Kingdom of the Netherlands
Holland Innovation Network

Overview of hydrogen and fuel cell developments in China

By Holland Innovation Network China
Bente Verheul - January 2019

Preface

Dear reader,

This report presents the outcome of a study on hydrogen developments in China, performed by Bente Verheul, on behalf of the Holland Innovation Network in China. It aims to inform Dutch stakeholders, including companies, knowledge institutes and governments with ambitions in the field of international innovation and cooperation, about relevant hydrogen policies, technologies and projects in China, and stimulate knowledge intensive collaboration between both countries.

The Holland Innovation Network (Innovatie Attaché Netwerk in Dutch) is a worldwide network aiming to improve the innovative capabilities of the Netherlands. It provides a strong international network related to technology and science, stimulates knowledge sharing and promotes innovations between global innovation hotspots and the Netherlands.
Following the report "New Energy Vehicles; Developments in China, the Netherlands and prospects for Sino-Dutch cooperation in the field of commerce and policy [1]", the Holland Innovation Network in China identified an increasing interest for international collaboration in the field of hydrogen. We started our study on this topic in September 2018. We visited many events and we spoke with many hydrogen experts, who we wish to thank for their contributions!

We also wish to thank Bente Verheul, for her dedication to write this report. While writing the report, you showed your fullest motivation and interest. We are proud about the end result and hope you are to.

We expect this report to offer valuable insights to bring the bilateral cooperation between the Netherlands and China further. Besides the report, there is a database with a long list of Chinese organizations active in the field of hydrogen as well as events related to this industry. We look forward to hearing your thoughts and comments on this report.

We wish you a great read!

Taake Manning – Counsellor for Innovation, Technology and Science in Beijing
Anouk van der Steen – Officer for Innovation, Technology and Science in Shanghai

Shanghai, January 2019

List of abbreviations

BEV	Battery Electric Vehicle
CAE	Chinese Academy of Engineering
CAS	Chinese Academy of Sciences
CAST	China Association for Science and Technology
CCUS	Carbon Capture Utilization and Storage
CSIC	China Shipbuilding Industry Corporation
FCEV	Fuel Cell Electric Vehicle
FCVC	International Hydrogen Fuel Cell Vehicle Congress (in Rugao)
FYP	Five-Year Plan
GDL	Gas Diffusion Layer
HITIAC	Hydrogen Industrial Technology Innovation Alliance of China
HRS	Hydrogen Refueling Station
ICE	Internal Combustion Engine
IHFCA	International Hydrogen and Fuel Cell Association
IPHE	International Partnership on Hydrogen Energy
NDRC	National Development and Reform Commission
NEA	National Energy Administration
NEV	New Energy Vehicle
MEA	Membrane Electrode Assembly
MIIT	Ministry of Industry and Information Technology
MOF	Ministry of Finance
MOST	Ministry of Science and Technology
MOT	Ministry of Transport
PEMFC	Polymer Electrolyte Membrane Fuel Cell
PHEV	Plug-in Hybrid Electric Vehicle
SASAC	State-owned Assets Supervision and Administration Commission of the State Council
SMR	Steam Methane Reforming
SOE	Solid Oxide Electrolyzer
SOE	State-owned Enterprise
SOF	Solid Oxide Fuel Cell
UNDP	United Nations Development Program

1

Summary

Since the establishment of the Hydrogen Council in 2017 global interest for hydrogen has increased rapidly. Hydrogen's potential to achieve climate targets by decarbonizing several sectors has been acknowledged and several countries have developed hydrogen roadmaps. In the last few years, also China shows a rapid progress in relevant hydrogen activities.

China's initial interest in hydrogen comes from the automotive sector. China has established the largest NEV market worldwide and continues to foster the development of this sector. Aside for battery electric vehicles (BEV), also fuel cell vehicles are of importance. National and local policies set ambitious targets for the roll-out of hydrogen refueling stations (HRS) and the development of core technologies. In 2018, the fiscal subsidy policies for NEVs has been adjusted in favor of fuel cell electric vehicles (FCEVs) and large SOEs in the energy production sector, equipment manufacturing and automotive sector jointly established the China Hydrogen Alliance.

The storage and delivery part of China's hydrogen value chain is still weak and hindering the roll-out of HRS. No pipeline infrastructure is in place, liquid hydrogen transport is allowed for military purposes only and - because hydrogen is still classified as hazardous chemical product - on-site hydrogen generation is only allowed inside chemical parks. This inefficient system to store and deliver hydrogen leads to scattered developments and also limits the hydrogenation capacity of the current HRS. Until the regulations, codes and standards related to hydrogen are updated, developments are severely hindered.

Despite these unfavorable regulations, China has invested heavily in R&D related to PEM fuel cells and high-quality fuel cell power systems are produced in China by Re-Fire and SinoHytec using foreign fuel cell stacks. In 2018, China has put large fleets of FCEVs on the streets in Shanghai, Beijing, Zhengzhou, Foshan, Yancheng and Chengdu. Domestic companies are making progress in reducing platinum dosage in fuel cells (one of the main cost drivers) and are getting closer to international levels. China is initially focusing on fuel cell buses and commercial vehicles to improve public awareness, by gradually showcasing the safety of hydrogen as these vehicles require lower pressure storage tanks (35 MPa) than passenger cars. The 2022 Winter Olympics in Beijing and Zhangjiakou are an important target moment for China to showcase FCEVs, pushing the sector developments to a next level.

Other application areas which receive much attention elsewhere in the world such as urban heating are yet to be researched and supported on a larger scale by the Chinese government.

China's production path initially focuses on the production from coal and natural gas to accelerate the FCEV market. Although, China is challenged by high curtailment rates of renewables - due to the geographical mismatch between energy generation in north-western China and consumption areas in the coastal areas - which could be a (cleaner) source for hydrogen production. At this moment, domestic PEM electrolyzers are not advanced enough for large-scale conversion of electricity into hydrogen and foreign electrolyzers are still expensive.

Table of Contents

K

2
Introduction

New Energy Vehicles (NEVs) are increasingly gaining importance worldwide and receive much government support, as they help to address climate change and urban pollution challenges. China's automotive industry has managed to rapidly make progress in this field due to supportive government policies and substantive fiscal incentives for consumers. It has now established itself as the largest NEV market in the world by far. As early as 2010 China listed NEVs as one of its strategic emerging industries. In October 2016 the Energy Saving and New Energy Vehicle Technology Roadmap was published which includes a Hydrogen Fuel Cell Vehicle (FCV) Technology Roadmap. These developments have been documented in detail in early 2018 in the *New Energy Vehicles (developments in China, the Netherlands and prospects for Sino-Dutch cooperation in the field of commerce and policy)* report. One of the concluding remarks from this report is that we can expect increased interest and investments in **fuel cell electric vehicles (FCEVs)** in the coming decades. The Chinese government has set ambitious targets for 2020 and 2030 for FCEVs and the recent cuts in subsidies for battery electric vehicles (BEVs) also aims to push the automobile industry towards FCEVs in both the light duty as well as heavy duty segment. These strong ambitions are confirmed and supported by the recent wave of R&D projects, establishments of joint ventures, pilot projects and construction of hydrogen refueling stations (HRS).

The concluding remarks of the NEV report have been the starting point of this research, however this report will not solely focus on the automotive sector. **Hydrogen has several application areas**. Greenhouse gas (GHG) emission reductions can be achieved in the transportation, heating, natural gas and chemical industry when using hydrogen renewably generated by electrolysers[2].

The Netherlands

The Netherlands has developed a strong natural gas industry since the 1960s. However, to meet with the goals of the Paris Agreement and due to soil subsidence problems in Groningen the Dutch government decided in 2018 to phase out the use of natural gas until 2030. This has induced several research and pilot projects regarding the future of the gas pipeline network and the possibilities to retrofit it for hydrogen gas. The Netherlands is already the second largest hydrogen producer in Europe. This is currently mostly so-called *grey* hydrogen, produced via steam-methane reforming (SMR) of natural gas, or produced as by-product from chemical processes. However, with the increased offshore renewable energy capacity, the Netherlands has high potential to develop a *green* hydrogen economy. Hydrogen can contribute to emission reductions in the transportation sector, clean up the petrochemical industry and accelerate the energy transition. Governmental support for R&D, feasibility studies and business cases contribute to the development of the hydrogen sector, although it is still in an early stage. International cooperation is needed to develop the Dutch hydrogen sector and the Ministry of Economic Affairs and Climate Policy has appointed a special hydrogen envoy (Mr. Noé van Hulst) to stimulate international cooperation.

China

During the last decade China has established the largest NEV market worldwide and it continues to develop this industry with substantial backing at different government levels. China's large-scale interest in hydrogen is quite recent (± last five years). National and local policies acknowledge hydrogen's potential to address challenges such as high local pollution levels in cities and high curtailment rates of wind and solar PV power. At first sight it seems that China is focusing on using hydrogen for energy storage and as a transport fuel for automotive applications. In the Netherlands a wider range of applications is considered, especially related to using hydrogen in the natural gas network for urban heating. The technology gap between domestic and international products (such as PEM fuel cells and electrolysers) is still large and China's seeks international cooperation and joint ventures with foreign enterprises to accelerate technology development.

2.1 Goal of this report

This report aims to support cooperation between China and the Netherlands in the field of hydrogen and fuel cells. It will hopefully provide Dutch parties (researchers, companies as well as policymakers) with relevant information regarding the current status and planned developments in China. China has demonstrated that with economies of scale massive cost reductions can be achieved (e.g. in the field of solar PV and wind farms). Similar developments could take place in the hydrogen sector, enabling massive cost reductions of electrolyzers and fuel cells. This could support the Netherlands i.e. to construct large scale green hydrogen generation clusters.

Disclaimer

This report was written during the period September 2018 – January 2019 and presents the status quo of hydrogen developments in China. Situations in China tend to change rather quickly so please keep this in mind while reading the report. Published numbers on Chinese websites regarding fuel cell buses operating, hydrogen refueling stations (HRS) in operation or electrolysis projects in China are sometimes hard to fact-check so we have tried to only include those of which we are sure. Uncertainties, personal opinions and rumors are clearly presented as such. This being said, we hope that you will enjoy this report!

About Holland Innovation Network

Holland Innovation Network is part of the Dutch Ministry of Economic Affairs and Climate Policy that operates in multiple countries with a strong innovation capacity and/or potential. This network aims to improve the innovation capabilities of the Netherlands by linking global and Dutch innovation networks. Our focus areas are science, technology and innovation. In China we have offices in Beijing, Shanghai and Guangzhou. Our office facilitates research, high-tech development and innovation cooperation between the Netherlands and China. We represent the innovative sectors in the Netherlands and inform stakeholders about Chinese developments, opportunities and business models. Stakeholders include companies, universities, governments, and grant providers.

3
Policy context

3.1 Background

The four main drivers towards a hydrogen economy for China are energy security, climate change, air pollution and global competitiveness. China's energy security is challenged by the increasing need for energy and quick depletion of fossil fuels, while cities are struggling with unhealthy levels of pollution. Hydrogen can be produced from a variety of sources and help diversify China's energy system, which is currently still dominated by coal and dependent on imported oil and gas resources[3]. Since 2010, China has not only become the world's largest energy user, but also the largest producer of hydrogen. Almost all of the hydrogen production (95%) was derived from fossil energy due to production economics.[4] However, during the last decades China has also massively invested in renewable energy capacity and has become the world leader in terms of wind and solar power capacity. The production increased so quickly that more recently China started struggling with large amounts of renewable energy waste.

According to the National Energy Administration (NEA) approx. 6% of solar PV power in 2017 was unused[5] and the amount of lost wind power on average was 12%[6]. The lack of a unified national power grid and the large distances between energy generation (concentrated in western and northern China) and usage locations (eastern China) requires innovative solutions for storage problems.[7] By converting abundant renewable energy into hydrogen with the use of electrolyzers these storage issues can be resolved. The global competitiveness of China will be ensured if Chinese companies are able to take a leading position in the development of hydrogen and fuel cell technology. Despite still lagging behind (especially in key core technologies) international fuel cell technology levels, China has recently made rapid progress. The Fuel Cell Industry Review 2017 by E4Tech highlights[8]:

"China is on a mission. It wants new, clean, value-added industries. It understands that opportunity for fuel cells much as it did for PV (...) At the moment the main drive is technology acquisition – joint ventures, and investments, both successful and not."

National and local governments support the development of the sector with policies which will be discussed in this chapter.

3.2 Five-Year Plans and other programs

Five-Year Plans (FYP) in China are the overall guiding documents for the development of the country. Based on the Five-Year Plan for Economic and Social Development issued by the National Development and Reform Commission (NDRC) different ministries develop their own sector-specific development plans.[9]

Since hydrogen and fuel cells have various applications in different sectors, their development is affected by several policies. Hydrogen and fuel cells research in China began in the 1950s by the Dalian Institute of Chemical Physics (DICP), mainly focused on applications for space programs. In the late 1980s the National Hi-Tech Research and Development Program ("863") was launched to accelerate research-based technology commercialization in which several fuel cell and hydrogen technology projects are incorporated. Similarly, in 1997 the Basic Research Program ("973") started, through which also government funding is made available for hydrogen and fuel cell technologies. The latest Five-Year Plans all allocated funding towards the development of the sector [10]:

9th Five-Year Plan (1996-2000) – $4.75 million USD (from 973) and $60,000 USD (from 863)

10th Five-Year Plan (2001-2005) – Additional $4.75 million USD invested, as well $3.48 million USD into hydrogen from solar power. The Ministry of Science and Technology (MOST) approved of $139 million USD funding to advance hybrid-electrics and FCVs. Although most funding went to hybrid and electric vehicles, $40 million USD was invested in the research of fuel cell technologies. Via the 973 Program, Tsinghua University received $5.6 million USD funding for research on production, storage material and transmission of hydrogen and fuel cell membranes and catalysts.

11th Five-Year Plan (2006-2010) – $28.88 million USD allocated via the advanced energy technology fund for hydrogen and fuel cell technology and $23.74 million USD for FCEVs.

12th Five-Year Plan (2011-2015) – During the 12th Five-Year Plan, the government gave strong incentives to companies for accelerating the NEV market. While the BEV market continues to grow rapidly, FCEVs are seen as the next logical step. The plan emphasized green development and included binding energy targets. In 2011, $15.8 million USD was made available (through the 863 program) specifically for hydrogen and fuel cell research projects. The 973 program received $11.1 million USD funding for the development of solid-oxide fuel cells (SOFCs) and platinum-free fuel cells. Platinum is used for the catalyst of the (PEM) fuel cell and due to its high cost hinders mass implementation of fuel cells applications.

13th Five-Year Plan (2016-2020) – In the guidelines of the strategic emerging sectors of the latest Five-Year Plan hydrogen and fuel cells are incorporated in *Energy storage and distributed energy* and *New energy vehicles.* Local companies are encouraged to acquire the technologies for hydrogen production, storage and fuel cell systems in order to achieve the large-scale deployment of HRS and other fuel cell applications. The aim is to achieve mass production of FCEVs by 2020 and, based on the success story of PHEVs and BEVs in China, it is likely that the ambitious targets will be reached.

Specifically related to fuel cell technology development in China, figure 1 shows a timeline of projects and involved parties during the past FYPs.

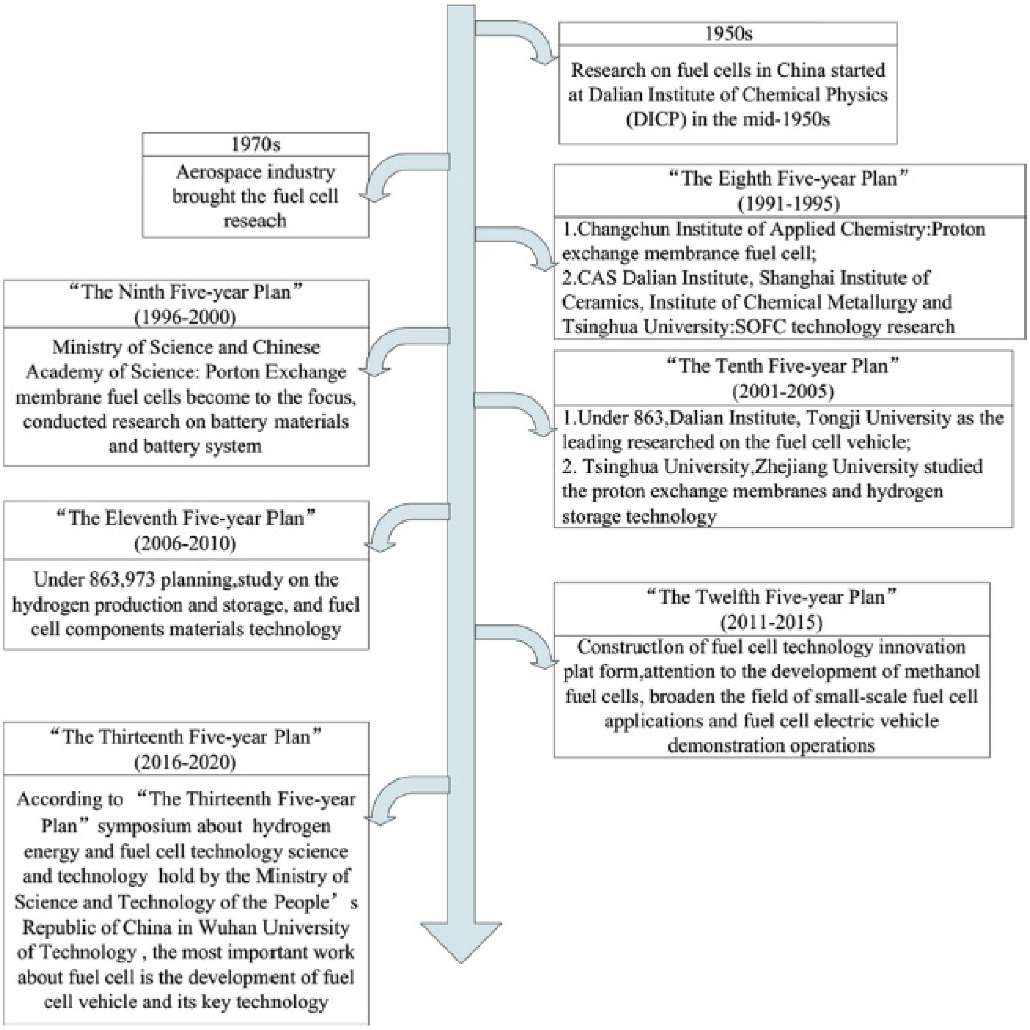

Figure 2: FCV Technology Roadmap (source: Anglo American)

3.2.1 National plans under the Five-Year Plans

As mentioned before, specific sectors are steered by different government entities on several administrative levels following the general guidelines from the Five-Year Plan. Related to the transportation sector, there are already more than 10 detailed plans on national level such as the 13th FYP for Urban Public Transport and 13th FYP for Standardization in Railway.[11] The most important of these high-level plans related to the hydrogen sector are discussed below.

