RIFS STUDY

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China's Emerging Hydrogen Economy

Policies, Institutions, Actors

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Executive Summary

The state of China's hydrogen economy

China is the largest hydrogen producer in the world, accounting for approximately one third of global output. Its production volume reached 33 million tons in 2020, of which currently only a small fraction (approximately 1 percent) is based on renewable energy-based electrolysis. Almost two thirds of production comes from coal, while natural gas and industrial by-products account for a little under 20 percent each. Only one percent was produced via electrolysis using renewable energy in 2020. Nevertheless, China represents a major producer of alkaline electrolyzers. Alkaline electrolyzers in China are estimated to cost as little as $200 per kW, significantly below estimated costs in Europe (approximately $1200 per kW). Given its abundant solar and wind resources in the North of the country and major hydropower resources in the South-West, China is expected to significantly increase production of renewable electricity-based hydrogen (hereafter renewable hydrogen). By 2030, the China Hydrogen Alliance predicts a share of 15 percent of total production. Costs of hydrogen produced by renew-able electricity supported by onshore wind and solar photovoltaics (PV) are currently between 22.5 and 33.6 yuan/kg (around US $3.53 to 5.27 per kg).

By far the most well-established application - apart from traditional uses of hydrogen - is the use of hydrogen in heavy-duty, commercial fuel cell vehicles. An increasing number of demonstration projects in hydrogen infrastructure have emerged in the past years, including hydrogen refueling stations, short-distance hydrogen pipelines and liquid hydrogen storage. Hydrogen development has been concentrated in four major clusters (i.e. Beijing-Tianjin-Hebei Region, the Yangtze River Delta, the Pearl River Delta and Ningdong Energy and Chemical Industry Base). Henan Province has also recently launched a new 'Hydrogen Corridor'. Chinese state-owned energy companies have played a major role in large-scale and capital-intensive hydrogen projects, including the construction of hydrogen refueling stations and pipelines. Private companies are investing in less capital-intensive hydrogen projects, such as equipment manufacturing or R&D of specific hydrogen technologies, especially in the fuel cell industry. The development of China's hydrogen value chain still lags behind advanced economies and remains dependent on technology imports in a number of areas such as core elements of fuel cells, hydrogen refueling stations and storage. The dependence on technology imports might delay China's hydrogen development, given the increasing geoeconomic rivalry and related policy measures to restrict technology transfer.

China's institutional environment governing hydrogen

As China's supreme governmental body, the State Council sets the broad goals of hydrogen development, as manifested in various five-year plans. The National Development and Reform Commissions (NDRC) is responsible for the drafting of the five-year plans and holds the main responsibility for governing China's energy sector with its subordinate agency, the National Energy Administration (NEA). Together with the Ministry of Industry and Information Technology (MIIT) and the Ministry Science and Technology (MOST), NDRC also plays a central role in promoting innovation and industrial development in hydrogen. The Ministry of Housing and Urban-Rural Development (MHURD) develops technical regulations for hydrogen infrastructure (e.g. hydrogen refueling stations). The Standardization Administration of the People's Republic of China (SAC) sets technical standards. The Ministry of Finance (MOF) oversees the design of subsidy schemes for supporting hydrogen development. China Development Bank (CDB), China's largest policy bank, has not issued any hydrogen-specific policies. However, CDB has declared its intention of supporting green transport, namely increasing the use of new energy vehicles (NEVs).

Local governments have been crucial players at the early stage of developing hydrogen in China, enabling the central government to 'test the waters' in the hydrogen sector. The provincial or municipal governments, or sometimes the local branches of the NDRC, are responsible for formulating hydrogen development plans for their geographical areas. Local governments work closely with various local branches of the respective central governments to promote different dimensions of the hydrogen economy in China. State-owned enterprises (SOEs) also cooperate with local administrations to implement their hydrogen development plans.

Hydrogen-related policy objectives

Promotion of the hydrogen sector in China dates back to 1986 and has strongly focused on fuel cells and related refueling infrastructure. Policymaking at the local level is more advanced than that at the central level. Before the issuance of the *Mid-and-Long-Term Hydrogen Industrial Development Plan* in March 2022, local governments had already issued hydrogen development plans, mainly focused on fuel cell vehicles and related infrastructure. The national hydrogen development plan identifies hydrogen's broader role in decarbonizing energy consumption and contributing to achieving carbon neutrality in hard-to-abate sectors, including the steel, transport and chemical industry. It aims to produce 100,000 to 200,000 tons of renewable hydrogen per year by 2025 and aims to thereby reduce 1 to 2 million tons of CO_2 emissions annually. Despite these ambitions to promote hydrogen production from renewable power, the *PRC Energy Law* (Draft) does not distinguish different forms of producing hydrogen, and hydrogen development plans adopted by local governments include both ambitious goals to expand renewable hydrogen and plans to scale up conventional hydrogen production in the chemical sector.

The plan also reconfirms China's longstanding aim to promote fuel cell vehicles and related technologies. By 2025, the central government is targeting 50,000 fuel cell vehicles. Building hydrogen refueling stations has figured in local hydrogen development plans since at least 2015. The role of hydrogen for the decarbonization of industry has only recently been addressed by Chinese policy makers. The national hydrogen development plan includes the aim to use renewable hydrogen as a source of industrial heat and to replace fossil fuels in ammonia production, methanol production and the refinery sector.

The hydrogen economy is also seen as an area with important potential for innovation and industrial development. While the government has emphasized fuel cells and fuel cell vehicles in the past, it has recently increased its attention to other segments of the hydrogen value chain. The national hydrogen development plan aims to improve the efficiency of hydrogen production based on renewable energy and to scale up and increase the productivity of related production equipment. The plan also stresses the importance of developing materials for hydrogen storage, which is viewed as a potential bottleneck for the development of China's hydrogen sector.

Finally, the hydrogen development plan has identified the development of technical standards as an important priority. In 2020, the China Hydrogen Alliance had already issued the *Standard and Evaluation of Low-carbon Hydrogen, Clean Hydrogen and Renewable Hydrogen* (2020), which defines different types of hydrogen based on their production process and their CO_2 emissions. The CO_2 benchmarks for clean and renewable hydrogen are equivalent to those of European schemes, while the benchmark for low-carbon hydrogen is significantly above the estimated CO_2 emission intensity of hydrogen based on natural gas. These standards do not serve as the reference for any government communication at this stage.

Support policies for hydrogen development

The *Mid-and-Long-Term Hydrogen Industrial Development Plan* (2021-2035) encourages investment in the hydrogen sector. The *Green Industry Guidance* (2019) and *the Notice of Issuing the Catalogue of Projects Supported by Green Bonds* (2021) specify following hydrogen projects as eligible for financial support: clean hydrogen production; hydrogen refueling stations; hydrogen storage facilities; hydrogen fuel cells; hydrogen fuel cell vehicles; and gaseous hydrogen blending into gas pipelines. This implies that investments in these areas may receive support via preferential loans, subsidies, industrial funds, preferential tax treatment, green bonds and potential financial incentives via the carbon trading market. A number of local governments have actively encouraged the establishment of industrial funds to finance hydrogen projects. The national hydrogen development plan also proposes 'supportive electricity prices' for hydrogen production based on renewable energy, which have already been in place in a number of localities.

Beyond the general investment support for hydrogen-related technologies, the Chinese government has implemented a range of instruments to support the manufacturing and deployment of fuel cell vehicles as well as related infrastructure, i.e. hydrogen refueling stations. To create demand for hydrogen fuel cell vehicles, the central government has granted subsidies to consumers who purchase hydrogen fuel cell vehicles. In addition, the central government announced a pilot city rewards scheme in 2020, which is intended to replace consumer subsidies in selected jurisdictions. Such pilot city schemes have been in place for the promotion of hydrogen refueling stations since 2014. Participating cities receive funding to support the manufacturing of equipment for refueling stations. The funds cannot be provided as direct subsidies for the construction of refueling stations. However, the participating cities provide local resources for this purpose. In addition to direct consumer subsidies and pilot city schemes, the central government has supported fuel cell vehicles via its Dual Credit Policy for NEVs. This provides automakers with credits when they exceed production targets for NEVs, which can compensate for deficits in meeting fleet-based fuel consumption targets.

Finally, China's emission trading scheme (ETS) is designed to decarbonize the carbon-intensive sectors of the national economy by pricing related carbon emissions According to the *Industrial Development Plans of New Energy Vehicles* (2021-2035), the State Council aims to stimulate automobile companies to develop NEVs, including hydrogen fuel cell vehicles, by expanding the ETS to fuel consumption in the transport sector. Similarly, the development of hydrogen in other sectors could benefit from the possible expansion of the ETS to the refinery, petrol-chemical, steel, paper, and cement industry. In addition, the ETS can contribute to the development of renewable hydrogen under the *Chinese Certified Emissions Reductions* scheme (CCER). The CCER regime is a supplement to the national ETS, consisting in the creation of offset allowances based on emission reduction projects (e.g. in the field of renewable energy).

Conclusion

China's promotion of the hydrogen sector is emblematic of its broader efforts to promote greenhouse gas reductions, while pursuing ambitious industrial development goals and promoting energy security. To date, industrial policy goals have clearly taken center stage, however. Short-term ambitions to promote renewable hydrogen are fairly modest compared to other major economies. Moreover, China is currently pursuing a diversified strategy in support of hydrogen supply, which includes all different types of hydrogen production, including coal-based hydrogen. Nevertheless, policy documents increasingly emphasize the potential of renewable hydrogen as a vehicle for stabilizing an electricity system based on variable renewable energy as well as broader decarbonization efforts. They also increasingly highlight the need to transition to an exclusively renewable hydrogen supply in the future. In a number of cases, local-level strategies have come out more strongly in support of renewable hydrogen than current central government policies. Central-level policies for hydrogen-based decarbonization of industry are only at a nascent stage. Similarly, China's ambitions to promote hydrogen storage and transport remain at a relatively early stage of development with an important emphasis on the promotion of innovation and acquisition of technological know-how.

Finally, both China's hydrogen strategy and the engagement of its energy SOEs do not appear to be strongly motivated by considerations of geopolitics at this stage. To be sure, Chinese officials are considering increasing opportunities for investment in hydrogen projects around the world. In this vein, the national hydrogen development plan considers the importance of the Belt and Road Initiative (BRI) for promoting hydrogen-related standards and investments. Beyond these geoeconomic considerations, the role of hydrogen as a future energy commodity and its geopolitical implications do not figure prominently in Chinese policy efforts. Indeed, due to China's relative abundance of renewable energy resources, it is does not exhibit major vulnerabilities related to the future provision of hydrogen. Conversely, hydrogen could even offer an opportunity to reduce its energy dependence in the future. This and other efforts to shape global hydrogen trade do not seem to be a significant driver of its policy efforts, however.

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List of Abbreviations

ASEAN	Association of Southeast Asian Nations
BRI	Belt and Road Initiative
CAFC	Corporate Average Fuel Consumption
CCER	Chinese Certified Emissions Reductions
CCUS	Carbon capture, usage and storage
CDB	China Development Bank
CNPC	China National Petroleum Corporation
CPC	Communist Party of China
CSRC	China Securities and Regulatory Commission
DRI	Direct-reduced iron
ETS	Emission trading scheme
GHG	Greenhouse gas
GUOFUHEE	Jiangsu Guofu Hydrogen Energy Equipment Co. Ltd
IEA	International Energy Agency
IHFCA	International Hydrogen Fuel Cell Association
MEE	Ministry of Ecology and Environment
MHURD	Ministry of Housing and Urban-Rural Development
MIIT	Ministry of Industry and Information Technology
MOF	Ministry of Finance
MOFCOM	Ministry of Commerce
MOST	Ministry of Science and Technology
MOT	Ministry of Transport
MoU	Memorandum of Understanding

NDRC	National Development and Reform Commissions
NEA	National Energy Administration
NEVs	New energy vehicles
NSFC	National Natural Science Foundation of China
PEM	Polymer electrolyte membrane
PBOC	People's Bank of China
PipeChina	China National Oil & Gas Piping Network Company
PV	Photovoltaics
SO	Solid oxide
SAC	Standardization Administration of China
SASAC	State-owned Assets Supervision and Administration Commission
SOEs	State-owned enterprises
SPIC	State Power Investment Corporation

1 Introduction

It is widely anticipated that hydrogen will play a crucial role in the global transition to climate-neutrality. Hydrogen offers opportunities to significantly reduce greenhouse gas (GHG) emissions from carbon-intensive industrial applications and other hard-to-abate sectors (IRENA, 2022; IEA, 2021). Its broader use as an energy carrier could also reduce reliance on fossil fuels and enhance energy security (Tiwari, 2021). As China is a major carbon emitter, it is important to consider how efforts to expand the use of hydrogen will contribute to its commitments to facilitating the global transition to climate-neutrality (State Council, 2021). In 2020, China invested 71.2 billion yuan (around US$10.5 billion) in hydrogen projects (Chen & Li, 2021), and China's investments accounted for 50 percent of total project volume in Asia by early 2021 (Haitong Securities, 2021).

Despite the importance of hydrogen in China for the global energy transition and the role of policy and regulation in this development, China's policy and regulation of hydrogen remains under researched. The present study aims to address this gap by studying China's past, present and future efforts to develop domestic hydrogen value chains by analyzing China's hydrogen policy and regulation. The study analyzes *The Mid-and-Long-Term Hydrogen Industrial Development Plan (2021-2035)* (2022) (herein after the national hydrogen development plan), hydrogen-related five-year plans and hydrogen-related policies issued by the central government and local governments. Interviews supplement the policy and regulatory analysis. To gain a better understanding of the current developments in the field of hydrogen in China and of the challenges facing the Chinese hydrogen industry, interviews were conducted with representatives from leading energy law firms and research institutions.

The report is structured as follows: Section 2, following this introduction, outlines the current status of the hydrogen sector in China. It presents current development across the hydrogen value chain and across various regions and outlines the role of state-owned enterprises (SOEs) and private firms in China's hydrogen economy. Section 3 presents the institutional context (i.e. the main government ministries and agencies) of Chinese hydrogen governance, both at the central and regional/local level. Section 4 discusses the main policy objectives pursued by both the central government and local actors in the hydrogen sector and traces their evolution over time. Section 5 gives an overview of the main policy instruments at the central and local level in support of hydrogen development. Section 6 discusses the main findings of the report.

2 The state of China's hydrogen economy

China is the largest hydrogen producer in the world, accounting for approximately one third of global output. Its production volume reached 33 million tons in 2020, of which currently only a small fraction (approximately 1 percent) is based on renewable energy-based electrolysis. Almost two thirds of production comes from coal, while natural gas and industrial by-products account for a little under 20 percent each. Nevertheless, China represents a major producer of alkaline electrolyzers. Alkaline electrolyzers in China are estimated to cost as little as $200 per kW, significantly below estimated costs in Europe (approximately $1200 per kW). Given its abundant solar and wind resources in the North of the country and major hydropower resources in the South-West, China is expected to significantly increase production of renewable electricity-based hydrogen. By 2030, the China Hydrogen Alliance predicts a share of 15 percent of total production. Costs of hydrogen produced from onshore wind and solar photovoltaics (PV) are currently between 22.5 and 33.6 yuan/kg (around US $3.53 to 5.27 per kg).

By far the most well-established application is the use of hydrogen in heavy-duty, commercial fuel cell vehicles. An increasing number of demonstration projects in hydrogen infrastructure have emerged in the past years, including an increasing number of hydrogen refueling stations, short-distance hydrogen pipelines and liquid hydrogen storage. Hydrogen development has been concentrated in four major clusters (i.e. Beijing-Tianjin-Hebei Region, the Yangtze River Delta, the Pearl River Delta and Ningdong Energy and Chemical Industry Base). Henan Province has also recently launched a new 'Hydrogen Corridor'.

Chinese state-owned energy companies have played a major role in large-scale and capital-intensive hydrogen projects, including the construction of hydrogen refueling stations and pipelines. Private companies are investing in less capital-intensive hydrogen projects, such as equipment manufacturing or R&D of specific hydrogen technologies, especially in the fuel cell industry. The development of China's hydrogen value chain still lags behind advanced economies and remains dependent on technology imports in a number of areas such as core elements of fuel cells, hydrogen refueling stations and storage. The dependence on technology imports might delay China's hydrogen development, given the increasing geoeconomic rivalry and related policy measures to restrict technology transfer.

China's hydrogen development is at an early stage. China's companies face important technological challenges, and cost reductions will be needed throughout the hydrogen value chain. Despite these challenges, both SOEs and private enterprises have made progress in hydrogen development including establishing pilot projects, developing storage technology, building short-distance hydrogen pipelines, and advance the use of fuel cell vehicles. The following section provides a more detailed of key developments to date.

2.1 An overview of China's hydrogen value chain: production, transport and use

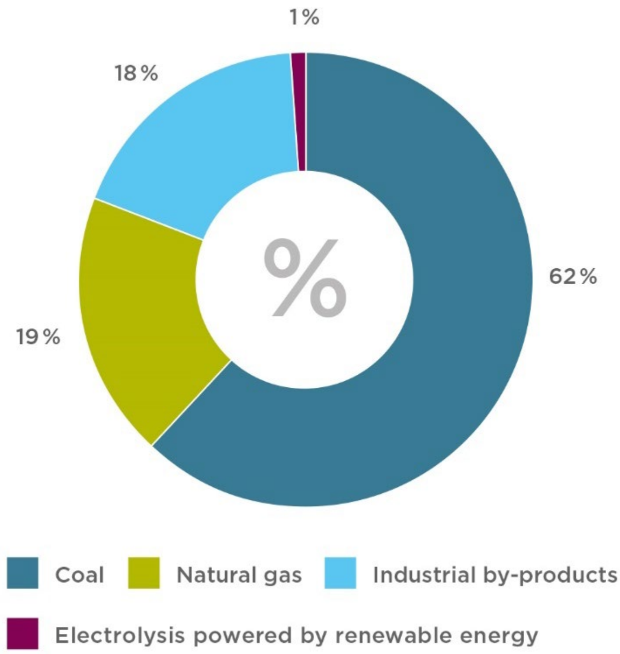
China is making efforts to develop hydrogen production, storage, and use (China Center for International Economic Exchanges, 2021; Yin, 2021; Sun & Yang, 2021). To date, China's hydrogen sector has been characterized primarily by developments in the following three areas: hydrogen production mainly from fossil fuels, an increasing number of demonstration projects in hydrogen infrastructure to link hydrogen supply and demand centers (e.g. short-distance hydrogen pipelines, liquid hydrogen storage, increasing numbers of hydrogen refueling stations), and hydrogen use in the automotive industry.

2.1.1 Production

China is the largest hydrogen producer in the world. China's hydrogen output accounts for roughly one third of total global output (Haitong Securities, 2021). In 2020, China produced around 33 million tons of hydrogen (International Ptx Hub, 2022). Of this, around 62 percent was produced from coal (Xu & Yu, 2021), around 19 percent from natural gas (Leadleo Industry Research Institute, 2021; AskCl Consulting (2021) and around 18 percent of hydrogen was produced from industrial by-products. Only 1 percent was produced via electrolysis with renewable energy, also referred to as "green hydrogen" (see Figure 1 on the following page). The research institute of the China Hydrogen Alliance has predicted that by 2030, the share of renewable electricity-based hydrogen (hereafter renewable hydrogen) could grow to approximately 15 percent (AskCI, 2022). As most of hydrogen is produced from coal at this early stage, there have been efforts to make use of carbon capture, use and storage (CCUS) technologies to reduce carbon emissions. However, these efforts have not progressed beyond the pilot stage (Xu et al., 2021; Meng et al., 2020; Wang et al., 2021). Before including the cost of CCS, the cost of producing hydrogen from coal in China is around US$1.2/kg (Xu et al., 2021)[1]. When including the cost of CCS, the cost of producing hydrogen from coal is estimated at approximately US$2.48 to 2.9 per kg (China Hydrogen Alliance, 2019; Xu et al., 2021). This is slightly above the International Energy Agency's (IEA) estimate of US$ 2.1 to 2.6 per kg (IEA, 2020).

[1] The statistics of the cost may vary depending on the calculation methodology.

Figure 1 China's hydrogen production in 2020



Source: Authors' own, based on Hydrogen Industrial Reports published in 2021 by Leadleo Industry Research Institute and AskCl Consulting

China's abundant renewable energy resources and its manufacturing of cost-competitive alkaline electrolyzers provide the potential to produce significant amounts of renewable hydrogen in the future. North China has abundant solar and wind resources and South-West China has rich hydropower resources (KAS, 2022; GGII Research Institute, 2021). As the cost of generating renewable energy in these regions decreases, shares of renewable hydrogen are expected to rise significantly. Furthermore, China is a global leader in the field of alkaline electrolysis (Xu & Yu, 2021). The productivity of alkaline electrolyzers in China is estimated at 1000 to 1200 m^3 per hour (Wen et al., 2019). Alkaline electrolyzers in China are estimated to cost as little as $200 per kW (Energy Transition Commission, 2019), significantly below estimated costs in Europe (approximately $1200 per kW) (Energy Transition Commission, 2019). Resulting costs of hydrogen produced by renewable electricity supported by onshore wind and solar photovoltaics (PV) are between 22.5 and 33.6 yuan per kg (around US $3.53 to 5.27 per kg) (S&P Global Commodity Insights, 2022; Xu et al., 2021). A large project sponsored by China's state-owned oil and gas company, to be launched in June 2023, is expected to bring down the cost of hydrogen production supported by solar power to US$ 2.67 (Renewables, 2022). The cost of producing hydrogen based on electrolysis with offshore wind has been estimated at US$5 to 10 per kg (S&P Global Commodity Insights, 2022). Although these costs are still higher than the cost of coal-based hydrogen (around US $1.01 to 1.16 per kg) (Xu et al., 2021; Wallstreet News, 2022a; China Hydrogen Alliance, 2019), they are generally in the lower range of the IEA's cost estimates for producing hydrogen via renewable electricity (currently between US$ 3 and 8 per kg) (IEA, 2021). Industry analysts predict that by 2060 renewable-based hydrogen will account for 80 percent of hydrogen supply in China, considering renewables growth (S&P Global Commodity Insights, 2022).

2.1.2 Storage and transport infrastructure

The divergence between energy supply and demand centers in China represents a challenge for the development of its hydrogen economy. North China has abundant coal resources and expertise in the processing of coal-based chemical products. North-West China and South-West China, such as Ningxia Province and Sichuan Province could be potential centers for the production of renewable hydrogen due to abundant renewable energy potential. East and South-East China are expected to be the major centers of hydrogen demand (Xu & Yu, 2021; Zhang et al., 2022).

The most commonly used hydrogen transport solutions in China are tube trailers and pipelines (Wang et al., 2017; Li et al., 2021), both of which pose specific challenges. Transport via tube trailers is costly and has safety risks (Du & Mu, 2021), while transport via pipelines requires capital-intensive infrastructural investments. Gas pipelines have been used on a small scale (Pan et al., 2020). Pure hydrogen pipelines also exist (see the map below) (Yang et al., 2021). Most of them are located in Bohai Bay and the Yangtze River Delta (People.cn, 2019). The longest so far is the Dingzhou-Gaobeidian pipeline in Hebei Province with a length of approximately 145 km (BJX, 2021a). Others include, for example, Jinling-Yangzi (approximately 32 km) and the Jiyuan-Luoyang pipeline (approximately 25 km) (Energynews, 2021), Baling-Changling pipeline (approximately 42 km), Tongliao Pipeline (approximately 7.8 km), a hydrogen pipeline in the Ningxia Energy and Chemical Base (approximately 1.2 km) and a hydrogen pipeline in Yumen Oilfield (5.77 km) (see Figure 2 on the following page for an overview of key hydrogen pipelines in China).

In China, hydrogen is usually stored as gaseous hydrogen, but China is developing liquid hydrogen storage (Wang et al., 2017; Li et al., 2021). Liquid hydrogen transport solutions are considered to be more cost-effective in the long term (Wang, 2021; Li et al., 2021). The development of storage and transport infrastructure for liquid hydrogen could significantly strengthen inter-provincial hydrogen trade (GUOFUHEE, 2021a). Whilst liquid hydrogen was previously used primarily in China's military, aviation, and aerospace industries (Hongda Xingye Co., 2021a), experts anticipate that it will be adopted more widely in industrial production, public transport, electricity supply and other energy-related purposes.

China is an active player in the construction of refueling stations for hydrogen use in the transport sector (see more details below). In early 2021, there were 146 hydrogen refueling stations, of which 136 actively operating, in China (China Energy, 2021a). Most of China's existing hydrogen refueling stations are repurposed gas stations (e.g. the gas-hydrogen refueling station in Zibo, Shandong (GUOFUHEE, 2021b) or petroleum stations (e.g. those built by Sinopec as discussed below). Despite progress, Chinese industry will have to continue to advance technology for hydrogen refueling stations (see section 2.1.4) and to scale up their construction for two main reasons (Dongwu Securities, 2022): First, the cost of hydrogen refueling based on 35MPa hydrogen refueling stations remains high (around 11.33 yuan/kg or US$ 2.69/kg). Second, existing hydrogen refueling stations do not operate at a capacity that would meet expected demand given current policy support for the scale-up of hydrogen fuel cell vehicles (see section 4) (Wen et al., 2021; Wu et al., 2021).

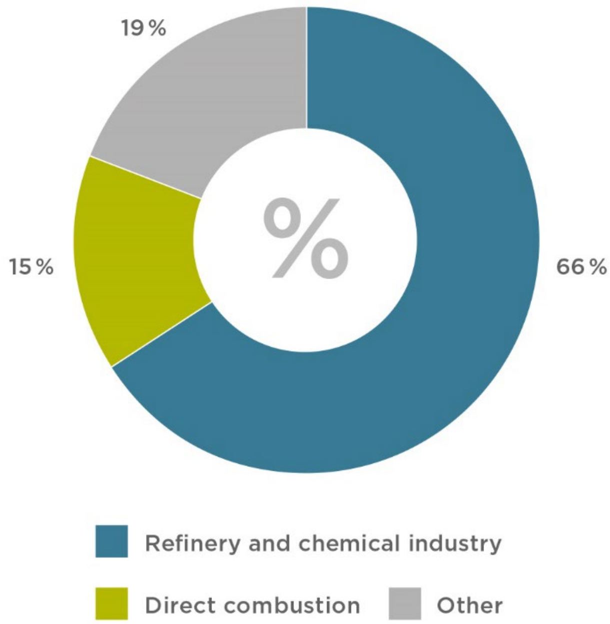
Figure 2 Major hydrogen pipelines in China

Source: Authors' own, based on BJX Hydrogen Energy, 'The Layout of Hydrogen Pipelines in China' (我国管道输氢分布地图), 2022.

2.1.3 Hydrogen use

In 2020, China's demand for hydrogen was between 20 million tons and 25 million tons (Guosen Securities, 2021; Wanlian Securities, 2021), representing around 22 to 27 percent of global hydrogen demand (IEA, 2021). According to the China Hydrogen Alliance, China's demand for hydrogen is predicted to reach 30 million tons by 2025, while the Beijing municipal government anticipates that China's demand for hydrogen could reach up to 60 million tons. It is currently utilized primarily in the chemical and refinery industry (Guosen Securities, 2021) and, on a smaller scale, as an industrial raw material (e.g., highly pure electron hydrogen) (Haitong Securities, 2021). Figure 3 on the following page offers an overview of hydrogen consumption in China in 2020 (Haitong Securities, 2021).

Figure 3 China's hydrogen consumption in 2020



Source: Authors' own, based on 'Hydrogen Energy: Challenges and Opportunities', (氢能源：痛点和机会), Haitong Securities, 2021

In recent years, steel producers in China have shown interest in the utilization of hydrogen in the steel industry (Chen et al., 2020; Orient Securities, 2021), considering the general policy call of achieving carbon peaking and carbon neutrality (see section 4.4.3). Pilot projects for decarbonizing steel production are underway in the steel industry based on hydrogen direct-reduced iron (DRI) and hydrogen plasma smelting reduction (Chen et al., 2020; Meng et al., 2020; Jiang et al., 2020). In Shanxi Province, a pilot project for commercially viable hydrogen-based DRI was able to lower CO_2 emissions in steelmaking from 1.8 tons of CO_2 per ton of steel to 0.6 ton of CO_2 per ton of steel (Zhu, 2021). The hydrogen used in this case is produced from coke oven gas. HBIS Group Co., a provincial, state-owned steel company in Hebei Province, signed a Memorandum of Understanding (MoU) with Tenova, a company that works on the sustainability of metal technology (Meng et al., 2020). Similarly, Jianlong Steel is trying to shift from coal- to hydrogen-based smelting reduction (Chen et al., 2020). In February 2022, Baogang Steel began a project to trial hydrogen DRI.

Finally, the development of fuel cells has been identified as a critical energy-related project in the state's high technology development plan early this century (Wang et al., 2013; Yi et al., 2018). China focuses on the R&D and industrialization of polymer electrolyte membrane (PEM) fuel cells and solid oxide (SO) fuel cells (China Hydrogen Alliance, 2019). Since 2017, fuel cells have been gradually introduced in ships, buses and commercial vehicles (Ling et al., 2019; Sun & Yang, 2021). However, hydrogen fuel cell vehicles account for just 0.4 percent of new energy vehicles (NEVs) in China (Haitong Securities, 2021). It is predicted that the number of hydrogen fuel cell vehicles will reach around

2 million by 2035 and around 11 million by 2060 (S&P Global Commodity Insights, 2022), which is more ambitious than policy objectives of deploying hydrogen fuel cell vehicles (see section 4.4.1)

2.1.4 China's insufficient technological capacities within the hydrogen value chain

Despite the current development in hydrogen production, storage, transport and use, the development of China's hydrogen value chain still lags behind advanced economies and remains dependent on technology imports in a number of areas such as core elements of fuel cells, hydrogen refueling stations and storage (Xu & Yu, 2021; Tu, 2020; Yu et al., 2021). For instance, China depends on imports of key parts of PEM electrolyzers (Wallstreet News, 2022a), which are more suitable for running on intermittent renewables than traditional alkaline systems (The Oxford Institute for Energy Studies, 2022). This is important for China, due to its policy objective of utilizing hydrogen as an option for balancing variable renewable energy (see section 4.4.2). Chinese firms also lack the capacity for large-scale manufacturing of platinum catalysts, needed for PEM fuel cell stacks (Haitong Securities, 2021). Other crucial components in the production of fuel cells, including proton membranes, carbon paper and air compressors, are also sourced from foreign suppliers (Tan & Yu, 2020). For instance, more than 99 percent of proton membranes are imported (Shanghai Securities, 2021). Similarly China lacks capacities in a number of storage and transport technologies. For example, current storage capacities only allow for the storage of 20MPa or 35MPa high-pressure gaseous hydrogen (Haitong Securities, 2021). China currently also lacks the technology needed to store and transport liquefied hydrogen (Chen et al., 2020). In neighboring Japan, liquid hydrogen accounts for 70 percent of storage capacity (Haitong Securities, 2021). Moreover, China's companies cannot independently manufacture refueling nozzles for hydrogen refueling stations (Wen et al., 2019).

The dependence on technology imports might delay China's hydrogen development, given the increasing geoeconomic rivalry and related policy measures to restrict technology transfer. China's overseas investments in the technology sector have been challenged by authorities of host states based on national security concerns (Reuters, 2016; O'Sullivan et al., 2017; Conrad B. & Genia K,, 2017). The US, for instance, has prevented the export of hydrogen liquefiers to China (Chen, et al. 2021). In spite of these challenges, policy and media reports view China as a potential competitor in hydrogen technology development (IRENA, 2022; Chan & He, 2021; Nakano, 2022; Eurasian Times, 2022).

2.2 Important regions of hydrogen development in China

Beijing-Tianjin-Hebei Region, the Yangtze River Delta, the Pearl River Delta, Ningdong Energy and Chemical Base (located in Ningxia Province) are important areas of hydrogen development in China (Sui, 2021; China Center for International Economic Exchanges, 2021). The emerging 'Hydrogen Corridor' located in Henan Province will be an important hydrogen cluster in Central China (see Figure 4 on the following page for a map of hydrogen clusters) Many cities and provinces in these areas, such as Shanghai and Hebei Province, can build on a well-developed heavy chemical industry for the development of hydrogen value chains (Securities Research, 2019), and concentrated industrial activities can help to spread the high costs of building hydrogen infrastructure across a larger number of players (Cleantech, 2019).

The **Beijing-Tianjin-Hebei Region** has made progress in hydrogen production based on renewable energy power and in developing fuel cell vehicles (He et al., 2021). According to NDRC, the city of Zhangjiakou, located in Hebei Province, is developing a renewable hydrogen production base (NDRC, 2015). In 2017, the first wind-to-hydrogen project in China was initiated in Zhangjiakou (Sun et al, 2019). In 2020, Hebei Province launched a demonstration project for hydrogen blending in natural gas pipelines (China Energy, 2021b). The region also provided more than 1,000 hydrogen fuel cell vehicles and more than 30 hydrogen refueling stations for the 2022 Beijing Winter Olympics (Wallstreet News, 2022b). Moreover, the HYPOWER project with an annual capacity of 1600 standard cube meters of renewable hydrogen production went into operation at the end of 2019 (China Energy, 2019).

Figure 4 Hydrogen clusters in China

Source: Authors own.

Cities located at the **Yangtze River Delta** have developed the hydrogen sector mainly by producing hydrogen from industrial by-products and focusing on hydrogen use in fuel cells (Zhu et al., 2021). In 2019, the state's first project for the purification and liquefaction of gaseous hydrogen was launched in Jiaxing, Zhejiang Province (Meng et al., 2020). The **Pearl River Delta** has the greatest number of hydrogen refueling stations (Meng et al., 2020). As of June 2021, 61 hydrogen refueling stations had been built or proposed or were under construction in Guangdong Province (Forward Economist, 2022). By building hydrogen refueling stations, this region is promoting the use of hydrogen fuel cell vehicles (Meng et al., 2020).

Ningdong Energy and Chemical Industry Base located in Ningxia Province has established itself as another major center for hydrogen production in China (CNPC, 2021). For this it has exploited existing industrial capacities in the coal-based chemical industry as well as its relatively low-cost solar power and abundant land resources (NingXia State-owned Capital Operation Group, 2020). It produces hydrogen based on coal, methanol (methanol steam reforming), industrial by-products and renewable electricity (GGII Research Institute, 2021). The region's annual production of coal-based hydrogen lies at about 2.35 million tons of hydrogen (BJX, 2021b). A growing number of renewable hydrogen projects have also been established to restructure its local energy industry (CNPC, 2021). As discussed in Section 2.1, an important factor affecting the cost competitiveness of renewable hydrogen is the price of renewable energy. Hydrogen production in Ningxia Province, where renewable energy is becoming increasingly competitive (around 0.5~0.7 yuan/kw / US$ 0.078~0.11/kwh) (Economic Information Daily, 2021; Ningxia DRC, 2021), is well positioned as a result (China Coal Association, 2021; Meng et al., 2020)). In April 2020, the world's largest-scale demonstration project for hydrogen production based on solar power was launched (BJX, 2021b). It is expected to produce 300,000 tons of renewable hydrogen by 2025, according to the director of Ningdong industrial development center (Ningxia News, 2022). The produced hydrogen will be stored in fuel cells and used in the chemical industry or the public transport sector. By using renewable hydrogen to meet the hydrogen needs of the chemical industry and fuel cell vehicles, this project will help to reduce coal consumption in this base by around 25.4 million tons annually (China Coal Association, 2021; Meng et al., 2020).

Henan Province has only recently launched a new 'Hydrogen Corridor', in response to the national hydrogen development plan (Henan Government, 2021). This hydrogen corridor is planned to connect the hydrogen cluster in the Beijing-Tianjin-Hebei Region, the hydrogen cluster in the Pearl River Delta, and hydrogen value chains in Hong Kong (China Energy, 2022). Furthermore, since Zhengzhou, the capital city of Henan Province, has been a pilot city for the development of fuel cell vehicles, this corridor will advance innovation and manufacturing in the fuel cell vehicle sector(Finance Eastmoney, 2022).

2.3 The role of state-owned enterprises (SOEs) and the private sector in China's hydrogen economy

Both state-owned enterprises (SOEs) and privately-owned firms are exploring the opportunities of developing hydrogen value chains and contributing to the operation of hydrogen clusters located in those important regions. The following sub-section describes the most prominent activities being pursued by these two groups.

SOEs have to date invested primarily in large-scale and capital-intensive hydrogen projects, including the construction of hydrogen refueling stations and pipelines. Interviewees explained that these invest-ments may not necessarily be profitable, in spite of subsidies. However, such projects provide these energy SOEs with opportunities to explore the potential of hydrogen-related business. They have en-tered the hydrogen industry mainly by relying on their existing business (Downs, 2021). According to one interviewee, where hydrogen investments build on existing energy assets, the owners of these assets have become important players in its promotion. SOEs have dominated China's traditional en-ergy sectors and are likely to continue to influence the national economy by pursuing growth in the hydrogen sector (Zhao, Liu, & Jamasb, 2021; SPIC, 2019). In the following, activities of major energy SOEs are described in more detail (see Table 1 on the following page for an overview).

China National Petroleum Corporation (CNPC) and Sinopec are government-owned national oil and gas corporations. They are leveraging their expertise in the petrochemical sector as well as the oil and gas sector more broadly (Zhao, Liu, & Jamasb, 2021; Ling, 2019). CNPC, which owns most of the pipeline assets in China, is positioned to play a significant role in hydrogen transport (International Gas, 2017). Its pipeline design branch has established a new energy innovation center, which is developing new energy innovations for the hydrogen economy and provides services including consultancy, design, and contracting projects (BJX, 2021a). CNPC won the bid for the Dingzhou-Gaobeidian pipeline in Hebei Province (BJX, 2021a) and one of its subsidiaries built the Jiyuan-Luoyang pipeline in 2015 (Yang et al., 2021). It also facilitates hydrogen transport in the Beijing-Tianjin-Hebei Region and promotes hydrogen across the region (Yang et al., 2021).

Table 1 Contribution of key energy SOEs to China's hydrogen development

Hydrogen value Chains	Companies			
	CNPC	Sinopec	PipeChina	SPIC
Production	▪ Demonstration project for hydrogen production based on hydropower in Yumen in 2022	▪ Production of hydrogen from petrol-chemical products ▪ Produce green hydrogen in Xinjiang and Inner Mongolia		▪ Production of hydrogen based on solar power
Storage and transportation	▪ Construction of Dingzhou-Gaobeidian pipeline	▪ Construction of hydrogen refueling stations in hydrogen industrial clusters	▪ Plans to build hydrogen pipelines and to implement hydrogen blending in gas pipelines	▪ Deployment of first nation-wide project of hydrogen blended gas ▪ Plans to construct petrol-hydrogen-electricity stations
Use	▪ Hydrogen (conventional) use in refineries ▪ Promotion of hydrogen fuel cell vehicles in Beijing	▪ Plans to utilize renewable electricity-based hydrogens in refineries ▪ Promotion of hydrogen fuel cell vehicles in Guangdong province		▪ Promotion of hydrogen fuel cell vehicles in Yangtze River Delta and Hainan province

Source: Authors' own, based on company reports and media reports.

In 2020, China National Oil & Gas Piping Network Company (PipeChina) was established by the Chinese government to own and operate pipeline assets (Xinhua, 2021a). The establishment of PipeChina represents China's efforts to encourage third-party access to transmission networks (Reuters, 2019a). An analyst argues that PipeChina will play an increasingly important role in hydrogen transport such as low concentration hydrogen blending (Tu, 2020). Indeed, PipeChina has set up a subsidiary focusing on infrastructure construction in 2020 (Ofweek, 2022). This subsidiary will be responsible for the construction of hydrogen pipelines and hydrogen blending in gas pipelines, thus providing more accesses for hydrogen producers (GG-FC, 2021). It should be noted that CNPC owns a dominant share of PipeChina (around 29.9%) (East Money, 2020). Therefore, CNPC is very likely to continue influencing hydrogen transport through PipeChina.

Sinopec has the ambition of expanding its market share in the hydrogen sector by leveraging its status as the leading supplier of refined-oil and petrol-chemical products (China Petrol Association, 2019). The company is currently the largest hydrogen producer in China and can produce hydrogen from its chemical by-products or directly from coal and gas (Sinopec, 2021a). In 2020, Sinopec had the capacity to produce around 3.5 million tons of hydrogen, accounting for 14 percent of China's 2020 production (Sinopec, 2021b). The company also ventured into renewable hydrogen production in 2020 (Sinopect, 2021b) and has established operations in Xinjiang and Inner Mongolia (SASAC, 2021a). Sinopec's renewable hydrogen production plant in Xinjiang will provide climate-friendly hydrogen for chemicals production, thus helping to decarbonize chemical factories in Xinjiang (KAS, 2022). Sinopec is also a crucial player in the development of hydrogen infrastructure, and it announced in 2021 that it will build more than 1000 hydrogen refueling stations during the 14th five-year period (2021-2025) (China Energy, 2021c). Sinopec's Luoyang branch invested in the Jiyuan-Luoyang pipeline, and a subsidiary of Sinopec built the Baling-Changling hydrogen pipeline in 2014. The company has also been involved in developing infrastructure in different industrial clusters (China Center for International Economic Exchanges, 2021), leveraging its petrol-refueling network to this end (Energy Review, 2021). The company has been a frontrunner in the construction of hydrogen refueling stations in the Pearl River Delta (Ling, 2019) and built the country's first petrol-hydrogen combined station in Foshan, Guangdong in July 2019 (SASAC, 2019). The company is also engaged in the construction of hydrogen refueling stations in Beijing-Tianjin-Hebei Region and the Yangtze River Delta (Sinopec, 2020) and aims to continue to advance the construction of hydrogen refueling stations and storage facilities, mainly by repurposing existing petrol/gas stations (Sinopec, 2020). In the downstream, Sinopec launched in 2020 the first phase of a major hydrogen fuel cell hydrogen supply project (Sinopec, 2021c). It is so far the biggest hydrogen supply project in Guangdong Province and will meet demand for hydrogen in the western part of Guangdong Province (SASAC, 2021b).

Hydrogen development is also an important part of the State Power Investment Corporation's (SPIC) corporate development plan. The State Power Investment Corporation (SPIC) is building on existing capacities in the power sector to explore opportunities in the field of electricity-based hydrogen production. The company focuses on coordinating the development of renewable power with electricity-based hydrogen production (SPIC, 2020a; SPIC, 2021a). Since 2019, SPIC and its subsidiaries in Ningxia have developed the National Comprehensive Demonstration Project for Hydrogen Production by Solar Water Electrolysis to support the development of hydrogen value chains (SASAC, 2020; BJX, 2021b). This project has been in commercial operation since July of 2021 (SPIC, 2021b). In 2019, Siemens and SPIC signed a MOU establishing cooperation in the field of renewable hydrogen (Sina, 2020). To implement this MOU, the hydrogen subsidiary of SPIC signed another MOU with Siemens Energy in 2020 for the delivery of a PEM electrolyzer to supply hydrogen in the Beijing Winter Olympics (Radowitz, 2020). In the mid-stream, SPIC also realized the first nation-wide project for hydrogen blending in a natural gas pipeline in 2019 (BJX, 2019). Its success suggests that related solutions can be expanded in the near future (Wang, 2021). With respect to downstream use, SPIC promotes the application of hydrogen fuel cell vehicles in Ningbo (Yangtze River Delta) and also meets the demand for hydrogen in public transport in Hainan, South China (SPIC, 2020b; SPIC, 2021a). Furthermore, to advance hydrogen technology innovation, SPIC set up the Hydrogen Energy Technology Development Corp. in 2017 to work on the R&D and manufacturing of equipment for water electrolysis and fuel cells (SPIC, 2021a).

Private companies play various roles in developing hydrogen value chains, from upstream to transport to downstream. Upstream, private companies, such as ALLY HI-TECH, Ningxia Baofeng Energy and Longi, are advancing hydrogen production technology (e.g., the manufacturing of electrolyzers). In the mid-stream, private companies, such as CIMC Enric, FULLCYRO, Hongda Xingye Co.Ltd., and Jiangsu Guofu Hydrogen Energy Equipment Co. Ltd. (GUOFUHEE), are emerging in the field of equipment manufacturing and innovation for hydrogen storage and transport. FULLCYRO and Hongda Xingye Co.Ltd. are pioneers in the field of liquid hydrogen storage. In the downstream, private companies, for example, Wuxi BEST, Nanning Baling Technology and YAPP Automotive, are man-ufacturing elements of fuel cells or developing fuel cell vehicles. YAPP Automotive is developing on-board hydrogen storage to accelerate the use of fuel cell vehicles.

Foreign companies have been actively contributing to China's hydrogen development as well. The *Catalogue of Industries for Encouraging Foreign Investment 2020* included projects of hydrogen production, storage, transport, liquification, the manufacturing of hydrogen equipment, and the construction of hydrogen refueling stations (NDRC, 2020). The *Special Management Measures for the Market Entry of Foreign Investment (Negative List) (2021 Version)* does not impose restrictions on the involvement of foreign parties in hydrogen projects (NDRC & MOFCOM, 2021). For instance, Bosch and Ballard produce components of fuel cells in China. Toyota and Hyundai have also been investing in the production of fuel cell vehicles.

Most of the private companies are investing in less capital-intensive hydrogen projects such as equipment manufacturing or R&D of specific hydrogen technologies, especially in the fuel cell industry (Yang & Gao, 2020; Zhao, Liu, & Jamasb, 2021; China Hydrogen Alliace, 2019). In contrast to SOEs, they do not rely on fixed assets such as petrol or gas-refueling stations to support the development of hydrogen value chains. Important areas of private sector engagement include research in the field of liquid hydrogen, equipment and services for hydrogen refueling stations and the production of electricity-based hydrogen (KAS, 2022). Hongda Xingye Co.Ltd., Jiangsu Guofu Hydrogen Energy Equipment Co. Ltd. (GUOFUHEE) and Ningxia Baofeng Energy, respectively, are important actors in those important areas and are frequently mentioned in media reports.

Hongda Xingye, a publicly listed company in the industry of energy and resources, has played a crucial role in the R&D of liquid hydrogen (Hongda Xingye Co., 2021a). In April 2020, the company built the state's first commercial liquid hydrogen plant in Inner Mongolia, serving Guangzhou in the Pearl River Delta (Hongda Xingye Co., 2021b). Hongda Xingye Co.Ltd. has also launched projects for the construction of mobile liquid-hydrogen refueling stations that will serve fuel cell buses (Hongda Xingye Co., 2021c).

GUOFUHEE was established in 2016 to specifically provide hydrogen-related services and components (e.g. equipment for hydrogen refueling stations) (GUOFUHEE, 2021c). GUOFUHEE has supplied equipment for the construction of hydrogen refueling stations built by Sinopec in the Beijing-Tianjin-Hebei Region (GUOFUHEE, 2021d), the Pearl River Delta (GUOFUHEE, 2021e), and the Yangtze River Delta (GUOFUHEE, 2021f). In the Yangtze River Delta, the company established a hydrogen industrial base in Zhangjiagang, Jiangsu Province (GUOFUHEE, 2021g). In the Pearl River Delta, GUOFUHEE is engaged in R&D for the direct production of electricity-based hydrogen within hydrogen refueling stations (GUOFUHEE, 2021h) and for the advancement of technological innovation for the storage, transport, and use of liquid hydrogen (BJX, 2021c).

Ningxia Baofeng Energy, a crucial player in the Ningdong Energy and Chemical Base, is engaged in the development of renewable hydrogen production. It has established an electrolyzer with a capacity of 20,000 standard cube meters, powered by a 200MW solar PV power plant (CFEJ, 2021; IRENA, 2021). The project has a production volume of 160 million cubic meters of hydrogen (IRENA, 2021). According to its Social Sustainability Report, Baofeng plans to engage in broader activities aimed at promoting the use of hydrogen to reduce around 445,000 tons of CO_2 emissions and the consumption of 254,000 tons of coal every year (Baofeng Energy, 2021; Climate Change Data Portal, 2021; SASAC, 2020).

3 China's institutional environment governing hydrogen development

As China's supreme governmental body, the State Council sets the broad goals of hydrogen development, as manifested in various five-year plans. The National Development and Reform Commission (NDRC) is responsible for the drafting of the five-year plans and holds the main responsibility for governing China's energy sector with its subordinate agency, the National Energy Administration (NEA). Together with the Ministry of Industry and Information Technology (MIIT) and the Ministry of Science and Technology (MOST), NDRC also plays a central role in promoting innovation and industrial development in hydrogen. The Ministry of Housing and Urban-Rural Development (MHURD) develops regulations for hydrogen infrastructure, such as hydrogen refueling stations. The Standardization Administration of the People's Republic of China (SAC) sets technical standards. The Ministry of Finance (MOF) oversees the design of subsidy schemes for supporting hydrogen development. China Development Bank (CDB), China's largest policy bank, has not issued any hydrogen-specific policies. However, CDB has declared its intention to support green transport, namely increasing the use of new energy vehicles (NEVs).

Local governments have been crucial players at the early stage of developing hydrogen in China, enabling the central government to 'test the waters' in the hydrogen sector. The provincial or municipal governments, or sometimes the local branches of the NDRC, are responsible for formulating hydrogen development plans in their jurisdictions. Local governments work closely with various local branches of the respective central governments to promote different dimensions of the hydrogen economy. SOEs also cooperate with local administrations to implement their hydrogen development plans.

This section provides an overview of the relevant institutional environment for the development and promotion of a hydrogen economy in China. It first identifies the main governmental bodies governing different dimensions of China's hydrogen economy and briefly outlines their role. This also includes China Development Bank, China's most prominent "policy bank", and major SOEs, given their close links to responsible ministries. Next, it provides an overview of local hydrogen governance in China. Finally, it discusses the regulatory environment governing SOEs in the hydrogen sector.

3.1 National hydrogen governance

The **State Council** stands at the top of the government structure and in accordance with the Communist Party of China sets the broad goals for hydrogen development, as manifested in various five-year plans (The CPC Central Committee & State Council, 2021a; NEA, 2020a). The **National Development and Reform Commission** (**NDRC)**, directly under the State Council, is the leading ministry that governs China's energy sector with its subordinate agency, the National Energy Administration (NEA). In accordance with the State Council, it has issued the *Mid-and-Long-Term Hydrogen Industrial Development Plan (2021-2035)* (2022) (herein after the national hydrogen development plan) to provide overall guidance for the development of hydrogen. NDRC is also tasked with the promotion of technological innovation in low-carbon hydrogen production, storage, transport, and application (especially in fuel cell vehicles and energy storage) (see section 4.5) (NDRC & NEA, 2021; NDRC & NEA, 2016). NDRC also takes the lead in formulating industry guidance or catalogues that list the hydrogen industry as a green or 'encouraged' industry (NDRC et al., 2019). NDRC's industry guidance or catalogues reflect the governmental priorities of industrial development and give indications on whether the certain industry can benefit from policy support (see section 5). In collaboration with the People's Bank of China (PBOC) and China Securities and Regulatory Commission (CSRC), NDRC also adjusts and revises the *Catalogue of Projects Supported by Green Bonds*, which determines the eligibility of technologies for financing via green bonds (PBOC et al., 2020; PBOC et al., 2021). The **National Energy Administration** (**NEA)** is tasked with the drafting of laws and regulations in the energy sector (State Council, 2014a). NEA has included the promotion of hydrogen technological innovation and industrial development in its working plan (NEA, 2020a). The **State-owned Assets Supervision and Administration Commission (SASAC) of the State Council**, which reports directly to the State Council, is responsible for supervising and managing state-owned enterprises (SOEs), including those in the energy sector. It can thus influence SOEs hydrogen-related strategies and plans.

The **Ministry of Industry and Information Technology (MIIT)** has played a leading role in promoting hydrogen use in public transport. Since 2012, MIIT has led the 'interdepartmental coordination mechanism for developing the energy efficiency and new energy automobile industry' in which hydrogen fuel cell vehicles are included (State Council, 2012). Within this mechanism, MIIT has been working with NDRC, the Ministry of Science and Technology (MOST), the Ministry of Transport (MOT), the Ministry of Housing and Urban-Rural Development (MHURD), the State-Owned Assets Supervision and Administration Commission (SASAC) and the Ministry of Finance (MOF) to coordinate the policies of promoting NEVs with the policies of energy, transport and information technology (State Council, 2012; State Council 2020b). The leaderships of these central ministries have meetings annually to identify their missions. For example, in 2019, their meeting focused on the safe use of NEVs (e.g. the safety standards of fuel cells) (EVPartner, 2019). Their latest 2022 inter-ministerial meeting led by MIIT highlighted the following goals in the sector of NEVs, which includes fuel vehicles: implementing *Industrial Development Plans of New Energy Vehicles (2021-2035)* (2020), improving financial support mechanisms to NEVs (e.g. preferential tax policies), advancing the construction of refueling facilities, and designing the path of the green development of China's automobile industry (MIIT, 2022). MIIT also participates in setting the technical standards of hydrogen fuel cell vehicles (as discussed in more detail in section 4.3) (MIIT, 2020c; MIIT, 2021).

The **Ministry of Science and Technology (MOST)** supports hydrogen development by promoting technology innovation in the sector as well as the use of hydrogen fuel cell vehicles and the construction of hydrogen refueling stations, in collaboration with other ministries (e.g. MIIT). The program of 'National Science and Technology Major Project of the Ministry of Science and Technology of China' was established to help China boost its industrial development (State Council, 2006).[2] Since the implementation of the *13th Five-Year Plan* (2016 to 2020), it has included renewable hydrogen production, safe hydrogen storage and transport, highly-efficient hydrogen use, and the core technology of hydrogen fuel cell vehicles (MOST, 2021a).

The **Ministry of Housing and Urban-Rural Development (MHURD)** develops technical regulations for parts of the hydrogen infrastructure (MHURD, 2021). The **Standardization Administration of the People's Republic of China (SAC)** releases hydrogen technical standards including those for liquid hydrogen storage and hydrogen fuels, with support from different industrial associations or research institutes (e.g., China Automotive Engineering Research Institute) (SAC, 2021a). The **Ministry of Finance (MOF)** oversees the design of subsidy and award mechanisms for supporting hydrogen development (MOF, 2015). Since 2014, MOF, in coordination with MOST, MIIT and NDRC, has reviewed the application of pilot cities or city clusters for rewards for building qualified hydrogen refueling stations (see section 5) (MOF et al., 2014). Since 2016, MOF, with the support from MOST, MIIT and NDRC, has been responsible for designing the subsidy scheme to promote the use of NEVs (MOF et al., 2015; MOF et al. 2020a; MOF et al. 2019). MOF, in collaboration with MIIT, MOST, NDRC and NEA, is also tasked with granting rewards to pilot city clusters that promote the use of NEVs (e.g. