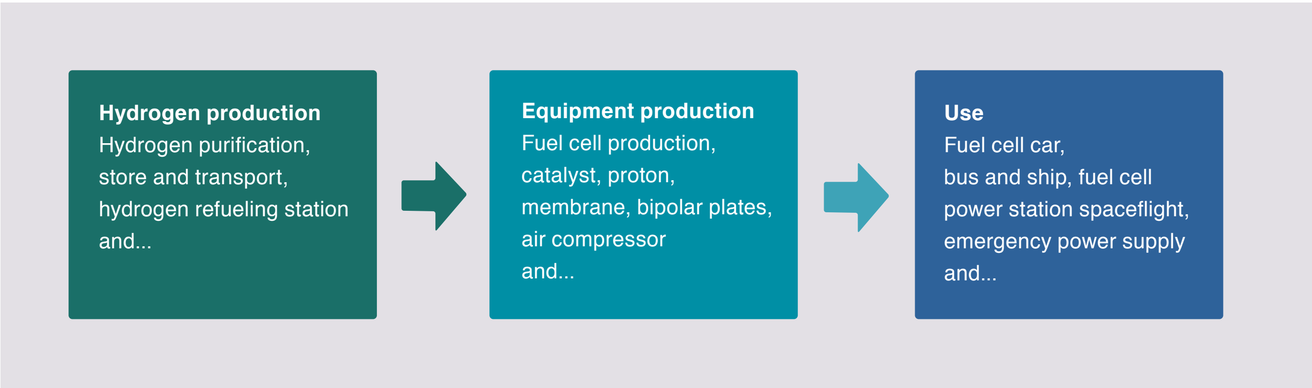

Figure 6: Hydrogen energy industry chain
Source: Current situation and prospect analysis of hydrogen energy industry chain[6]

Hydrogen production can be divided into traditional hydrogen production methods and clean hydrogen production methods; using traditional fossil fuels, such as coal, oil and natural gas, as raw materials to produce hydrogen is the most used method nowadays. This method has mature technology in China and has built industrial production units. The advantages of this method of production are its mature technology, low cost and wide market application. The most widely used technologies are coal to hydrogen and methane to hydrogen. The emerging clean hydrogen production technology, due to its high cost and relatively immature equipment manufacturing, can improve the efficiency of hydrogen production and reduce pollution, but it is not favored by most manufacturers due to the cost issues. The main clean methods of hydrogen production include electrolysis of water and electrolysis of renewable energy.

From the point of view of hydrogen transportation, current hydrogen storage methods widely used include high pressure hydrogen storage, liquid hydrogen storage, metal oxide hydrogen storage, carbon-based material hydrogen storage, and chemical hydrogen storage.

Up to February 2020, 64 hydrogenation stations have been built in China. Although great progress has been made, there is still a gap compared with the anticipated 100 stations.

In terms of intermediate manufacturing and application manufacturing, most enterprises in China focus on intermediate manufacturing, including hydrogen fuel cell engines, bipolar plates, stacks, catalysts and some laboratory test equipment and inspection equipment, etc.