13th FYP for Technological Innovation in Transportation

The 13th Five Year Plan for Technological Innovation in Transportation was released in May 2017 by the Ministry of Science and Technology (MOST) and the Ministry of Transport (MOT). No specific targets are mentioned in these overarching guiding documents. However, the frequency of which certain technologies or industries are mentioned gives an indication of the importance that the Chinese government gives to the development of the sector. In short, the plan emphasizes the need for[12]:

- In-depth research and industrialization of key materials of FCEVs to improve the performance and durability, while reducing the costs of fuel cell stacks
- More R&D to ensure technology breakthroughs in auxiliary systems such as air compressors, hydrogen circulation pumps, and their system integration technologies
- Upgrading the fuel cell power system technology by increasing the power density of the FCEV engine
- Improving hydrogen storage and transportation technology and the construction of HRS.
- Formulate standards for the 70 MPa hydrogen cylinders for on-board storage.
- Developing 70 MPa hydrogen refilling equipment (nozzles, dispensers etc.)
- The establishment of a R&D innovation and test evaluation platform focusing on core technologies of FCs, FC stacks and FC engine systems.

"Made in China 2025"

The State Council in 2015 issued this 10-year plan which aims to improve the Chinese manufacturing industry. New Energy Vehicles and Equipment are one of the 10 priority sectors mentioned. The plan includes an energy equipment implementation plan and goals for hundreds kW to MW SOFC-distributed power generation systems, which requires the development of key technologies such as catalytic materials, membrane and electrode, high-temperature interconnectors, increased lifetime and industrialization.[13]

Following this Made in China 2025 plan, in 2016 the Energy Saving and New Energy Vehicle **Technology Roadmap was published, which includes a Technology Roadmap for Hydrogen Fuel Cell Vehicles.**[14] China's target for FCEVs deployment is to deploy one million by 2030 and together with electric vehicles to achieve zero emission by 2050. The path to achieve this is summarized in the table below:

Year	HRS	FCV's
2020	>100 stations	5,000 FCVs in demonstration (60% commercial vehicles)
2025	>300 stations	50,000 FCVs in service (80% passenger cars)
2030	>1,000 stations (>50% of H2 production from renewable sources)	Overall > 1 million FCVs in service

Table 1: China's development goals (from FCV Technology Roadmap)

China aims to reach these targets by increasing R&D in key materials and technologies, by improving application technologies (power systems, vehicle integration) and by implementing demonstration projects.

In the category *key common technologies* fuel cell stacks by 2020 need to have a power density of 2.0 kW/kg, lifespan of 5,000 hours and cold start < - 30∞C. For 2025, these targets are increased to a cold start of < -40∞C, power density 2.5 kW/kg and lifespan of >6,000 hours. These targets are further narrowed down in performance parameters of specific parts of the PEMFC, i.e. membrane electrode assembly (MEA), catalyst, bipolar plate, proton exchange membrane (PEM).

		2020	2025	2030
Overall objective		Small scale public sector demonstration in selected areas (5,000 FCVs)	Large-scale development of FC passenger cars and service vehicles in urban areas (50,000 FCVs)	Large-scale commercial deployment of passenger cars and commercial vehicles (one million FCV's)
		Fuel cell system production capacity >1,000 units per enterprise	Fuel cell system production capacity >10,000 units per enterprise	Fuel cell system production capacity >100,000 units per enterprise
Hydrogen fuel cell vehicles	Functional requirements	Cold start -30°C, power system structure optimisation, FCV cost close to all-electric vehicles	Cold start -40°C, small volume production, FCV cost similar to hybrid vechile	FCV overall performance comparable with traditional ICE vehicles – achieving competitive advantage
	Commercial vehicle	Cost ≥ RMB 1.5 million	Cost ≥ RMB 1.0 million	Cost ≥ RMB 600,000
	Passenger car	Max speed ≥ 160km/h Lifespan 200,000km Cost ≥ RMB 300,000	Max speed ≥ 170km/h Lifespan 250,000km Cost ≥ RMB 200,000	Max speed ≥ 180km/h Lifespan 300,000km Cost ≥ RMB 180,000
Hydrogen infrastucture	H_2 supply	Decentralised hydrogen production from renewable sources; industrial by-products such as coke-oven gas		Decentralised H_2 production from renewable sources
	H_2 delivery	High pressure hydrogen storage and delivery	• Cryogenic liquid * hydrogen delivery	High density organic liquid hydrogen storage ** and delivery at normal pressure
	HRS	100 stations	350 stations	1,000 stations

Figure 2: FCV Technology Roadmap (source: Anglo American [15])

For the fuel cell engine system targets are set for specific power, efficiency, environmental adaptability, durability and costs. The commercial roll-out of FCEVs will start with combined driven technology (fuel cell and power battery) similar to international models which are currently on the market, and then shift to completely hydrogen fuel cell powered vehicles by 2030.

Until 2025 - as highlighted in the hydrogen infrastructure technology roadmap (section 4.5.2 of the FCV Technology Roadmap) - hydrogen will be generated from both fossil and renewable sources. By 2020 the goal is to have a distributed hydrogen production system with locally produced hydrogen (via onsite electrolysis) at refueling stations. Liquid hydrogen transport is also expected to be deployed by 2020, which will require government regulatory approvals. Currently hydrogen is only allowed to be transported as compressed gas, as every truck can only carry as much as 200-300kg between production site and HRS it is hindering the roll-out of HRS. Liquid hydrogen would enable a much larger capacity (almost 10 times the volume) for distribution and storage. The progress of FCEVs is intertwined with the development of HRS, and until 2020 China plans to focus on 35 MPa HRS to serve the hydrogen demand of commercial vehicles.

Energy Development Strategy Action Plan (2014-2020)

This plan from the State Council sets targets for energy conservation in the power, industrial, building and transport sector. Coal consumption is limited to 4.2 billion tons and clear proposals are made to develop the natural gas sector further: the share of natural gas in the total primary energy mix should rise to more than 10% and over 120,000km of natural gas pipelines should be in use by 2020. Furthermore, the installed capacity of hydro, wind- and solar power is expected to reach 350 GW, 200 GW and 100GW respectively.[16] On the 10th of December 2016 the NEA adopted the 13th Renewable Energy Development Five Year Plan (2016-2020) in line with the 13th FYP mentioned above and the Energy Development Strategy Action Plan from 2014. One of the key objectives stated in this plan is to resolve the renewable power curtailment problems[17], where hydrogen could play a main role.

Energy Innovation Action Plan (2016-2030)

In April 2016, the National Development and Reform Commission (NDRC) and National Energy Administration (NEA) released a plan focused on energy technology innovation. Until 2030 this plan deals with challenges such as resource insecurity, pollution, energy inefficiency and grid inflexibility. The document is in line with the goals of the 13th Energy Technology Innovation Five-Year Plan (2016-2020).[18] Fifteen areas for technological innovation are highlighted in the plan including hydrogen and fuel cell technologies and advanced energy storage. The plan highlights the need for research along the entire hydrogen value chain: hydrogen production from fossil fuel sources (coal gasification and methane reformation), hydrogen purification, the development of key materials and technologies in hydrogen transport and storage, hydrogen fueling stations, hydrogen production standards and business models as well as research on PEMFC technologies.[19] The 2020 target for hydrogen and fuel cell technology is to achieve a rated output power of PEM fuel cells of 50 – 100 kW power, FC systems > 300 Wh/kg, FC stacks > 3000 W/L and service life > 5000 hour.[20]

3.2.2 Financial policy scheme for NEVs

In addition to the discussed development plans the financial subsidy scheme implemented to support the NEV industry is a key policy tool that enabled the rapid NEV developments in China. The subsidy scheme is discussed in detail in the earlier mentioned NEV report published by the Dutch Embassy in Beijing in September 2018. The national subsidy scheme for NEVs has been updated in June 2018 to boost high-quality development. The recent update decreases subsidies for BEVs and PHEVs, while FCEVS subsidies remain unchanged. The New Energy Vehicle Model Recommendation for Promotion and Application Catalogue of the Ministry of Industry and Information Technology (MIIT) includes all vehicle models that can receive subsidy. In addition to national level subsidies many cities provide local subsidies, and other incentives related to license plate acquisition. The scheme below shows how the financial support for FCEVs is being calculated.

The subsidy standard and technical indicators of FCV

Subsidy formula :
- Subsidy of passenger vehicles=min{P (Rated power of fuel cell system) ×B (Subsidy standard) ×C (Subsidy coefficients) , M (Upper limit of subsidy) }
- Subsidy of commercial vehicles =M (Upper limit of subsidy) × C (Subsidy coefficients)

Vehicle types	B (Subsidy standard)	M (Upper limit of subsidy)
Passenger vehicles	6 thousand/kW	200 thousand/car
Light passenger cars and trucks	-	300 thousand/car
Large and medium buses, medium and heavy trucks	-	500 thousand/car

R (The ratio of the rated power of fuel cell system to the rated power of driving motor)	C (Subsidy coefficients)
R < 30	0
30≤R < 40	0.8
40≤R < 50	0.9
50≤R	1

Other technical requirements :
- P (passenger vehicles) ≥10 kW , P (commercial vehicles) ≥30 kW
- Electric driving range of FCV ≥300 km
- The fuel cell of FCV should meet the requirements of storage temperature of the ***Proton Exchange Membrane Fuel Cell Modules for Road Vehicles*** (Standard number GB/T33978-2017) , The storage temperature range of the module needs to be reached -40℃~60℃

Figure 3: Subsidy scheme for FCEVs (Source: CATARC)

This translates to $32,000 USD purchase subsidy for FC passenger cars and $48,000 – 79,000 USD purchase subsidy for FC buses and trucks. For FC Buses in order to receive subsidies, the buses are required to drive at least 200,000 km/year. In addition, for HRS with at least 200 kg capacity there is $0.62 million USD funding available. In months following the national update, local financial policies in Guangdong, Hainan, Shandong, Tianjin, Henan, Foshan and Dalian were updated accordingly. Local subsidies across China range from ratios compared to national subsidies of 1:1 in Wuhan to 1:0.3 in Henan province.

3.2.3 Other national-level projects

Since 2003 the United Nations Development Program (UNDP) has been working together with the Ministry of Science and Technology (MOST) on the commercialization of fuel cell buses in China. This ongoing project contributes to the (technology) development of the hydrogen sector in China and will be discussed briefly together with other relevant projects.

UNDP-GEF-MOST Project

Together with the United Nations Development Program (UNDP), MOST implemented two phases of the Global Environment Facility (GEF) Fuel Cell Bus Technology demonstration projects between 2003 and 2012. During these first two phases, 12 prototype FC buses manufactured by Daimler-Chrysler, SAIC Motor, and Foton completed a cumulative distance of more than 262,000 km during the 2008 Beijing Olympics and 2010 Shanghai Expo. MOST was the head of the Project Advisory Committee and thus providing overall advice and guidance to the project at national level and reviewing the project work plan.[22] One of the outcomes of the Phase II demonstration project were following vehicle improvements: the project began with 2nd generation FC Buses costing 5 million RMB ($0.7 million USD) with 80 kW FC stacks and a lifetime of less than 2000 hours to 3rd generation FC Buses costing 2.6 million RMB ($0.4 million USD) with 50 kW FC stacks and a longer lifetime of more than 4000 hours.[23]

The third phase of the project was launched in August 2016 by MOST together with MOF under the name "Accelerating the Development and Commercialization of Fuel Cell Vehicles in China". The project addresses problems such as lack of advanced FCV technologies, hydrogen fuel infrastructure, policy and legal framework issues as well as how to increase stakeholder's engagement and public awareness. The project consists of public-private partnerships with enterprises like SAIC Motor, Yutong and BAIC Motor. The five demonstration cities that were selected include Beijing, Shanghai, Zhengzhou (Henan), Foshan (Guangdong) and Yancheng (Jiangsu).

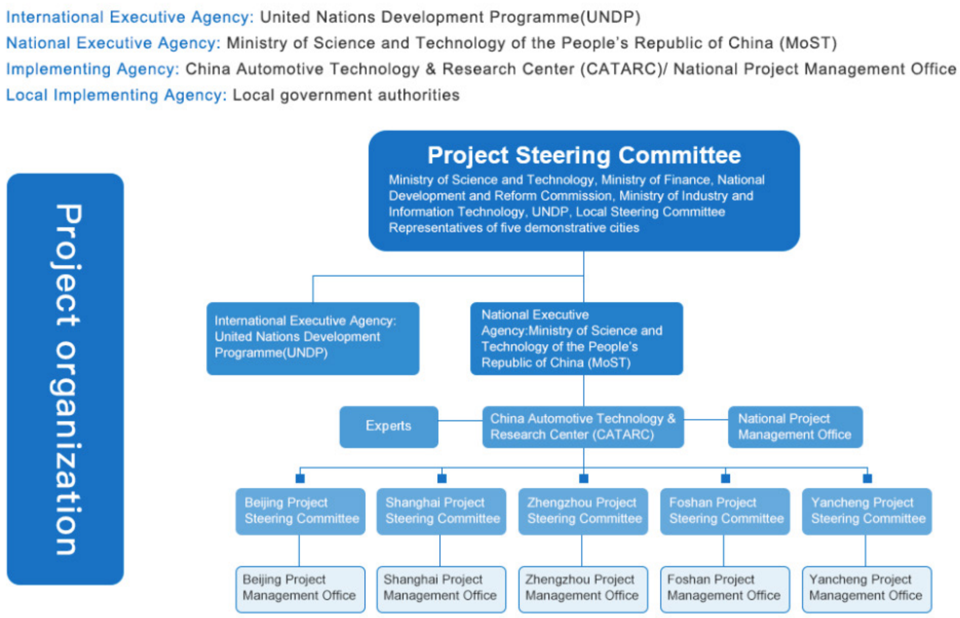

Figure 4: Organization chart of UNDP/GEF/MOST project (source ChinaFCV)

Part of the requirements of the UNDP project is that by 2020 all of the demonstration cities need to ensure the completion of 200,000-kilometer operation of FC buses. By the end of 2018, in all five cities FC buses are being operated:

In September 2018, during the launch of FC buses in Shanghai, an UNDP project meeting was held where all local Project Management Offices (PMOs) introduced their project progress. This is shortly summarized in the table below:

City	Status
Shanghai	6 FC buses, 50 FC cars, 28 FC postal trucks, 20 FC shuttle mini-buses, 500 FC logistics vehicles are running on the streets. Shanghai Hydrogen Demonstration, Application and Innovation Alliance has been set up.
Beijing	Originally planned were 10 FC buses and 5 FC logistic vehicles. Project officer stated that now 15 FC buses, 30 FC shuttle mini-buses and 5 FC logistic vehicles will be put into use within in 2018.
Zhengzhou	2 FC buses have been running for more than a month, more will be added to the fleet.
Foshan	Plan is to have 300 FCEVs operating in Nanhai district by 2020, and 1000 FCEVs in Foshan until 2020. FC buses have been in operation in Sanshui District, Foshan and nearby Yunfu since 2016. On 20 December 2018, another 70 FC buses were put into operation in Foshan and the city already has 4 HRS with 7 more under construction.
Yancheng	10 FC buses will be running in 2018, and 50-100 more will be running in 2019. However, at the time of finishing this report (January 2019) only two FC buses are in operation.

During the meeting local PMOs addressed the following problems:

- Insufficient policies and regulations make the construction of HRS difficult. It is often unknown which local government department is responsible for approval. Since there are no national unified standards, each pilot city has to seek its own procedure for approval. Under current Chinese policies, hydrogen cylinders in FCEVs are supposed to be removed every year for safety checks, but according to several experts this is actually more dangerous. [31]

- Currently no standard regulations are being published for the establishment of HRS. It is even unknown if the land should be categorized as commercial land or industrial land (which influences the land price).

- High prices of FCEVs: currently a lot of subsidy of local and central government is needed to give consumers a competitive price. The competitiveness, which will be helped by high production volumes, needs to increase so government subsidies can be reduced (following the example of PHEVs and BEVs).

- There is insufficient public awareness, which causes the approval of new HRS to usually take at least 3-6 months. The people making decisions and business cases lack experience. Hydrogen is often associated with hydrogen bombs. For example, during big holidays or events the hydrogen supply in Shanghai is being stopped for the sake of safety.

According to the project organization, the five demonstration cities take a lead for promoting the establishment of necessary standards and regulations. In addition, the team will organize an international study tour for government officials of the five pilot cities to help them to learn more about hydrogen and its related industry. Through the learning experiences of the pilot projects, under the request of the Ministry of Industry and Information Technology (MIIT), the team will facilitate the establishment of other hydrogen cities in China, such as Tianjin, Zibo and Weifang.

Hydrogen Economy Pilot Rugao

In addition to the Fuel Cell Bus Demonstration project, the UNDP-China Hydrogen Economy Pilot was officially launched in Rugao, Jiangsu province in August 2016. The project aims to find answers to current questions regarding the economic viability of hydrogen production and transportation, as well as increase public awareness.[32] The project will also address the barriers caused by a lack of systematic policy making for hydrogen economy policy development (under component 5) and investigate the possibilities to the hydrogen economy model into the carbon trading market.[33] The methodology to include hydrogen applications in carbon trading was launched in April 2018 in Beijing and was developed jointly with China International Center for Economic and Technical Exchanges (CICETE) of the Ministry of Commerce, and Rugao Economic and Technological Development Zone. The methodology targets the applications of FC technologies in the transportation and combined heat and power (CHP) sectors.[34]

Hydrogen Corridor Development Plan in Yangtze River Delta Region

In April 2018, IHFCA and China-SAE together with experts from the participating cities Shanghai, Nantong, Rugao, Yancheng and Suzhou defined a hydrogen corridor development plan based on the existing highway network. In the long-term all cities in the Yangtze River Delta will be included. The development plan marks the first time that China plans to build trans-provincial and cross-regional hydrogen infrastructure for FCEV development.[35]

3.3 Important players

The policy context for hydrogen and fuel cells is shaped mainly by the Ministry of Science and Technology (MOST), Ministry of Industry and Information Technology (MIIT), Ministry of Transport (MOT), State-owned Assets Supervision and Administration Commission of the State Council (SASAC), National Energy Administration (NEA) and National Development and Reform Commission (NDRC). All of these government bodies are also involved in the national level China Hydrogen Alliance.

Ministry of Science and Technology (MOST)

The Ministry of Science and Technology promotes the R&D and development of new industries in China. The previously mentioned " 863" and "973" national plans receive funding from MOST and include several projects related to fuel cell technology development. For example, the following projects have recently been supported related to a special type of fuel cells (Solid Oxide Fuel Cells):[36]

- *Fundamental Research on Carbon-based Solid Fuel Cell System* – from January 2012 until August 2016 led by University of Mining and Technology, Beijing ($4.95 USD granted) together with University of Science and Technology of China, Institute of Physics (CAS), Shanghai Institute of Ceramics (CAS), Tsinghua University, Harbin Institute of Technology, Shanghai Jiaotong University, University of Science and Technology Beijing, Institute of Chemical Defense and Huatsing Power Science and Technology Co., Ltd.

- *Key Technology of Fuel Cell and Distributed Generation System* – from 2011 until 2014 led by Dalian Institute of Chemical Physics (DICP) ($11.66 million USD granted) together with Ningbo Institute of Material Technologies and Engineering (NIMTE), Huazhong University of Science and Technology (HUST) and Shanghai Institute of Ceramics (CAS).

- *2-kW Flat Type Medium Temperature Solid Oxide Fuel Cell System* – led by Shanghai Institute of Ceramics, Chinese Academy of Science.

