



Research on the Development of the Fuel Cell Vehicle Industry in the Beijing-Tianjin-Hebei Region

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1 Status Quo and Trends of the Domestic and Global Fuel Cell Vehicle (FCV) Industry

1.1 Global Status Quo and Trends

1.1.1 The Development of FCV is Expected to Accelerate

During the past years the FCV technology has been substantially advanced, with automobile companies like Toyota, Honda, Hyundai already launching flagship commercial FCV since 2014, and is being increasingly promoted as an attractive alternative power source. FCV have entered a new stage in which industrialisation and market-oriented development are accelerating. By the end of 2018, more than 12,000 FCV have been sold worldwide [1].

In 2050, the annual demand for hydrogen is expected to increase tenfold, and hydrogen energy is likely to be able to meet 18 % of the total global energy demand. The Hydrogen Council estimates in its 2017 report „Scale

Development of Hydrogen Energy - Sustainable Path of Future Global Energy Transition“ that hydrogen energy is going to play a key role in the future energy conversion if the temperature increase due to global warming can be controlled at 2 °C in the future. A forecast of the hydrogen energy demand until 2050 is shown in Figure 1. In 2050, hydrogen production is expected to reach about 80 EJ – ten times higher than the demand in 2015. Hydrogen energy is expected to meet 18 % of global the total energy consumption and 12 % of major energy consumption. According to the predictions of the Hydrogen Council, hydrogen energy and fuel cell technology

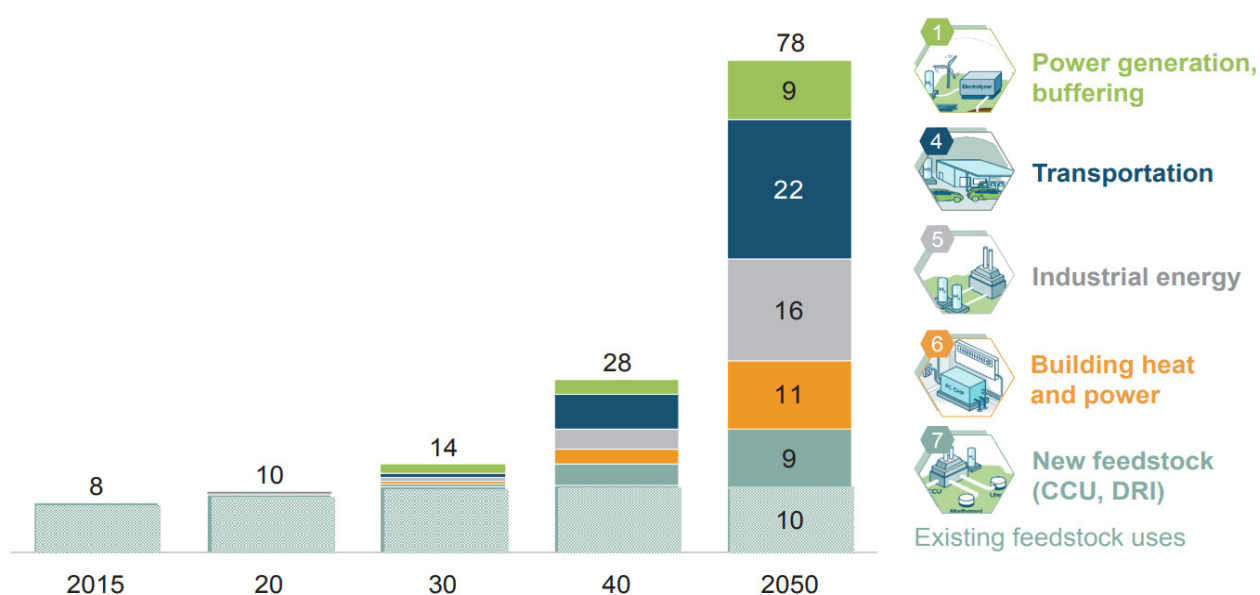


Figure 1: Prediction of Future Demand for Hydrogen Energy. (Hydrogen Council 2017)

gy have a high growth potential and are going to become increasingly important for the decarbonisation of the transportation sector. By 2030, around one twelfth of all vehicles in countries like Germany, Japan and Korea and regions like California are expected to be fuel cell passenger vehicles. It is further estimated that the global FCV fleet is going to count 10 to 15 million passenger vehicles and 500,000 trucks. Moreover, fuel cell technology is also going to be used in trains and ships. By 2050, the FCV fleet is expected to already reach 400 million passenger vehicles, accounting for

25 % of the total fleet, 5 million trucks, accounting for 30 % of the total fleet, 15 million buses, accounting for 25 % of the total fleet, and hydrogen-powered trains accounting for 20 % of the total fleet. The United States (U.S.), Europe, Japan and other developed countries and regions regard the development of hydrogen energy as an important energy strategy. Hydrogen energy is considered an important source for sustainable low-carbon solutions for energy supply and thus promotes low-carbon energy consumption.

Countries and regions	Current development strategies and goals
U.S.	<i>Establishing an energy system for the application of hydrogen energy on a large scale</i> The energy system for the integration of hydrogen energy on a large-scale will include both clean energy such as natural gas, wind energy and solar energy and nuclear energy as well as coal and other energy sources for hydrogen production, hydrogen storage and transportation systems, and hydrogen use in transportation, chemicals, metallurgy and other industries.
EU	<i>Promoting the integration of hydrogen energy and transportation</i> Hydrogen energy is an important support for the development of renewable energy. The implementation plan for the improvement of hydrogen energy and fuel cells covers a period from 2014 to 2020 and supports the production, storage and transportation of hydrogen energy, as well as the application of hydrogen energy in power generation and transportation.
Japan	<i>Releasing a basic hydrogen energy strategy in 2017 which aims to establish a hydrogen energy society</i> Japan aims at forming the world's leading hydrogen energy and fuel cell market. The FCV fleet is expected to count 40,000 vehicles by 2020 and be expanded to 200,000 vehicles by 2025. Moreover, 160 hydrogen refuelling stations are going to be built by 2020 and 320 by 2025. The supply of low-carbon hydrogen energy is going to be further developed, and the application of hydrogen energy in power generation, transportation and fixed cogeneration systems shall be realized.

Table 1: Development Goals and Strategies for the Hydrogen Industry in the Key Regions.

1.1.2 Improving Technology Drives the Commercialisation of FCV

Total Mileage of Passenger FCV

Table 2 shows a comparison of different relevant parameters of foreign FVC. The power of the battery systems is about 100 kW. The fuel cell power system is the main power source, and the matched power battery energy reaches about 1 kWh. Most onboard hydrogen storage systems have a pressure of 70 MPa. According to the assessment of the U.S. Department of

Energy regarding fuel cell passenger vehicles in operation, the travel characteristics of FCV are similar to those of traditional gasoline vehicles. The maximum mileage of FCV is close to 480,000 km, the maximum operating time of fuel cell stack systems is more than 5,600 h, and the average fuel efficiency is 1.2 kg/100 km.

Parameters	Toyota Mirai	Hyundai ix35	Honda Clarity	Hyundai NEXO
Weight	1,850 kg	2,290 kg	1,875 kg	2,210 kg
Maximum speed	175 km/h	160 km/h	166 km/h	179 km/h
0–100 km/h acceleration time	9.6 s	12.5 s	8.8 s	9.7 s
Power of fuel cell battery power system	114 kW	124 kW	103 kW	135 kW
Low temperature performance	-30 °C	-30 °C	-30 °C	-30 °C
Parameters of hydrogen system	122.4 l 4.92 kg	144 l 5.64 kg	141 l 5.67 kg	156.6 l 6.33 kg
Parameters of electric motor	113 kW 335 N·m	100 kW 300 N·m	130 kW 300 N·m	120 kW 395 N·m
Parameters of battery	1.6 kWh NI–MH battery (nickel-metal hydride battery)	0.95 kWh Lithium-ion battery	-	1.56 kWh Lithium-ion battery
Driving range	650 km	594 km	750 km	754 km

Table 2: Parameter Comparison of Fuel Cell Passenger Vehicles.

Operation Requirements

Fuel cell batteries are the main power source for commercial FCV. Normally those battery systems contain graphite bipolar plates and their power exceeds 100 kW. An exception are Toyota's

Parameters	America Van Hool	America New Flyer	Japan Toyota
Power of fuel cell battery	120 kW	150 kW	2 × 114 kW
Electric motor power or torque	2 × 85 kW	2 × 85 kW	2 × 110 kW
Hydrogen bottle	35 MPa	35 MPa	70 MPa
Number of bottles	8	8	10
Quantity of hydrogen	40 kg	56 kg	600 l
Durability	18,000 h	8,000 h	-
Driving range	483 km	483 km	-

Table 3: Parameter Comparison of Fuel Cell Buses.

battery systems which use bipolar metal plate fuel cell stacks. For the energy storage systems of fuel cell buses 35 MPa hydrogen storage bottles are used. According to the U.S. Department of Energy, the development of fuel cell buses is currently in the stage of technology demonstration and verification, which equals the level 6–8 out of 9 on a scale for technology maturity. The assessment of more than 30 fuel cell buses which are currently in operation found great improvements in terms of the reliability, economy and durability of the buses. The average fault-free mileage of assessed fuel cell buses is more than 7,000 km. The average fault-free mileage of fuel cell stack systems is 29,000 km with a maximum of 38,000 km. The average driving mileage of fuel cell buses is more than 200,000 km, and their average operation time is more than 13,000 h.

Cost Reduction of Fuel Cell Stacks through R&D

The cost of fuel cell batteries decreased by 60% in ten years, and the durability of batte-

ries keeps improving. According to the U.S. Department of Energy, the cost of 80 kW vehicle fuel cell systems decreased to USD 5/kW (500,000 units/year are produced) and the cost of fuel cell stacks (a part of the fuel cell system) decreased to USD 19/kW. The R&D mainly includes the reduction of the platinum dosage in catalysts to 0.125 g/cm² and the increase of the power density of membrane electrodes to 1.095 W/cm² leading to cost reductions. However, R&D is also conducted on nonplatinum catalysts. The average life expectancy of fuel cell batteries is 3,800 h for passenger vehicles and 6,200 h for commercial vehicles under the condition that the voltage is decreased by at most 10% [2]. Conducting R&D on vital parts. The Japanese Honda Motor Company has developed high-yield Membrane Electrode Assembly (MEA) technology and replaced the specialshaped MEA structure with a rectangular structure. As the usage of this structure improves the utilisation rate of materials and simplifies the manufacturing process, it helps to accelerate production progress.

1.1.3 Accelerating the Construction of Global Hydrogen Energy Infrastructure

Hydrogen Production Technologies

Hydrogen is mainly produced using natural gas, by-product hydrogen purification and water electrolysis. The hydrogen production technology of natural gas reforming is relatively mature and has been applied for many years. In recent years, research institutes have been conducting small-scale demonstrations on the hydrogen production from the direct dissociation of natural gas. At present, hydrogen production through the purification of hydrogen as an industrial by-product and from renewable energy have become important low-carbon hydrogen production methods.

The widely applied main technology of the purification of hydrogen as an industrial by-product is membrane separation and pressure (temperature) transformation adsorption. However, if the hydrogen is to be used for FCV, it faces the problem of excessive impurities such as carbon monoxide and water vapour, requiring further optimisation and purification in the process. In terms of hydrogen production by water electrolysis, more than 40 renewable energy hydrogen production projects have been launched in European countries. That means that the water electrolysis is completely powered by renewable energies. Alkaline

electrolysis is currently the most mature and economical way to produce hydrogen using water electrolysis. Proton exchange membrane electrolysis and solid oxide electrolysis – two other hydrogen production methods - are not yet widely used.

Hydrogen Storage and Transportation

In terms of storage and transportation, mainly high-pressure or liquid hydrogen is used. High-pressure hydrogen storage and transportation involves hydrogen being transported in hydrogen storage cylinders ranging from Types I to IV. Type III and Type IV cylinders have major technology and cost advantages over lower cylinder types, as their weight ratio can already reach 5%. Liquid hydrogen transportation describes hydrogen being transported after liquefaction. The weight ratio of transported liquid hydrogen can reach more than 7%, but liquefaction plants are needed in the upstream, and the energy required for liquefaction is 10–13 kWh/kg of hydrogen. To reduce the energy consumption and cost of hydrogen liquefaction, methods like gas cogeneration and comprehensive cooling capacity utilisation are widely used. In addition to the above-mentioned two physical modes of hydrogen transportation, also the demonstration of hydrogen transportation carriers has been launched overseas. They mainly involve

liquid organic hydrogen storage materials wherein the weight ratio of hydrogen storage can reach 7%. However, the method is still in the R&D phase and only being demonstrated on a small scale due to its high energy consumption, high reaction temperature and the lacking ability to adequately control impurities.

Hydrogen Refuelling Stations

Major countries have promulgated and released plans to accelerate the construction of hydrogen energy infrastructure. By the end of 2018, there were 369 hydrogen refuelling stations worldwide, of which 48 were newly established. At the national level, Japan (96 stations), Germany (60 stations) and the United States (42 stations) ranked in the top three, and China (23 stations) ranked fourth [3]. Hydrogen refuelling stations can be divided into liquid and gas hydrogen refuelling stations, with a refuelling pressure of 70 MPa. Both types supply gaseous hydrogen for the refuelling of vehicles. The only difference is the aggregate state of the stored hydrogen. At present, about one third of the world's hydrogen refuelling stations are liquid hydrogen refuelling stations. The pressure level for hydrogen refuelling of the refuelling stations is 70 MPa, while the pressure level of a few initial demonstration bus hydrogen refuelling stations is 35 MPa. In terms of the construction scale of the stations, the amount of hydrogen supplied to ve-

hicles at hydrogen refuelling stations in foreign countries reaches at most 600 kg per day. In terms of construction modes, single hydrogen refuelling stations have been integrated into joint-constructed stations with hydrogen/oil/natural gas refuelling and hydrogen refuelling/charging to reduce land use and investment costs. Initially independent hydrogen refuelling stations have been interlinked, and the construction of hydrogen energy corridors has been started.