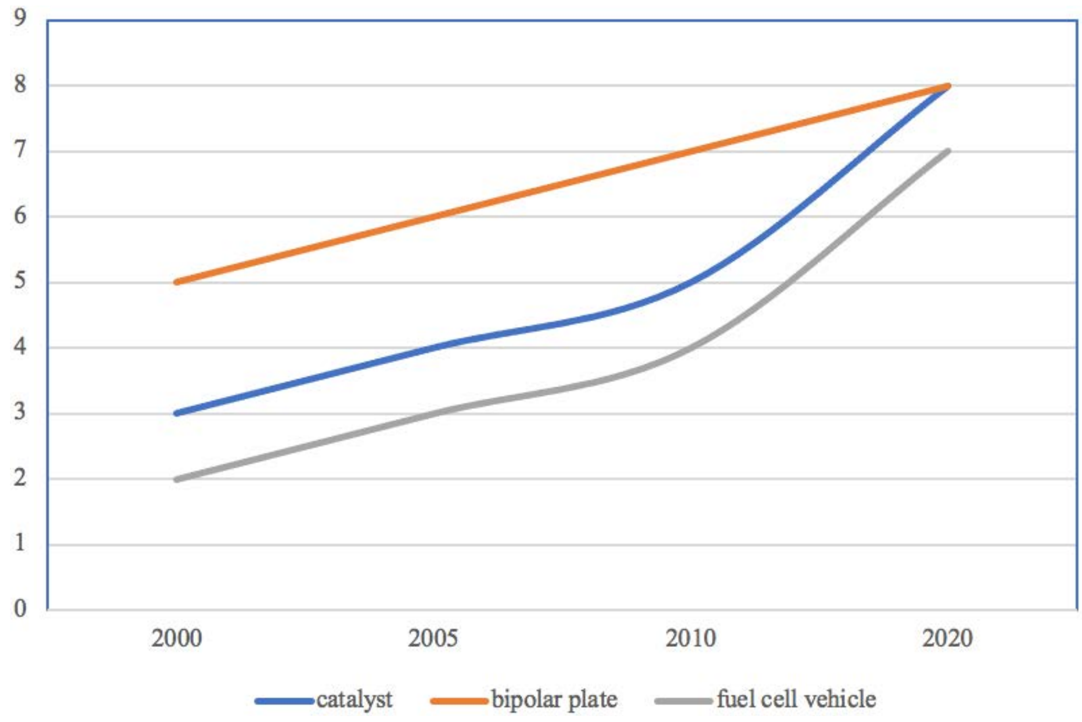

Figure 7: TRL development of China's hydrogen energy and charging system
Edited and drawn by Xiang Cheng

Catalysts

Although there are a lot of catalyst materials developed at present, few of them have been put into practical and commercial use. However, their performance has been greatly improved. A breakthrough has been made in the study of DMFC (Direct Methanol Fuel Cells) anode catalysts by combinatorial electrochemistry. Compared with commercial PtRu (Platinum Ruthenium – atomic ratio 1:1), the obtained PtRu OS IR catalyst has 40% higher catalytic activity.

After 2010, with the emphasis on hydrogen energy, domestic enterprises, research institutes and universities have increased their research efforts on catalysts. In the following decade, the level of domestic catalysts improved rapidly, but there is no obvious advantage in cost control compared with imported catalysts, and they have not been widely used in applications.

Bipolar plates

Since the beginning of this century, as the fuel cell began to enter the Chinese people's field of vision, there has been research on fuel cell-related components in China. Most of the patents related to bipolar plates were applied from 2000 to 2010 (proton exchange membrane fuel cell bipolar plates and various materials used to manufacture bipolar plates).

After 2010, there were some new technologies (ultrasonic dispersion technology) and the application of composite materials in bipolar plates. The research and production of bipolar plates in China has a certain standard; it can cope with the development of fuel cells.

Related enterprises and research institutions are: Antai Technology, Tomorrow Hydrogen Energy, Wuhan University of Technology, etc.

The materials and related components required by fuel cells have a certain production capacity in China and have begun to take shape, and can cope with the current application status of domestic fuel cells. However, optimizing the use of fuel cells, such as the energy supply of electric vehicles, has not made such good progress.

Fuel cell vehicles

The application of fuel cells provides an important way of travel that can change future traffic patterns. Since the beginning of this century, Europe and the United States have successively announced that they will take fuel cell vehicles as the key direction of development. At the same time, China's domestic research on fuel cell vehicles is still in a 'wait-and-see' state. Although research on fuel cells is in progress, the development of fuel cell vehicles is still limited. The research is mainly on its raw materials and key components, and has not formed a complete industrial chain, let alone applied it to the automobile. It is only in the last two to three years that some domestic automobile companies have formed corresponding fuel cell vehicles, but most of them have not been promoted in the market. At present, the new energy vehicles in China are mainly electric vehicles.

PART FIVE
ANALYSIS AND CHALLENGES

At present, fossil-based energy consumption accounts for more than 85% of China's total energy consumption.