In addition to funding from MOST, during the 2002-2015 period, more than 140 SOFC research projects were supported by the National Natural Science Foundation of China (NSFC) totaling around 60 million RMB ($8.75 million USD) related to new materials, new designs, new (fundamental) theories and methods.

In 2017, MOST gave government funding to five hydrogen and fuel cell projects. The total amount of subsidies was roughly 217 million RMB ($34.4 million USD). The projects are briefly shown in the table below and mainly focus on automotive applications of fuel cells:

Project	Lead agency	Funding (USD mln.)	Duration (years)
Research on FC Stack Process Modeling, Simulation, State Observation and Life Evaluation Methods	Xi'an Jiaotong University	2.9	4
Key Technology Research and Platform Development of High Power FC Engine	China FAW Group Co., Ltd.	13.4	4
Development of High Performance Long-life FC Engine System	South China University of Technology	8.6	4
R&D of Fast Dynamic Response FC Engine for automotive	Institute 712 (CSIC)	7.3	4
Sino-German FCV International Cooperation (Demonstration and Application)	Tongji University	2.2	4

Table 2: Government investment in 2017 (Source: Zhang, C. (2018))

In 2018, MOST selected six projects for the National Key Research and Development Plan "New Energy Vehicles". The total amount of subsidies accounted approx. 486 million RMB ($70.09 million USD). Not only is the investment more than double compared to 2017, the funding is now prioritizing industry players instead of universities as shown below:

Project	Lead agency	Funding (USD mln.)	Duration (years)
Full-power fuel cell passenger car power system platform and vehicle development	Dongfeng Motor Co., Ltd.	7.56	3
Extended-program fuel cell power system platform and vehicle integration	BAIC Motor Co. Ltd.	7.39	3
Fuel cell bus electric-electric deep hybrid system platform	Zhengzhou Yutong Bus Co. Ltd.	7.62	3
High-environment adaptive road bus fuel cell power system	Tsinghua University	8.01	3
Research on Demonstration Operation of Multiple Fuel Cell Vehicles in Typical Areas	CATARC Co., Ltd.	6.79	3
Fuel cell engine and commercial vehicle industrialization technology and application	Weichai Power Co., Ltd.	32.71	3

Table 3: Government investment in 2018 (Source: Zhang, C. (2019))

3.3.1 Alliances

This section will briefly present the main alliances in(cluding) China related to hydrogen and fuel cells. All of them have been established quite recently and have a slightly different focus.

International Partnership for Hydrogen and Fuel cells in the Economy (IPHE) [37]
The International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) was established in 2003 and consists of 18 member countries and the European Commission. IPHE's objective is to facilitate and accelerate the transition to clean and efficient energy and mobility systems using hydrogen and fuel cell technologies in different sectors. The latest Steering Committee Meeting took place in December 2018.

Mission Innovation [38]
Mission Innovation (MI) is a global initiative of 23 countries and the European Union to accelerate global clean energy innovation. MI was announced in November 2015 at COP21. Participating countries have committed to seek to double their governments' clean energy R&D investments over five years, while encouraging greater levels of private sector investment in clean energy technologies. Several ministers from participating countries are involved. MI has developed eight Innovation Challenges. The Renewable and Clean Hydrogen Innovation Challenge was launched at the third Mission Innovation Ministerial in May 2018. Germany, Australia and the European Commission take a lead in the Hydrogen Innovation Challenge. China has joined the challenge as participant, as well as the Netherlands.

China Hydrogen Alliance [39]

The China Hydrogen Alliance was formally established in February 2018 to enhance the development of China's hydrogen sector. The alliance consists of large (state-owned) companies in the energy production sector, equipment manufacturing, automotive sector and several universities. It is expected that the State Owned Enterprises (SOEs) such as Sinopec and Shenghua can take a lead in developing national regulations as they have a strong lobby position.[40] The alliance is supported and supervised by various government organizations (MOST, MIIT, MOF, MOT, SASAC, NEA, NDB, CAS, CAE, CAST, SAC). CHN Energy, China's largest power company with 350,000 employees, serves as chair. In October 2018 it hosted the first China Hydrogen Energy and Fuel Cell Industry Forum in Haikou, Hainan. The alliance includes also international enterprises such as Air Products, Air Liquide and Linde gas, who are actively contributing to hydrogen developments in China.

In March 2018, Air Products signed an agreement with Shenghua New Energy to provide two hydrogen dispensers for the first commercial HRS in Rugao, Jiangsu.[41] In September 2018, it signed agreements with Beijing Sinoscience Fullcryo Technology Co., Ltd – a subsidiary of China Academy of Sciences - to construct liquid hydrogen-based fueling stations in China. [42]

International Hydrogen Fuel Cell Association (IHFCA) [43]

The International Hydrogen Fuel Cell Association is an international non-governmental organization to promote global hydrogen and fuel cell collaboration. The association has over 60 members and aims to integrate the resources across the entire hydrogen fuel cell chain. The main activities include organizing the International Hydrogen Fuel Cell Vehicle Congress in Rugao, the FCV itinerant tour in the Yangtze River Delta region and promoting development of HRS roll-out and hydrogen and FCV standards and regulations. Part of the activities of the IHFCA are aimed at increasing public awareness through various informational communication platforms and public media as well to support the introduction of NEVs. Compared with the other two alliances, IFHCA is focused on the automotive sector and not involved in hydrogen usage for other applications.

Hydrogen Industrial Technology Innovation Alliance of China (HITIAC) [44]

HITIAC is a non-profit organization formed by companies, universities, research institutions and other industry partners in September 2017, dedicated to the research and development of hydrogen energy technologies. The alliance is supervised by China Industry-University-Research Institute Collaboration Association (CIUR). The secretariat is based in Wuhan, Hubei province where also several involved parties are based. The entire hydrogen chain is involved in the alliance, from upstream chemical industry, hydrogen storage & transportation, energy storage to automobile enterprises, and renewable energy organizations (such as CECEP Wind-power Corporation and China General Nuclear Power Group). The only international member currently is McPhy (alkaline electrolyzer enterprise) who joined the alliance after a hydrogen mission organized by the French government to Wuhan in 2018. The members share their business models and experiences and visit international exhibitions together (i.e. 2019 Tokyo Exhibition and 2019 Hannover fair). HITIAC consists mainly of small medium enterprises (SMEs). Compared to the SOEs in the China Hydrogen Alliance, their lobby strength regarding influencing (upcoming) standards and regulations is expected to be smaller.

Shenzhen Hydrogen and Fuel Cell Association [45]

Shenzhen Hydrogen and Fuel Cell Association (SHFCA) was initiated and supported by the Development and Reform Commission of Shenzhen Municipality. Established in 2017, the association has a little over 30 academic and business members along the hydrogen chain and is still in the early development stage. The initial focus is accelerating the deployment of fuel cell technologies in the transportation sector, but SHFCA isn't limited to this sector only. Members include Tsinghua University, Harbin Institute of Technology, Skywell, Kewell, State Fuel Cell Corporation (SFCC) and HydraV.

3.4 Local policy context

Local governments have committed themselves to support the development of the sector and several cities and regions published their own development plans based on the higher-level plans. The local plans have many common elements: they mention specific targets for the number of HRS and vehicles as well as the need for the development of core technologies. Based on the existing clusters related to the hydrogen industry in China, a few of these local plans are briefly discussed here.

Shanghai – Shanghai Fuel Cell Vehicle Development Plan [46]
The development plan was published in September 2017 and outlines 3 development stages: short term (2017-2020), medium term (2021-2025) and long term (2026-2030). Currently, Shanghai is already a leader in China's FCEV industry with relevant up- and downstream companies concentrated in Shanghai Chemical Industry Park (SCIP) and Jiading district. Quickly after the release of this development plan, SCIP signed a strategic cooperation framework agreement with SAIC Motor to jointly promote the commercial operation of FCEVs. The overall objective of the plan is to build an entire FCEV value chain and promote FCEV commercialization. The specific targets are summarized in the table below.

Stages	Targets
Short Term	5-10 HRS; 3,000 FC commercial vehicles
Medium Term	50 HRS; 20,000 FC passenger cars, 10,000 FC commercial vehicles
Long Term	FCEV value chain output of RMB 300 billion (approx. $45 billion USD) – no specific number of vehicles mentioned

In May 2018, Shanghai Municipal Science and Technology Commission issued the "Financial Subsidy Scheme for the Promotion and Application of Fuel Cell Vehicles in Shanghai" which clarified that FCEVs will receive a purchase subsidy in accordance with the central subsidy of 1:0.5. A subsidy of 1:1 will be granted if the FC system reaches a rated power of at least 50% of the power of the electromotor or not less than 60 kW. [47] In this way complete FCEVs are encouraged more than electric cars with a small fuel cell system acting as range extender.

Shandong - New Energy Industry Development Plan 2018-2028
The province released its New Energy Industry Development Plan 2018-2028. BEVs, PHEVs and FCEVs are expected to be the most important pillars. Related to the hydrogen energy industry, the total annual output value in Shandong should reach 50 billion RMB (6.4 billion EUR) until 2028.[48] The government will support leading FCEV and hydrogen enterprises by establishing industry clusters and demonstration parks.[49] The main developments will be in Jinan, Qingdao and Weifang. In the latter, the HQ of automobile powertrain manufacturer Weichai Power is located.

Zhangjiagang - Three-Year Action Plan for Hydrogen Energy Industry Development (2018-2020)[50]
In January 2019, the local government of Zhangjiagang, Jiangsu province published this plan to promote the development of a large-scale hydrogen energy industry, supporting existing hydrogen-related enterprises. The target annual output value of the hydrogen energy industry will exceed 10 billion RMB ($1.46 billion USD) by 2020. According to the document there are currently 30 hydrogen-related enterprises in Zhangjiagang covering the entire hydrogen value chain. The present steel (e.g. Shagang Group, Yonggang Group) and chemical industries (e.g. Twolions Zhangjiagang Fine Chemicals) provide abundant hydrogen. Relevant enterprises for hydrogen storage, transportation and HRS are also present in Zhangjiagang with the HQ of Furui and CIMC Sanctum Cryogenic Equipment. Furthermore, the fuel cell industry is represented by the JV between Nedstack, Hymove and Huaxia and by the global fuel cell manufacturer Horizon Fuel Cell Technologies. The R&D activities in Zhangjiagang are also actively progressing: in July 2018 the signing ceremony was held for the Suzhou Hydrogen Industry Innovation Center in Zhangjiagang and recently the Hydrogen New Energy Research Institute was jointly established by the municipal government, Southeast University (from Nanjing) and Furui.

The development plans mention the need for a hydrogen pipeline network, in order to improve the supply network. In comparison, the H2tools database from the Pacific Northwest National Laboratory (USA) shows that in September 2016, the USA had over 2500 km of hydrogen pipeline infrastructure installed, Europe over 1500 km and the rest of the world only around 330km. A pipeline network supports the roll-out of HRS. Zhangjiagang plans to build 10 HRS in the next three years and operation 10 demonstration bus routes with 200 FC buses.

The local government provides financial support for the development of the sector. The R&D institutions involved in the construction of the Suzhou Hydrogen Energy Industry Innovation Center receive 20% subsidy of the investment in R&D equipment up to max. 5 billion RMB ($730 million USD).

To support the roll-out of HRS as quickly as possible, the city provides the following subsidies:

- 30% of the investment for the equipment or up to max. 3 million RMB ($0.4 million USD) for a 35 MPa HRS with hydrogenation capacity of 500 kg/d or 70 MPa HRS with 200 kg/d.

- 30% of the investment for the equipment or up to max. 5 million RMB ($0.7 million USD) for a 35 MPa HRS with hydrogenation capacity of 1000 kg/d or a 70 MPa HRS with 400 kg/d.

Subsidies to support breakthroughs in key components are also in place:

- 10% of the R&D funds of a project or up to max 1 million RMB ($0.15 million USD) is available for projects related to hydrogen liquefaction equipment, high pressure storage hydrogen equipment, liquid hydrogen storage equipment, fuel cell and power systems when new products are put into production and operation. In case the key component or equipment set are recognized as the first of the kind in the province, the subsidy will be granted at 10% of the unit price of the single set of equipment, up to max 5 million RMB ($0.7 million USD).

The development plan shows the strong commitment of the Chinese government and the strong financial backing that enterprises receive from the government to accelerate hydrogen sector developments.

Wuhan – Wuhan Hydrogen Industry Development Plan
Wuhan is very eager to become a hydrogen city and has a solid foundation to develop a hydrogen and fuel cell industry. The two main pillars of the Wuhan Economic & Technological Development Zone (WEDZ) are the automobile and electronics industry. Furthermore, the nearby heavy industries (i.e. Wuhan Iron and Steel Corporation) provide an adequate supply of (by-product) hydrogen. Due to the strong automobile industry, the initial focus of the development plans seems to be hydrogen for transportation applications. In October 2019, Wuhan will be the host of the “World Military Games” which spurs current developments.

The Wuhan Economic and Information Commission highlights several steps to be taken to develop the hydrogen energy industry. Firstly, the government will improve its local policy system by establishing more standards and improving laws and regulations. It aims to strengthen guidance for the industry and to create synergy between leading enterprises. In line with this, the city approved the construction of a hydrogen fuel cell industrial park in 2018. The city wants to accelerate the fuel cell vehicle industry by offering financial support to the FCEV industry, by actively promoting the construction of HRS, and operating FC bus demonstration projects.

In January 2018, the proposal for the development plan of the hydrogen energy industry was released during a meeting in Wuhan Economic and Technological Development Zone. In early 2018 the construction for a hydrogen fuel cell industrial park began, after agreements between VISION Group and the Administrative Committee of the Wuhan Economic and Technological Development Zone were signed in November 2017. The (Shenzhen-based) VISION Group invested $1.75 billion USD to build the park, where - according to the development plan - more than 100 enterprises involved in the fuel cell automobile industry with overall revenue of $16 billion USD will be located by 2025.[51] The aim is to create a production base with an annual capacity of at least 100,000 units in three to five years.[52]

In February 2018, Wuhan Municipal Economic and Trade Commission together with other government bodies jointly issued the “Detailed Rules for the Implementation of Local Financial Subsidy Funds for the Promotion and Application of New Energy Vehicles in Wuhan”. Purchase subsidies for FCEVs follow the 1:1 ratio with the central government subsidies.[53]

In March 2018 the "Administrative Measures for the Approval and Management of the Hydrogenation Station of Wuhan Economic and Technological Development Zone" was released to improve the approval process for the construction of HRS. The document clarified the process for project site selection, construction and operation and related regulations to HRS and thus easing the roll-out of hydrogen infrastructure. As a result, in September 2018 the first HRS opened in Wuhan.[54]

According to the plan, until 2020 (phase I) 20 HRS will be constructed in the city to support the 2,000 – 3,000 FC buses and commercial vehicles operating. By 2025 (Phase II) this should be increased to 30-100 HRS and the number of vehicles (buses, commercial and passenger cars) will reach 10,000-30,000.[55]

Tianjin – Three-Year Action Plan for the Development of the Tianjin New Energy Industry (2018-2020)[56]
In line with the earlier mentioned national plans, the Tianjin Municipal People's Government Office released a new energy industry development plan in October 2018. The plan discusses the future of industries such as NEVs, lithium-ion batteries as well as the hydrogen energy and fuel cells. The government expects the total value

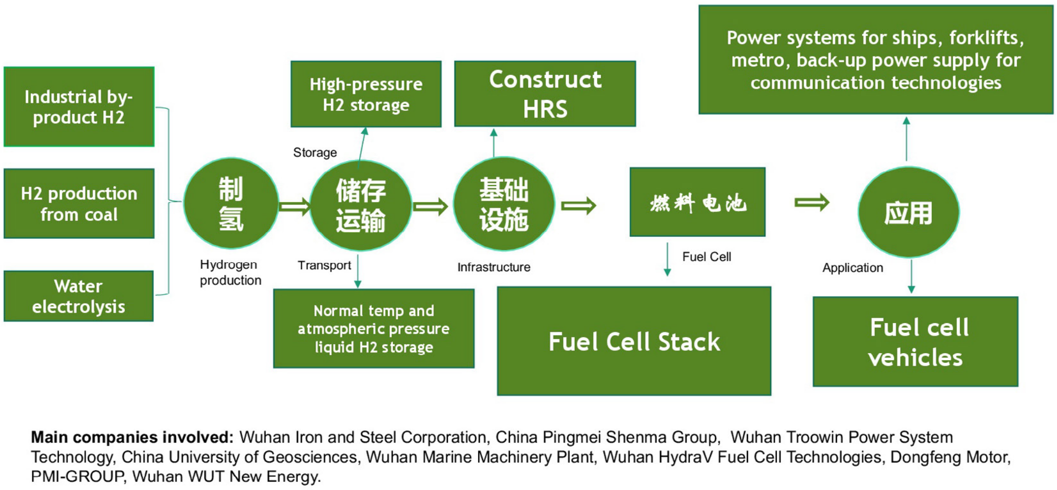

Figure 5: Proposal Hydrogen Economy Wuhan (translated and adapted version from Li Linqing, Wuhan Economic and Information Commission)

output of the hydrogen energy and fuel cell industry to be 8 billion RMB by 2020.

Firstly, the government aims to promote the development of fuel cells by improving the business environment in Tianjin to support current and attract new companies. In line with this goal, the Tianjin government hosted a small conference in Shenzhen on October 12th, 2018 to attract enterprises such as State Fuel Cell Corporation (SFCC) to set up in Tianjin.[57] Furthermore, the government wants to guide Beijing Blue-G Power New Energy Technology Co., Ltd., whose production line is already based in Tianjin, to cooperate with Tianjin Lishen Battery Joint-Stock Co., Ltd. to jointly develop high performance hydrogen fuel cells and their key materials.

Secondly, the plan aims to reduce the costs of key material technologies (such as PEM and catalysts) by supporting research at universities with the purpose to localize production lines. In addition to technology development of key components, efforts will be made to promote the development of auxiliary systems to improve the integration performance of FC stack components.

Thirdly, the goal is to support large chemical and energy companies to transform and improve the safety of hydrogen production via industrial by-products. In addition, accelerate the R&D of the equipment of Tianjin Hydrogen Production Equipment Co., Ltd, one of the leading players in the global water electrolysis market.

Finally, by fostering cooperation between companies such as Beijing CTIC Technology Co., Ltd. and Shanghai HyFun Energy Technology Co., Ltd. the fuel cell automotive sector can accelerate by improving on-board hydrogen storage (35 MPa and 70 MPa), refilling equipment (hydrogen compressor, high-pressure hydrogen storage tank) and the construction of HRS.