1.2 Domestic Progress and Trends

1.2.1 Progress in the FCV Industry

FCV Production Demonstration Projects in China

China has set a focus on developing FCV commercial vehicles like buses and urban logistics vehicles. In 2017 and 2018, the output of these two kinds of vehicles reached

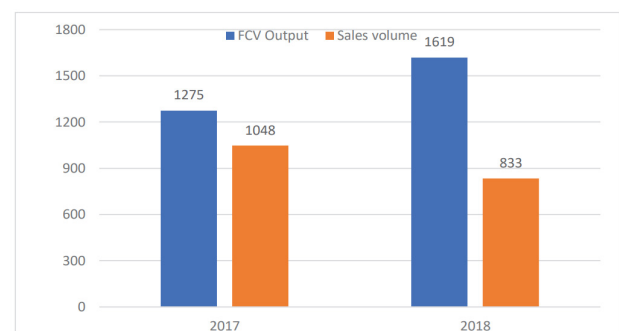


Figure 2: Domestic Production of FCV.



Figure 3: FCV Demonstration Areas in China.

1,275 and 1,619 respectively. Yutong, Foton and Zhongtong developed several fuel cell buses and started a demonstration operation with 1,000 vehicles. In September 2016, a project to promote the development of the commercialisation of FCV in China was launched, which is supported by the Global Environment Facility (GEF). Within the project the demonstration operation of 100 fuel cell buses, passenger vehicles and logistics vehicles will be carried out in Beijing, Shanghai, Zhengzhou, Foshan and Yancheng. In addition, small-scale demonstration operations have also been carried out in various cities such as Zhangjiakou, Chengdu, Datong and Rugao. The Chinese companies JD.com and Shentong also started the demonstration operation of fuel cell logistic vehicles. With an increasing number of FCV demonstrations, the construction of hydrogen refuelling stations in China has begun to accelerate. Before 2015, there were only three

hydrogen refuelling stations in China, while 23 stations had been put into operation by the end of 2018.

Development of the Fuel Cell Industry in China

Today, there are more than 200 registered companies related to FCV in China, covering the whole industry chain of fuel cell stacks, key materials and components, fuel cell power systems, vehicles, hydrogen infrastructure, etc. Overall, China has realised the industrialisation of fuel cell stacks and key components and materials, as well as carbon paper, hydrogen circulating pumps and other components and materials. In terms of fuel cell stacks, the company Sunrise Power has developed composite bipolar plate and metal bipolar plate fuel cell stacks which have been applied in the commercial vehicle FCV80 of SAIC MAXUS and

the passenger vehicle 950 of Roewe. A batch production line including membrane electrodes, bipolar plates, stack assemblies and system integration has been formed, with a capacity reaching 5 million in 2018. Guangdong Sinosynergy and Shanghai Pearl have also formed their own fuel cell stack capacities. In terms of membrane electrodes, Sunrise Power Co., Ltd.'s batch production capacity has reached 5,000 m²/year. In conjunction with its incubated high-tech company Sunlaite New Energy Technology Co., Ltd., Nanjing University built a catalyst production line with an output of 300 kg/year and a membrane electrode production line with an output of 6,000 m²/year. Wuhan WUT New Energy Co., Ltd. also formed a membrane electrode capacity of 2,000 m²/year. In terms of key materials and components, Shanghai Zhizhen New Energy Equipment Co., Ltd., jointly established by Shanghai Jiaotong University and SAIC Motor, constructed a bipolar metal plate production line with an annual output of 500,000. Shandong Dongyue's production capacity of proton exchange membranes has reached 10,000 m²/year. With the cooperation of universities and companies, Tsinghua University developed a technology for mass production of fuel cell catalysts and built a mass production line with a capacity of 1,200 g per day. International companies that produce key components have strengthened their industrial distribution in China. Canadian Ballard Power

Systems established two joint ventures: Guangdong Sinosynergy Ballard Hydrogen Power Company, established in 2016 with Guangdong Sinosynergy Hydrogen Energy Co., Ltd., focuses on the manufacture and assembly of FCvelocity®-9SSL fuel cell stacks. Shanghai Edrive Co., Ltd., was established in 2017 with Zhongshan Broad-Ocean Motor Co., Ltd. The joint venture uses the fuel cell stacks produced by Guangdong Sinosynergy Hydrogen Energy Co., Ltd. to produce and sell 30 kW and 85 kW FCvelocity® fuel cell engines.

Regional Promotion Plans for the FCV Industry in China

Concrete development concepts for supporting the development of the hydrogen energy and FCV industry have been issued in Shanghai, Suzhou, Wuhan and Rugao. The development of the hydrogen energy and FCV industry has also been made an important strategy in many local plans, for example in Beijing, Hebei, Shandong and Foshan. Led by China SAE, the „Yangtze River Delta Hydrogen Corridor Construction and Development Plan“ was launched in Shanghai on 28th April 2018, to promote the integrated development of hydrogen energy in the Yangtze River Delta region [4]. It includes plans for the construction of hydrogen infrastructure in the Yangtze River Delta, which is a suitable potential piloting region for the large-scale development of hy-

drogen infrastructure in other key areas of the country in the future.

Urban	Planning Objectives
Shanghai: <i>Shanghai FCV Development Plan</i>	By 2020, 5 to 10 hydrogen refuelling stations and two demonstration zones for passenger vehicles are going to be established with an operation scale of 3,000 vehicles. The annual output value of the whole FCV industry chain is expected to exceed RMB 15 billion.
Suzhou: <i>Guidelines for the Development of the Hydrogen Energy Industry (Trial)</i>	By 2020, nearly 10 hydrogen refuelling stations are going to be built to promote the development of buses, logistics vehicles and municipal sanitation vehicles. The annual output value of the hydrogen energy industry chain is expected to exceed RMB 10 billion. In 2025, nearly 40 hydrogen refuelling stations are going to be built with 10,000 vehicles for demonstration.
Wuhan: <i>Planning for the Development of the Hydrogen Energy Industry</i>	By 2020, 5 to 20 hydrogen refuelling stations are going to be built with 2,000 to 3,000 vehicles for demonstration. In 2025, 30 to 100 hydrogen refuelling stations are going to be built with 10,000 to 30,000 vehicles for demonstration. Efforts will be made for the annual output value of the whole hydrogen fuel cell industry chain to exceed RMB 100 billion.
Foshan: <i>New Energy Vehicle (NEV) Industry Development Plan</i>	By 2025, 5,000 fuel cell forklifts, 10,000 fuel cell passenger vehicles and 5,000 fuel cell buses are going to be popularized in Nanhai District.
Rugao: <i>Development Route of Hydrogen Economy and Technology</i>	By 2020, the total output value of the hydrogen fuel cell industry is expected to be around RMB 10 billion.
Hebei: <i>Three-year Action Plan for the Development of Strategic Emerging Industries in Hebei Province</i>	By 2020, a basic industrial system of hydrogen production, storage, transportation, refuelling and utilization is going to be established. The R&D and industrialization of high-efficiency hydrogen production, purification, storage, transportation and refuelling stations at the Handan Hydrogen Energy Application Industrial Base is going to be accelerated to promote the commercial application of complete sets of production units.
Beijing: <i>Guidance on Accelerating Scientific and Technological Innovation and Cultivating the New Energy Intelligent Automobile Industry in Beijing</i>	The capacity for key components is going to be enhanced, and both the R&D and production capacity of fuel cell stacks and systems, hydrogen circulating pumps, air compressors and other parts, as well as high-pressure hydrogen storage, liquid hydrogen storage, etc. shall be increased.
Shandong: <i>Development Plan for the Strategic Emerging Industries of Shandong Province during the "13th Five-Year Plan"</i>	The R&D and industrialization of new types of batteries such as fuel cells and hydrogen energy batteries are going to be undertaken. Innovations in the production, control and monitoring equipment of high-performance and high-reliability power batteries are going to be actively promoted to enhance power battery engineering and industrialization capability.

Table 4: Hydrogen Energy and FCV Planning in Major Provinces and Cities of China.

International Cooperation and Exchanges in the Hydrogen FCV Industry

China integrates the resources of all stakeholders and promotes international cooperation and exchange by participating in international projects and establishing international organisations. In 2016, with the approval of the Ministry of Science and Technology (MoST) and the China Association for Science and Technology, China SAE joined the Advanced Fuel Cell Cooperation Program (AFC TCP) of the International Energy Agency, which promotes international cooperation and exchange in the field of advanced fuel cell batteries. There are currently 13 members of the Cooperation Program: Austria, China, Denmark, France, Germany, Israel, Italy, Japan, Korea, Mexico, Sweden, Switzerland and the United States. The VVT Technical Research Centre of Finland and the National Centre for Hydrogen and Fuel Cell Technology of Spain are sponsors of the program. In 2016, with the support of MoST and the China Association for Science and Technology, China SAE launched the International Hydrogen Fuel Cell Association to build an international platform which covers the whole industry chain, promotes the commercialisation of fuel cells and accelerates the development of international hydrogen fuel cell technology and industries. At present, there are more than 50 members in the association, covering a broad range of areas such as

fuel cell key materials, stacks, power systems, whole vehicle integration and hydrogen infrastructure. In May 2018, the Renewable and Clean Hydrogen Innovation Challenge (IC-8) was launched during the third Mission Innovation Ministerial (MI-3) in Malmo, Sweden. The project aims to accelerate the establishment of a global hydrogen market by solving key problems faced by the hydrogen production, storage, transportation and application. The project was initiated by Australia, Germany and the European Union. As a founding member country China has also joined the project.

1.2.2 Assessment of the Technical Progress of Hydrogen FCV

Demonstration and Verification of Passenger Vehicle Start-up Technology

Among all of China's automobile manufacturers, only SAIC has introduced a fuel cell passenger vehicle, the Roewe 950, with its own brand. Through R&D and the preliminary industrialisation of this vehicle, China shows its strength in the key technology of fuel cell power systems and the entire vehicle integration, and formed and promoted the rudiments of the hydrogen FCV industry chain. The main parameters of the SAIC Roewe 950 are shown in Table 5. The fuel cell system used in this vehicle was developed by Sunrise Power. The



Figure 4: SAIC Roewe 950. (Roewe, no date)

rated power of the fuel cell stack reaches 43 kW, the specific power reaches 2 kW/l, the mass-specific power of the system reaches 500 W/kg, and the life span is 5,000 h. The fuel stack can be stored and started up at low temperatures of -20°C . A water management system without a humidifier for the fuel cell cathode and a hydrogen cycle control system with active anode pressure control have been

successfully developed for this vehicle. The hydrogen is stored in 70 MPa aluminum inner-liner hydrogen bottles wound in carbon fibre, with a mass hydrogen storage ratio of 3.5 % and a volumetric hydrogen storage density of 25 g/l. At present, 40 Roewe 950 vehicles have been put into demonstration operation in Shanghai. Next to SAIC, also FAW, DFMC, Great Wall and many other companies started to develop a product layout for fuel cell passenger vehicles. FAW developed an integrated design for medium and high power fuel cell engines. Its fuel cell power system has rated power of 55 kW, a volumetric specific power of 300 W/l and a weight ratio of 360 W/kg. The integrated design scheme of the fuel cell engine is shown in Figure 5.

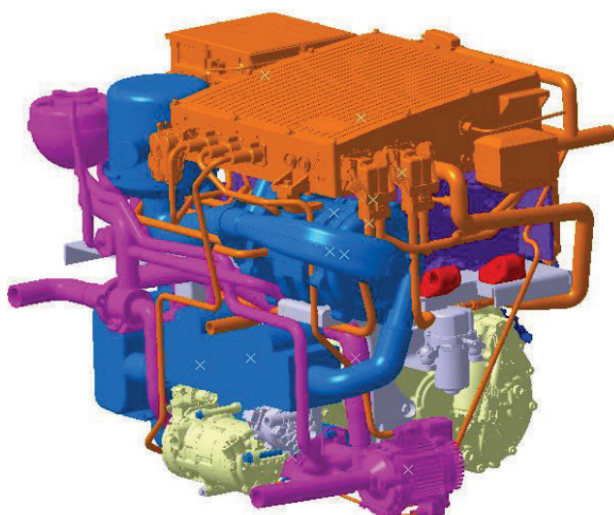


Figure 5: Diagram of FAW Fuel Cell Engine. (FAW, no date)

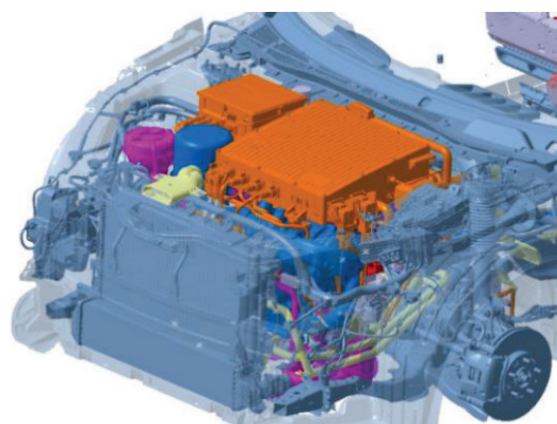


Figure 6: Cabin Arrangement of FAW Fuel Cell Engine. (FAW, no date)

Length, width and height (mm)	4,996×1,857×1,502
Curb weight (kg)	2,080
0–100 km/h acceleration time (s)	12
Max. speed (km/h)	160
Max. gradient (%)	25%
Endurance mileage (constant speed/NEDC) (km)	430/350
Start-up performance at low temperature (°C)	-20
Hydrogen bottle capacity (kg)	4.2
Hydrogen bottle pressure (bar)	700
Hydrogen consumption per 100 km	1.0

Table 5: Key Parameters of the SAIC Roewe 950.