In 2018, China's hydrogen production was 21 million tons, accounting for 2.7% of the total energy according to the calorific value of energy management. According to the prediction of the China hydrogen energy alliance, hydrogen energy will account for 5% of total energy consumption in 2030, and 10% of China's thermal energy by 2050.[9]

According to the market forecast, China's hydrogen production will exceed 20 million tons in 2020. China hydrogen energy alliance predicts that China's hydrogen demand will reach 35 million tons by 2030, with a compound annual growth rate of 5.76%.

In 2050, China's hydrogen demand will be close to 60 million tons. Hydrogen energy is increasingly more widely used in China, and the market development speed is growing rapidly.[10]

Hydrogen production can support the huge demand for hydrogen energy in the future, and the production mode using stable raw materials as its source should be electrolytic water hydrogen production. However, at present, due to the high cost, electrolytic water only accounts for about 4% in the hydrogen energy preparation industry, offering no competitive advantage over other methods.[11]

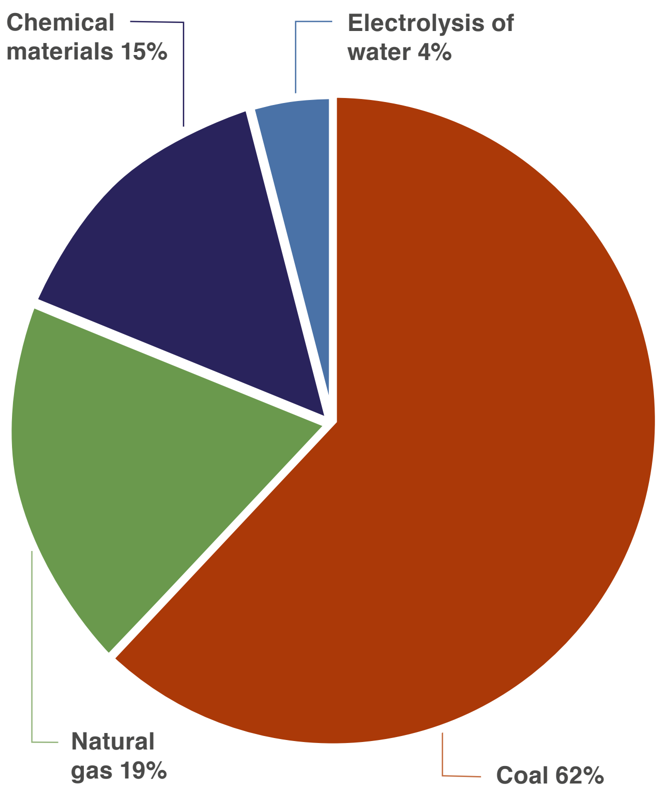

Figure 8: Chinese methods of hydrogen production
Source: Research and prospect of industrial hydrogen production route in China[9]

Challenges

If we want to enter the hydrogen energy society more quickly, and if we want to adopt fuel cell vehicles as our routine way of daily travel, we must face the following challenges:

1. The cost of hydrogen fuel cell vehicles is high, and consumers can choose traditional fuel luxury brand vehicles for less than the price of hydrogen.
2. Safety problems in the use of hydrogen fuel vehicles are still a challenge.
3. The density and the diffusion of the hydrogenation station is limited and not sufficient to cover long distance driving, thus limiting the operational range and proving inconvenient to operators and users.

The above three points are the main challenges that are obvious at present, as seen from a user's perspective.

There are several reasons for the high manufacturing cost of hydrogen fuel cell vehicles:

- The production of key components depends on import from international suppliers .
- The scales of economy of the entire vehicle and transportation industry have not yet been identified or achieved.

To solve these challenges Chinese catalysts/ developers need to be able to form a more efficient eco-system and develop the entire value chain of the industrial production without relying on expensive imports of technologies and components.

In addition, once new technologies can be used to make breakthroughs in hydrogen production, the cost of hydrogen fuel can be reduced, and the use cost of vehicles can be effectively reduced, which will greatly reduce the overall cost of hydrogen fuel vehicles.

