An overview of the present development status of fuel cell vehicle industry under the dual-carbon situations

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Keywords: Fuel cell, Motor vehicle, Industrial chain, Operational promotion.

Abstract. With global energy crisis and environmental issues becoming more and more prominent, the automotive industry is facing unprecedented challenges and changes, energy saving and new energy vehicles have become the strategic focus of national scientific and technological development. In which, hydrogen fuel cell vehicle has aroused great attention as one of major technical schemes because of advantages such as no pollution, zero emission, long range and fuel supply quickness and convenience. As a new type of clean energy technology, fuel cell has gradually become the focus of research for science research institutes, automotive enterprises and power system suppliers at present. This paper summarizes the present development status, technical level and operation promotion status of fuel cell vehicle industry chain, analyzes the influence of relevant policy environment from the aspect of support of national and local governments to the industry, and puts forward the development issues of fuel cell and the prospect in the next step.

1 Introduction

At present, major countries of the world attach great importance to the development of hydrogen energy and fuel cell, and some countries or regions have raised hydrogen energy to the height of national energy strategy. At the 75th session of the General Assembly of the United Nations, General Secretary Xi Jinping made an important deployment regarding carbon dioxide emission: continuously strengthen the support for research, development and industrialization of hydrogen energy and fuel cell. China will raise nationally determined contributions and adopt stronger policies and measures, so as to reach peak carbon dioxide emission by 2030 and achieve carbon neutrality by 2060 [1][2][3]. Zero-carbon hydrogen energy is an effective means for energy system to achieve in-depth decarbonization, and with the continuously increasing technical maturity and continuously decreasing cost of fuel cell,

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mass use of fuel cell is started in automotive field. Developed countries and regions such as the United States, Europe and Japan have strengthened investment and policy support in hydrogen energy research and development in succession, focusing on five major application fields such as passenger car, hydrogen refueling station, public bus, hydrogen generation by water electrolysis and truck [4]. The cost of hydrogen fuel cell passenger car has dropped from USD 1 million/unit before 2005 to an acceptable range of USD 50,000 to USD 100,000/unit. As of August 2019, a total of 18,299 units of fuel cell vehicles had been sold accumulatively worldwide, with more than 400 hydrogen refueling stations built. [6]

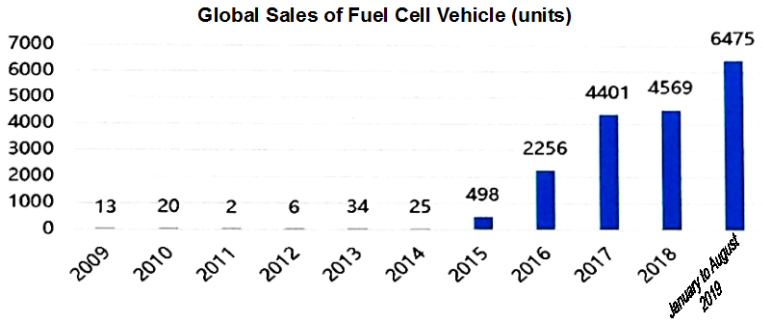

Fig. 1. Global sales of fuel cell vehicle.

On 12 March 2019, Ministry of Economy, Trade and Industry of Japan released a new version of *Hydrogen/Fuel Cell Strategic Roadmap*, and formulated "Hydrogen/Fuel Cell Technology Development Strategy" at the same time, which specifies not only specific technology development projects but also goals for each field in the roadmap. The strategy focuses on three major technical fields: fuel cell technology field, hydrogen supply chain field and electrolytic technology field. Ten projects such as vehicular fuel cell, stationary device fuel cell, large-scale hydrogen production and hydrogen generation by water were identified as priority fields, research and development of technology were promoted through mutual cooperation. The general goal is to realize on-road operation of 200,000 units of fuel cell vehicle by 2025, 800,000 units by 2030, and development of 900 hydrogen refueling stations in the fuel cell supply network. [7] [8]