The Commercialisation of Commercial FCV

The commercialisation of China's commercial FCV has been accelerated. Yutong, Foton and Zhongtong developed a number of fuel cell buses and started the demonstration operation of more than 1,000 vehicles. Fuel cell passenger buses in China are mainly run with hybrid technology. The average power is provided by the fuel cell battery, and peak power is provided by the power battery. The endurance mileage has been increased by optimizing control strategies and reducing the weight of vehicles with a lightweight design and now reaches more than 450 km under working conditions.

Compared to 2015, the endurance mileage, fuel economy and life span have been improved, but costs are with RMB 200,000 still on the same level as in 2015 and therefore far higher than the set goal of less than RMB 150,000 in 2020.



Figure 7: Yutong 12-Meter Fuel Cell Bus.
(Yutong, no date)

Parameters	Level in 2015	Objectives in 2020	2018	Current situation and level in foreign countries
Endurance mileage (km)	300	500	450	483
0–50 km/h acceleration time (s)	22	20	18.9	-
Fuel economy (kg/100 km)	< 8.5	< 7.0	6.8	8.3
Max. speed (km/h)	80	80	69	113
Cold start-up temperature (°C)	-10	-20	-30	-30
Life span (10,000 kilometers)	10	40	15	16
Cost (RMB 10,000)	200	< 150	200	1,000

Table 6: Main Technical Indicators of Commercial FCV. (Yutong, no date)

Parameters	Level in 2015	Objectives in 2020	2018	Current situation and level in foreign countries
Rated power (kW)	50	60	60	130 (US Hybrid)
Max. efficiency (%)	50	55	53	64 (Toyota)
Mass specific power (W/kg)	180	300	266	332 (Ballard)
Cold start-up temperature (°C)	-10	-20	-20	-30 (Toyota)
Life span (h)	3,000	10,000	10,000	25,000 (Ballard)
System cost (RMB/kW)	8,000	5,000	20,000 (100 vehicles)	-

Table 7: Main Technical Indicators of Commercial FCV Power Systems.

1.2.3 Assessment of Technical Progress of Hydrogen FCV Infrastructure

China has built a hydrogen supply system with industrial by-product hydrogen with its source in the Yangtze River Delta region and started a wind power hydrogen production project in Zhangjiakou. Hydrogen is mainly stored and transported in Type I hydrogen bottles with a pressure of 20 MPa. A total of 23 hydrogen refuelling stations have been built.

Type	Level in 2015	Objectives in 2020	2018	Current Situation and Level in Foreign Countries
Hydrogen Production	Coke oven gas/industrial byproduct hydrogen	Hydrogen production from wind power, photovoltaic power and hydroelectric power	Hydrogen supply from coke oven gas, chlor-alkali byproduct hydrogen and synthetic ammonia byproduct hydrogen has been initially formed in the Yangtze River Delta region, but data on the hydrogen quality is insufficient. The construction of a wind power hydrogen production demonstration and application project has commenced in Zhangjiakou	Japan mainly produces hydrogen through hydrogen by-products The U.S. mainly produces hydrogen through the natural gas reformation Europe has carried out more than 40 projects in the field of water electrolysis hydrogen production from renewable energy sources
Hydrogen Purification Technology	Hydrogen separation and purification technology with high efficiency and low cost		Adsorption purification technology with voltage transformation	Adsorption purification technology with voltage transformation
Hydrogen Storage and Transportation	Gas state at a high pressure of 20 MPa	> Gas state at a high pressure of 45 MPa or low[1]temperature liquid hydrogen	Gaseous hydrogen at a pressure of 20 MPa Transported by Type I hydrogen bottles	Gaseous hydrogen at a pressure above 20 MPa and transported by Type IV hydrogen bottles Transported in a liquid hydrogen state
Hydrogen Refueling Stations (units)	6	100	23	300 stations have been built
Hydrogen Refueling Pressure	35 MPa	35 MPa/70 MPa	2 hydrogen refuelling stations at a pressure of 70 MPa Changshu Hydrogen Refuelling Station, Greatwall Hydrogen Refuelling Station and Rugao Hydrogen Refuelling Station of CHN Energy (under construction) The other stations use a pressure of 35 MPa	Hydrogen refuelling stations in foreign countries use a pressure of 70 MPa

Table 8: Technical Progress of Hydrogen Refueling Infrastructure.

Hydrogen Production Technologies in China

Due to cost and environmental benefits, the hydrogen used in hydrogen FCV is mainly produced through the purification of by-product hydrogen. The main technology applied in the purification of by-product hydrogen is membrane separation and voltage (temperature)

transformation adsorption, which has been developed many years and is already widely applied in the industry. However, due to strict requirements regarding impurities in hydrogen for FCV, the process requires further optimisation. In terms of liquid hydrogen production, the only production facilities in China are in Beijing: CASC 101 has a daily production capacity of one ton of liquid hydrogen, and

Hainan Aerospace Launch Base has the ability to produce liquid hydrogen but does not produce it yet. In terms of hydrogen quality testing, there are no third-party testing institutions in China. Since June 2018, the Beijing Institute of Low Carbon and Clean Energy of CHN Energy has the ability to test the quality of hydrogen for the use in FCV. In addition, the construction of testing institutions has been launched in Foshan, Yunfu and Rugao.

Hydrogen Storage and Transportation in China

Domestically, hydrogen is transported in Type I high-pressure bottles with a maximum pressure of 20 MPa. Standards for the transportation of liquid hydrogen are being developed and expected to be released in 2019. After the official implementation it will be possible to transport liquid hydrogen for civil use. In addition to the abovementioned two physical modes of hydrogen transportation, China is also engaging in the development of hydrogen storage in metals and organic materials. The application of these technologies though is limited to demonstration and small-scale.

Hydrogen Refuelling Stations in China

14 hydrogen refuelling stations have been built,

and 23 more are under construction. In terms of hydrogen storage modes in stations, they are only gaseous hydrogen refuelling stations, and no liquid hydrogen refuelling stations in China. Great Wall Automobile is in the design process of a liquid hydrogen refuelling station which is expected to be completed in 2019. As for the hydrogen sources, China's hydrogen is mainly imported from foreign countries. All domestic hydrogen refuelling stations use a pressure of 35 MPa except Dalian Hydrogen Refuelling Station which uses a pressure of 70 MPa. Scheduled to be completed in October, Rugao Hydrogen Refuelling Station of CHN Energy is going to have two pressure levels of 35 and 70 MPa and a daily hydrogen refuelling capacity of 1,000 kg per day (in ten hours).

Development of Type III Bottles

In terms of onboard hydrogen storage, several companies have successfully developed a composite hydrogen bottle with an aluminium liner fully wound in carbon fibre (Type III bottle) having a pressure of 70 MPa. Such bottles have a water volume of 67 l, a bare weight of 76 kg and a hydrogen storage density of 3.5 wt%. They are designed and manufactured according to 'TSGR0009 Safety Technical Supervision Regulations for Vehicle Hydrogen Bottles [5], GB/T 35544 Bottle with Aluminium Liner Fully Wound in Carbon Fiber for Compressed Hydrogen of Vehicles [6] and

other related standard specifications.

1.3 Opportunities and Challenges for the Development of FCV in China

1.3.1 Favourable Conditions for the Developing of FCV

The relevant government departments and local governments take the development of hydrogen energy and FCV as an important strategic direction. China has issued a series of development plans for the fields of science and technology, transportation, manufacturing and automotive industries, all of which include hydrogen energy and fuel cell technology in their strategies. The local governments of Beijing, Shanghai, Liaoning, Anhui, Hubei, Jiangsu, Zhejiang and Guangdong have been increasingly supporting the development of hydrogen energy and FCV and issued numerous strategies and plans in this field. China is rich in hydrogen energy resources which can help to support the large-scale development of hydrogen FCV. China has access to diverse hydrogen resources. It not only possesses abundant by-product hydrogen (coke oven gas, methanol made from coal, synthetic ammonia, chlor-alkali chemical by-product hydrogen, etc.) but can also produce hydrogen through water electrolysis using wind energy, photovoltaic, hydraulic and other renewable energies. Next to green energies, China also ma-

kes high use of traditional energies during the hydrogen production process. Examples for this are hydrogen production from coal gasification and natural gas reforming. According to the statistics [7], China could obtain more than 80 billion m³ of industrial by-product hydrogen at a low-cost every year compared to pure hydrogen production, which would support the development of a large-scale hydrogen energy economy in the country. The FCV industry in China benefits from the rich R&D foundation, industrial technology expertise and marketing experience in the broad field of NEV. China attaches great importance to the development of NEV. Having been operating in the industry for more than ten years, government divisions and multiple industries have accumulated rich experience in the R&D, industrialisation, popularisation and application of NEV, and have formed a strong technical system and industrial foundation for the electrical driving system, which will effectively support the healthy development of China's hydrogen FCV. China has the world's biggest single automobile market which can lead the global development of hydrogen FCV due to its large scale. China's automotive industry has developed rapidly, and both its production and sales volume have ranked first in the world for eight consecutive years. Still, the market has further growth potential, as urbanisation rates keep increasing. The large-scale application of hydrogen FCV in China is likely to lead the

development of a global industrialisation of the technology. National policies strongly support the development of FCV and hydrogen energy has been mentioned in the government work report for the first time. In the past two years, relevant ministries have issued policies to support the development of FCV. “National innovation driven development strategy program” [8], “‘13th Five-year’ plan on scientific and technological innovation” [9], “‘13th Five-year’ plan for the development of strategic emerging industries” [10], “Made in China 2015” [11], “Medium and long-term development plan for the automotive industry” [12], “‘13th Five-year’ plan for scientific and technological innovation in transportation” [13] have listed the development of hydrogen energy and fuel cell technology as key missions, and fuel cell vehicles as key support areas. In 2019, the government mentioned to construct charging and hydrogenation facilities for the first time. During the two sessions, “hydrogen energy” became a new focus, and the state has attached great importance to the development of hydrogen energy from the policy level.

1.3.2 Bottlenecks in the Commercialisation Process of Hydrogen FCV

China’s core technology is still inferior to foreign technologies. For example, the power density of domestic hydrogen fuel cell is only 2.0 kW/l, compared to 3.1 kW/l of foreign

fuel cells; the lowest cold start-up temperature of entire domestic vehicles is -20 °C, while it can be -30 °C in foreign countries. The effective development of the hydrogen fuel cell industry has started only recently. In consequence, the industry chain is relatively weak, the production capacity is insufficient, and some vital parts are missing. Key materials like catalysts, proton exchange membranes and carbon paper for fuel cell batteries in China are mostly being developed in laboratories; the capacity for fuel cell stacks and systems is still insufficient; and core components like large capacity hydrogen compressors, air compressors, hydrogen circulation pumps and 70 MPa hydrogen bottles (Type IV) with plastic liners wound in carbon fibre are not yet equipped with mature technology. Hydrogen supply and the construction of hydrogen refuelling stations face a series of problems, and the price of hydrogen is still high. China possesses abundant, low-cost hydrogen sources but has not yet formed a large-scale hydrogen supply system for FCV. At the same time, the cost of hydrogen transportation and hydrogen refuelling station operation is still high. The price of hydrogen exceeds the cost of fuel, and a sustainable business model has not yet been formed. In addition, problems remain in the construction of hydrogen refuelling stations such as imperfect standards and unclear responsibilities of approval authorities for land use and construction. The standards and re-

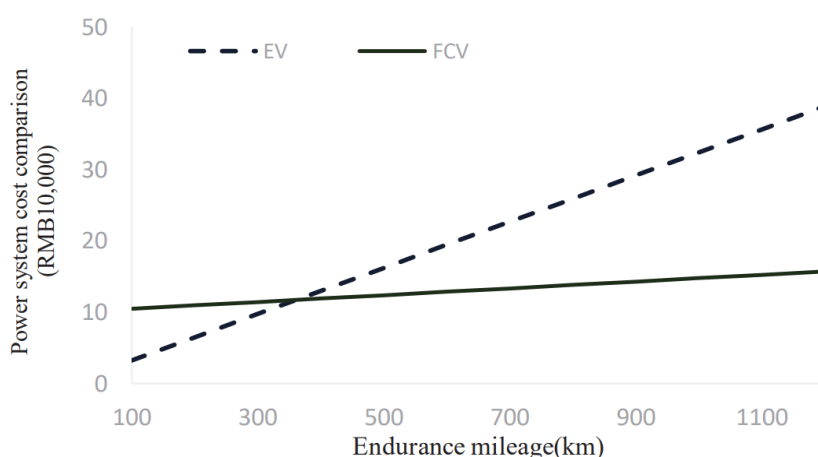
gulations are still imperfect, and the foundations of trial ability are relatively weak. Safety requirements and trial methods of hydrogen storage and transportation systems, construction and operation specifications of hydrogen refuelling stations, hydrogen quality requirements for vehicles, standards for 70 MPa Type IV hydrogen bottles and trial methods for the performance of fuel cell systems need to be improved. Also, comprehensive testing and evaluation for components, systems, entire vehicles and hydrogen energy have not yet been established.