Foshan

Foshan is one of the five demonstration cities of the UNDP bus commercialization project and the government has set out ambitious plans for the development of the NEV industry. During the 13th FYP Foshan planned to invest 900 million RMB ($131 million USD) to support the promotion and application of new energy buses and supporting infrastructure construction. In the short-term Foshan plans to build 28 HRS in 2019 (adding to the 2 existing HRS) and put 1,000 FC buses into use.[58]

Foshan has strong local purchasing subsidies for FCEVs (1:1 with national subsidies) as well as for the construction and operation of HRS. A maximum subsidy of 8 million RMB ($1.2 million USD) is available for the construction of a HRS. The exact amount of subsidy depends on the daily hydrogenation capacity provided (350 kg, 500 kg or > 500 kg) and the year the HRS is completed. Foshan also provides subsidies for the operation of the HRS to address the "chicken-egg problem" and start the market. The following subsidies are granted:[59]

- $2.9 USD/kg H2 with a sales price of $5.8 USD or less (2018-2019)
- $2.0 USD/kg H2 with a sales price of $5.1 USD or less (2020-2021)
- $1.3 USD/kg H2 with a sales price of $4.4 USD or less (2022)

In April 2015 Nanhai district of Foshan published its New Energy Automobile Industry Development Plan (2015-2025) with the aim to become a leading FCEV core components R&D and production base in the Pearl River Delta. Following the plan, the local government issued several supporting action plans. For example in April 2018, the "Foshan Nanhai District Support Methods on Promoting Construction and Operation of Hydrogen Filling Stations and Operations of FCEVs" was published, revealing the details about financial support mechanisms for companies.

Foshan houses the South China Base of National Fuel Cell and Hydrogen Technology Research Center. Guangdong New Energy Vehicle Industry Base (located in Danzao Town, Nanhai district) has leading industries in hydrogen-rich materials, hydrogen production equipment R&D and fuel cell powertrains.[60] In Yunfu (close to Foshan) the entire up- and downstream industries of the hydrogen value chain are concentrated due to the strong efforts of the local government. Locally produced stacks by a plant of the JV between Ballard and Guangdong Synergy are immediately assembled into a FC powertrain at the next-door mass production line of Re-Fire. The table below highlights some of the recent developments in Foshan:

Date	Project / Announcement
Mar 2017	CRRC Qingdao Sifang Co., Ltd. has been awarded the contract by Foshan government to produce 8 hydrogen trams. The trams are equipped with FCveloCity FC engines. A Phase 1 deployment of 5 trams is planned to begin in the first half of 2019, with additional trams planned for deployment in subsequent operational phases.
Sept 2017	Local government of Nanhai district signed a cooperation agreement with Hangzhou Changjiang Automobile Co., Ltd. for a Hydrogen Power R&D Center and vehicle production project (total investment $1.75 billion USD) in Danzao Town, Nanhai.
Dec 2017	Impact Coatings (Sweden) signed a cooperation agreement with fuel cell manufacturer Guangdong Telos Auto Power Systems Co., Ltd. and the City Council of Foshan to jointly develop fuel cell systems.
May 2018	Nanhai District Government and Edelman (Aideman) Hydrogen Equipment Co., Ltd. signed a project investment agreement. Edelman (Aideman) will invest $436 million USD to promote the hydrogen fuel cell production project in Danzao and build a FC powertrain production base, producing 80,000 – 100,000 units/year.
Aug 2018	Commencement ceremony was held for the construction of 8 new HRS with the investment ranging from 12.5 million RMB ($1.8 million USD) to 29.85 million RMB ($4.3 million USD). Only one of them is a completely new station, the others are retrofits of current gas or LPG refueling stations. On December 20th the first station with a daily hydrogenation capacity up to 500kg in Chancheng district was completed and 70 FC buses were put into operation.

3.5 Conclusion

The national government supports hydrogen developments in China by providing substantial financial support and setting targets in policies. Strong leadership from high-level politician Wan Gang shows the government's commitment to develop this sector. Wan Gang[61] is advocating the development of FCEVs at high-level events such as EV100 and FCVC and constantly urging relevant departments in China to follow international example in establishing regulations and technical standards, one of the main barriers currently hindering Chinese developments. In 2018, MOST provided over $70 million USD to national hydrogen and fuel cell R&D projects. In contrast with 2017 this funding mainly advanced industry players, showing the government's will to accelerate industrialization. Based on the national-level plans, several regions and cities developed local policies. Some of these policies only highlight general goals, whereas others have very specific financial incentives to support leading companies in their region and to attract new companies. As a result, local hydrogen economies are emerging in areas with abundant hydrogen leading to scattered developments with a lack of national integration. This is also caused by the lack of large-scale infrastructure which could support integration between regions. This phenomenon is not only occurring in the hydrogen sector but can be seen in several sectors in China. The next chapter related to industry developments will showcase how local OEMs dominate regional developments.

4
Industry

This chapter will focus on the current market developments in the Chinese hydrogen industry covering the entire hydrogen value chain from production to applications

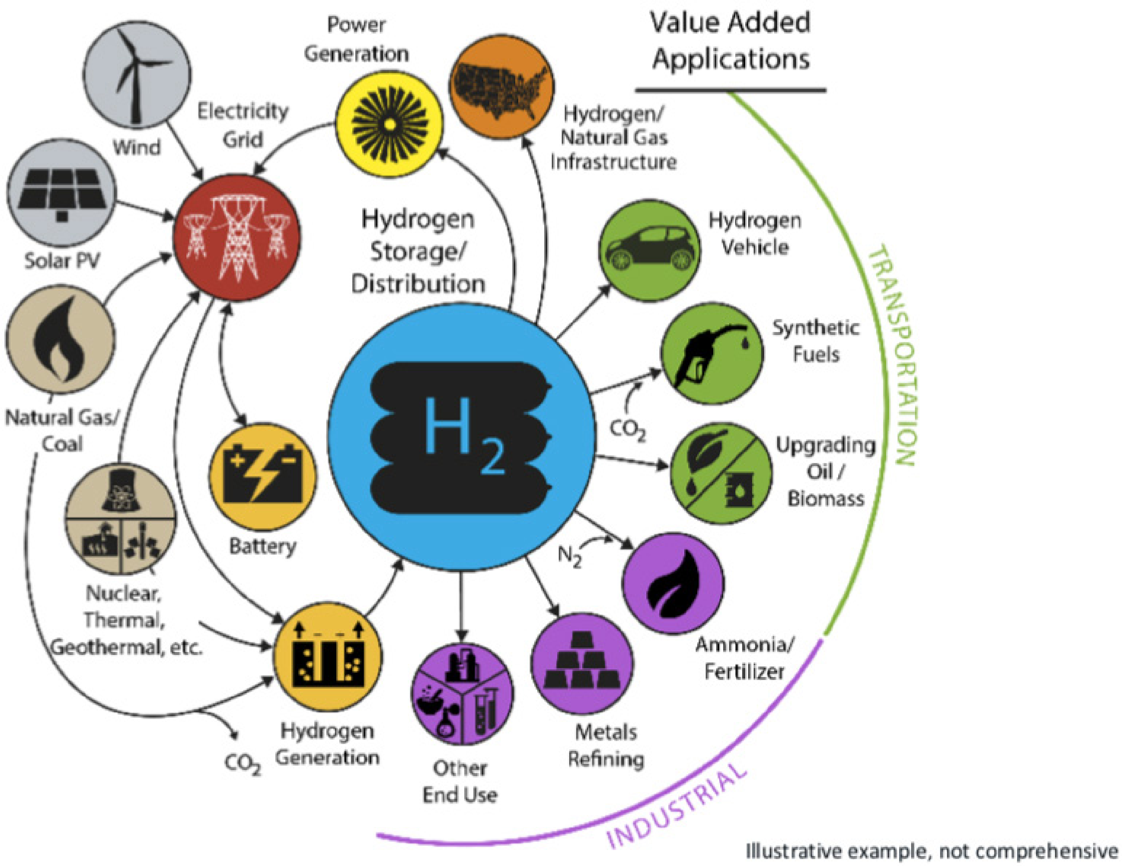

Figure 6: Hydrogen chain (Source: National Renewable Energy Laboratory)

4.1 Hydrogen production

The terms grey, blue and green hydrogen are commonly used when referring to different hydrogen production methods. Grey hydrogen refers to hydrogen production from fossil sources, such as coal, oil and natural gas, where during the production process CO2 is emitted. Grey hydrogen becomes blue hydrogen when Carbon Capture Utilization and Storage (CCUS) is applied during the production process. Green hydrogen is produced by splitting water into hydrogen and oxygen (electrolysis) using renewable electricity from i.e. wind or solar power. The recent worldwide interest in hydrogen is mainly because of green hydrogen's potential to enable the transition towards a climate-neutral society.

China is the world's largest hydrogen producer and in 2016 annual production reached 21 million tons. In addition, 11.89 million tons of by-product hydrogen were produced of which 90% was recycled back into the industry. By-product hydrogen can also be used to generate electricity by using a fuel cell power plant. In 2016 a 2MW PEM fuel cell power plant was opened in Yingkou, Liaoning which was jointly developed by AkzoNobel, Nedstack, MTSA Technopower, Johnson Matthey Fuel Cells Limited and Politecnico di Milano.[62]

Hydrogen can be produced from any locally available primary energy source and then transformed into a different energy form for diverse end-use applications.[63] Most of the hydrogen produced in 2016 in China came from fossil sources. However, China's energy sources are geographically spread out and local hydrogen economies will probably follow different paths for hydrogen production based on their local strengths.

4.1.1 Coal gasification

China became the largest hydrogen producer worldwide in 2010. Most of this is obtained from coal via gasification which requires high temperatures (about 1400∞C). China has nearly 1.000 coal gasifiers in operation. Coal gasification is the cleanest, yet most complex method of coal utilization and accounts for 5% of China's total coal consumption.[64] Most coal resources are located in the western and northern part of China, in the provinces Shanxi, Shaanxi, and Inner Mongolia which together account for 65% of the nation's resources.[65] This poses challenges to the storage and transportation of the hydrogen. Most of the demand is located in the Yangtze River Delta and Pearl River Delta, while there is no large-scale hydrogen pipeline network constructed yet. Mr. Yingpeng Zhao from AT&M (a subsidiary of state-owned China Iron & Steel Research Institute) said that discussions about a north-south hydrogen gas pipeline are currently in an early phase. Although hydrogen production via coal gasification is by far the cheapest method, coal demand in China has actually been declining since 2014 due to the "Make the skies blue again" initiative from Chinese Premier Li Keqiang. The IEA predicts that more than 100 Mt of coal currently used in the residential and industrial sectors (steel and cement excluded) is to be replaced by natural gas.[66]

4.1.2 Steam methane reforming (SMR) of natural gas

Since the 1990s the national government has promoted the construction natural gas pipeline network. In 2010 the total length of the natural gas pipeline amounted 36,000 km and by 2014 this number had already reached 82,000 km. The Energy Development Strategy Action Plan (2014-2020) mentions a clear proposal to reach over 120,000 km of natural gas pipeline by 2020.[67] In China, the three natural gas provinces in Changqing,[68] Tarim and Sichuan each have reserves with more than 1 x 1012 m3 and strongly contributed to the 10% increase between 2016 and 2017 in national gas production.[69]

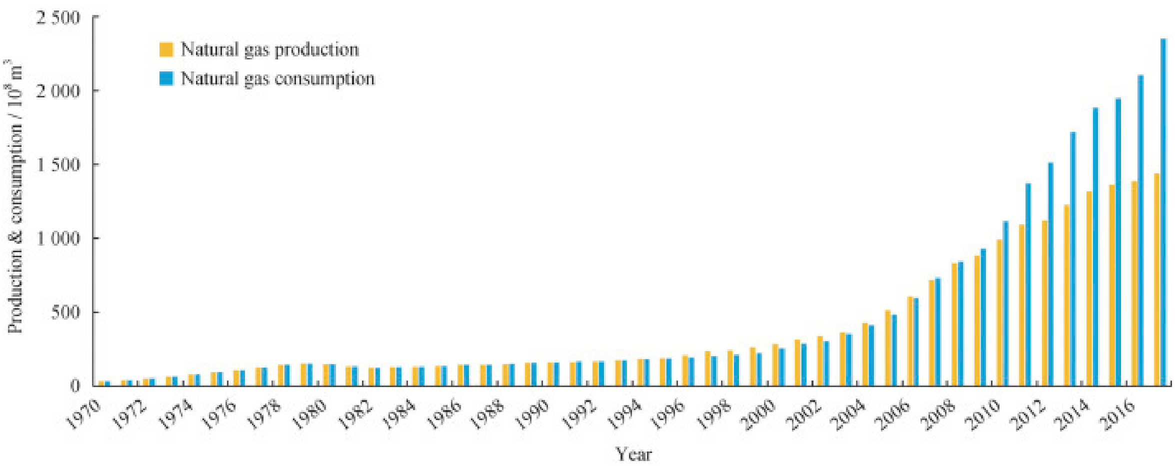

Figure 7: Natural gas production and consumption from 1970 to 2017 (Source: Zou, C. (2018))

Hydrogen can be directly produced from natural gas via several processes. Steam-methane reforming (SMR) is the most commonly used and mature technology for industrial hydrogen production. The main international players in the Chinese SMR-market are Air Liquide, Air Products, Linde and Messer. The main Chinese players are Ally Hi-tech (Sichuan), Shanghai Huaxi Chemical Industry Science & Technology and Shanghai Hualin Industrial Gases (a JV between Linde and Shanghai Coking & Chemical Corporation).[70] During SMR high levels of CO2 are emitted (on average 7 kg CO2/kg H2),[71] but studies have shown that CO2 could be captured from an SMR plant with an overall capture rate ranging between 53% to 90%.[72] The integration of CCS could thus substantively reduce greenhouse gas emissions. China has recently installed (and planned) several CCS installations at coal plants. Because of China's redundant coal resources, hydrogen production via coal gasification is about 20% cheaper than hydrogen from natural gas production.[73] Dr. Jimmy Li from the National Institute of Clean-and-low-carbon Energy (NICE) therefore also argues that hydrogen from natural gas will not be competitive in China.[74]

4.1.3 Power-to-Gas (P2G) with water electrolysis

Global interest for P2G has increased rapidly and it is regarded as an important technology to realize large-scale renewable energy integration. European countries, the USA and Japan are taking a leading position in the R&D of P2G technology, whereas China just started research in this field.[75] Over the last decade China has invested heavily in renewable energy capacity and enabled massive cost reductions in the solar PV and wind power market. In 2017 the total installed capacity reached 619 GW according to IRENA.[76] However, this rapid increase of installed capacity has also led to curtailment problems; in 2016 on average 17% of wind power was curtailed, while in some regions the curtailment rate reached 38%. The national average for solar curtailment in 2016 was 19.7%, with peaks of 32%.

Figure 8: Wind curtailment rates reached another peak in 2016 (Source: Energy Brainpool)

The curtailment situation showed improvement again in 2017 with curtailment rates for wind and solar power dropping to 12% and 6% respectively. However, the geographical mismatch between generation areas in the north-west and load consumption centers in the eastern coastal provinces remains, posing challenges to China's power system.[78]

To address these challenges, in October 2017 a national-level policy document (the "Guiding Opinions on Promoting Energy Storage Technology and Industry Development") was jointly published by NDRC, MOF, MOST, MIIT and NEA. The document focuses on the development of a smart electricity grid and battery technologies.[79] It is striking that hydrogen is not mentioned here as possible storage technology (!) Hydrogen (as recognized in the Energy Innovation Action Plan 2016-2030) could also enable advanced energy storage by using renewably produced electricity to split water via electrolysis into oxygen and hydrogen molecules. Renewable energy storage in hydrogen has great potential due to its high energy density, long-term storability and ability to transfer the electricity into other energy sectors.[80]

Commonly, water electrolyzers are classified into three main categories: alkaline, polymer-electrolyte membrane (PEM) and solid oxide electrolyzers (SOE). All have slightly different operating principles. The most established and well matured technique is alkaline electrolysis, which main advantages are low costs (not using noble electrodes) and long-term stability. On the other hand, PEMs and SOEs offer a more compact design and make operation at differential pressures feasible and favorable. Due to the solid form of the electrolyte, the systems are more dynamic with a faster response rate upon application of variable power load.[81] It seems that PEM electrolyzers are the most suitable to deal with high current densities, variable partial load, overload and on-off conditions. Further cost reduction (especially regarding the expensive platinum catalyst) is still required in this market segment to go from project manufacturing towards product manufacturing.[82]

In 2017, the capital costs for alkaline electrolysis systems were around 1000€/kWel and 2000€/kWel for PEM systems (based on 1MWel systems). SOE systems are not widely commercially available, and costs estimates lie above 2000€/kWel. This means that with current technological standards alkaline electrolysis hydrogen production costs around two to three times more compared to hydrogen production from natural gas via SMR.[83] A recent literature review (2018) from Chinese researchers at Tsinghua University summarizes the three electrolysis technologies as following:

TABLE I
COMPARISON OF THE THREE ELECTROLYSIS TECHNOLOGIES

Characteristic	ALKALINE	PEM	High-temperature
Charge carrier	OH^-	H^+	O^{2-}
Current density (A/cm^2)	< 0.5	< 2	< 0.5
Unit cell voltage (V)	> 1.9	> 1.8	> 1
Temperature (°C)	60–80	60–80	700–1000
Working pressure (bar)	< 15	< 60	< 3
System efficiency	55%–67%	60%–70%	90%–95%
Minimum load	30%–40%	0–10%	0–10%
Dynamic response	Slow	Fast	Fast
Common capacity	MW level	< MW level	kW level
Installation cost (€/W)	0.8–1.1	1.3–2.3	0.9–5*

*Since high-temperature electrolysis hasn't been put into large-scale commercialization and promotion, its cost varies in different reports and applications.

Figure 9: Comparison between electrolysis technologies (Source: Xing, X. et al. (2018))

For the specific case of China, hydrogen production from coal is much cheaper than from natural gas. In the largest chemical coke base of China (of Pingmei Shenma Group) in Wuhan the production cost for 1 cubic meter hydrogen is about 1.4 RMB (€17.7 cents). After adding costs for pressure and storage technologies, the cost of preparing 1kg hydrogen is around 18 RMB (€ 2.3). According to the Wuhan Economic and Information Commission these production costs are three times less than hydrogen production via water electrolysis.[84]

The global electrolyzer market is developing quickly: according to the World Economic Forum electrolyzers prices went down from €2-€4 million per MW a few years ago to around €0.5 million right now.[85] Alkaline electrolyzers are already commercially available in China and the most important domestic producers are Tianjin Mainland Hydrogen Equipment Co., Ltd. (THE) and Beijing CEI Technology Co., Ltd. THE is a world leading supplier of alkaline electrolyzers and has delivered more than 400 production plants since 1994. THE has a partnership with HydrogenPro (Norway, established in 2013) who holds all exclusive rights for THE's business activities in Europe and USA. HydrogenPro has been selected in October 2018 by H2V INDUSTRY for a large-scale P2G project (5 times 100 MW hydrogen production units) over a five-year period in Dunkerque, France.[86] Another domestic manufacturer, Suzhou JingLi Hydrogen Production Equipment Co., Ltd. signed cooperation agreements in August 2018 with Dalian Institute of Chemical Physics for new hydrogen generation via water electrolysis technology research and is also part of the "973" National Research Program "Large Scale Hydrogen Production of Wind Power".[87] The domestic alkaline electrolyzers are highly competitive with international products.

In contrast, for PEM electrolyzers the technology gap between domestic Chinese manufacturers and international manufacturers is still substantial. As mentioned earlier, PEM electrolyzers have several advantages over alkaline, especially when dealing with the intermittent energy production from renewables. Another big advantage is that PEM electrolyzer modules require about 20% of the space compared to alkaline modules. In China, PEM electrolyzers are (mostly) produced by a subsidiary of China Shipbuilding Industry Corporation (718th Research Institute "*Peric*") and by Shandong Saikesaisi Hydrogen Energy Co., Ltd, which are both based in Shandong province.

Global market leaders for (large-scale) PEM electrolyzers are Hydrogenics, Siemens, ITM Power and nel. Siemens has implemented PEM electrolyzers in several German projects (i.e. Power2Gas) with capacity ranges of 3 – 6 MW, however only started developing its Chinese market for PEM electrolyzers in Q4 2018.[88] Hydrogenics and nel have been active in China for a longer time period and are engaged in several projects. It seems that ITM Power is not yet active in the Chinese market but mentions that it is closely watching the developments in China and India in its Annual Report 2017.[89] ITM Power is currently involved in the largest PEM electrolyser project worldwide (10 MW) for Shell in Germany. Over the last three years the price of ITM's electrolysers has halved to $1,000 USD/kW.[90]

Hydrogenics' portfolio consists of both PEM fuel cells and PEM electrolyzers. The company has strongly entered the Chinese market over the last decade, especially with its fuel cell technology. In 2016 Hydrogenics signed an $13.5 million USD agreement with SinoHytec for the delivery of fuel cells in China. Before that, Hydrogenics and SinoHytec had been working together already for several years. The P2G-industry in China isn't very developed yet, so no strong agreements between Hydrogenics and a Chinese counterpart have been made for PEM electrolyzers yet.

Nel (Norway), originally an alkaline electrolyzer supplier acquired Proton OnSite (USA), a PEM electrolyzer supplier in 2017. In August 2018 nel announced to scale up its production capacity to 360 MW/year mainly to serve the American market.[91] In December 2016 Proton OnSite already signed a contract with Guangdong Synergy Hydrogen Power Technology Co., Ltd. to provide 13 MW PEM electrolyzers for the deployment of FC buses in Foshan and Yunfu.[92] However, by the end of 2018 only 4 MW has been delivered and the other 9MW still awaits follow-up from Chinese partners.[93] Due to regulations, on-site production of hydrogen (via electrolysis, or SMR) is only allowed within chemical parks. The planned 8 HRS in Foshan which are currently under construction will therefore receive their hydrogen via tube trailers.

The table below provides a compact overview of the current Chinese enterprises active in the electrolyzer market.

Enterprise	Type	Short description
718th Research Institute of China Shipbuilding Industry Corporation	PEM/ Alkaline	State-level R&D institute, with more than 2000 employees engaged in the production of electrolyzers. Offers different electrolysis solutions, i.e. container with production capacity 100Nm3/h with H2 purity of 99.999%.
Shandong Saikesaisi Hydrogen Energy	PEM	Affiliated to Shandong Saikesaisi Group; focus on pure water electrolysis hydrogen production equipment using Solid Polymer Electrolyte (SPE). Its M1000 model has a production capacity on 1000 Nm3/h with 99.9995% purity. The smaller QLES-H260 series (output capacity 260 Nm3/h) has a power consumption of 5.0 kWh/Nm3.
Beijing CEI Technology	PEM	R&D and production of PEM electrolyzers; one of main players in Chinese market for PEM electrolyzers development. No product specifications are publicly available on their website.
Suzhou JingLi Hydrogen Production Equipment	Alkaline	Around 180 employees, focusing in R&D and production of alkaline electrolyzers.
Yangzhou Chungdean Hydrogen Equipment	Alkaline	National high-tech company; Production rate 0.1 Nm3/h – 2000 Nm3/h with six series of their main product.
Tianjin Mainland Hydrogen Equipment	Alkaline	Global market player for alkaline electrolyzers, working together with large corporation such as Baosteel Group & Air Liquide.
Shaanxi Huaqin New Energy Technology	Alkaline	Based in Xi'an High-tech Industrial Development Zone. R&D and production of alkaline electrolyzers.
Suzhou Suqing Hydrogen Equipment	Alkaline	Small producer of alkaline electrolyzers.

Table 4: Chinese electrolyzer companies (see database for more detailed information)

4MW Electrolyzer Power-to-Gas Project

In June 2015, McPhy signed a €6.4 million contract with Jiantou Yanshan Wind Energy (a subsidiary of state-owned manufacturer Hebei Construction and Investment Group Co., Ltd.) for the delivery of alkaline electrolyzers to turn the surplus energy of the 200 MW windfarm into hydrogen. The 4MW hydrogen equipment was delivered in June 2017 and consists of two McLyzer 400 modules, transformers, power electronics, a purification and drying unit and solid-state storage module.[94] However, via other sources we learned that in December 2018 the machines were not being operated.[95] In addition to this project, in October 2018 McPhy and Hebei Construction and Investment Cooperation Group signed a MoU for the construction of a Hebei-Brandenburg Hybrid Power Plant in Guyuan.[96]

In the future: hydrogen production from urban waste?

Wuhuan Engineering Co., Ltd. is an enterprise based in Wuhan working on converting urban waste into hydrogen oil which can safely be stored and transported. The company is the Chinese partner of THERMOSELECT AG (Lichtenstein) – Vivera Corporation. The company via high temperature gasification converts different kinds of waste into i.e. syngas. Currently THERMOSELECT plants have been operating already in Japan, Germany and Italy and potential projects are under discussion in China. The construction of the (module-based) plant takes 18 months, so perhaps in 1-2 years such plants will be operating in China. The plant has a capacity to process 400 ton waste/day, and thus supply sufficient hydrogen oil for at least 15 HRS.

Conclusion

The Chinese market for hydrogen production from renewables is still in an early stage. The domestic alkaline electrolyzer equipment from THE and CEI are globally competitive products, but as mentioned, alkaline electrolyzers are less suitable than PEM electrolyzers for P2G from the intermittent power generation of renewables. Therefore, although converting redundant renewable electricity into hydrogen would help China reduce its massive curtailment percentages, PEM electrolyzers are still very costly. The technology gap between domestic and international products is also still large. Currently, Hydrogenics, nel and Siemens are working on plans to localize their production lines which will allow further cost reductions.[97] Scientific researchers from Switzerland in 2017 compared the specific price of electrolyzers per production capacity, which is shown in the figure below. They also remark that it is striking to see that Chinese suppliers offer products that are significantly cheaper than equivalent Western products, but that there is no certainty about the reliability and quality of these low-cost solutions. Chinese PEM electrolysers with a production capacity of 180 Nl/h are offered for $5400 USD.[98]

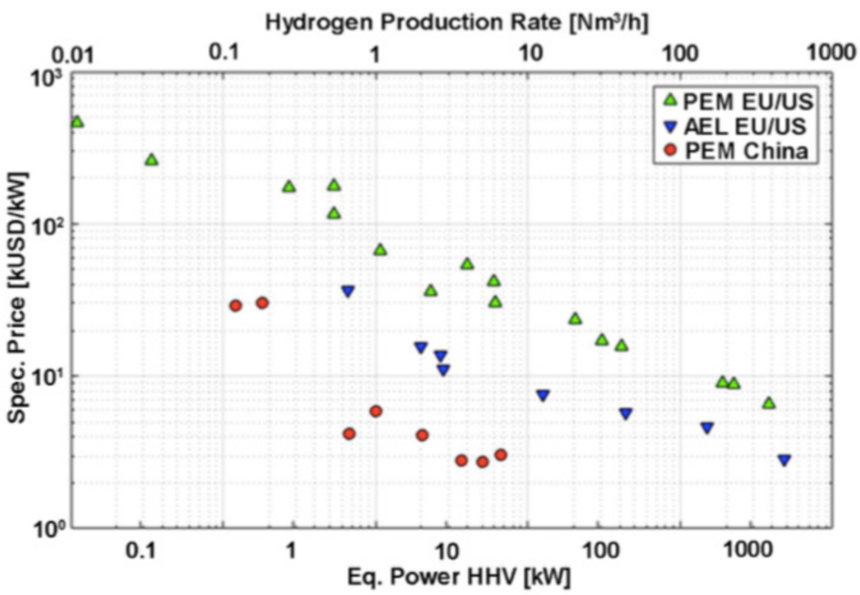

Table 5: Specific price of electrolysers per production capacity (Source: Gallandat et al. (2017))

After speaking with several Chinese scientists, policymakers and businessmen, it seems that China's pathway for hydrogen production is to first use its abundant fossil fuel sources due to the much lower prices. The recent "China Coal Hydrogen Production Annual Report 2018" from Asia Chemical Consulting also proved this point: from 2010 until 2018, there were 6 new large-scale coal hydrogen projects established with a total hydrogen production scale of 80.5 million m³/hour. At present, several more projects are planned for coal-based hydrogen production. By initially keeping traditional hydrogen production methods, the market for hydrogen applications (e.g. transportation, blending hydrogen in natural gas network for urban heating) can be developed rather quickly. Later, the production methods can be shifted towards more sustainable production.

4.2 Storage and distribution

After hydrogen is produced it needs to be stored and transported. As traditionally hydrogen has mainly been used as a chemical feedstock for industrial processes, the current transport technologies are designed for industry handling: either compressed under high pressures (gaseous) or under very low temperatures (liquid). This poses challenges to the public roll-out of hydrogen for i.e. transportation applications. A hydrogen economy requires a supply network that accommodates both centralized and decentralized (on-site) hydrogen production facilities and pipelines to distribute hydrogen between high-demand areas.[99] Transmission by pipeline is a low cost alternative to deliver large amounts of hydrogen under low pressure, but requires large initial capital investments to construct the infrastructure.[100] As mentioned earlier in this report, discussions about a north-south hydrogen pipeline in China are in an early phase. In addition to the three main transportation methods for hydrogen, progress has also been made in finding alternative methods by using carbon-hydrogen bonds (so-called Liquid Organic Hydrogen Carriers) to enable safe and efficient transport at ambient conditions.[101] This section will highlight the developments in China regarding storage and distribution of hydrogen.

Gaseous transport

Twenty HRS are currently in operation in China. They mostly receive their hydrogen from nearby industries via compressed gas tube trailers, which have a capacity of about 200-300kg per truck. A few HRS (located inside chemical parks) such as the Beijing and Dalian HRS have on-site hydrogen production. For transporting larger volumes, several pressurized gas cylinders or tubes can be bundled together on so-called CGH 2 tube trailers. The costs gaseous transport become prohibitive for distances greater than 300 km from the production location.[102] This is the main reason that currently hydrogen developments are located in regions where there is abundant hydrogen nearby, either produced from primary energy sources or as by-product from industrial processes.

Liquid transport

For longer distances liquefied hydrogen is the preferred transportation option because the transport volume of a liquid carrier is roughly 10-12 times larger. However, liquid hydrogen transport in China is currently still restricted to military purposes, posing great challenges to the roll-out of HRS in China. There are already several domestic companies that developed equipment (such as cryogenic tanks) for liquid hydrogen handling, but new regulations, codes and standards (RCS) are required to improve China's supply chain. At the FCVC in October 2018, Air Liquide and several other companies highlighted this issue. In November 2018, the vice-president of the State Council proposed to categorize hydrogen as an energy fuel instead of hazardous chemical, which was underlined once more by Mr. Wan Gang at the EV100 meeting in January 2019. It shows that high-level government officials are working on addressing this problem although it might still take time.

Chinese enterprises working on liquid hydrogen transport (equipment) are Fullcryo, working together with Air Products, and Furui, which has more than 40 patents related to liquid hydrogen. The latter is involved in an industrial hydrogen liquefaction project in Weinan, Shanxi with a capacity of 8.5t/d 200 m^3 liquid hydrogen tanks. Furui founded the subsidiary Jiangsu Tianchuang Hydrorigin Co., Ltd together with Cowin Capital and Haichang Gas that invests in the construction and operation of large hydrogen liquefaction plants as well as liquid hydrogen storage and transportation equipment. This surprisingly shows that technology development is taking place, although current regulations are not supporting this.

In summary, the hydrogen supply chain in China is very weak due to the current regulations and classifications of hydrogen. An update of these regulations is essential to advance the sector and achieve the targets set out in national policies (300 HRS by 2025). Foreign enterprises with extensive experience related to liquid hydrogen such as Air Liquide, Air Products, Linde and so on can help China improving its supply chain as most of them are already very active in China.

Liquid Organic Hydrogen Carriers (LOHCs)

LOHCs allow for safe and efficient transport of hydrogen at ambient conditions. LOHC-based hydrogen transport and storage is not restricted to one type of hydrogen production, but can be based on both grey, green or by-product hydrogen production.[103] The (commercially available) technology is rather young. Globally there are only a few products commercially available and Technology Readiness Level (TRL) regarding application fields is still very different. LOHC systems consist of pairs of hydrogen-lean (LOHC-) and hydrogen-rich (LOHC+) organic compounds that store hydrogen by repeated hydrogenation and dehydrogenation cycles using a catalyst.[104] Advantages of LOHCs are the safe and convenient handling (as the hydrogen 'oil' is a diesel-like liquid) and low prices.[105] The delivery capacity of LOHC is four times more than regular tank tube trailers for gaseous hydrogen.[106]

The global market for LOHC technology consists of 3 main players: Chiyoda Corporation (Japan), Hydrogenious (Germany) and Hynertech (China). Chiyoda started R&D activities into a high performance dehydrating catalyst as early as 2002 and successfully developed its LOHC methylcyclohexane (MCH) in 2011, naming the product SPERA.[107] In 2013 a demonstration plant was set up in Yokohama and the maturity of SPERA is estimated to be TRL 9.[108] Following the plans of the Japanese government outlined in the Strategic Roadmap for Hydrogen and Fuel Cells (2016), SPERA technology enables large-scale hydrogen import from overseas, for example from Australia.[109]

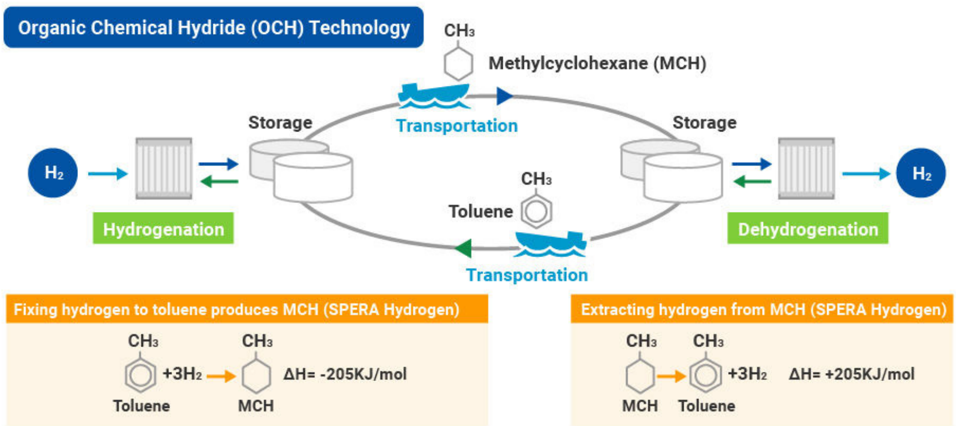

Figure 10: SPERA LOHC technology from Chiyoda Corporation

Another global market player for LOHC technology, Hydrogenious, was founded in 2013 as spin-off from Friedrich-Alexander-University Erlangen-Nürnberg (FAU). The technology of Hydrogenious uses dibenzyltoluene as carrier, which is currently available for around 4-5$/kg.[110] Anglo American Platinum is one of the shareholders of the company, as platinum and palladium are used as catalyst to separate the carrier and hydrogen in the ReleaseBOX.[111] In December 2017, Hydrogenious entered into a collaboration agreement with Zhongshan Borad-Ocean Motor Co., Ltd. for the construction of a first LOHC-pilot HRS (for buses) in China to start operation beginning 2019. The plans include the roll-out of more HRS in China, after setting up local production, operation and service for the LOHC systems in China.[112] In early 2018, Hydrogenious was listed in the Global CleanTech 100 as one of the most promising clean technology companies globally.[113] Hydrogenious works together with HyGear (Dutch) and VTT (Finland) in the HySTOC project from FCH-JU which runs from January 2018 until the end of 2020. The HySTOC project will demonstrate the distribution of high purity hydrogen (ISO 14687:2-2012) to a commercial HRS in Finland.[114]

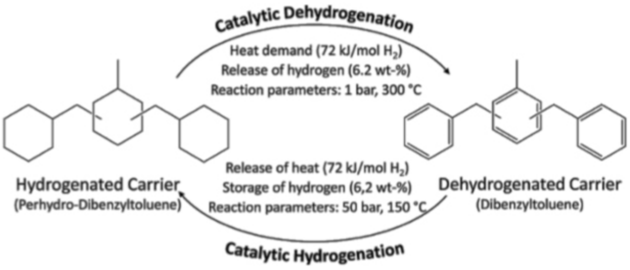

Figure 11: LOHC Technology of Hydrogenious

Chinese LOHC player Hynertech was founded in 2014 by China University of Geosciences (Wuhan) and other partners in Jiangsu province. Originally based in Jiangsu, the company moved in September 2017 to Wuhan Airport Economic & Technological Development Zone where it works together i.e. with Yangzijiang Automobile Group Co., Ltd., Tri-Ring Group, Jiangsu Qingyang Energy Chemical Group Co., Ltd. and Tongji University. The carrier and catalyst material that Hynertech uses isn't publicly available in their product presentations or website. Publicly available information does show that Hynertech's LOHC desorption temperature is lower (200 ∞C) compared to Chiyoda (>350∞C) and Hydrogenious (>320∞C) and provides 99.99% pure hydrogen (no extra purification devices required for usage in PEM fuel cells). Beginning 2018 Hynertech announced to build two new production bases for its LOHC technology, and in June 2018 launched the first normal temperature and pressure fuel cell logistics vehicle in Wuhan - together with Tri-Ring Group and Wuhan Jinhuang Industry.[115]

4.3 Fuel cells

This section will discuss the fuel cell, a device that converts chemical energy of a fuel (e.g. hydrogen) and an oxidant into electricity. As shown in the table below, there are several types of fuel cells which can be used for different application purposes. The focus of this section will be on PEMFCs and SOFCs. PEM fuel cells are most suitable for automotive applications due to i.e. their low operating temperature, low weight and compactness, and high power density. The high cost of the platinum-based catalysts used in PEMFCs is a barrier for the large scale adoption of these fuel cells. Furthermore, PEMFCs are sensitive to fuel impurities which requires the hydrogen to be 99.999% pure. Ongoing research activities related to PEMFCs therefore focus on finding alternative materials as fuel cell catalyst, as well as the modelling of cell dynamics and control.[116]

Table 1. Comparison of different types of Fuel Cells.

Fuel Cell	Operating Temperature (°C)	Power (kW)	Efficiency (%)	Application
PEM (Polymer Electrolyte Membrane)	60–110	0.01–250	40%–55%	Portable, Mobile, Low power generation.
AFC (Alkaline Fuel Cell)	70–130	0.1–50	50%–70%	Mobile, space, military.
PAFC (Phosphoric Acid Fuel Cell)	175–210	50–1000	40%–45%	Medium to large scale power generation and CHP (Combined Heat and Power).
MCFC (Molten Carbonate Fuel Cell)	550–650	200–100,000	50%–60%	Large scale power generation.
SOFC (Solid Oxide Fuel Cell)	500–1000	0.5–2000	40%–72%	Vehicle auxiliary power units, medium to large scale power generation and CHP, off-grid power and micro CHP.
DMFC (Direct Methanol Fuel Cell)	70–130	0.001–100	40%	Mobile, portable.

Table 6: Types of fuel cells (Irshad et al. (2016))

4.3.1 Polymer Electrolyte Membrane Fuel Cells (PEMFCs)

During the last decade Chinese enterprises along the entire fuel cell chain have been established from fuel cell material suppliers to fuel cell stack integrators. Fuel cell stacks consist of a number of parts: power regulators, air compressors and humidifiers, gas diffusion layer (GDL), diaphragms, bipolar plate, membrane electrode assembly (MEA) and catalysts. This 0.01 mm thin membrane together with the (platinum) catalyst is one of the main cost drivers of fuel cell stacks. The costs of the other components have decreased significantly due to increased production and is relatively low nowadays. Reducing the platinum dosage, improving the cost performance of the proton exchange membrane[117] and improving the process of making the stack is the key to reducing costs.[118] Leading universities in China researching PEMFC technology are Tsinghua University, Tongji University, Dalian Institute of Chemical Physics, Wuhan University of Technology, Shanghai Jiaotong University and Southern University of Science and Technology.[119] This research is mostly aimed at finding improved core components, new materials and non-noble metal catalysts.

This section will briefly discuss the leading companies in China developing PEMFCs. The development of domestic PEMFC technology is essential for the development of China's FCEV industry and thus targeted in several policies. Global market leaders in PEMFC technology are still foreign enterprises such as Ballard, Hydrogenics, PowerCell, ElringKlinger and Proton Motor. Ballard is very active in the Chinese market and in 2016 established a production base (capacity 20,000 stacks/year) in Yunfu, Guangzhou in a JV with Synergy.[120] But also Chinese players are quickly arriving to the scene.

The development of PEMFC technology in China was initiated by the Dalian Institute of Chemical Physics (DICP) in the mid-1950s. In 2001, DICP established the spin-off Sunrise Power, which is now one China's leading PEMFC companies. The other main shareholder is SAIC Motor, who invested in the company in 2007. Sunrise Power has been involved in the drafting of several standards in China (e.g. GB/T 20042.2-2008 Proton exchange membrane fuel cell – General technical specification of fuel cell stacks). In 2018, Sunrise first achieved to develop a stack (HYMOD®-300) with more than 5,000 hours of durability using membranes from the US-based W.L. Gore & Associates.[121] The commercialized HYMOD-36 FC Module has a rated power of 36 kW and power density of 1.3 kW/L. This stack is used in SAIC Motor's Maxus FCV80 light passenger vehicle (launched in 2017) and FC Roewe750 passenger car.[122] In 2018, 20 Maxus FCV80 were put into operation in Shanghai Chemical Industry Park (SCIP) and another 40 in Fushun, Liaoning.[123] Since 2016, Sunrise Power also cooperates with FAW Group which started the production of fuel cell engines for its Hongqi H5 series.

Shanghai Shen-Li Technology was established in 1998 and since then has closely worked together with Tongji University. It has developed several stacks with a rated power up to 40 kW. The SL-CM-40kW stack with a cold start of -20∞C is most suitable for automotive applications. In addition to fuel cell stacks, Shen-Li has also developed gas cylinders (35 MPa) for on-board hydrogen storage and 10 kW power systems for (Class II) forklifts.

Wuhan Himalaya Optoelectronics Technology was founded in 2008 and works together with Tsinghua University. The Himalaya-36k stack has a rated power of 36 kW and power density of 1.86 kW/L. The company works together with Zhongzhi New Energy Vehicle (HQ in Chengdu) for independently developing a 10.5m fuel cell bus.[124]

Wuhan TROOWIN Power System Technology was founded in 2011. The company develops small fuel cell power systems (HyLite) up to 1.2 kW for i.e. unmanned aerial vehicle (UAV) as well as fuel cell engines (TW4500) with a rated power of 45 kW. TROOWIN has developed fuel cell buses with Dongfeng Motor (EQ6100FCEV) and SUNLONG (SLK6750GFCEVZ) which are both included in the NEV catalogue of the Ministry of Industry and Information Technology.[125]

Horizon Fuel Cell Technologies, established in Singapore in 2003, is a global PEMFC player delivering modules up to 100kW power. It opened a subsidiary (a JV with the government of Rugao) and manufacturing base in Rugao, Jiangsu province in 2017. In 2018, researchers from Horizon announced that they made technology breakthroughs by developing a 0.85mm thin (graphite) bipolar plate with a power density of 4 kW/L. Horizon focuses on stationary high-power systems.[126]

During the last two years several new enterprises arrived to the scene. For example, HydraV which was founded by the Vision Group (HQ in Shenzhen, stock code: 002733) to coordinate and manage Vision Group's investments and development in the fuel cell industry. The Vision Group is the largest lead-acid battery exporter in China. HydraV is manufacturing several critical fuel cell components and trying to integrate this entire chain from catalysts, PEM, MEA, to FC stacks, DC/DC converters, H2 production and storage. HydraV aims to contribute to making Wuhan and Datong leading hydrogen cities by establishing large (fuel cell system) production facilities of 3 billion RMB ($437 million USD) investment each. The first phase of Wuhan's production center was completed by the end of 2018 and has a planned annual capacity of 10,000 stacks. The first phase of Datong's production center is already in operation with an annual capacity of 30,000 stacks. HydraV constructed 1 HRS in Wuhan (daily refueling capacity of 1000kg and storage capacity of 1000kg) and 1 HRS in Datong, where another is under construction. Figure 12 shows where the Vision Group is active along the hydrogen and fuel cell chain.

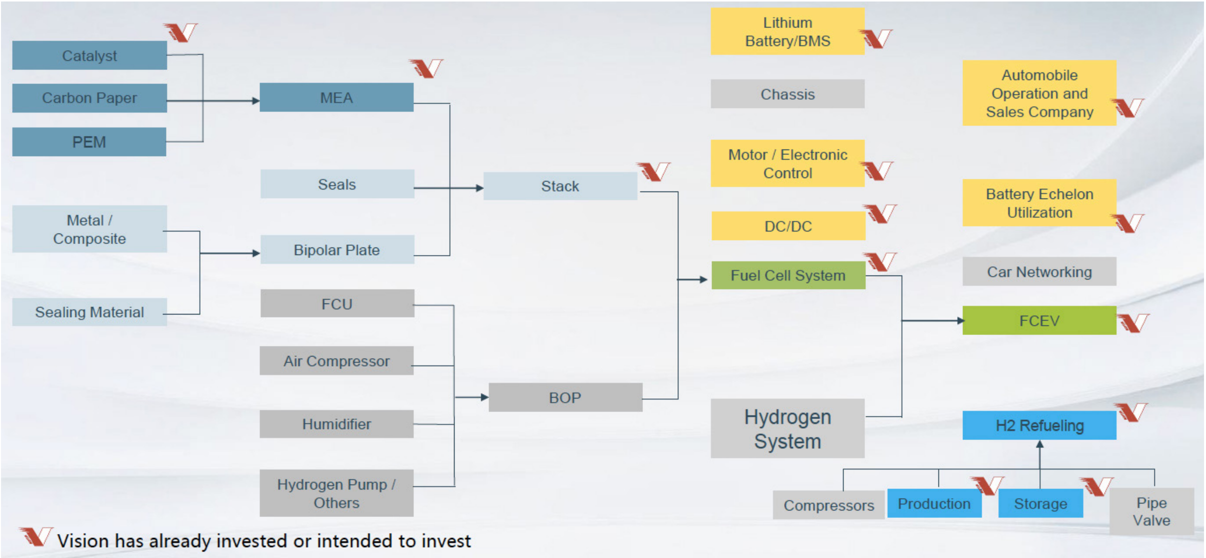

Figure 12: Business activities of HydraV

During a press conference in January 2019, HydraV showed that 2018 was a year full of milestones. The company set up its mass production centers and managed to independently develop a 45 kW fuel cell engine with leading power-to-volume and mass-to-volume ratios in China. They started constructing HRS and delivered 70 FC buses to Wuhan and Datong. They plan to expand this number to 300-1000 in 2019 as well as to set up an electronic control platform for fuel cell buses operations and maintenances.[127]

Another newcomer, Foshan CleanEst Energy Technology, was established in 2017 by Tsinghua graduates. In the short time period they have already developed several stacks (power range 10 kW-36kW). The Cleanest Engine-E30 (fuel cell engine) has a rated power of 30 kW and system efficiency of >53%. The company collaborates i.e. with Tsinghua university, Dongfeng Motor and China Shipbuilding Industry Corporation (CSIC). In Beijing, Innoreagen Power Technology was also established in 2017 and offers stacks with a power range 5-80 kW. Innoreagen's fuel cell engine has a rated power of 32 kW and system efficiency of >45%. The company already signed cooperation agreements with Snowman and the local governments in Datong and Rugao. The quality of the products of these newcomers remains to be seen, but it clearly shows the current momentum in China for advancing fuel cell technology. In addition to these companies, there are several SMEs developing small-scale stacks for mobile backup power or UAVs such as Dongguan Zonetron Energy and Nekson Power Technology.

In addition to PEMFC stack enterprises, China has plenty of players researching or supplying fuel cell materials such as AEET (supplier of GDL to i.e. Plug Power), Dongyue federation (PEM supplier), Snowman (air supply systems supplier), Sino-platinum (supplier of platinum fuel cell catalysts), Shanghai Hongjun Industrial (graphite bipolar plate), Shanghai Yoogle Metal (metal bipolar plate) and Shenzhen Southerntech Fuel Cell (MEA supplier).

4.3.2 Solid Oxide Fuel Cells (SOFC)

In recent years, SOFCs have received increasingly more attention from researchers due to their better efficiency and durability compared to other types of fuel cells. One of the biggest advantages of SOFCs is their ability to co-generate high levels of heat (greater than 600∞C) during conversion, which can be used in end-use applications and the flexibility in choosing different fuels (H_2, CO, CH_4) for their operation. In contrast with PEMFCs, alongside H_2O also CO_2 is produced at the anode.[128] Currently, SOFCs have not reached large-scale commercialization and research is focused on finding innovative materials that can reduce the manufacturing costs of SOFCs and enhance its lifetime. Generally speaking, SOFCs are categorized into two major types (planar and tubular) related to their geometrical configuration. Planar designs have lower fabrication costs, but sealing is one of the critical issues. Tabular design does not demand complex sealing and has thus been assessed to be more secure than the planar design since the gap between air and fuel is sealed separately.[129]

Research developments

As mentioned in the policy sector, MOST supports the R&D of SOFCs through several financial grants. The Chinese research activities related to SOFCs are extensive, and summarized in the table below, taken from Lu et al. (2018).[130] At the 2017 FCH2 Symposium in Birmingham, Tsinghua University Professor Min-Fang Han mentioned as much as 60+ universities, institutes and companies and 1000+ researchers in China in SOFC related works.[131]

Organization	Research focus
Shanghai Institute of Ceramics (CAS)	Focuses on plate type and MW level; max. power density of 151 mW/cm2 at 700°C was obtained in the SOFC mode. Also researching TiC/hastelloy composites for intermediate-temperature SOFC interconnect.
Dalian Institute of Chemical Physics (CAS)	The Division of Fuel Cell and Battery, Dalian National Laboratory for Clean Energy has a research team related to medium temperature SOFCs: developed a novel cathode material ($PrBa_{0.92}CoCuO_{6-d}$). Also researching new sealing coatings, applying Mn-Co spinel coating on the SUS430 alloy.
China University of Mining & Technology (Beijing)	The Union Research Center of Fuel Cell worked together with Shanghai Jiaotong University in 2005 to jointly develop a coal gasification fuel cell. Involved in the national "863" project (carbon-based SOFCs). Their work on cost reductions is preparing SOFCs for industrialization. Professor Xu developed a newly SOFC with max power density of 348 and 324 mW/cm2 at 800 and 850°C respectively.
Ningbo Institute of Industrial Technology (CAS)	The Ningbo Institute of Material technology and Engineering (NIMTE) has a SOFC R&D platform consisting of 100 researchers. They have developed anode-supported, electrolyte-supported and electric pile module technology. The spin-off company SOFCMAN produces powders, cells, stacks, systems as well as a variety of SOFC testing equipment. SOFCMAN is currently developing a 200 kW SOFC system.
Harbin Institute of Technology	Professor Sun's research team has made great breakthroughs with SOFCs core technologies, developing new cathode materials ($La_{0.8}Sr_{0.2}MnO_3$/ $Zr_{0.92}Y_{0.08}O_2$).
University of Science and Technology China (USTC)	The SOFC Research Team at the Department of Materials Science & Engineering focuses on key materials of SOFCs. Meng's group completed the national "863" project related to the key materials and preparation technology for intermediate temperature SOFCs and completed the national "973" project.
Changchun Institute of Applied Chemistry (CAS)	Working on cathode materials for intermediate-temperature SOFCs; the developed cell under dry CH_4 conditions shows a max. power density of 379 mW/cm2 at 600°C with long-term stability.
Sun Yat-sen University	The Advanced Energy Materials Research Laboratory at the School of Physics and Engineering focuses on developing new materials for fuel cells.

Organization	Research focus
Huazhong University of Science and Technology	Professor Li together with researchers from Huazhong has independently developed a 5 kW SOFC power system which reached international advanced levels of efficiency. Using a new composite cathode material of La2NiO4.d-coated PrBa0.5Sr0.5Co1.5Fe0.5O5.d (PBSCF) is prepared for the intermediate temperature SOFCs.
Northeastern University	Professor Geng conducted research on planar SOFC interconnect applications, focusing on MnCU metallic coatings.
Nanjing Tech University	Professor Shao developed a low-cost, durable electro catalyst for the oxygen reduction reaction (ORR).
Qingdao University	Professor Wang demonstrated new electrolyte and cathode materials with a max power density of 348 mW/cm2 at 700∞C.
Jilin University	Professor Niu developed a new SOFC using a nickel-free double perovskite anode material with a max power density of 547 mW/cm2 at 800∞C.
Tianjin University	The State Key Laboratory for Chemical Engineering at the School of Chemical Engineering focuses on low or intermediate temperature SOFCs by using nanocomposites; the developed SOFC has a max power density of 1704 mW/ cm2 at 650∞C.
Tsinghua University	Mao Zongqiang from the Institute of Nuclear and New Energy Technology made great achievements in the direction of low temperature SOFCs, successfully developing new electrolyte materials which exhibit much higher ionic conductivity.
Xi'an Jiaotong University	Professor Wang develop a new electrolyte material, resulting in a SOFC with max power density of 592 mW/ cm2 at 750∞C.
Hubei University	Dr. Zhu is the first researcher who discovered the electrolyte-free SOFC (EEFC) and introduced this in China in 2012.
Southnorth University	Professor Chen has developed a symmetrical cello composed of Ce0.9Gd0.1O2-d electrolyte.

Commercial developments

The global SOFC market is defined by enterprises such as Altrex Energy, Bloom Energy, Convion, Siemens, SOLIDpower, Ceres Power, Redox Power Systems etc. An overview of these players can be found in the IEA publication The yellow pages of SOFC technology – *international status of SOFC deployment 2017*.[132] Chinese market players include Chaozhou Three-Circle Co., Ltd, G-cell Technology Co., Ltd, Huatsing Jingkun New Energy Technology Co., Ltd, ISOFC Dynamic Co., Ltd. and SOFCMAN Energy Technology Co., Ltd. The domestic industrialization is still in the beginning phase.

In May 2018 (finalized in December 2018), Ceres Power (UK) announced a strategic collaboration with Weichai Power to jointly develop a SOFC range extender system FC buses.[133] It includes a JV agreement, a license agreement to transfer key technology to the JV and a new £9 million ($11.39 million USD) joint development agreement. It also triggered a further £28m ($35.44 million USD) equity injection into Ceres Power, bringing Weichai's total stake in Ceres to 20%.[134] It is expected that the local manufacturing in China will enable substantial costs reductions due to economies of scale principles.

Company	Description
Chaozhou Three-Circle	Established in 1970, develops i.e. anode supported SOFCs, SOFCs electrolyte membranes and SOFC stacks.
G-cell Technology	Founded in 2013, a JV between Japanese SHINCRON and University of Science and Technology of China (USTC). Provider of 1 kW power stations.
Suzhou Huatsing Jingkun Power System	High-tech enterprise founded in 2010, working together with several universities and has over thirty patents for sealing materials, interconnectors. Produces SOFC key materials, power generation systems, FC test systems and related services.
SOFCMAN Energy Technology	Founded in 2014 as spin-off from NIMTE (see above). It produces powders, cells, stacks, systems as well as a variety of SOFC testing equipment. SOFCMAN is currently developing a 200 kW SOFC system.
ISOFC Dynamic	Founded in 2015 in Foshan, focus on research of SOFCs: current main products of the company include intermediate temperature SOFC/battery system, SOFC tubes and key ceramic components.

4.4 Fuel cell applications

Fuel cells and hydrogen can be used for different end use applications, as shown by the figure at the beginning of chapter 4. Due to the already strong NEV industry in China, initially the main focus in China seems to be using hydrogen for transportation purposes. However, (fundamental) research and projects are carried out related to all kinds of applications which will be briefly presented in this section.

4.4.1 Gas to Power (G2P)

In 2016, several Dutch companies delivered a 2 MW PEM fuel cell power plant to Ynnovate Sanzheng Fine Chemicals Co., Ltd in Yingkou, Liaoning province. The by-product hydrogen is used to generate approx. 20% the power requirement of Ynnovate's production processes. Although other Chinese parties have expressed their interest, no other similar projects have been announced due to the high investment costs of PEM fuel cells. As mentioned earlier, stack producer Horizon Fuel Cell Technologies does focus its business activities on stationary power applications.

4.4.2 Hydrogen for Urban Heating

At the Inaugural International Symposium on Energy Storage and Hydrogen Technologies Professor Shi from the Tsinghua-Sichuan Energy Internet Research Institute in Chengdu presented research related to blending hydrogen in the natural gas pipelines for cooking and heating of households in Sichuan province. The university is conducting laboratory tests where up to 17% of hydrogen is blended into the natural gas network. This is still fundamental research and there are not yet any pilot projects or demonstration sites in China. Many houses and public buildings in China are still heated with coal-based boilers. China is still working of the phase-out of these coal-fired boilers towards gas-based boilers.

4.4.3 Transportation

In the early 2000s the Chinese government assigned the development of FCEVs to Tongji and Tsinghua University. Tongji worked closely together with Shen-Li Technology, a leading Chinese PEMFC technology company. In 2001, Shanghai Fuel Cell Vehicle Powertrain (SFCV) was established as spin-off from Tongji University together with SAIC Motor. Tsinghua University took the lead in the fuel cell bus development efforts, working together with Dalian Institute of Chemical Physics (DCIP) and its spin-off Sunrise Power. Although initially using domestic PEMFCs for developing FCEV prototypes, Chinese OEMs and universities quickly started using Ballard's superior fuel cells instead.[135] The first two phases of the UNDP-GEF-MOST Fuel Cell Bus Commercial Demonstration Project were important accelerators for FCEV development in China. Fuel Cell Buses were demonstrated during the 2008 Beijing Olympics and 2010 World Expo Shanghai with a cumulative mileage of nearly 300,000 km.[136]

By 2010, China listed NEVs as one of the seven strategic emerging industries and lately more focus has been given to FCEVs. Financial incentives for NEVs have been revised in 2018 where incentives for FCEVs remained the same, but subsidies for BEVs were reduced.[137] To give a first idea of the momentum and pace of current developments in China, the table below highlights a few of China's recent projects or announcements.

Date	Project/Announcement
Aug 2017	SinoHytec. Co., Ltd. starts operation of its automated production line for FC engines in Zhangjiakou, Hebei province. Investment in the factory totaled $150 million USD; the production center covers an area of 30,000 m2 and can make 10,000 engines/year.
Oct 2017	CRRC Tangshan Railway Vehicle Company begins trial operation of a fuel cell tram with FC stacks from Ballard Power Systems.
Feb 2018	Shanghai Municipal Government released the *Implementation measures on encouraging the purchase and use of new energy vehicles*. Subsidies for FCEVs are increased, while subsidies for PHEVs decrease.
Feb 2018	Two FC Buses start operation in Chengdu, Sichuan province and the first HRS is opened (supplying 400kg H_2/day), marking a milestone for hydrogen utilization in the south-west of China. By mid-2018 10 buses were in commercial operation.
June 2018	Air Liquide and Chinese startup STNE signed a partnership to accelerate the roll-out of FC trucks in China. STNE currently operates an HRS in Shanghai and a fleet of 500 FC trucks. Air Liquide will provide STNE with expertise in the entire H_2 supply chain, from production and storage to distribution.
July 2018	500 logistics FC trucks of JD.com started operating in Shanghai, after their license plates were obtained by the end of 2017. The trucks use the 2 HRS in Jiading district, where the H_2 retailing prices is about 40 RMB ($6.4 USD)/kg.
Aug 2018	Two FC buses started commercial operation in Zhengzhou, Henan. Another 18 buses will follow.
Aug 2018	First batch of 25 FC buses produced by Yutong is delivered to Zhangjiakou.
Aug 2018	Launching ceremony of the construction of 8 HRS in Foshan, Guangdong. Adding to the existing two HRS, Foshan will have the most HRS in China.
Sept 2018	Six FC buses started commercial operation in Jiading district, Shanghai.
Sept 2018	Two FC buses (and an HRS) started trial operations in the East Lake High-tech Development Zone, Wuhan.
Oct 2018	Five FC Buses started operation in Beijing.

As shown in the table above, China initially strongly focuses on commercial vehicles and buses for accelerating its FCEV market. The first reason for this approach is that higher pressure technologies (on-board storage tanks, dispensers at HRS) are still under development. Initially focusing on 35 MPa technologies in commercial vehicles and buses gives China time to develop these technologies and gain experience with hydrogen safety. Secondly, the travel pattern of these vehicles is either set or more easily predictable so fewer HRS are required to serve a large fleet. Finally, public awareness for FCEVs needs to be improved as Chinese citizens (as well as government officials) seem reluctant, not only because currently passenger FCEVs are still rather expensive but mainly because they are concerned about the safety of hydrogen. As mentioned in the policy chapter IHFCA and the UNDP are actively trying to address this issue by organizing large-scale promotion events such as "2018 Hydrogen Fuel Cell Vehicle Itinerant (FCVI) Exhibition & Roadshow in the Yangtze River Delta". This 4-day event showcased many FCEV models in Rugao, Nantong and in Shanghai. The event included public lectures (open to anyone interested) regarding FCEV technologies and safety of hydrogen and opportunities test-drive FCEVs to experience the security and reliability of these vehicles. [138]

China's plan is to gradually increase safety standards. The timeline target for 70 MPa cylinders and 70 MPa HRS seems to be 2020, as documented in the *2016 China Bluebook on Hydrogen Energy Industrial Infrastructure*.[139] This means that currently private vehicles are not allowed on the streets as the related Chinese standards for 70 MPa on-board storage (model IV hydrogen tanks) are still under development. In 2018, several Chinese enterprises developed 70 MPa on-board storage cylinders but these cannot be sold yet. Tianhai Industry developed a 70 MPa model IV hydrogen tank according to ASME standards as well as Sinoma and Furui. Several industry players indicated that they expect the according standards to be implemented in 2019.

SAIC Motor first started developing fuel cell passenger vehicles in 2001. Its latest model (950 Roewe) first went on display in Beijing in 2014. It has a SAIC 200 fuel cell system with 42 kW rated power, a power volume density of 1.9 kW/L and durability of 5000 hours. Compared with international fuel cell cars (Toyota Mirai, Honda Clarity and Hyundai Nexo), the acceleration capacity (0-100 km/h in 12s) is less fast and the volume of the hydrogen tank is 1-2 kg less (4.18 kg) resulting in a lower driving range.[140] In addition to SAIC Motor, FAW plans to mass produce its Hongqi H5 series in a fuel cell edition in 2019. Other OEMs are currently still focused on the heavy-duty segment.

Fuel cell engines

The Chinese market has several companies producing fuel cell engines, providing powertrain solutions to OEMs. The leading companies in this sector are Re-Fire (HQ in Shanghai), working together with Ballard, and SinoHytec (HQ in Beijing), working together with Hydrogenics.

Re-Fire since 2014 has rapidly developed into a mature company with over 370 employees and a mass production line operating in Yunfu, Guangdong province. The Phase I capacity of the production line is 5,000 sets/year which is expandable up to 20,000 sets/year. At present, more than 50% of all operating FC commercial vehicles in China are equipped with fuel cell engines and powertrain solutions made by Re-Fire. The CAVEN 3 (32 kW) and CAVEN 4 (46 kW) models are in mass production, and CAVEN 7 (80 kW) will start production in 2019. Its subsidiary company Shenzhen Suyun Technology Co., Ltd. builds and manages a cloud-based telematics monitoring platform to enable the real-time data tracking capability of powertrain and vehicle components for all Re-Fire FCEVs deployed in the field. The China Association of Automobile Manufacturers and China Automotive Power Battery Industry Innovation Alliance jointly announced the first White List companies for hydrogen fuel cell industry in May 2018 where Re-Fire was listed. A New R&D Center will be opened in Shanghai in 2019. In January 2019 Re-Fire signed an agreement with the government of Nanhai district, Foshan on the investment and construction of the "Re-Fire Hydrogen Energy Industry Base Project" in Nanhai district. The total investment of the first phase of the project is 2.16 billion RMB focusing on the R&D and industrialization of key technologies for FCEVs.[141]

	CAVEN 3	CAVEN 4	CAVEN 5
Rated Power (kW)	32	46	80
Dimension (L*W*H in mm)	890*480*375	926*550*408	
Weight (kg)	135	160	
Peak Efficiency (%)	55	56	60%
Durability (h)	>12,000	>12,000	>12,000
Freeze Start (°C)	-15	-15	-20

Table 7: Fuel cell engines of Re-Fire

SinoHytec is a state-level high tech enterprise focusing on the R&D and industrialization of FC engines. The company has been involved in several national "863" research projects (e.g. *Renewable Hydrogen Production and HCNG Urban Bus Development Project*). SinoHytec works together i.e. with Yutong Bus, Zhongtong Bus and CRRC. In 2016 SinoHytec entered into an agreement with Hydrogenics for the co-development and supply of fuel cell power systems designed for the Chinese market. In 2017, SinoHytec started operating its mass production line in Zhangjiakou with a capacity of 10,000 FC engines/year. In addition to developing FC powertrain systems, SinoHytec constructed China's first HRS in 2006 inside Beijing New Energy Vehicle Demonstration Park and has been operating it until today. In January 2019 SinoHytec signed a collaboration agreement with Beiqi Foton and State Power Investment Corporation (SPIC) for promoting fuel cell transportation in the Beijing – Tianjin-Hebei region, jointly serving the 2022 Winter Olympics.[142]

	YHTG60	YHTG30	YHT30	
Rated Power (kW)	63	31.3	30	60
Dimension (L*W*H in mm)	1270*750*665	848*645*600	1114*770*391	1148*656*723
Weight (kg)	248	135	180	<340
Peak Efficiency (%)	55			
Durability (h)				
Freeze Start (°C)	-30	-30	-30	-40

Table 8: Fuel cell engines of SinoHytec

Other companies providing or working on fuel cell powertrain solutions worth mentioning are Shanghai Fuel Cell Vehicle Powertrain, HydroT Technology, Foresight energy, Weichai Power, Dongfang Fuel Cell Technology, Guangdong Tailuosi (Telos) Auto Power Systems and Edelman (Aideman) Hydrogen Equipment, a Sino-German JV which was established in 2016.

Domestic OEMs

Chinese OEMs are working together with foreign companies to import core technologies, but independently developed FCEVs are also beginning to appear. A short overview of the leading OEMs developing or already commercializing FCEVs in China is shown below. Please note that this list is not exhaustive and other OEMs can be found in the excel database.

Company	Region	Activities
Foton	Beijing	Foton AUV has been working closely with Tsinghua University and SinoHytec since 2006; provided FC buses for 2008 Beijing Olympics. In 2017-28 during EV100 Forum, Foton delivered 30 shuttle buses (BJ6852). In February 2018 Foton won an order of 49 FC buses for Zhangjiakou to be used during Winter Olympics in 2022.
SAIC Motor	Shanghai	State-owned automotive manufacturing company with several subsidiaries (see Sunwin below). Started developing FCEVs in the early 2000s working together i.e. with General Motors, Volkswagen and Tongji University. Its commercially available FC passenger car Roewe 950 first went on display in Beijing in 2014. Agreement with Shanghai Chemical Industry Park (SCIP) for the delivery of FC vans (first batch 100 FCEVs), SAIC Chase FCV80.
Skywell	Nanjing	First hydrogen fuel cell bus unveiled in Wuhan, co-developed with Wuhan Tiger Fuel Cell Vehicle in December 2017. Agreements signed to produce 3,000 FC buses in the next two years. Subsidiary Nanjing Jinlong Bus Manufacturing Co., Ltd. will deliver buses to Datong, Shanxi province in 2019.
GWM	Baoding	In June 2018, GWM established its hydrogen technology center focusing on testing and trial-manufacturing of all FCEV core components. First Chinese automaker to have joined the international Hydrogen Council. Since August 2018 has 74% shares of Shanghai Fuel cell Vehicle Power System Co., Ltd. and signed a MoU with H2 Mobility (German HRS operator). No FCEV commercially available yet.
Yutong	Zhengzhou	Large-scale bus manufacturer based in Henan province. In January 2018, Zhengzhou Municipal Government approved Yutong's plans to construct a Fuel Cell & Hydrogen Engineering Research Center. In February 2018 won an order for 25 (of their 3rd generation) FC buses operating during the 2022 Winter Olympics. FC models: ZK6105FCEVG2, ZK6125FCEVG6, ZK6125FCEVG7.
Dongfeng	Wuhan	One of China's leading automakers. Manufactured the 500 FC logistic trucks which are currently operating in Shanghai. FC models: EQ5080XXYTFCEV1, EQ5080XLCTFCEV2, EQ6700LAFCEV.
Sunwin	Shanghai	Wholly owned subsidiary of SAIC Motor. SAIC has been developing FC trucks since 2008, with fuel cells provided by Sunrise Power. Produced a whole range of NEV buses and several FCEV models (SWB6129FC and SWB6128FCEV01). Sunwin and SAIC developed the 6 FC buses operating in Shanghai since September 2018.
Aoxin	Yancheng	Developed commercial vehicles: JAX5080XXYFCEV1 and JAX5027XXYFCEV1. Large R&D department for FC technology (60% of employees).
Shudu	Chengdu	Shudu Bus is a brand of Chengdu Bus Co., Ltd. which develops FC buses (CDK6900). 10 FC buses are currently operating in Chengdu, jointly produced with Dongfang Electric Corporation.
King Long	Xiamen	King Long is a leading bus manufacturer in China. Started R&D of FC buses in 2010 and started cooperating with Ballard in 2015 to jointly develop FC buses. In April 2018 King Long officially released a 12-meter Hydrogen Fuel Cell City Bus (XMQ6127AGFCEV).
Wuzhoulong	Shenzhen	First fuel cell bus model was used during the 2011 Shenzhen Universiade. In 2017 the OEM established a hydrogen fuel cell research institute. In June 2018 the OEM (together with HydraV) delivered its 10.5m FC bus to Datong. Model: FDG6850FCEV
Feichi	Foshan	Has developed several FC buses and trucks (FSQ6120FCEVG, FSQ6700FCEVG, FSQ6860FCEVG, FSQ6110FCEVG1, FSQ5080XXYFCEV). In 2016, 12 FC buses (developed in cooperation with Ballard, Re-Fire, Furuise and Synergy) were deployed for operation in Foshan.

Company	Region	Activities
FAW	Changchun	The large SOE opened its NEV R&D center in Shanghai in 2017. In October 2018 FAW started the production of FC engines for its Hongqi H5 series. Cars are expected to be commercially available in 2019.
Zhongtong	Liaocheng	Zhongtong is a leading electric bus manufacturer which started R&D on fuel cell buses in 2015 together with Broad-Ocean Motor and delivered its first FCEV models (LCK6900FCEV) to the market in 2017.
Sinotruk	Jinan	Sinotruk is a leading heady-duty commercial vehicle manufacturer in China. In December 2017, Sinotruk released its hydrogen power light truck.
Changjiang	Hangzhou	Hangzhou Changjiang is a subsidiary of FDG Electric Vehicles Limited. The company signed a cooperative agreement with Nanhai District, Foshan government in 2017 for a Hydrogen Power (Foshan) R&D Center and vehicle production project in Danzao, Nanhai.
Ankai	Hefei	Ankai is a subsidiary of Jianghuai Automobile Co., Ltd. and NEV manufacturing leader. Developed a FC Bus (HFF6850G03FCEV) with Ballard-powered stacks.
Geely	Hangzhou	Privately-held global automotive group. Started R&D in NEVs in early 2000s, especially intensive R&D relation to methanol combustion engines. Geely is expected to release mass-produced FC passenger cars by 2025.

The production of FCEVs is increasing rapidly. In 2017, 1,272 FCEVs were produced in China, an increase of more than 100% compared with 2015-2016 (639 vehicles). Most of the FCEVs sold in 2017 were produced by Dongfeng (500+) and Youngman (400+).[143] In 2018 the production output was 1,619 FCEVs, a year-on-year increase of 27%. Emerging leaders are Zhongtong (790 FCEVs) and Feichi (386 FCEVs).[144] It is hard to determine the exact number of vehicles actually operating on the streets since Chinese sources can be unreliable and contradictory, as also mentioned by E4Tech in their Fuel Cell Industry Review 2018. Ballard estimates that around 1,500 fuel cell trucks and buses are currently licensed and permitted in China. In comparison: as of January 1, 2019, almost 6,000 FC passenger cars are deployed on the roads in the United States and 2,500 FC passenger cars in Japan.[145]

China still has trouble putting their produced vehicles in service and the business climate in China remains complex. In 2018 problems occurred between Ballard its Chinese business partner. Ballard removed the remaining value of their contract ($138 million USD) with JV partner Guangdong Synergy due to Synergy's inability to meet its purchase commitments regarding MEAs.[146] Hydrogenics also stated that things in China were moving more slowly (regarding subsidy approvals, HRS roll-out and FCEV certifications) than expected.[147]

Hydrogen Refueling Stations

The lack of regulations and standards for the construction and operation of HRS in China has hindered the roll-out of hydrogen infrastructure. Several Chinese sources mention different numbers of HRS in operation, making it hard to give an exact number.[148] Based on a scientific paper published by the end of 2018, we expect that 21 HRS are currently in operation, most of them offering a filling pressure of 35 MPa, following the development plans to first focus on the roll-out of commercial FCEVs. Not all of these HRS operate commercially, most of them are only used by demonstration vehicles.

Around double the amount of stations are planned to be in operation in 2019 with stations in the provinces Shanxi, Anhui, Hebei, Jiangsu, Shanghai, Zhejiang and Guangdong.[149] Ballard also estimates that another 40+ HRS are currently under construction.[150] China still lags behind global levels of key compressor technologies, so focusing first on the lower filling pressure of 35 MPa enables China to already start developing the FCEV market, while simultaneously working on compressor technology development. The table below shows an overview of the current HRS in China.[151]

No.	City	Name	Category	Finish Year	H2 storage Capacity and Pressure	Filling Capacity	Filling Pressure	State
1	Beijing	Yongfeng	Stationary	2006	165 kg, 45 MPa	200 kg/day	35 MPa	In use
2	Shanghai	Anting	Stationary	2007	165 kg, 45 MPa	200 kg/day	35 MPa	In use
3	Zhengzhou	Yutong	Stationary	2015	165 kg, 45 MPa	250 + 1000 kg/day	35 MPa	In use
4	Yunfu	Synergy	Stationary	2016	165 kg, 45 MPa	300 kg/day	35 MPa	In use
5	Dalian	Tongji-Sunrise	Stationary	2016	90 MPa	20 kg/day	70 MPa	In use
6	Foshan	Nanhai Ruihui	Stationary	2017	234 kg, 45 MPa	350 kg/day	35 MPa	In use
7	Shanghai	Shanghai Edrive	Container	2017	165 kg, 45 MPa	500 kg/day	35 MPa	In use
8	Zhongshan	Broadocean	Container	2017		500 kg/day	35 MPa	In use
9	Changshu	Toyota	Stationary	2017	90 MPa		70 MPa	In use
10	Nantong	Bing Energy	Temporary	2017	150 kg, 45 MPa	60 kg/day	35 MPa	In use
11	Shanghai	Godpower	Temporary	2017			35 MPa	In use
12	Jiaxing	Aideman	Temporary	2017			35 MPa	In use
13	Foshan	Sanshui	Temporary	2017		100 kg/day	35 MPa	In use
14	Shiyan	Dongfeng	Container	2018		500 kg/day	35 MPa	In use
15	Chengdu	Jinxing	Container	2018	234 kg, 45 MPa	500 kg/day	35 MPa	In use
16	Shanghai	Jiangqiao	Container	2018	464 kg, 45 MPa	750 kg/day	35 MPa	In use
17	Wuhan	Zhongji	Stationary	2018		200 kg/day	35 MPa	In use
18	Xinbin	Muhai	Container	2018		450 kg/day	35 MPa	In use
19	Zhangjiakou	Haiboer	Stationary	2018		1350 kg/day	35 MPa	In use
20	Yunfu	Luoding	Stationary	2018		500 kg/day	35 MPa	In use

Table 10: Hydrogen Refueling Stations in China (Source: Liu et al. (2018)[152]

China's first HRS for FC buses opened in November 2006, as part of the UNDP-GEF-MOST project. The station was jointly built by BP, Tsinghua University and SinoHytec with hydrogen supply from an external natural gas reformer (using technology from Air Products). The first public 70 MPa HRS in Dalian, built jointly by Tongji University and Sunrise Power Co., Ltd. uses wind and solar power for on-site hydrogen production. The construction was an important milestone for the advancement of HRS technologies in China and set several national standards:

- GB/T34584-2017: Safety Technical Regulations for Hydrogen Refueling Station
- T/CECA-G 0015-2017 Proton Exchange Membrane Fuel Cell Vehicle Fuel Hydrogen
- GB/T31138-2014 Compressed hydrogen dispenser for vehicles
- GB/T 34583-2017 Safety technical requirements for hydrogen storage devices used in hydrogen fueling station

The above table shows a rapid expansion of HRS across China during the last two years. However, several changes in national regulations and standards could enable a faster expansion of the number of HRS. E4Tech also remarked that the lack of infrastructure in China have led to slower roll-out than anticipated. Current problems (as shortly discussed in the policy chapter of this report):

- Regulatory problems with on-site hydrogen production. Due to the current classification of hydrogen as hazardous chemical, on-site production is only allowed within chemical parks. This *hazardous chemical* classification also means that different government authorities are involved for a regular refueling station, making the approval procedures complicated. In addition, the construction cost of the HRS depend on the type of land use (industrial or commercial).[153]

- Once the liquid transport of hydrogen is allowed by the government, much larger amounts of hydrogen can be transported. In September 2018, Air Products signed a cooperation with Beijing Sinoscience Fullcryo Technology Co., Ltd for the development of China's first commercial-scale liquid hydrogen-based fueling station.[154]

The current regulations also hinder innovative foreign HRS solutions. Norwegian company nel produces very compact HRS (occupies only 7 m2) which can easily be integrated into existing refueling stations, but due to Chinese national level regulations - the compressor needs to be 20m away from other main components - such stations currently cannot be implemented in China.

Chinese companies involved in the construction and operation of HRS are large companies such as Sinopec (Yunfu HRS) and PetroChina (Wuhan HRS), but also several smaller and newly established companies, i.e. Shanghai Elite Energy and Technology (entrusts the Anting HRS in Shanghai), Shanghai SinoTran New Energy Automobile Operation, Shanghai Hyfun Energy Technology, Shanghai Hyfuture Industrial, Foshan Ruihui Energy and Wuhan Zhongji Hydrogen Energy Development. Leading companies producing HRS equipment (such as dispenser etc.) are Zhangjiagang Furui Hydrogen Power Equipment, Shanghai Sunwise New Energy Systems and Shanghai Houpu Excellence Hydrogen Energy Technology.

Trams

Hydrogen trains produced by Alstom in cooperation with Hydrogenics and nel recently started commercial operation in Germany. China has also been researching the use of fuel cells for rail transport. In September 2015, Ballard signed a joint development agreement and supply agreement with CRRC Qingdao Sifang Co., Ltd. to develop fuel cell engines specifically designed for low floor trams.[155] By October 2017, the first fuel cell powered tram was put into commercial operation in Tangshan, Hebei province. In March 2017, CRRC signed another contract to deliver eight fuel cell trams to Foshan. The trams are equipped with 200 kW engines from Ballard and are expected to begin commercial operation in 2019 in Gaoming district. The trams can run for 100km before refueling is required.

Shipping industry

In Europe, Japan and the USA there are several ongoing projects related to fuel cell-powered vessels. However, without supporting government subsidies in place, China is lagging behind in this industry. The state-owned 712th Research Institute of China Shipbuilding Industry Corporation (CSIC), also called Wuhan Institute of Marine Electric Propulsion, is researching the application of fuel cells in the shipping industry. Furthermore, the Guangzhou subsidiary of China State Shipbuilding Corporation (CSSC) is researching fuel cell ships. Several sources highlight that these developments are still in an early phase.

4.4.4 Logistics

More than 20,000 hydrogen forklifts are being used already in warehouses, stores and manufacturing facilities throughout the United States.[156] Major developments in this market occurred in 2017 when Plug Power entered into agreements with Walmart and Amazon. Also in Europe, fuel cell forklift deployments continued to grow in 2018 with 120 hydrogen forklifts inaugurated at Carrefour in France.[157] Global players in this market segment are (i.e.) Plug Power, Nuvera Fuel Cells (subsidiary of Hyster-Yale Materials Handling, a leading lift truck manufacturer), Toyota, Linde Material Handling and Hydrogenics. Hydrogen forklifts are not researched on a large-scale in China, but this can change in the future as China houses large forklift manufacturers such as Anhui Forklift Group and Hangcha Group. Shanghai Shen-Li and Innoreagen both offer fuel cell stack solutions for forklift applications.

Plug Power and Nuvera Fuel Cells both entered the Chinese fuel cell market. Plug Power signed a MoU with Furui Special Equipment Co., Ltd. in November 2016 along with a Chinese OEM to develop vehicles equipped with Plug Power's fuel cell engine systems for the expanding industrial electric vehicle market in China.[158] Nuvera Fuel Cells announced an agreement with Zhejiang Runfeng Hydrogen Engine Co., Ltd. (ZRHE) in August 2018 to manufacture and assemble fuel cell engines, for use in the Chinese NEV market. ZHRE is licensed to manufacture and sell Nuvera's current generation (45 kW) fuel cell stack over the next three years.[159] In addition, in December 2018 Nuvera signed an agreement with the local government of Fuyung district, Hangzhou for a local production site of Nuvera fuel cell stacks beginning in 2019. This will enable Nuvera to deliver fuel cell systems more quickly to its partners in China.[160]

4.5 Clusters

Due to the vastness of China and the lack of national hydrogen infrastructure, local hydrogen economies will develop in regions with cheap primary energy sources and large amounts of by-product hydrogen. The five UNDP demonstration cities as discussed before will take a lead, where already various hydrogen related companies are based. In this section other regions which haven't been discussed in detail before will be highlighted.

Shandong province

The capital of Shandong province, Jinan has set out ambitious goals to become a hydrogen hub. Shandong houses one fifth of China's oil refining capacity with 90 percent of China's private refiners and several heavy industries such as steel and cement factories. However, these small refiners only have a small share in the domestic petrochemical market which is dominated by large state-owned enterprises and foreign major players (such as Exxon Mobil). New government plans aim to reduce the output of diesel and gasoline by 2025 and merge smaller refineries into large scale petrochemical complexes.[161] The initiative for a hydrogen industry is led by Shandong Heavy Industry Group Co., Ltd. (SHIG), a state-owned heavy machinery and manufacturing company and its subsidiary Weichai Power Co., Ltd.

In 2018, SHIG took over the control of Zhongtong Bus supporting SHIG's development plan for the new energy automotive industry. China National Heavy Duty Truck Group Co., Ltd. (SinoTruk Group), the largest heavy-duty truck maker in China has its HQ in Jinan. The first prototype hydrogen cell truck was launched in December 2017 with all core technology parts imported from abroad. On December 17th 2018, UQM Technologies (USA) announced that it won a $1.8 million USD contract from a major fuel cell system supplier in China for UQM's Fuel Cell Compressor System (a combined electric motor, inverter and compressor module).[162] Although the Chinese OEM remained anonymous in the press release, there is a high chance that this is Sinotruk after plans for a JV between UQM Technologies and Sinotruk for the manufacture and sales of electric propulsion systems in China were first announced in September 2017.[163]

Recently, several agreements and investments in the hydrogen and fuel cell sector have been made by SHIG and Weichai Power:

- In November 2017, Weichai Power and Bosch signed a cooperation agreement to jointly establish fuel cells and related components. The two companies have been working together already for 15 years.[164]

- In December 2017, a cooperation framework agreement was signed between China Iron & Steel Research Institute (CISRI) Da Hui Investment Co., Ltd., Shandong Guohui Investment Co., Ltd. and Jinan Pilot Zone for Replacing Old Growth Drivers with New Ones to jointly develop a Hydrogen Valley.[165] The Jinan Pilot Zone was the first regional state strategy approved after the 19th National Congress of the Communist Party of China. Hydrogen energy is included in the initial development orientation as important new technology.[166]

- In August 2018, Weichai signed agreements with Ballard and Westport Fuel Systems. As part of a national key NEV project ("technology of fuel cell engine and commercial vehicle industrialization and its application"), Weichai will build a demonstration project of the whole industrial chain needed for the industrialization of FCEVS. SHIG signed a strategic agreement with the local government in Jinan which kicked of the "Green Power, Hydrogen City" demonstration project.[167] Weichai Power will work together with 12 other enterprises, universities and research institutes to develop fuel cells.[168]

- In October 2018 at the 2018 China Hydrogen Energy and Fuel Cell Industry Summit (organized by the China Hydrogen Alliance), Weichai power signed the "Framework Agreement on the R&D of 200-ton Hydrogen Mining Trucks" together with the National Energy Group and Beijing National Institute of Low Carbon Clean Energy (NICE).[169]

- In November 2018, Weichai gained a 19.9% interest in Ballard with an equity investment of $163.3 million. The collaboration includes the establishment of a JV with technology transfer or Ballard's next-generation fuel cell stack.[170]

- In December 2018, collaboration agreements, first announced in May 2018, between Weichai Power and Ceres Power were finalized. The collaboration includes technology transfer, a JV agreement with the commitment to establish a manufacturing base (of SOFC) in China and an equity investment from Weichai Power of £28 million ($35.2 million USD).[171]

- In January 2019, the Shandong Hydrogen and Fuel Cell Alliance was founded in Jinan. A complete list of all invited parties can be found in the attached excel database. The board of directors is formed by large corporations such as Shandong Heavy Industry Group, Shandong Steel Group, Shandong Energy Group, Weichai Power, Sinotruk, CRRC Qingdao Sifang and Air Liquide. Invited to the inaugural meeting were several universities (Tongji, Nanjing University, Huazhong Univeristy of Science and Technology) as well as companies along the hydrogen chain such as Furui Hydrogen Equipment, Chengdu Huaqi Houpu Electromechanical Equipment and CSIC 718th Research Institute.

- At the same meeting Air Liquide and (coal mining SOE) Yankuang Group Co., Ltd. signed an agreement to jointly make plans for the development of hydrogen energy infrastructure and FCEVs in Shandong province.[172]

Above mentioned announcements and collaborations are in line with the 13th FYP, in which the acquisition of (foreign) core technologies is encouraged. It is still unclear what will actually come out of the collaboration agreements, but it does show that in Shandong province powerful state-owned companies are committed to develop the hydrogen sector. However, one should also keep in mind that currently these plans all set out to develop a **coal-based** hydrogen economy whereas in the Netherlands the focus is on developing a green hydrogen economy.

Datong, Shanxi province - From Coal to Hydrogen?

Datong, known as the coal capital of China has laid out new industrial development plans focusing more on new energy and hydrogen projects. The city is challenged with severe air pollution caused by the coal-fired power plants, as the region is under pressure to keep the coal consumption levels unchanged from 2015-2020.[173] The hydrogen developments in Datong are currently still in an early phase, but the abundant nearby coal resources provide cheap hydrogen to help accelerate the FCEV market. In 2018, HydraV invested heavily in Datong's hydrogen sector (3 billion RMB for its fuel cell mass production center) and in July 2018 Innoreagen Power Technology Co., Ltd. established a new Datong subsidiary, which signed an investment cooperation agreement Datong Municipal Government in August. Some significant developments from 2018:

- In September the Datong Municipal Government signed an 1.08 billion RMB agreement for the purchase of 300 FC buses until December 31, 2019 for Datong's first bus demonstration project. At the same time the construction of the first HRS begun. In December 2018, the first 40 FC buses were delivered. The buses were manufactured by HydraV in cooperation with Nanjing Jinlong Bus Manufacturing Co., Ltd. (subsidiary of Skywell) and Zhongtong Bus.[174] The FC engine system (XTQX3045C) is developed independently by HydraV and guarantees the normal operation of the vehicle under conditions up to -30°C.[175]

- On December 9th a hydrogen energy industry development forum was hosted in Datong gathering more than 100 scholars, government officials and industry players to discuss the transformation of the city towards a hydrogen city.

4.6. Conclusion

China's hydrogen and fuel cell sector is developing impressively, but the overall value chain is still weak due to both unfavorable regulations and technology gaps. The current prohibition of liquid hydrogen transport leads to scattered developments around local (fossil and by-product) production locations and lack of integration on provincial or national level. Fuel cell companies are improving their stacks and new companies are on the rise, but the quality of core technologies is still behind international levels. Fuel cell applications are currently focused on the automotive sector, especially the heavy-duty vehicles segment. Many OEMs are committed to developing FCEVs but still rely on foreign stacks leading to higher costs. Other application areas such as urban heating, Gas-to-Power are not picked up yet. At this point, updated regulations, codes and standards are the most important factor for advancing the sector further.

5
Events

Increasingly more hydrogen and fuel cell events are hosted in China providing a good platform to meet with interesting Chinese parties. During the research period of this report (September 2018 – January 2019) we attended and learned about several events. This chapter aims to give an idea which events fit with various interests. An overview of (other) past and upcoming events can also be found in the database excel sheet attached to this report.

International Hydrogen Fuel Cell Vehicle Congress (FCVC)

A yearly high-level event jointly organized by IHFCA and China-SAE with a substantial number of international participants. The last edition attracted more than 1,500 participants and the exhibition area hosted around 50 organizations. In addition to plenary sessions, several theme-based parallel sessions were organized. The congress hosted presentations by high-level government officials (e.g. Wan Gang, previous Minister of Science and Technology) and company officials (e.g. Randy MacEwen, CEO of Ballard) as well as leading scientists from e.g. Tongji University.

International Hydrogen Energy and Fuel Cell Technology and Product Expo Foshan (CHFC)

During the conference in 2018 the latest policies, systems and roadmaps of hydrogen and fuel cell industry were discussed, while more than 130 companies were hosted in the exhibition area. In comparison with FCVC there seems to be a stronger focus on the exhibition area and on SMEs, such as suppliers of components such as valves, compressors, membranes etc. While there were also large international players, such as AkzoNobel, Air Products and Ballard present.

Inaugural International Symposium on Energy Storage and Hydrogen Technologies

This symposium organized by the University of Science and Technology of China (USTC) and Hydrogen Industrial Technology Innovation Alliance of China (HITIAC) attracted around 100 Chinese participants in 2018. The presentations focused on fundamental research and were rather technically driven. It gave us an insight in the Chinese research and SMEs' community, but is less relevant for seeking direct business opportunities.

Important upcoming events in 2019

- China International Hydrogen and Fuel Cell
  Conference & Exhibition (CHFCE Beijing) – May 6-8 2019

- Shanghai International Hydrogen and Fuel Cell Transportation Application
  Conference & Exhibition (CHFCE Shanghai) – September 5-7 2019

- 4th International Hydrogen Fuel Cell Vehicle
  Congress (FCVC) – September 26-28 2019

- 3rd International Hydrogen Energy and Fuel Cell Technology
  and Product Expo Foshan (CHFC) – expected November 2019, but dates not yet available.

6

Opportunities for collaboration

There are various indications that China is seeking international cooperation to accelerate hydrogen developments. Firstly, China is taking part of international groups such as IPHE and Mission Innovation. Secondly, leading Chinese companies (e.g. Re-Fire, Great Wall Motors) have joined the Hydrogen Council. Thirdly, various Chinese companies are actively investing in foreign companies. For example, Weichai Power in 2018 gained a 20% interest in Ballard[176] and a 10% equity holding in Ceres Power.[177] In November 2017, Dewei Group Holdings from Beijing established a JV called Fuel Cell Powertrain (FCP) together with German Power Train Technology in Chemnitz, Germany. The JV closely works together with TU Chemnitz. TU Chemnitz focuses on the Chinese market and ultimately intends to open a local manufacturing facility in China.[178] On the other side, we also see an interest from foreign countries and companies to cooperate with China. Several foreign enterprises are participating in the Chinese market already, have set up local production facilities and/ or joined newly established Chinese alliances.

The rest of this chapter will focus on new opportunities for collaboration between China and the Netherlands specifically, on government as well as industry level.

Government to Government (G2G) collaboration

In order to set up a G2G collaboration between China and the Netherlands in the field of hydrogen, it's advised to relate to an already existing agreement. This part describes some existing G2G collaborations, possibly relevant to include hydrogen.

The Ministry of Economic Affairs and Climate Policy in the Netherlands is collaborating with the National Energy Administration of China, in areas of such as clean coal technology, smart grid development, energy efficiency improvement. This is part of an MoU in the field of energy. Another MoU between these two parties includes cooperation in the field of wind energy. Both MoUs are rather broad, creating the opportunity to add hydrogen as a new cooperation area.

In 2018, the Dutch Ministry of Infrastructure and Water Management signed a MoU with CATARC related to Zero Emission Vehicles (ZEVs). The Netherlands has high ambitions in greening its transport sector and has already established a dense network of electric charging points. China has become the global NEV market leader and collaboration can help the Netherlands learn about the use of different policy instruments to establish a larger ZEV market in the Netherlands. The initial focus is on electric vehicles, while fuel cell vehicles can be added if all parties agree.

Business

The Chinese market provides large business opportunities for Dutch companies, particularly since the technology gap between domestic and foreign products in China is still substantial. In addition, by setting up local production lines in China, foreign companies can achieve cost reductions. Some opportunities:

- Global leaders for PEM electrolyzer such as Siemens, nel, ITM Power have large business opportunities in China because of two reasons. Firstly, the country is challenged by large curtailment rates of renewables and secondly, domestic companies have so far only developed small PEM electrolyzers.

- China's hydrogen value chain, especially the storage and distribution part, is still weak. Enterprises like Air Liquide, Lind Gas and Air Products are eager to help.

- High-pressure technologies are also not advanced yet, creating business opportunities for companies providing this technology e.g. PDC machines or HyET.

- Chinese fuel cell stacks are still dependent on importing core parts. Suppliers of MEAs, catalysts or GDL are of interest. They should take into consideration that Chinese enterprises are making rapid progress in this field, mainly due to strong government funding for R&D.

Sino-Dutch industry collaboration is interesting for the Netherlands in two ways. On one hand, companies can benefit from a big market in China. Several Dutch companies have already (partially) entered the Chinese market. For example, in 2016, Nedstack together with MTSA Technopower and AkzoNobel delivered the world's first 2MW power station to its Chinese customer Ynnovate. The following year Nedstack and Hymove formalized a cooperation with Huaxia and established a JV called Huahe in Zhangjiagang. The localized production line will start operation in Q1 2019. Other players like Shell and Hygear are actively searching for possibilities to contribute to the roll-out of HRS in China.

It is important to note that precautions are required. The hydrogen and fuel cell business in China remains tricky (often protected). There are always a few examples of JV agreements between Chinese and foreign companies that causes problems. Nevertheless, the excel database attached to this report hopefully provides helpful insights in the Chinese market(players). Sharing knowledge with other Dutch companies via platforms such as NWBA or H2Platform can possibly help you by deciding on your strategy.

On the other hand, once the technology in China is more advanced (reaching international levels), the – often cheaper - Chinese products could help the Netherlands in establishing a green hydrogen economy. It is however good to realize the differences between both countries. China's initial focus is on (heavy-duty) automotive applications, whereas the Netherlands engages with hydrogen as connector of several sectors: green hydrogen production from renewables, retrofitting the gas infrastructure network, using hydrogen for urban heating and using green hydrogen as feedstock for chemical processes. Therefore, probably other types of technologies and companies are involved.

Looking ahead

Holland Innovation Network China will continue to follow hydrogen sector developments in China and plan a suitable follow-up for this research, such as organizing events and missions. In May 2019 we will attend and give a presentation at the China International Hydrogen and Fuel Cell Conference & Exhibition (CHFCE) in Beijing. In Q3-4 2019 a hydrogen mission to Wuhan (and probably another region of interest) is being organized. In case you are interested to join such events, feel free to reach out.

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