The main safety problems and solutions are as follows:

1. **On-board hydrogen storage safety**
   To eliminate the potential safety hazard, in addition to developing more reliable high-pressure resistant materials, it is necessary to strengthen the safety monitoring of high-pressure storage devices, and to discover or synthesize metal hydrides as soon as possible.
2. **Safe transportation of hydrogen on board**
   We can start from two aspects of prevention and monitoring, select pipeline and component materials according to high standards, and fully consider their reliability and sensitivity; in addition, we can optimize the monitoring and alarm system and processing system, and consider the location and quantity of sensors.
3. **Fuel cell system safety**
   The national standard “safety requirements for fuel cell stack of fuel cell electric vehicles” (GB / t36288-2018) specifies the safety requirements of fuel cell stack for fuel cell electric vehicles. In addition, it is necessary to monitor and calculate the inlet and outlet temperatures, pressure and flow rates of reaction gas and coolant in the fuel cell reactor. To prevent hydrogen accumulation, forced ventilation is necessary.

In the early stages, we can build more oil and hydrogen integrated filling stations, which will not only increase the density of hydrogenation stations, but also increase the revenue of the station when, to begin with, there are not many hydrogenation vehicles. Compared with the construction of a pure hydrogenation station, the construction costs and operation risks are reduced.

PART SIX - CONCLUSIONS

Compared with the more mature pure electric vehicle based on batteries as energy source, the hydrogen fuel vehicle is still in a very early but rapidly maturing stage. In terms of the safety performance and technology, as well as the corresponding infrastructure, including hydrogenation stations, hydrogen storage, hydrogen transportation and so on, the hydrogen fuel vehicle is relatively immature and not widely used.

Since 2010, China has begun to attach importance to the development of hydrogen fuel vehicles and has successively issued relevant policies. While vigorously promoting electric vehicles, China has increased the research on hydrogen fuel vehicles and the popularization of relevant knowledge. In recent years, relatively mature standards to produce fuel vehicles have been formed, and the policy welfare at the national level has not declined. In the new decade of the 21st century, hydrogen fuel vehicles will usher in a big leap for China.

As the upstream of the hydrogen energy industry, blue hydrogen, which is the industrial by-product of hydrogen, is still the main source of hydrogen energy in China. The industrial by-product of hydrogen has a large output and low cost, which can meet the current domestic hydrogen consumption level. However, in the future, green hydrogen, which is produced in a pollution-free way, will be the main consumer product. With regard to transportation and transportation of hydrogen storage, the widely used hydrogen storage methods include high pressure hydrogen storage, liquid hydrogen storage, metal oxide hydrogen storage, carbon-based materials hydrogen storage, and chemical hydrogen storage. In the field of hydrogen fuel cell vehicles, high pressure gaseous hydrogen storage is the most mature technology and widely used. Looking to the midstream of the hydrogen energy industry, production of relevant equipment and raw materials, most of the key core components required for domestic hydrogen fuel vehicles are domestically produced, catalysts (TRL, bipolar plates, exchange membranes, etc.) are listed in the paper. China has been able to independently produce qualified products and enter the market.

As far as the application of products (fuel vehicles) is concerned, this paper cites the cases of pioneers of fuel cell vehicles, such as Japanese and Korean automobile brands. At present, they have achieved high sales volumes and won some loyal users. The annual sales volume steadily increases. Although the fuel cell vehicles produced by domestic independent brands have been able to produce and pass the road test, the domestic market competition has become increasingly fierce. Users do not know enough about related products, do not have full confidence, its use conditions are not mature, the construction density of hydrogenation station is too low, it is not convenient for people to travel, and the cost of car purchase is relatively high. Therefore, at present, the main focus of domestic hydrogen fuel cell vehicles in China is still buses, because they have fixed lines and service times, and relatively regular hydrogenation times, which is convenient for planning.

Finally, hydrogen energy in China is facing the trend of rapid development in speed and in scale. Clean energy hydrogen production and energy utilization are still in the early but rapidly growing stage of development. Soon, hydrogen energy great development potential in the field of domestic transportation, heavy freight transportation, and electric energy storage.

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