2 Analysis of the Application Potential of FCV in the Commercial Field

2.1 Positioning and Applicable Fields of FCV Among NEV

In terms of the current cost of power systems, FCV are suitable for long range and high load vehicle types. The comparison of the cost of power systems for FCV and electric vehicles (EV) shows that the cost of power systems for EV is lower than for FCV in case the endurance mileage is less than 290 km. Starting from a mileage of 290 km, the cost of power systems for EV is higher than for FCV and when the endurance mileage is more than 500 km, the cost of power systems for FCV is 50 % lower than that for EV. In terms of application scenarios, trucks are mainly used as logistics vehicles, which are divided into urban logistics vehicles, regional trunk logistics vehicles and out-of-town logistics vehicles. Logistics ve-

hicles in cities (Type N1 and N2 vehicles) have a maximum daily driving distance of less than 200 km, an average maximum speed of less than 80 km/h and an average daily driving radius of less than 50 km. On a regional level trunk logistics vehicles have an average daily driving radius of 100–300 km and an average maximum daily driving mileage of 150–600 km; out-of-town logistics vehicles have a maximum speed of less than 200 km/h, an average daily driving radius of more than 300 km and an average maximum driving mileage of more than 600 km. They are mostly Type N3 vehicles. In terms of buses, city buses and inter-city buses are the main types. City buses have a maximum speed of less than 70 km/h, an average daily driving radius of less than 50 km and an average maximum daily driving



(Note: The cost of the power battery is calculated at RMB 1.8/Wh and 180 Wh/kg; the cost of a fuel cell power system is calculated according to a commercial cost (predicted value in 2030) of RMB 800/kW; and the cost of a hydrogen bottle is calculated according to the price of Type III bottle, i.e., RMB 10,000 per bottle.)

Figure 8: Comparison of Power System Cost between FCV and EV.



Figure 9: Applicable Fields of EV and FCV.

mileage of less than 150 km. They are mainly Type M2 and M3 vehicles. Inter-city buses have a maximum speed of less than 120 km/h, an average daily driving radius of more than 200 km and an average maximum daily driving mileage of more than 500 km. Based on the analysis above, hydrogen FCV have cost advantages for city trunk logistics vehicles, inter-city logistics vehicles and inter-city buses, and great application potential. Their promotion mainly depends on the construction of hydrogen refuelling infrastructure. Total cost of ownership (TCO) and convenience need to be taken into consideration in the application of urban delivery vehicles. This matter will be analyzed in detail in the next section.

2.2 Study on the application potential of FCV based on the TCO

Urban logistics vehicles are mainly operated by

individuals and transportation companies for whom cost is an important variable. This section compares and analyzes the TCO of FCV, traditional vehicles and pure EV from the perspective of economic feasibility.

2.2.1 Method and key parameters

The TCO appraisal model of automobile life cycles is established in this study from the perspective of consumers, as shown in Figure 10. The TCO includes the initial cost, cost to use and cost to scrap and recycle. As a trading market for used NEV has not yet been completely established, and there is no mature method for estimating the scrapping and recycling cost of NEV, these costs have not been taken into account in this study. Where PC is the initial cost (this study takes into account such factors as purchase cost, purchase tax,

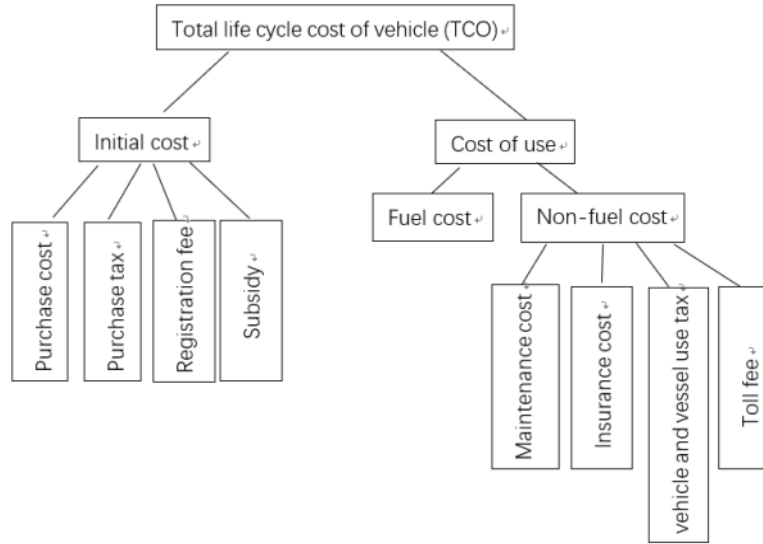


Figure 10: Composition of Automobile Lifecycle Cost.
(Note: see Formula 1 for the calculation of automobile life-cycle cost.)

$$TCO_n = PC + \sum_{i=1}^n \frac{FC_i + MC_i + IC_i + TC_i + OC_i}{(1+r)^{i-1}}$$

Formula 1: The Calculation of Automobile Life-Cycle Cost.

registration fee and subsidy); i is a particular year; 452 is the fuel cost in the i th year; MC_i is the maintenance cost in the i th year; IC_i is the insurance expense; TC_i is the vehicle and vessel use tax; OC_i are other operational costs such as toll charges; and r is the discount rate.

fuel cell logistics vehicle (FCV30) with fuel cell power of 30 kW and a light diesel truck are selected for the calculation of life-cycle costs in this study.

Initial cost

In this study, the initial cost of the vehicle includes the purchase cost, purchase tax, registration fee, subsidy and other factors. The registration fee for each type of vehicle is about RMB 500, and the detailed analysis of other costs is as follows.

2.2.2 Comparison Among Light Logistics Vehicles

To compare the TCO of hydrogen FCV with pure EV and traditional diesel vehicles, a typical pure electric logistics vehicle (EV300) with a continuous driving range of 300 km, a

Purchase cost

Taking a light truck under 7.5 tons as the benchmark model, the configuration parameters of the EV300 and FCEV30 are shown in Table 9, and the configuration parameters of the benchmark model are shown in Figures 11 and 12. In this study, the incremental cost of the EV300 and FCEV30 due to the structural difference of the power system was evaluated using the bottom-up approach. The cost of the power battery in 2018, 2020, 2025 and 2030 is set at RMB 1.8/Wh, 1.0/Wh, 0.9/Wh and

0.8/Wh respectively; the cost of the fuel cell power system in 2018, 2020, 2025 and 2030 is set at RMB 10,000/kW, 5,000/kW, 1,500/kW and 800/kW respectively; other parameter settings and data are shown in part B5 of the Blue Book of the Automotive Industry (Research Report on the Development of China's Automotive Industry) [17]. Based on the benchmark price for a typical logistics van of RMB 120,000 (source: industry research data), the purchase prices of the four types of vehicles in 2018, 2020, 2025 and 2030 are shown in Table 10.

Parameters	BEV300 (HQG5043XXYEVS)	FCEV30 (Dongfeng Auto logistics vehicles)
FC (kW)	-	30
Motor (kW)	85	120
Battery (kWh)	76 (Energy Type)	22 (Power Type)

Table 9: Configuration Parameters of EV and FCEV.



Figure 11: Pure Electric Logistics Vehicle of Dongfeng Auto HQG5043XXYEVS.



Fuel Cell Logistics Vehicle of Dongfeng Auto. (Dongfeng Auto, no date)

Vehicle model	Diesel vehicle	EV300	FCEV 30
Purchase price in 2018	120,000	222,332	471,252
Purchase price in 2020	156,300	186,550	306,640
Purchase price in 2025	160,710	174,985	188,190
Purchase price in 2030	161,970	161,495	155,021

Table 10: FCV Purchase Price Forecast.

Purchase tax

Vehicle purchase tax is the taxable price multiplied by the tax rate, wherein the taxable price is the purchase price with invoice price minus the value added tax (VAT) of 17 %, and the vehicle purchase tax rate is 10 %. That is, vehicle purchase tax = vehicle price plus 1.17 times 10 %.

Subsidies

According to the subsidies scheme for the promotion of NEV in 2018 stipulated in the Notice on the Adjustment of the Financial Subsidies Policy for New Energy Vehicles' Promotion and Application (CJ [2018] No. 18) [18], the EV300 and FCEV30 should receive subsidies of RMB 57,400 and RMB 300,000 respectively. Regarding future subsidies for NEV, this study assumes that by 2020 subsidies for pure electric logistics vehicles will be reduced to 0.6 times of those in 2018, and being abolished afterwards; and subsidies for the FCEV30 will be reduced to 75% of those

in 2018 by 2020, and 50% of those in 2020 by 2025, with a total abolishment after 2030.

Usage costs

The vehicle usage costs considered in this study include fuel costs, maintenance costs, insurance costs, vehicle and vessel use tax, road and toll charges, etc. Because the usage costs belong to intertemporal consumption, the present value analysis theory is introduced in this study, and the discount rate is 8 %.

Fuel costs

The energy consumptions of the three vehicle types are shown in Table 11. The energy consumption of the traditional diesel logistics vehicle is 13 l/100 km. Prices per unit of energy consumption are shown in Table 12. The diesel price is RMB 6.65/l, and it is assumed that the price is going to increase by 5 % in 2020, 2025 and 2030 respectively. For EV, it is assumed that the electricity price by public charging stations is going to be around RMB

1/kwh. The fuel cost of equals the cost of diesel vehicles when the hydrogen price is around RMB 40/kg. This study assumes that the hydrogen price is RMB 40/kg in 2018 (Zhangjiakou research data), and then is going to decrease by 20 % in 2020 and by further 20 % every five years after 2020. Calculated in this study at 150 km per day and 350 days per year, the average annual driving range of a vehicle is 52,500 km/year.

Energy consumption per 100 km		
Vehicle Type	Unit	Energy consumption
Diesel vehicle	L/100 km	13
EV300	kWh/100 km	25
FCEV 30	kg/100 km	8

Table 11: Fuel Consumption per 100 km of Five Types of Vehicle.

Type	Unit	Price
Diesel in 2018	RMB/l	6.7
Diesel in 2020		7.0
Diesel in 2025		7.3
Diesel in 2030		7.7
Electric - private charging	RMB/kWh	1.0
Hydrogen 2017	RMB/kg	40
Hydrogen in 2020		32
Hydrogen in 2025		26
Hydrogen in 2030		20

Table 12: Prices of Different Types of Fuel.

Non-Fuel usage cost

Non-fuel usage costs include the insurance cost, vehicle use tax, maintenance cost and human cost. According to the survey, the maintenance cost of diesel vehicles is about RMB 2,500. According to the Analysis of the Total Life Cycle Cost of Pure Electric City Buses

from the Perspective of Consumers [19], the maintenance costs of BEV are 85.46 % those of traditional vehicles. This study assumes that FCV share the same maintenance cost. As for the vehicle and vessel use tax, according to the Notice on the Preferential Policy for the New Energy Vehicle and Vessel Tax (CS [2015] No. 51) [20], China waives the vehicle and vessel

tax on NEV to promote energy conservation and encourage the use of new energy. In this study it is assumed that by 2020, the tax on pure BEV is going to be halved and the tax on FCV is going to be exempted; by 2025, the tax on BEV is going to be charged at 75 % and the tax on FCV is going to be halved; and by 2030, BEV are no longer going to be tax exempt, and the tax on FCV is going to be charged at 75 %. As for the human cost, new energy logistics vehicles with blue license plates require drivers to hold a C license, while traditional diesel vehicles with yellow license plates require a B2 license. It is assumed that the salaries of employees holding C and B2 licenses are about RMB 4,000/month and RMB 6,000/month respectively.

Analysis of the total life cycle cost (TCO)

The cost in 2018, 2020, 2025 and 2030 is calculated by summing up the vehicles' initial costs and usage costs. The TCO of the three types of vehicles with different lives span is shown in Figures 13, 14, 15 and 16 respectively. In the context of the purchase subsidy in 2018, the purchase cost of FCV significantly higher than that of BEV and traditional diesel vehicles. When an ownership is within one year, the purchase cost of BEV will be more higher than that of traditional diesel vehicles. if an ownership exceeds one year, the purcha-

se cost of traditional diesel vehicles will be higher than BEV. With the slow reduction of purchase subsidies and vehicle costs, in 2020, within two years of ownership, the purchase cost of FCV will be lower than that of traditional diesel vehicles but higher than pure BEV. However, if an ownership exceeds two years, the cost of FCV is going to be more expensive than BEV and traditional diesel vehicles. Although purchase subsidies for BEV are going to be eliminated and FCV subsidies reduced after 2020, the purchase cost of FCV and BEV will still be lower than that of traditional diesel vehicles in 2025. The cost of FCV will be lower than that of traditional diesel vehicles but higher than BEV if the period of ownership is less than seven years; otherwise the cost of FCV will be slightly more than that of BEV and traditional diesel vehicles. After the elimination of subsidies for all vehicle purchases after 2025, the purchase cost and TCO of FCV and BEV will still be lower than that of traditional diesel vehicles, and the cost of FCV will be slightly more than that of BEV in 2030.

Therefore, under the current subsidy situation, the total cost of FCV is significantly higher than that of BEV and traditional diesel vehicles in the field of urban logistics vehicles. With the decrease of purchase subsidies, the total cost of FCV in urban logistics vehicles in 2020 is still higher than that of traditional diesel vehicles and BEV, but the cost gap with traditional diesel vehicles is going to be shrinking.

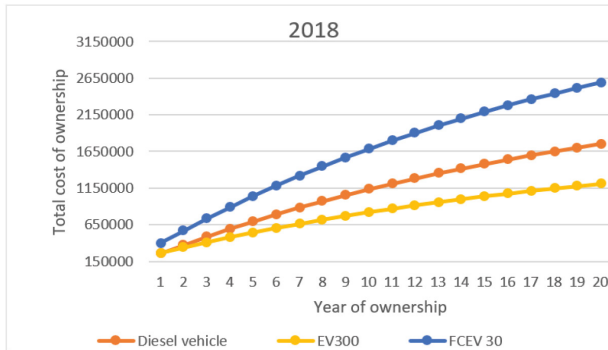


Figure 13: TCO of Three Vehicle Types in 2018.

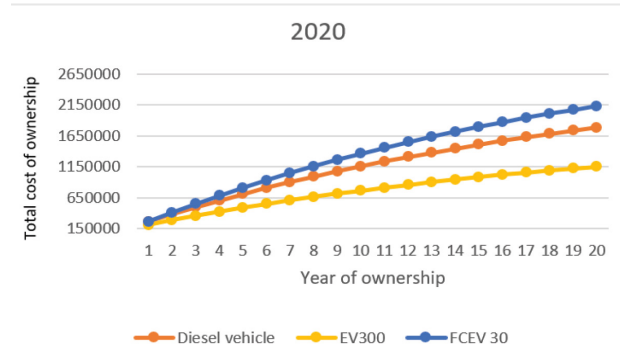


Figure 14: TCO of Three Vehicle Types in 2020.

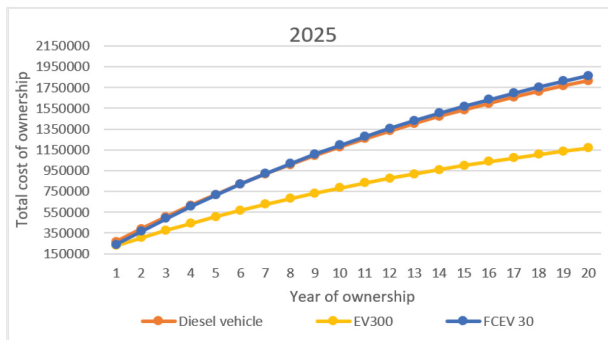


Figure 15: TCO of Three Vehicle Types in 2025.

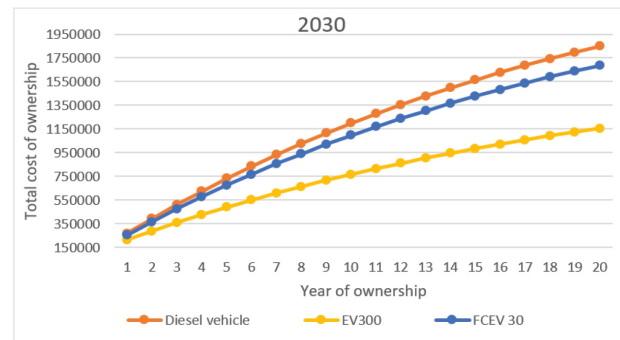


Figure 16: TCO of Three Vehicle Types in 2030.

With purchase subsidies removed and the subsidies decreasing of FCV, the TCO of FCV is going to be equivalent to that of the traditional diesel vehicles but higher than BEV; with the all types of vehicles remove the purchase subsidies, the TCO of FCV in urban logistics is lower than that of traditional diesel but higher than BEV.

2.3 Analysis of the development potential of FCV with the total investment cost of infrastructure construction.

2.3.1 Method and Key Parameters

This study compares and analyzes the cost of the infrastructure for EV and FCV in the context of different development scales, (excluding the cost of land, only including the cost of equipment) based on the energy consumption level and activity level of both vehicle types, and the service level of charging stations and hydrogen refuelling stations.

Key parameters of the vehicles:

In this study, the average annual driving range of the two vehicle types assessed is 15,000 km, while the energy consumption of EV is 22

kWh/100 km and the energy consumption of FCV is 1.05 kg/100 km. The energy consumption value of an FCV takes the Toyota Mirai as a reference, as it has the largest commercialisation scale, and the EV takes the corresponding energy consumption of a typical B-class vehicle as a reference. The electricity demand of an EV and the hydrogen refuelling demand of an FCV under different vehicle scales can be calculated according to the key parameters of the vehicles. The specific parameters and calculation results are shown in Table 13.

Key parameters of charging infrastructure:

In the calculation of charging poles, where fast charging poles are allocated in accordance with vehicle scales of 10,000, 100,000, 1 million and 20 million vehicles. The ratio of fast charging stations to the charging demand is 15 %, 15 %, 20 % and 20 % respectively. Slow charging poles are mostly used for home charging or workplace charging, and the allocation

quantity shall be calculated in accordance with the mode of vehicle charging poles. According to estimates by the China Electric Vehicle Charging Infrastructure Promotion Alliance, the construction rate of slow charging poles was 77 % in 2016 and 88 % in 2017. Where the vehicle scales are 10,000, 100,000, 1 million and 20 million vehicles, the construction rate of slow charging poles is 50 %, 60 %, 88 % and 90 % respectively. According to industry survey results by SAE, the current power of fast charging poles is mainly 60 kW, and the cost is RMB 100,000/pile; high-power charging are going to dominate the future direction of development, and the cost is expected to be reduced to RMB 70,000. According to the National Energy Administration and related studies, the utilisation rate of public charging poles in 2016 and 2017 was less than 10 % and

Vehicle scale and operation parameters		BEVs		FCVs	
Vehicle scale (10000 vehicles)	Average annual driving range (km)	Power consumption per 100 km (kWh/100 km)	Electricity demand (GWh/year)	Hydrogen consumption (kg/100 km)	Hydrogen demand (tons/year)
1	15,000	22	27	1.05	0.1575
10	15,000	22	270	1.05	1.575
100	15,000	22	2,700	1.05	15.75
2,000	15,000	22	54,000	1.05	315

Table 13: Key Parameters of Vehicles and Electricity and Hydrogen Demands.

Vehicle scale (10,000 vehicles)	Charging power of fast charging poles (kW)	Utilization rate of fast charging poles	Ratio of fast charging poles to charging demand	Cost of a fast charging pole (RMB 10,000/pile)	Construction rate of slow charging poles	Cost of a slow charging pole (RMB 10,000/pile)
1	28	7%	15%	20	50%	1.5
10	40	10%	15%	15	60%	1.2
100	60	15%	20%	10	88%	1
2,000	80	30%	20%	7	90%	0.7

Table 14: Key Parameters of Charging Infrastructure.

15 % respectively. Where the vehicle scales are 10,000, 100,000, 1 million and 20 million vehicles, the utilisation rates of fast refuelling poles are 7 %, 10 %, 15 % and 30 % respectively. Meanwhile, charging efficiency is around 85 %. The current cost of a slow charging pole - about RMB 10,000 - may be reduced to RMB 7,000 in the future. The specific parameter settings of vehicle scales in this study are shown in Table 14.

Key parameters of hydrogen refuelling infrastructure: This study mainly considers hydrogen refuelling stations with external hydrogen supply for the calculation. According to the survey, the main scale of hydrogen refuelling stations on the market is 500 kg/day. As the FCV number is going to increase in the future, the respective refuelling stations are expected to become more efficient. When the vehicle scale reaches 10,000, hydrogen refuel-

ling stations with a refuelling capacity of 500 kg/day are going to cost about RMB 6.5 million. Counting in cost reductions resulting from scalisation and technological progress in the future, the cost of a station with a refuelling capacity of 500 kg/day is going to be reduced to RMB 5.5 million. When the vehicle scale reaches 1 to 20 million, hydrogen refuelling stations with a refuelling capacity of 1,000 kg/day (twice the former capacity) are expected to cost RMB 5.07 million and 4.05 million respectively. When the FCV fleet reaches 20 million, the utilisation rate of hydrogen refuelling stations is going to reach 50 % the rate of current mature gas stations. When the vehicle scale is 10,000, 100,000, and 1 million, the utilisation rate of hydrogen refuelling stations is expected to be 20 %, 25 % and 35 % respectively. The specific parameters of hydrogen refuelling infrastructure are shown in Table 15.

Vehicle scale (10000 vehicles)	Parameters of hydrogen refuelling stations		
	Maximum hydrogen refuelling (kg/day)	Utilization rate	Cost of hydrogen refuelling station (RMB 10 ⁴ /station)
1	500	20%	650
10	500	25%	550
100	1,000	35%	507
2,000	1,000	50%	405

Table 15: Parameters of Hydrogen Refuelling Stations Corresponding to Different Vehicle Sales.

2.3.2 Conclusion and Analysis

The demand for charging and hydrogen refuelling infrastructure at different vehicle scales can be calculated according to the electricity demand of an EV and the hydrogen refuelling demand of an FCV on the one hand and the supply capacity of charging and hydrogen refuelling infrastructure on the other hand, as shown in Table 16.

Comparison between the investment scales of the hydrogen refuelling infrastructure and charging infrastructure: the total investment cost and unit vehicle investment cost of charging and hydrogen refuelling infrastructure corresponding to different vehicle scales are calculated according to the cost and demand scale of unit charging and hydrogen refuelling infrastructure. The results are shown in Figure 17. When the vehicle scale is less than 100,000, the investment cost of hydrogen

Vehicle scale (10,000 vehicles)	Charging pole scale		Hydrogen refuelling station scale
	Fast charging pole (10,000 poles)	Slow charging pole (10,000 poles)	Number of hydrogen refuelling stations
1	0.07	0.50	44
10	0.34	6.0	350
100	2.0	88	1,250
2,000	15	1,800	17,500

Table 16: Charging and Hydrogen Refuelling Infrastructure Scale Corresponding to Different Vehicle Sales.

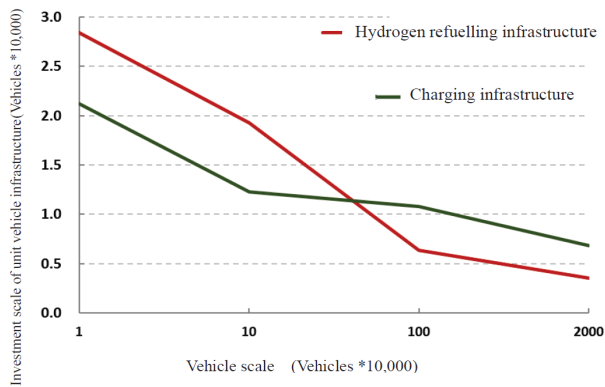


Figure 17: Investment Contrast between Charging and Hydrogen Refuelling Infrastructure at Different Vehicle Scales.

refuelling infrastructure is greater than that of charging facilities; when the vehicle scale exceeds 100,000, the cost of hydrogen stations is going to drop and when the vehicle scale reaches about 650,000, the total investment scale of hydrogen refuelling infrastructure is going to be the same as that of charging facilities. Once the vehicle scale reaches 1 million, the total investment scale of hydrogen refuelling infrastructure is going to be 40% lower than that of charging facilities.

2.4 Analysis of the Application Potential of FCV

Considering technology, industry, infrastructure and other factors, FCV are going to be mainly used in the field of public transport by 2020, and widely used in urban logistics in 2020–2025. From 2025 to 2030, their use in suburban transportation, intercity buses

and other fields is likely to start, and in 2030, FCV are going to be widely used in the field of commercial vehicles. The application scale of FCV in each time node is shown in the following figure. According to the National Manufacturing Power Strategy Consultancy Committee and China SAE entrusted by the Ministry of Industry and Information Technology, more than 500 experts in the industry are cooperating on conducting research for the Energy-saving and New Energy Vehicle Technology Roadmap, and they propose the following development goals for the Roadmap of Hydrogen FCV. There are going to be 5,000 demonstration vehicles in 2020, with commercial vehicles accounting for 60 % and passenger vehicles accounting for 40 %; 50,000 demonstration vehicles in 2025, including 10,000 commercial vehicles and 40,000 passenger vehicles; and 1 million demonstration vehicles in 2030 [21].

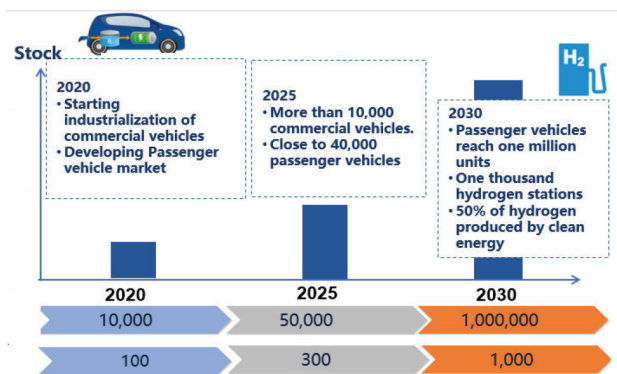


Figure 18: Development Goals for FCV and Hydrogen Refuelling Stations.

3 Vision for FCV Development in the Beijing-Tianjin-Hebei Region (JJJ)

3.1 Brief Introduction to the JJJ Region

Located in North China, the JJJ region consists of Beijing, Tianjin and Baoding, Langfang, Tangshan, Zhangjiakou, Qinhuangdao, Hengshui, Chengde, Cangzhou, Anyang, Xingtai and Shijiazhuang of Hebei Province. It is the heart of the Northern Bohai Rim in China, has a land area of 218,000 km² and a population of about 110 million people. The region is known as a heavy industry base focusing on key industries like automobile, electronics, machinery as well as iron and steel. It is also the political, cultural, international and technological innovation center of China. The JJJ region, which has a temperate continental monsoon climate with a medium temperature, is known as „an urban agglomeration with the capital as the core, a national engine of economic growth through mass entrepreneurship and innovation, a region for development and reform, and a demonstration area for ecological restoration and environmental improvement“. The different cities and regions hold different positions: Beijing is the „national center of politics, culture, international communication and science and technology“; Tianjin is the „national advanced industrial manufacturing base, shipping hub of Northern China and financial innovation demonstration area“; Hebei Province is the „national commercial trading and logistics base, pilot zone of industrial trans-

formation and upgrading, demonstration zone of urbanisation and urban-rural integration, and ecological environment supporting zone of the JJJ region“. JJJ cities push forward the development and cooperate on the integration of the economy, ecology, energy and science and technology.

3.2 Advantages in the Development of FCV

As a region initiating the R&D, industrialisation and demonstration operation of hydrogen energy and FCV, the JJJ region has a good foundation and strong conditions for the promotion of FCV.

3.2.1 Regional and Resource Characteristics

The regional proximity and comprehensive transportation network is the basis for the development of the hydrogen energy and FCV industry in the JJJ region. In terms of geographical position, Beijing and Tianjin are closely adjacent to each other in Hebei. With a well-developed highway transportation network, FCV can contribute substantially to the passenger and freight demand in the JJJ region. Adjacent regions are also going to play an important role in the formation of a networked hydrogen supply system.

The JJJ region is rich in renewable energy sources and has capacity to provide hydrogen energy for the development of FCV. There are rich wind and solar energy resources in Zhangjiakou, Bashang District of Chengde, Qinhuangdao, the coastal area of Cangzhou as well as in the Taihang Mountain and Yanshan Mountain areas in Hebei Province. In Zhangjiakou, Bashang District of Chengde, Tangshan and the coastal area of Cangzhou, 1 million kW wind power bases have been constructed. According to Hebei renewable energy ‘13th Five-year’ plan [22], the proportion of renewable energy power generation in the power supply structure is going to increase significantly, accounting for more than 41 % of total installed capacity by 2020. Its share of generating capacity in total electricity consumption is expected double from 2015, rising to more than 13 %. The total utilisation of renewable energy is equivalent to 23 million tons of standard coal. The share of renewable energy in total energy consumption is going to double to seven percent in 2020 from 3.2 % in 2015. Abundant renewable electricity can provide abundant clean hydrogen resources for the JJJ region. In addition, Hebei Province is the second largest coke production base in China, in which coke oven gas is a by-product. Purifying the by-product coke oven gas in the JJJ region can also become an important source of hydrogen energy. Considering hydrogen production by coke oven gas, Chlorine-alkali indus-

try and renewable sources, the total supply of hydrogen energy in the “JJJ” region was 157.7 thousand tons of H_2 /year. (shows in 5.1). The JJJ region is going to supply 998.1 thousand of hydrogen passenger vehicles based on 15 thousand km annual mileage and 158 kg hydrogen energy consumption per year. As for hydrogen bus, it is estimated that annual mileage and hydrogen consumptions are 60 thousand km and 6816 kg respectively, the JJJ region can supply 23.1 thousand of hydrogen buses. If heavy truck (loading 30tons) can drive 60 thousand km and consume 9,000 kg hydrogen energy, the JJJ region can supply 17.5 thousand of hydrogen trucks.

3.2.2 Industrial Structure and Characteristics of the JJJ Region

The JJJ region has established a relatively complete industrial chain of hydrogen energy and FCV and is heavily engaging in both R&D and commercial application of FCV technology. In terms of R&D, Tsinghua University in Beijing has major R&D and testing capabilities in fuel cell catalysts, fuel cell stacks and fuel cell systems. In terms of key parts and components, SinoHytec has strong supporting capacity for commercial FCV as one of the largest fuel cell system manufacturers in China. In terms of finished vehicles, several automobile manufacturers like BAIC Group, Foton, Great Wall and BYD Auto have a number of production

bases for passenger vehicles and commercial vehicles the JJJ region; and in terms of the hydrogen supply chain, the JJJ region has the ability to produce hydrogen using renewable energies. Also, many companies in the field of hydrogen storage, transportation and the construction of refuelling stations like PERIC, Hydrosys, Nowogen and CASC are operating in the region. Moreover, the development of industrial institutions in the JJJ region is going to provide opportunities for the development of the hydrogen energy and FCV industry. The JJJ regions has numerous advantages over other regions in China, mainly lying in its geography and historical importance that make the area an economic and political focal area. As a national political, cultural and financial center, Beijing ranks first on a national level in the prestige of universities, scientific research institutions and gathers many of the country's most talented human resources. Tianjin is an important port city with a highly developed manufacturing industry. Although Beijing and Tianjin have the region's strongest and most solid general macroeconomic conditions, major R&D achievements in the transformation of the FCV industry and the development of FCV facilities in the JJJ region are mainly realised in Hebei. The industries of the three regions are at different development stages and thus also differ in industry focus, demand and development goals. These differences can be beneficial, as some dimensions of the de-

velopment of one of the three regions can be complementary to another.

As the proportion of road transportation for goods is especially high in the JJJ region, there is a high demand for sustainable vehicle solutions such as FCV. Highway transportation of goods is the main part of the region's total transportation, accounting for up to 84 %, significantly higher than the national proportion of 76.8 %. There is a seemingly unreasonable high concentration of cargo transport at major distribution points with more than 60 % of the cargo throughput of the Tianjin-Hebei port cluster relying on highway transportation [23]. Highways also play the most important role for the region's passenger mobility with a proportion of more than 75% of the total transportation, although the proportion of railway passenger traffic volume has been increasing year by year [24].

In 2017, the cargo throughput in Tangshan port, Tianjin port, Huanghua port and Qinhuangdao port reached 565.4 million tons, 502.84 million tons, 269.57 million tons, and 244.8 million tons respectively. The overall cargo throughput of the JJJ regions totaled 1.582 billion tons in 2017. Assuming that 60 % share of road transport, the highway freight volumes amount to about 949 million tons. Calculated according to each truck that transports 30 tons with 400 km transport distance, and consumes 100 kilograms of diesel, the truck has to trans-

port 63.26 million times. If the FCV replaces trucks to transport, it can save 6.326 million tons of fuel [25].

3.2.3 Demonstrations of FCV in the JJJ Region

The JJJ region has more than ten years of experience with the demonstration operation of FCV. Altogether more than 100 vehicles have been used for demonstration, mainly in the field of public transportation. As early as 2008 during the Beijing Olympic Games, fuel cell passenger vehicles and buses were demonstrated. In May 2017, sixty 8.5-meter fuel cell buses that were jointly developed by Foton, the BAIC Group and SinoHytec were put into operation in Beijing as commuter buses and commercial vehicles. In Phase III of the UNEP/GEF FCV commercial demonstration project launched in 2017, five 12-meter Foton Ouhui Generation III fuel cell buses were demonstrated. In 2018, forty-nine 10.5-meter Foton hydrogen fuel cell city buses were delivered to Zhangjiakou in bulk. In terms of hydrogen

refuelling stations, Yongfeng Refuelling Station which was built during the Beijing Olympic Games has been in operation for more than ten years. SinoHytec has also invested RMB 300 million into building a large hydrogen production plant in Zhangjiakou with an area of 150 mu (around 24.75 acres), a daily hydrogen production capacity of 20 tons and an annual hydrogen production capacity of 6,000 tons, which will be enough for the refuelling of more than 1,500 fuel cell buses in the JJJ region.

3.2.4 An Important Driving Force: Control of Air Pollution

Since 2010, the national government attached great importance to air pollution control in the JJJ region. A series of policies, including the Guidelines for the Joint Prevention and Control of Air Pollution to Improve Regional Air Quality, Detailed Rules for the Implementation of the Air Pollution Prevention and Control Action Plan in the JJJ Region and Surrounding Areas, Stronger Measures on the

Zone	Application vehicle type and scale
2008 during the Beijing Olympic Games	Fuel cell buses and business vehicles
2017 in Beijing	5 × 12 m Foton fuel cell buses
2018 in Zhangjiakou	49 × 10.5 m Foton fuel cell buses

Table 17: Current Situation of FCV Demonstration Operation in the JJJ Region.

Prevention and Control of Air Pollution in the JJJ Region, Work Plan for Air Pollution Prevention and Control in the JJJ Region and Surrounding Areas in 2017, and Action Plan for the Comprehensive Prevention and Control of Air Pollution in the JJJ Region in Autumn and Winter 2017–2018, has been issued to implement joint control and prevention of air pollution in the JJJ region. In May 2018, a new analysis about the sources of fine particulate matter (PM_{2.5}) in Beijing was released. Local emissions account for two thirds and regional transmission accounts for one-third of the annual PM_{2.5} emissions in Beijing. The PM_{2.5} from regional transmission accounts for about 20 micrograms/m³ in the average annual PM_{2.5} concentration of 58 micrograms/m³ in 2017. Meanwhile, contribution of regional transmission rises along with an increasing pollution level, with the daily regional transmission of heavy pollution accounting for 55–75 %. Among the current sources of PM_{2.5} in the local atmosphere in Beijing, mobile sources like vehicles account for the largest proportion of up to 45 %. Among mobile sources, diesel vehicles entering the Beijing area contribute the most. Therefore, to solve the air pollution problem in Beijing, (I) regional transmission could be controlled with regional joint defence and control, and (II) efforts could be made to solve the exhaust pollution of motor vehicles in Beijing, especially pollution caused by heavy diesel vehicles in transit.

In June 2018, on the basis of the completed five-year action plan for air pollution prevention and control, the State Council issued the Three-year Blue Sky Protection Campaign Action Plan which specifies action fields for air pollution control by 2020 and marks the beginning of the second phase of air pollution control. Key areas are the JJJ region from a geographic standpoint and diesel trucks from an industry perspective. In this action plan it has also been mentioned that “the upgrading of the vehicle and ship industry structure shall be accelerated. NEV shall be promoted. The production and sales of NEV will reach about 2 million in 2020. The use of new or clean energy vehicles in fields like public transportation, environmental sanitation, postal services, vehicle rental and commuting services in the city shall be accelerated, and shall account for 80 % of the total vehicle fleet in key areas.”

FCV can achieve zero emissions while in operation and low emissions throughout their overall life cycle, making the FCV development an important tool for realising urban traffic cleanliness, controlling urban vehicle pollution and replacing diesel trucks. FCV commercial vehicles, for instance, can reduce emissions by more than 30 % in their life cycle compared to traditional diesel vehicles if the industrial by-product hydrogen production path is adopted; and FCV emit zero emissions in their life cycle if renewable energy sources like solar and wind energy are used for the hydrogen

production. Considering the characteristics of renewable energy in JJJ, it is widely believed that FCV are going to be an important strategic support for achieving goals formulated in the Blue Sky Protection Campaign and Diesel Vehicle Pollution Control.

3.2.5 Enterprises Accelerate the Development of Hydrogen Energy and FCV.

The National Energy Group accelerates to promulgated policies for hydrogen production and hydrogen refueling stations construction. It has dedicated to technology R&D in wind energy, electric energy, and coal to produce hydrogen energy. In addition, it also accelerates the deployment of hydrogen energy infrastructures such as transportation, storage, and refueling station. China's Hydrogen Energy and Fuel Cell Industry Innovation Strategic Alliance was established by the State Grid and private sector. The aim is to increase R&D investment in fuel cell systems such as membrane electrodes, bipolar plates, high-efficiency packaging of stacks, and auxiliary systems. In addition, large enterprises such as China National Chemical Corporation, Aerospace Science and Technology, Sinopec and CNPC have deployed hydrogen and fuel cell industries in the JJJ region.

3.3 Challenges for the Development of the FCV Industry in the JJJ Region

At present, there are numerous FCV cooperation projects in the JJJ region, but they are rather superficial and only yielded average results. The five main factors restricting the development of the FCV industry in the JJJ region are the following:

3.3.1 Insufficient Regional Planning for the Development of the Hydrogen Energy and FCV Industries

Regional planning for an efficient development of the FCV-related industries can not only generate more policy support but also encourage the development in other regions. Since the release of the Outline of Coordinated Development Plan in the JJJ Region [26], the development of the JJJ region has become a major national strategy, which formulates environmental protection, transportation and industrial upgrading and transfer as the three key areas for development. In 2016, the JJJ Transportation Integration Plan was released, and the integration of transportation remains one of the main focal areas in the development of the JJJ region. The JJJ region formed a fourlevel „state-region-city-transportation“ working mechanism and established a regular consultation system focused on the synthesis of infrastructure construction, public

transport and intercity passenger transport services. However, this consultation only involves transportation departments. In consequence, cooperation is lacking between relevant departments of urban logistics and freight transportation such as commerce departments, development and reform departments, planning departments and other relevant stakeholders. Moreover, there is a lack of coordination and cooperation among the promulgated policies of different cities in the development of low-carbon and clean transportation due to an insufficient overall planning at the regional level. Beijing, Tianjin and Hebei have successively released local plans for the development of NEV which involve development plans for FCV but lack respective plans for reasonable regional development planning. As a result, the functional positioning, the industry chain division of labour and resource allocation in the development of hydrogen energy and FCV in JJJ are not clear and a community of interests cannot be formed. This makes it difficult to achieve complementary regional advantages and win-win cooperations.

3.3.2 Lack of a development model with core technology leading applications

At present, the relatively mature FCV technology in the JJJ region provides a good basis for the industry. Still, JJJ has not yet established

a localized supply chain for key materials and core components such as the core technology of fuel cell stacks, fuel cell membrane electrodes, proton exchange membranes and carbon paper. On a technology level, the rated power of the graphite bipolar plate stack can currently reach 60 kW, and its life span can reach 4,000 hours, while the power demands of medium and heavy goods vehicles generally exceed 100 kW, and their life span requires more than 15,000 hours. In terms of costs, fuel cell power systems require RMB 10,000/kW. In this phase, the purchase price of an FCV is two to five times the equivalent model of traditional fuel vehicles, and 1.5 to 2.5 times than the equivalent model of the purchase price of EV. The cost of using hydrogen is also high. The price of hydrogen for vehicles is generally between 60 and 70 RMB/kg, which is twice that of traditional fuel vehicles and six times that of EV. In terms of application, the current demonstration application of FCV in the JJJ region is mainly implemented for buses and has not yet been extended to fuel cell trucks, urban logistics vehicles and other fields.