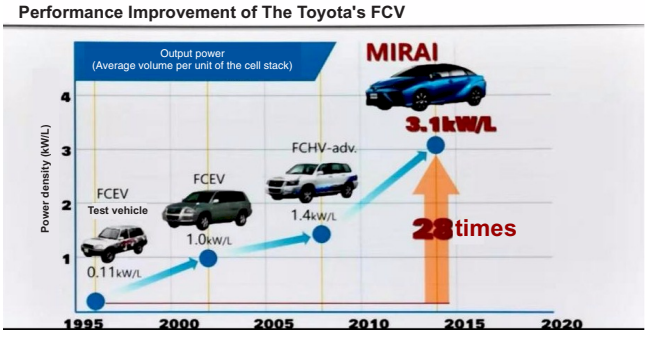

Fig. 2. Performance improvement of the Toyota's FCV.

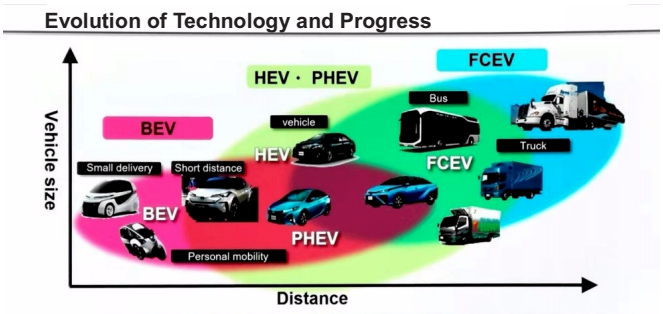

Fig. 3. Evolution of technology and progress.

In late February, European Fuel Cell and Hydrogen Energy Joint Undertaking (FCH-JU) released *Hydrogen Roadmap Europe: A Sustainable Pathway for the European Energy Transition* which sets out a roadmap for hydrogen energy development facing 2030 and 2050, points the direction for large-scale deployment of hydrogen energy and fuel cell in Europe, and demonstrates the social and economic benefits of hydrogen energy development: the hydrogen energy industry will generate approximately 130 billion euros of production value for EU by 2030 and 820 billion euros by 2050.

Germany has set up Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie -Gmbh (NOW-Gmbh) in the field of hydrogen energy and fuel cell to carry out work in related fields. In 2006, German Government and industrial and scientific community entered into a strategic alliance to launch a major 10-year project called National Innovation Program for Hydrogen and Fuel Cell Technology (NIP), and achieved remarkable achievements: NIP has invested a total of approximately 710 million euros in 750 projects; in addition, self-financing fund of 690 million euros in financially aided project, and 20 million euros of financial aid from third-party; a total of 240 enterprises, 50 scientific research and education institutions and the public departments have received financial aid form NIP; on the basis of the practice summary and experience of the first phase, Germany has also proposed Hydrogen and Fuel Cell Technology Plan (NIP2) for 2016 to 2026 (the second phase), so as to ensure the continuation of research and development, and the federal government plans to provide approximately financial aid of 1.4 billion euros as public support funding over the next decade. At the present phase, importance is mainly attached to solving the issue of market development, establishing the corresponding infrastructure, and continuously providing policy and economic support for the foundation in various fields such as hydrogen production, hydrogen transportation, residential energy supply, industrial application, and special application of fuel cell in the future. The two major governmental departments, BMVI and BMW, are responsible for providing policy support for the NIP program, while NOW organization implements and coordinates the program. [8]

(Map of distribution of hydrogen refueling station in Germany at present (2018) Source: German Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie-Gmbh (NOW-Gmbh) website: https://www.now-gmbh.de/)

Fig. 4. Map of distribution of hydrogen refueling station in Germany at present.

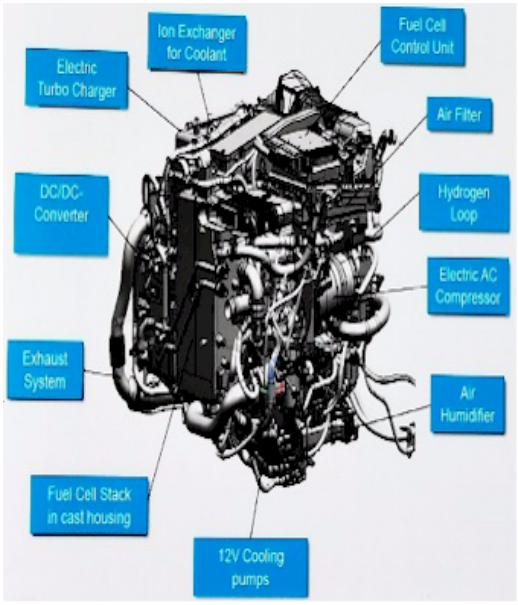

Fig. 5. Benz fuel cell engine system.

On 28 March 2019, Premier Li Keqiang of the State Council proposed to incorporate hydrogen energy into the country's emerging industries for the first time at annual conference of Boao Forum for Asia. “Promote the construction of facilities such as charging and hydrogen refueling.” This was clearly stated in the *Government Work Report* in National People's Congress and Chinese People’s Political Consultative Conference in 2019. As a result, the hydrogen fuel cell industry has clearly become a national strategy. On 11 October,

Li Keqiang hosted a meeting of National Energy Administration to emphasize to propel the transformation and upgrading of energy production and consumption and ensure energy security. And proposed "to speed up tackling of key problems for key technologies and major equipment for the development and utilization of energy, and explore commercialization path of advanced energy storage and hydrogen energy, etc." According to the latest statistics released by China Association of Automobile Manufactures, a total of 4,679 units of fuel cell vehicles were sold accumulatively nationwide from 2016 to September 2019, with 35 hydrogen refueling stations. [9] [10]

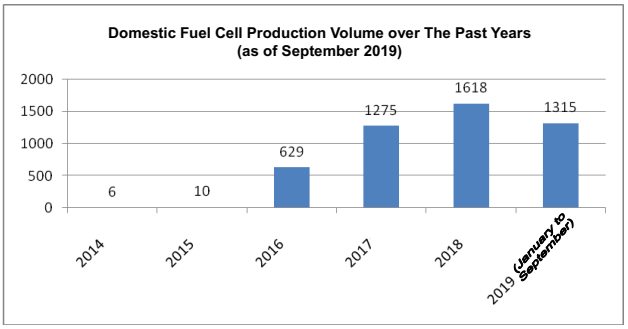

Fig. 6. Domestic fuel cell production volume over the past years.

2 The current situations of domestic industrial chain

At present, 135 fuel cell vehicle models, 35 complete vehicle manufacturers and 37 hydrogen fuel cell manufacturers are listed in fuel cell announcement of China, and 35 hydrogen refueling stations have been established [11]. Especially since 2016, some regions of China have introduced fuel cell industry development plan, promoting the formation of regional industrial cluster, including the concentration area around Beijing in North China region, the concentration area of Yangtze River Delta and the concentration area of Pearl River Delta in South China.

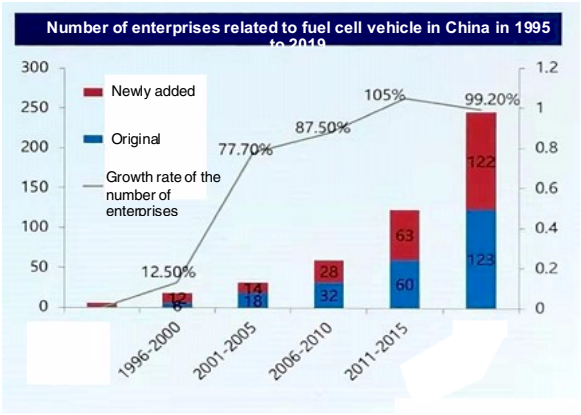

Fig. 7. The situations of regional development of fuel cell and enterprise scale in China.

There are numerous enterprises related to vehicular fuel cell in North China, the full industrial chain of vehicular fuel cell in Beijing-Tianjin-Hebei region has been basically formed, representative enterprises are CHN Energy Group, Huaneng Group, Sinopec, PetroChina, State Power Investment Corporation, Mainland Hydrogen, Beijing Tianhai,

Beijing SinoHytec, Foton Motor, Great Wall Motor and so on. At present, the fuel cell vehicles operating in Beijing-Tianjin-Hebei regions are equipped with the fuel cell power system of Beijing SinoHytec, including 140 units of group buses, 79 units of public buses and 25 units of logistics vehicles. Recently, Beijing SinoHytec, Toyota Motor and Beiqi Foton have carried out cooperation in the field of hydrogen fuel cell bus, this cooperation will help to enhance the level of development of hydrogen energy and fuel cell vehicles in China, and promote the industry to achieve leaping development. The first product model jointly promoted by the three parties is based on the technological advantages and industrial accumulation of all parties in the fields of the cell stack, fuel cell power system, and complete vehicle integration, etc. Other fuel cell vehicle models will be introduced later to provide better quality solutions for different application scenarios of hydrogen fuel cell vehicles in China; in the first nationally approved renewable energy demonstration and construction zone in Zhangjiakou City, there are abundant wind power and photovoltaic resources which can be used for hydrogen generation by water electrolysis, leveraging the development opportunities of 2022 Winter Olympics to vigorously develop hydrogen energy and fuel cell industry, SinoHytec has completed construction of the country's first semi-automated fuel cell engine production line and smoothly brought it into production, the first-phase production capacity is 2,000 units per year, and the second-phase production capacity will be 10,000 units per year after completion of the second-phase construction. At present, 75 units of fuel cell public buses have been brought into operation in Zhangjiakou; the first fuel cell engine production line of Shanxi invested and constructed by Vision HydraV of Datong of Shanxi has been brought into operation, the construction of industrial park of Datong Datong HydraV Yun Ding Hydrogen Tech Co., Ltd. was comprehensively started in 2019, the fuel cell bus demonstration operation was performed in 2019, and 71 units of fuel cell vehicles have been brought into operation in Datong.

The vehicular fuel cell industrial chain in Yangtze River Delta region is relatively complete, Shanghai has taken the lead in issuing *Hydrogen Fuel Cell Vehicle Industry Plan* in China, and then Suzhou and Zhangjiagang have also released fuel cell industry plan in succession. Representing enterprises are Shanghai SinoFuelCell, Shanghai REFIRE, Shanghai Sunwise, Shanghai HYFUN, Shanghai EDrive, Suzhou Foresight, Furuise Hydrogen Energy, Nantong Bing Energy, SAIC Motor and Suzhou King Long and so on. There are currently 858 units of fuel cell vehicles operating in Shanghai, 60% of which are fuel cell logistic vehicles. 7 units of fuel cell public buses are operating in Zhangjiagang and hydrogen town has been constructed in Rugao, Jiangsu Province. Representative fuel cell enterprises in Zhejiang include CEMT Hydrogen Energy, Youngman Automobile and so on. Ningbo has issued *Guideline of Ningbo for Speeding Up the Development of Hydrogen Energy Industry*, CEMT Hydrogen Energy Equipment Co. , Ltd. mainly produces fuel cell core components and cell stack and provides powertrain, the company's goal is to form crisscross industrial interconnection with global, national and local hydrogen energy equipment industry and new energy vehicle industry, propel the development of industrial chain enterprises and the industrial upgrading and structural transformation of the entire region, and construct hydrogen energy town in Taizhou; relevant enterprises related to fuel cell of Anhui include Mingtian Hydrogen Energy and Ankai Bus, etc.

The development of vehicular fuel cell in Pearl River Delta region focuses on linkage between hydrogen energy and fuel cell. On 26 to 28 October, the “UNDP Hydrogen Industry Conference 2019” was organized and convened under the theme of “Hydrogen · World Connection · Future Creation”. In recent years, represented by Foshan, promotion of fuel cell industry has been raised to the height of development of strategic emerging industries, hydrogen energy promotion demonstration leading group has been established, and arrangement has been made for three major hydrogen energy industry bases such as “Guangdong New Energy Vehicle Base” in Nanhai of Foshan, “Modern Hydrogen Energy

Tram Repair/Construction Base" in Gaoming of Foshan and hydrogen energy industry base jointly established in Foshan and Yunfu, *Foshan Hydrogen Energy Industry Development Plan (2018 to 2030*) was issued in 2018, Yuncheng Hydrogen Energy Town was established in Yunfu, and the examination and approval procedure for the construction of hydrogen refueling station is also clarified at the same time. Representative enterprises include Guangdong Sinosynergy-Refire, Sinosynergy, SinoHyKey, Broad-Ocean Motor, Wuzhoulong, Changjiang EV, Feichi Bus, Guangdong Telos, Shenzhen Nanke, Guangshun New Energy and so on. At present, Guangdong Province has the largest number of in-operation fuel cell vehicles, totaling 1,676 units, including 345 units of fuel cell bus and 1,331 units of logistic vehicle.

In recent years, the industrial repositioning and a new wave of innovation and business establishment brought by China's economic transformation have propelled the huge evolution of new energy and transportation field. Hydrogen energy and fuel cell industry has become an important approach for upgrading and transformation of local industry.

The core cities of industrial research, development and demonstration such as Beijing, Shanghai and Foshan have successfully hatched a batch of innovative high-tech enterprises focusing on the research, development, design and testing of key materials, core components and systems such as cell stack and hydrogen system, have made breakthroughs in the introduction and transformation of international advanced technology, and have propelled the localization and commercialization process of fuel cell components & vehicles and hydrogen storage and transportation equipment in the corresponding regions. As important application cities, Foshan and Wuhan have not only expanded the business scope and technical application fields of enterprises from Beijing, Tianjin, Hebei and East China in the process of energetic invitation of businessmen to open companies, but also have promoted the transformation and upgrading of local supply enterprises. In the future, the promotion effect of these segments will continue to radiate many regions of the country, providing new solutions for local industrial transformation and upgrading.

It can be expected that if the localization capability is substantially improved, the minimum economic lot size of economies of scale can be formed, and the system cost will be close to diesel engine as of 2025.

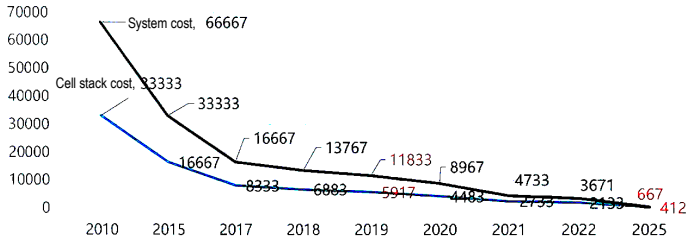

Fig. 8. Decrement and trend of average cost of fuel cell system and cell stack.

Hydrogen industry chain is long and the situation is complex, and there may be hundreds of combination scenarios from upstream production to downstream application. At present, less than 2% of hydrogen is used as energy source, the burden is heavy and the road is long for hydrogen energy application.

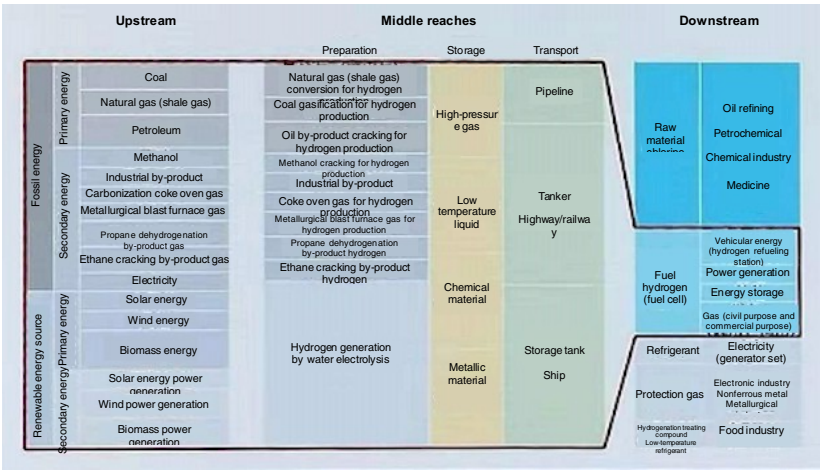

Fig. 9. Composition of hydrogen energy industry Chain.

The embryonic form of industrial chain system covering hydrogen production, hydrogen storage, hydrogen refueling, fuel cell, key components and compete vehicle has been initially established in China, and industrial cluster has been initially displayed. The industrial chain of hydrogen fuel cell vehicle industry mainly includes hydrogen production, hydrogen storage, hydrogen transportation and hydrogen refueling procedures at the upstream; fuel cell key material, component and their system integration at the midstream, as well as complete vehicle manufacturing and demonstration operation at the downstream.

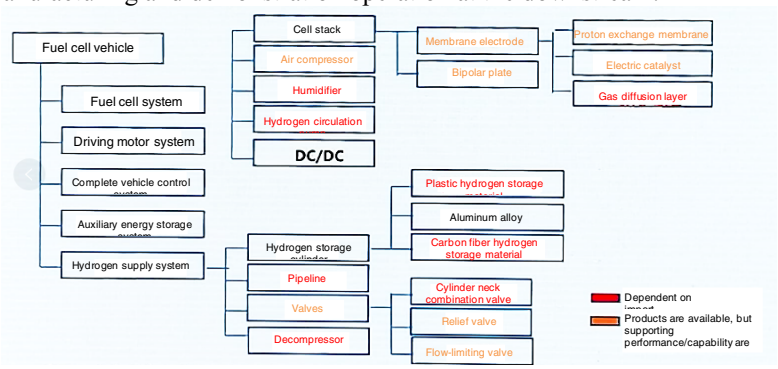

Fig. 10. Schematic diagram of the degree of independent supply of key components for fuel cell vehicles in China.

3 Fuel cell vehicle operation promotion situations

The global fuel cell vehicle industry is still in a small-scale demonstration operation phase, the number of vehicles in operation was 18,000 units in 2016 to 2019, and was very little in comparison with the global vehicle ownership which was approximately 1.3 billion units (statistics in 2018) worldwide. Among the traditional auto makers, only Toyota, Honda, Hyundai and Chinese enterprises have performed small volume production of fuel cell vehicle.

At present, 3,518 units of hydrogen fuel cell vehicles are registered online according to the monitoring data of the national monitoring platform. In which, the number of hydrogen fuel cell logistic vehicles is 2,230 units which is the largest, the number of hydrogen fuel cell

buses is 1,285 units (including 776 units of public bus) and the number of hydrogen fuel cell passenger cars is 3 units. The vehicles are distributed in 13 provinces and 24 different cities, in which number of promotion of fuel cell vehicles in TOP10 cities is shown below:

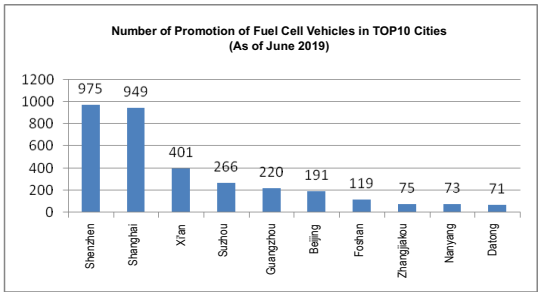

Fig. 11. Number of promotion of fuel cell vehicles in TOP10 Cities.

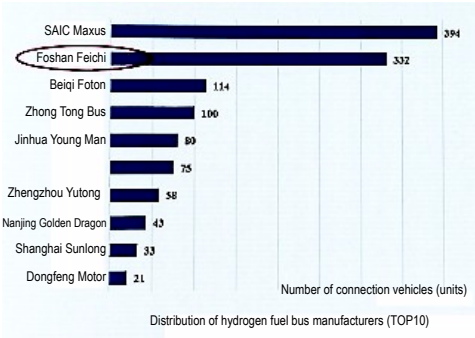

Fig. 12. Distribution of fuel cell bus manufacturers (TOP10).

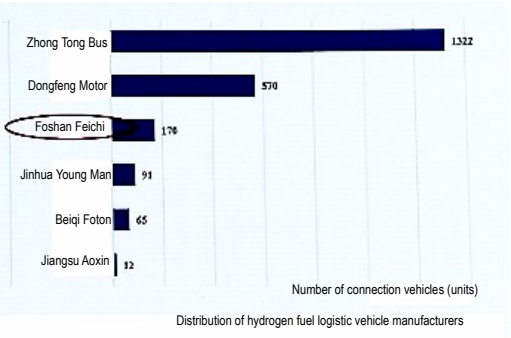

Fig. 13. Distribution of fuel cell logistic vehicle manufacturers.

According to the hydrogen refueling position of hydrogen fuel cell vehicles and formed national hydrogen refueling thermodynamic chart, the distribution of hydrogen refueling station position is relatively concentrated. And hydrogen refueling stations are generally located in the suburban area of city, and hydrogen refueling is not very convenient. In particular, it is not beneficial for large-scale development in the next step.

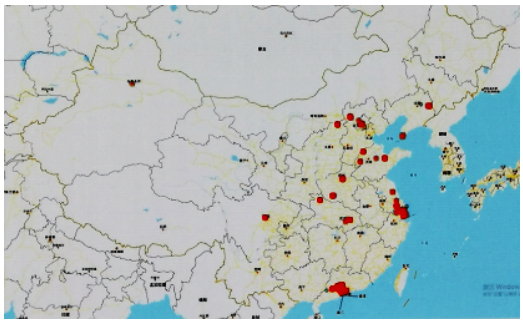

Fig. 14. Distribution of in-use hydrogen refueling stations for fuel cell vehicle in China.

In summary, it is necessary to further strengthen the market-oriented demonstration operation, promote the collaboration with hydrogen fuel cell vehicle industry, create a good market atmosphere, and promote the healthy development of hydrogen fuel cell vehicle industry. The shortage of hydrogen refueling stations is one of the important factors

restricting the development of hydrogen fuel cell vehicle industry, it is necessary to speed up the construction of hydrogen refueling station and the formulation of relevant standards to ensure the efficient operation of vehicles. At the same time, with the continuous expansion of fuel cell vehicle demonstration operation scale, it is urgent to establish safety control standard and monitoring system dedicated for hydrogen fuel cell as soon as possible.

4 Policy influence

From the point of view of global hydrogen fuel cell policy, Europe, the United States, Japan and South Korea have clarified the national strategic position of hydrogen energy and fuel cell vehicles, and introduced policies such as vehicle purchase subsidy, reduction or exemption of tax and fee, hydrogen refueling station construction subsidy, research and development support.

In late February, European Fuel Cell and Hydrogen Joint Undertaking (FCH-JU) released *Hydrogen Roadmap Europe: A Sustainable Pathway for the European Energy Transition* which sets out a roadmap for hydrogen energy development facing 2030 and 2050, points the direction for large-scale deployment of hydrogen energy and fuel cell in Europe, and demonstrates the social and economic benefits of hydrogen energy development: the hydrogen industry will generate approximately 130 billion euros of production value for EU by 2030 and 820 billion euros by 2050. By March 2018, UK offered a subsidy of up to 4,500 pounds for purchase of passenger car of FCEV as per 35% of sales price. Denmark is exempt from the first registration tax for FCEVs registered before 2020. By 30 June 2019, Germany provides consumers with a fixed subsidy of 4,000 euros.

In 2005, the United States issued *U.S. New Energy Act of 2005*, which implements tax credit for purchase of FCEV, the amount of tax credit is 50% of cost added in comparison with the purchase of a fuel vehicle of the same level, and the Act was revised in 2012 to implement tax credit at three levels as per fuel cell price and efficiency, etc. The policy was extended in 2018 to 2022, while a tax credit of 30% to 50% is granted to hydrogen refueling stations. California implemented a FCEV purchase subsidy of USD 5,000 in 2010.

Japan established a subsidy system in 2012, and has made adjustment for several times, and the subsidy amount in 2017 was two-thirds of the added cost for purchase of FCEV in comparison with purchase of fuel vehicle of the same level. Subsidies for hydrogen refueling stations of up to 50% of the cost of investment were provided starting from 2013.

China's policy: with the gradual improvement of technological maturity and the decline of cost, fuel cell vehicle development has aroused more and more attention from the State. Fuel cell vehicle policy system has been initially formed, and most of policies are scattered in various supportive policies related to new energy vehicle, including comprehensive macro-policy, industrial management policy, science and technology innovation policy as well as fiscal and tax incentive policies. Local governments have also introduced supporting policies for hydrogen energy and fuel cell to seize the commanding height for a new round of industrial development.

5 Thoughts and prospects regarding the development of fuel cell vehicle

Fuel cell vehicle industry is still in the stage of small-scale demonstration operation, and the industrial development is a long-term continuously iterating process. China has a relatively good foundation in the field of fuel cell bus, domestic enterprises such as Yutong, Foton, Zhongtong and Dongfeng are capable of independent production, and have grasped certain degree of integration technology, but the dependency of core components of hydrogen fuel cell system on foreign countries is still high.

As can be seen from the previous operation data, application characteristics of domestic fuel cell vehicle are: the majority of domestic fuel cell vehicles are commercial vehicles, and one of the backgrounds for application and promotion in the field of commercial vehicles is the large degree of dependence on subsidy in China, and the majority lies in commercial operation in China at present, and passenger car project technology and industrialization are relatively easy to achieve, but its operation is sensitive to changes in production costs, if the subsidy policy is not as high as expected, its development may be seriously frustrated. The long-term sustainable development of fuel cell may be constrained by the lack of top-level design in the energy field. According to the experience of foreign countries, for example, rather than have proposed the development of fuel cell vehicles at the level of revitalization of the automotive industry, Japan and South Korea have incorporated the development of fuel cell vehicles in the macro-strategy of hydrogen energy society, that is, fuel cell vehicle strategy is subordinate to the national energy strategy.

According to the research and forecast by Massachusetts Institute of Technology of USA, number of hydrogen fuel cell vehicles will exceed 16 million units in the world in 2035. Application of hydrogen fuel cell car, bus and heavy-duty goods vehicle in countries such as Japan, Europe and the United States has guided the direction of technical development and verified the technology of hydrogen fuel cell vehicle and the feasibility of promotion. With the decrease of fuel cell cost, the improvement of technology and the continuous promotion of hydrogen infrastructure, the industrialization of fuel cell vehicle enters small-scale mass production phase from initial introduction phase, and virtuous circle has been formed initially, more vehicle models will enter more application fields in the future.

Funding project: Supported by the key project of intergovernmental international cooperation in science and technology innovation, China (No.2018YFE0105300).

References

1. Presiding over the ninth meeting of Central Finance and Economy Committee, Xi Jinping emphasized to promote the normalized, healthy and sustainable development of platform economy, and integrate carbon peaking and carbon neutrality into the overall layout of ecological civilization construction. Research on Ideological and Political Work, 2021, 9-10.
2. China Hydrogen Alliance. White Paper on Hydrogen Energy and Fuel Cell Industry of China (EB/OL). (2019-06-29) [2020-05-15]. http://h2cn.org/publicati/215.html.
3. Government Work Report (EB/OL). (2019-05-05). http://www.gov.cn/zhuanti/2019qglh/2019lhzfgzbg/.
4. Main national hydrogen energy policies focus on five major application fields [EB/OL] (2019-10-23) [2020-05-15]. http://www.js.xinhuanet.com/2019-10/23/c_1125140236.htm.
5. Mao Zongqiang. The world's hydrogen energy is booming, China's hydrogen energy is accumulating power for development [J]. Solar Energy, 2016(7): 16-19, 80.
6. Annual Report on Hydrogen Refueling Stations in the World in 2019 [EB/OL]. (2020-02-25)[2020-05-15]. http://www.nengyuanjie.net/article/34401.html.
7. Zhang Zhen, Wan Hong, Du Guomin, et al. Experience and Enlightenment of Japanese Energy Enterprises for Developing Hydrogen Energy Business [J]. Petroleum Science and Technology Forum, 2019, 38(4): 58-63.

8. Fu Guanyun and Xiong Huawen. Hydrogen Energy Development Mode in Japan, Germany and the United States and the Enlightenment [J]. Macroeconomic Management, 2020(6): 84-90.
9. China Hydrogen Alliance. White Paper on Hydrogen Energy and Fuel Cell Industry of China (EB/OL). (2019-06-29) [2020-05-15]. http://h2cn.org/publicati/215.html.
10. Gao Hui, Yang Yan, Zhao Xu, et al. The Current Situations and Thoughts regarding the Development of Hydrogen Energy Industry at Home and Abroad [J]. International Petroleum Economics, 2019, 27(4): 9-17.
11. China Business Research Institute. 2019 Research Report for Fuel Cell Market Prospect [J]. China Electrical Equipment Industry, 2019(4):23-31.