3.3.3 Inadequate coverage of infrastructure

The development of FCV requires the support of the hydrogen energy supply system and hydrogenation infrastructure. In terms of hydrogen storage and transportation, the clas-

sification of hydrogen as a dangerous chemical creates policy obstacles for its storage and transportation. For the respective construction of hydrogen stations, safety, fire protection and other approval procedures are not clearly defined. Also, no network of hydrogenation stations covering the whole JJJ region has been formed yet and the reliability of the hydrogen station infrastructure requires further testing and technological improvements. Therefore, the JJJ region has not yet formed a clean lowcarbon and low-cost hydrogen supply system.

3.4 Planning supports the development of FCV in the JJJ region

Four concrete measures can accelerate the development of the FCV industry in JJJ: the formulation of integrated plans for hydrogen energy and FCV at the regional level, the clear definition of the further development of joint technology, the consideration of core technological breakthroughs, industrial chain docking, infrastructure construction, integrated transportation systems and other FCV-related subjects, and the promotion of links in the FCV industry chain in the region. The Plan sheds a light on the role of technology in the supply of clean hydrogen energy and the development of urban freight and medium and heavy FCV, puts forward an integrated construction plan for hydrogen energy infrastructure in the re-

gion, clarifies the strategic positioning of each region and contributes to the overall integration of the FCV supply chain. Hebei Province is already stimulating its development of new energy, FCV and other emerging industries by producing renewable hydrogen energy on a large scale. Especially in Zhangjiakou, the province is promoting its economic transformation towards a green low-carbon development. According to the Plan, Beijing and Tianjin are supposed to engage in demonstration projects of the fuel cell technology used in urban buses, intercity buses, urban logistics vehicles, port vehicles among others, thereby driving the integrated development of the hydrogen energy and FCV supply chain in the JJJ region.

4 Recommendation for the Development of FCV in the JJJ Region

4.1 International Cooperation Between China and Germany on the „Hydrogen Valley“ Joint Demonstration Project in the JJJ Region

The current FCV research European countries – Germany in particular - consider Power-to-Gas (P2G) demonstration projects as especially important. In this kind of projects renewable energy sources like wind power and solar energy are used to produce hydrogen from water and store this hydrogen on a large scale. An effective distribution form of hydrogen is realised via gas pipelines. As of today, there are about 40 P2G projects in Europe with more than 20 P2G projects located in Germany.

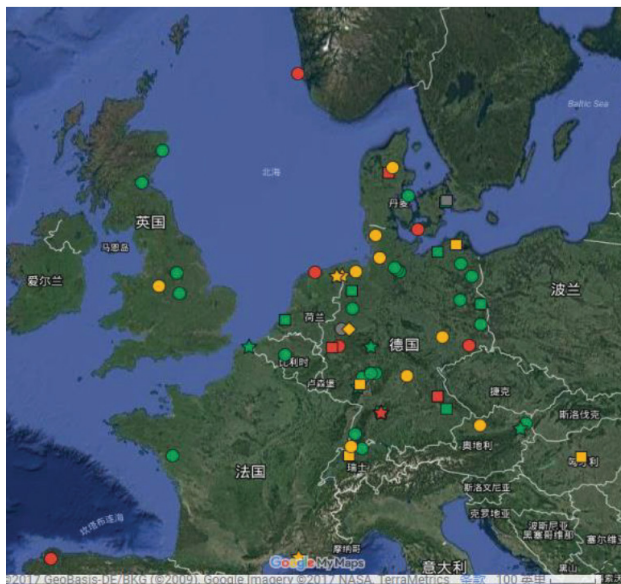


Figure 19: P2G Projects in Europe.
(Europeanpowertogas, no date)

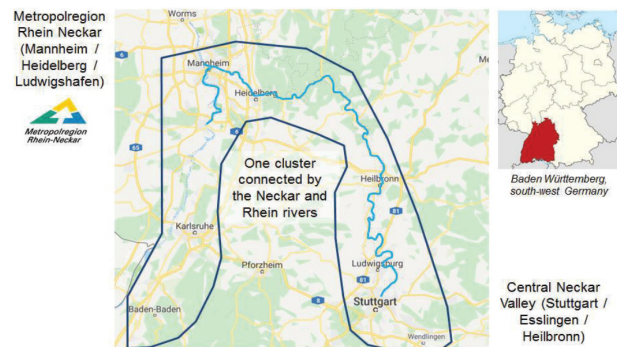


Figure 20: „Hydrogen Valley“ Demonstration Area in Germany. (E-Mobil BW, no date)

Therefore, SAE recommend hydrogen production powered by wind and solar energy on a large scale and the start of demonstration projects in qualified areas like Yanqing and Zhangbei in China or the German Rhine-Neckar Metropolitan area (Mannheim/Heidelberg/Port Ludwig). Moreover, the plans for hydrogen development should be line with the Sino-German demonstration project of the „Hydrogen Valley“ in the JJJ region with the construction of the Zhangjiakou-Beijing as a „Low-carbon Olympic Zone“.

Zhangbei District is especially suitable for the hydrogen production from renewable energy. Also the waste reduction, the usage of excess wind and solar energy and the integration of hydrogen energy and distributed energy in Zhangbei can be used to explore a set of feasible models for the industrial integration and development of renewable energy into the hydrogen energy economy.

4.1.1 Establishing a Comprehensive Hydrogen Production System in the JJJ Region

It is suggested to make full use of hydrogen energy resources such as coke oven gas, Chlor-alkali industry, and renewable resources to establish a comprehensive hydrogen production system in the JJJ region.

Coke oven gas to produce hydrogen

According to “China blue book on hydrogen industry infrastructure development 2018” [27], in 2017, the output of coke in China was 431 million tons, coke oven gas output was nearly 172.4 billion Nm^3 , the potential capacity of using coke oven gas to produce hydrogen around 566,400 tons of H_2 /year. In 2017, the coke output in Hebei and Tianjin was 48.13 million tons and 1.57 million tons. Therefore the potential capacity of using coke oven gas to produce hydrogen was around 653,00 tons of H_2 the JJJ region in that year.

Chlorine-alkali industrial by-product hydrogen

According to “China blue book on hydrogen industry infrastructure development 2018,” in 2017, the output of caustic soda in China was 33.65 million tons, and each ton of cau-

stic soda produced 25 kg of hydrogen. Assume that the short-interest ratio of Chlor alkali industry to produce hydrogen is 10 %, the potential capacity of using Chlor-alkali industry to produce hydrogen was around 84,100 tons of H_2 /year. In 2017, due to Hebei and Tianjin produced 1.2567million and 799,500 tons of caustic soda respectively, the potential capacity of using Chlorine-alkali industry to produced hydrogen was about 514,00 tons of H_2 /year the JJJ region in that year.

Renewable Energy to Produce Hydrogen

According to “China blue book on hydrogen industry infrastructure development 2018,” In 2017, the output of excess wind energy in China was 41.9 billion kWh. The potential of using excess wind energy to produced hydrogen in China was around 748,200 tons of H_2 /year when based on 5 kWh/ Nm^3 energy consumption. In 2017, the output of excess wind energy in Hebei was 2.03 billion kWh, and the potential of using excess wind energy to produced hydrogen was around 36,200 tons of H_2 /year in that year.

According to “China blue book on hydrogen industry infrastructure development 2018,” in 2017, the output of excess solar energy in China was 7.3 billion kWh. The potential of using excess solar energy to produced hy-

hydrogen in China was around 130,400 tons of H_2 /year when based on 5 kWh/ Nm^3 energy consumption. In 2017, the output of excess solar energy in Hebei was 93 million kWh, and the potential of using excess solar energy to produced hydrogen was around 1600 tons of H_2 /year in that year.

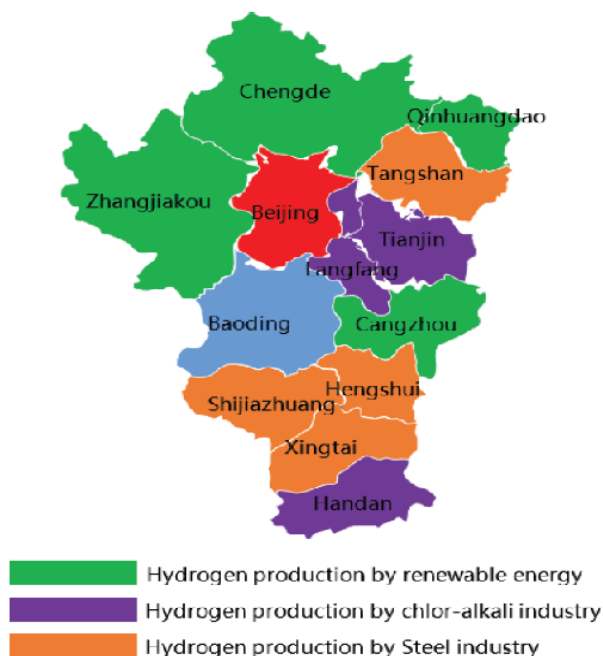


Figure 21: Distribution Map of Hydrogen Potential in the JJJ Region.

To sum up, in 2017, the total hydrogen energy supply in the JJJ region reached 157,700 tons of H_2 /year.

4.1.2 Establishing Storage and Transportation System in the JJJ Region

Building Hydrogen Pipelines

Pipeline transportation is an important way to carry hydrogen in large scale and longdistance. The pipeline transport pressure is generally 4.0 MPa with the advantages of large hydrogen transport volume, low energy consumption, and low cost. Beijing supports Yanshan Petrochemical Company to build a hydrogen pipeline around the sixth ring road of Beijing. In addition, Beijing plans to build a hydrogen pipeline from Zhangjiakou to Beijing in order to make full use of Zhangjiakou hydrogen resources. Besides, Xiong'an New Area is positioned as a low carbon city which is going to deploy underground infrastructure to achieve a stable and safe supply of clean energy. Xiong'an New Area is expected to build hydrogen pipelines, however, due to the high construction cost, it is considered to use existing pipeline facilities in the early stage.

Hydrogen Transportation by 20 MPa Long Tube Trailer

The long tube trailer is suitable for short-distance hydrogen transportation with a radius of about 200 km and the maximum load per trailer is about 300 kg. Long tube trailers are generally filled by compressors in a hydrogen plant, with an average of 8 hours per trailer.

Using 35 MPa III type cylinder of high pressure gaseous hydrogen storage

Type III bottles include two pressure types that 35 MPa and 70 MPa. In China, 35 MPa type III bottles are mainly used in vehicle hydrogen storage. 70 Mpa usage Standard GB T 35544-2017 “Fully-wrapped carbon fiber reinforced cylinders with an aluminum liner for the on-board storage of compressed hydrogen as a fuel for land vehicles” has been issued in China and used in the small and medium range of vehicles.

4.1.3 Establishing the JJJ Regional Hydrogen System

By 2022, the planning of hydrogen energy in the JJJ region can be classified as three parts:

- Commercial operation of hydrogen energy in the fields of bus, logistics, and taxis
- Focus on demonstrating hydrogen energy in emergency power supply, communication base station, distributed cogeneration, and micro-grid
- Innovative development of hydrogen energy in the fields of official vehicles and sanitation vehicles, etc [28].

4.2 Highlighting the Characteristics of Hydrogen FCV and Promoting Demonstration Projects

A focus lies on the promotion of FCV demonstration projects, the integration of hydrogen into the FCV industry, the implementation of hydrogen FCV demonstration projects with distinctive characteristics, and the formation

Phase	Number of Fuel Cell Battery Vehicles	Number of Hydrogen Refuelling Stations	Highway Coverage	Marks and Characteristics
2019–2021	>2,500 vehicles	>25 stations	3 highways	Zonal cooperation of hydrogen corridor
2021–2025	>5,000 vehicles	>200 stations	>10 highways	Reticular cooperation of hydrogen corridor
2026–2030	>10,000 vehicles	>500 stations	>20 highways	Overall cooperation of hydrogen corridor

Table 18: Field and Scale of Hydrogen Fuel Cell Industrial Demonstration in the JJJ Region.

Field	2019	2021	2025	2030
Bus	114	2,000	3,000	5,000
Logistics vehicles		500	1,500	3,000
Medium and heavy-duty trucks		30	500	2,000

Table 19: Demonstration Scale and Application Fields of FCV in the JJJ Region.

of development modes of the FCV industry in which concrete application scenarios and projects drive the industry development.

4.2.1 Continue to Steadily Develop FCV Demonstration Projects

Fuel cell batteries are planned to be introduced in buses, urban logistics vehicles, medium and heavy goods vehicles, and other fields in the context of demonstration projects until 2030, as shown in Tables 18 and 19.

Demonstration of fuel cell buses: 2,000, 3,000 and 5,000 fuel cell buses are going to be promoted by the years of 2019–2021, 2025 and 2030 respectively with an extension of the fleet, vehicle updates and new methods for recycling. The implementation of the fuel cell technology is going to vary among different bus categories.

Demonstration of fuel cell urban logistics vehicles: Also demonstration projects in the field of urban logistics are going to be en-

couraged. From 2019 to 2021, the demonstration operation of 500 fuel cell logistics vehicles is going to be launched; this number is expected to increase to 1,000 vehicles by 2025 and to 3,000 vehicles by 2030. Especially companies in the postal and logistics industry are going to use the technology.

Demonstration of medium and heavy-duty fuel cell trucks: By 2021, a multi-modal logistics network coordinated among Tianjin Port, Qinhuangdao Port, Tangshan Port, Huanghua Port and other major ports and logistics parks such as land ports and airports is planned to be constructed, and 30 medium and heavy duty fuel cell trucks are going to be used in demonstration projects in that region. The demonstration scale of medium and heavy-duty logistics trucks is planned to be expanded to 500 trucks by 2025 and 1,000 trucks by 2030. By 2030, the demonstration is also going to be extended geographically to the entire JJJ Logistics Zone. FCV are going to be mainly used by FCV companies and logistics centers.

4.2.2 Planning and Layout of Hydrogen Energy Infrastructure

The construction of a hydrogen refuelling infrastructure is going to be an integral part of the regional planning in the JJJ region, and a hydrogen energy supply system based on wind and solar hybrid hydrogen production is going to be built in a reasonable period in advance.

As there is a high demand for the usage of hydrogen energy in the transportation sector in the JJJ region, the medium and long-term hydrogen energy supply and demand of key urban agglomerations in the JJJ region will be analyzed. Moreover, the different development plans for fuel cell technology in various cities will be linked with market and cost-orientation and demand traction. This integration supports the construction of a hydrogen infrastructure network and the establishment of both a regional hydrogen energy corridor and a hydrogen energy supply system composed of hydrogen refuelling stations “from spots to line” and “from line to plane”.

By 2020, also with regard to the „Zero Carbon Winter Olympics“ in 2021, two hydrogen (hybrid) production plants using wind and solar energy and more than 20 hydrogen refuelling stations are going to be built in the Zhangjiakou region. Furthermore an intercity hydrogen corridor for hydrogen distribution covering more than 200 km is going to be built along

the Beijing-Zhangjiakou connection line. Potential forms of cooperation on the hydrogen refuelling infrastructure construction between the government and industrial stakeholders like energy companies, infrastructure construction companies and automobile manufacturers are going to be assessed, to meet the hydrogen demand for FCV during the Winter Olympic Games in 2021.

By 2025, the construction of the JJJ regional hydrogen corridor in the „post-Winter Olympics“ era is going to be based on the highway network in the JJJ region. Key cities like Zhangjiakou, Beijing, Baoding and Shijiazhuang are going to be taken as important connecting points of the hydrogen corridor in the JJJ region to build respective hydrogen infrastructure, and three high-speed hydrogen demonstration pipelines are going to be built between the connecting cities, as well as 25 hydrogen refuelling stations. These measures help to meet the needs of commercial vehicles in the field of public services such as intercity buses and logistics vehicles.

By 2030, the construction of the hydrogen infrastructure in JJJ's core cities is going to be expanded. More than 10 hydrogen highways (highways with respective hydrogen refuelling facilities) will be built between key cities, and more than 200 supporting hydrogenation stations are going to be built to meet the hydrogen demand of commercial vehicles such

as urban and intercity buses and logistics vehicles. Overall, an efficient integration of destination stations and connection stations, hydrogenation infrastructure and FCV is going to be achieved. Aiming at an expansion and commercialisation of the hydrogen refuelling infrastructure, hydrogen refuelling facilities are going to be gradually built throughout the whole JJJ region.

4.2.3 Improving the Coordination and the Evaluation of Demonstration Projects

A major focus lies on the surveillance platform of NEV and the technical assessment and safety monitoring of the demonstration process. Especially, insights into the vehicle production, sales and operation as well as into the hydrogen stations operation are going to be gained and the technical progress, economy and reliability of FCV and hydrogen stations are going to be assessed periodically. Also, references for technological R&D and industrialisation are going to be provided. Moreover, stakeholders can learn from valuable insights and best-practices that are derived from the assessment of demonstration projects, and finally promote the fast but healthy development of the FCV industry. At the same time, both the management and the monitoring of related processes are going to be strengthened.

4.3 Focusing on Key Areas and Substantially Increasing the Innovation Level of Technology

Under the support of the governments of Beijing, Tianjin and Hebei, an alliance for the development of the FCV industry consisting of various stakeholders like the respective governments, universities, research institutes and NEV industry-related companies was established. To further stimulate the development of the FCV industry and accelerate the development of technological innovations the multi-stakeholder alliance is going to create platforms for R&D and information sharing. Using the synergy effects from the alliance, the members can substantially contribute to the industrialisation of FCV and improve the competitiveness of the hydrogen industry in the JJJ region.

By organizing and implementing relevant scientific and technological projects, core competencies of fuel cell technology in the JJJ region are going to be built and both the R&D of single companies and the general R&D and application in the FCV field are going to be supported. Leading companies in the industry are going to be encouraged to establish engineering research centers and use these centers to engage in research projects on a national, provincial and local level.

4.3.1 Supporting Development of Key Fuel Cell Battery Components

A close cooperation between fuel cell companies, universities and scientific research institutions on the other hand is especially beneficial, as joint R&D on fuel cell batteries, fuel cell power systems and other key components can be conducted. Also, the transformation of scientific and technological outcomes will be promoted, and the technology of membrane electrodes, fuel cell stack integration and the entire vehicle power system integration is going to be further improved.

4.3.2 Developing backbone companies in the hydrogen fuel cell battery industry

The key support focus is going to lie on companies with strong innovation capabilities and key technologies in the field of the hydrogen fuel cell industry. This includes those companies being involved in the production of fuel cell materials and respective vital parts, fuel cell power systems and respective vital parts and entire FCV and those engaging in the production, storage and transportation of hydrogen and refuelling stations. Companies are going to be encouraged to establish R&D platforms and to carry out basic research on innovation.

Also, foreign companies are going to be en-

couraged to build R&D centers and to foster innovative operation modes with strong international competitiveness in the hydrogen fuel cell battery industry.

4.3.3 Integrating Resources and Building a Comprehensive Technological Innovation Platform

Key generic technology research shall be carried out to form an innovation platform that directly links the research institutes with the industrial base, thereby establishing an innovation alliance for the hydrogen fuel cell battery industry. There needs to be a close interaction between the involved companies, universities, scientific research institutes and other research projects, which gather in the JJJ region, as well as an effective interaction among all stakeholders throughout the supply chain.

By using the innovation platform, innovative technologies are going to be developed and the outcome of scientific and technological innovation is going to be shared. The government supports the R&D of product and process innovation in several projects, and explores ways to further ensure the growth of the FCV industry by supporting implementation projects that are likely to achieve breakthroughs in key technologies.

4.4 Creating a Global Brand of a Clean „Hydrogen Valley“ in the JJJ Region

SAE suggested to establish research platforms for cooperation in the field of the fuel cell battery supply chain between domestic and foreign companies, research institutions and industry organisations from the automobile, energy, electric power and logistics sector . Furthermore, they provide international support for the construction of the supply chain of hydrogen fuel cell batteries, R&D capability upgrading and the expansion of fuel cell battery applications, thereby increasing the international development level of the hydrogen fuel cell battery industry in the JJJ region.

4.5 Providing Support Land Supply and Approval Process

4.5.1 Flexible Land Supply

Meeting the land demand of the “hydrogen valley” project in the JJJ region. According to national industrial policies and land use planning in the JJJ region, Providing preferential policies based on the investment scale, construction progress and tax contribution of the hydrogen refueling station. Adopting a flexible land policy to reduce the construction cost of the hydrogen refueling station in the initial stage of promotion. Reducing the cost of land

for hydrogen refueling stations by renting bus stations, industrial parks, and logistics parks. In addition, to integrate existing gas station and hydrogenation infrastructure to accelerate the construction of hydrogen refueling station.

4.5.2 Approval Management

To accelerate improving the management standards for the design, construction, and operation of hydrogen refueling stations as well as approval process. The local “ministry of Housing and Urban-Rural Development” is responsible for managing the approval process and incorporating the approval process of the hydrogen refueling station into the gas system. The planned gas stations in the JJJ region should be equipped with a hydrogen refueling station or provide a construction land for construction.

5 References

- [1] International Energy Agency (IEA, 2019), „Global EV Outlook 2019“, IEA, Paris, Retrieved from: <https://www.iea.org/publications/reports/globalevoutlook2019/>
- [2] Kurtz, J. et Al. (2018), „Fuel Cell Electric Vehicle Evaluations“. National Renewable Energy Laboratory, Golden (CO).
- [3] <https://www.netinform.net/H2/H2stations/H2stations.aspx?Continent=EU90>
- [4] China Society of Automotive Engineers (SAE, 2019), 《长三角氢走廊建设发展规划》 [R] / „Development Concept for the Hydrogen Corridor of Yangtze Delta“. SAE, Beijing.
- [5] Sichuan Provincial Quality and Technology Supervision Bureau, National Cylinder Standardisation Commission, General Administration of Quality Supervision, Inspection and Quarantine (2009), 《TSGR0009-2009 车用气瓶安全技术监察规程》 / „TSGR009-2009 Hydrogen Gas Cylinder safety Technical Supervision Procedures“.
- [6] General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, China National Standardisation Administration (2017), 《GBT35544-2017 车用压缩氢气铝内胆碳纤维全缠绕气瓶》 / „GBT 35544-2017 Compressed Hydrogen Aluminum Liner Carbon Fiber Full-Wound Cylinders for Vehicles“.
- [7] China Society of Automotive Engineers (SAE China, 2018), 《关于加快促进氢能燃料电池汽车产业发展的政策研究，氢能基础设施供应及成本分析》 / Policy Research on Accelerating the Development of Hydrogen Fuel Cell Vehicle Industry, Hydrogen Energy Infrastructure Supply and Cost Analysis
- [8] CPC Central Committee, State Council (2016), 《国家创新驱动发展战略纲要》 / „National Innovation Driven Development Strategy Outline“
- [9] State Council (2016a), 《„十三五“ 国家科技创新规划》 / „13th Five-Year National Science and Technology Innovation Plan“
- [10] State Council (2016b), 《„十三五“ 国家战略性新兴产业发展规划》 / „13th Five-Year Plan for the Development of National Strategic of Emerging Industries“

-
- [11] State Council (2015), 《中国制造 2025》 / „Made in China 2025“
- [12] Ministry of Industry and Information Technology, National Development and Reform Commission, Ministry of Science and Technology (2017), 《汽车产业中长期发展规划》 / „Medium and Long-term Development Plan for the Automotive Industry“
- [13] Ministry of Science and Technology, Ministry of Transport (2012), 《“十三五”交通领域科技创新专项规划》 / „Special Plan for Science and Technology Innovation in the 13th Five-Year Plan for Transportation“
- [14] State Council (2012), 《节能与新能源汽车产业发展规划（2012—2020年）》
- [15] SAE China, National Energy Administration (2017), 《我国汽车行业中长期发展趋势及用能需求预测模型研究》 / „Forecasting Model Research on Medium and Long-Term Development Trend and Energy Demand of China’s Automotive Industry“
- [16] SAE China, China Automotive Technology Research Center, etc. (2018), 《新能源商用车积分政策管理》 / „New Energy Commercial Vehicles Integration Policy Management Thoughts“
- [17] Industrial Development Research Department of the Development Research Center of the State Council, China Automotive Engineering Society, Volkswagen Group China (2018), 《汽车蓝皮书（中国汽车产业发展报告2018）》 / „Automotive Blue Book (China Automotive Industry Development Report (2018))“
- [18] Ministry of Finance (2018), 《关于调整完善新能源汽车推广应用财政补贴政策的通知》 / „Notice on Adjusting and Improving the Financial Subsidy Policy for the Promotion and Application of New Energy Vehicles“
- [19] Wu, T., Ou, X., Lin, C. (2012), 《从消费者的视角分析纯电动城市客车的生命周期成本》 / „Analysis of the Life Cycle Cost of Pure Electric City Buses from the Perspective of Consumers“
- [20] Ministry of Finance, State Administration of Taxation, Ministry of Industry and Information Technology (2015), 《关于节约能源使用新能源车船车船税优惠政策的通知》 / „Notice on the Preferential Policies for Saving Energy and Using New Energy Vehicles, Vessels and Vessels“

-
- [21] Energy Saving and New Energy Vehicle Technology Roadmap Strategy Advisory Committee, SAE China (2016), 《节能与新能源汽车技术路线图》 / „Technology Roadmap for Energy Saving and New Energy Vehicles“
- [22] Hebei Provincial Development and Reform Commission (2016), 《河北省可再生能源发展“十三五”规划》 / „13th Five-Year Plan for Renewable Energy Development in Hebei Province“
- [23] Beijing Transportation Development Research Institute (2018), 《京津盐区域货物运输现状问题分析》 / „Analysis of the Status Quo of Regional Freight Transportation in JJJ Region“
- [24] Haibin College of Beijing Jiaotong University (2018), 《京津冀城市群客运枢纽规划布局的思考册》 / „Thinking on the Planning and Layout of JJJ Urban Passenger Transport Hubs“
- [25] Gan, Y. (2019) 《氢能如何改变我们的未来》 / „How does hydrogen can change our future?“
- [26] Political Bureau of the CPC Central Committee (2015), 《京津冀协同发展规划纲要》 / „JJJ Collaborative Development Plan“
- [27] China National Institute of Standardisation, the National Standardisation Technical Committee of Hydrogen Energy (2018), 《中国氢能产业基础设施发展蓝皮书(2018)》 / „China's hydrogen energy industry infrastructure development Blue Book (2018)“
- [28] Zhangjiakou City Development and Reform Commission, Tsinghua University Energy Conservation and New Energy Vehicle Engineering Center (2018), 《张家口市氢能产业规划》 / „Zhangjiakou Hydrogen Energy Industry Development Plan“

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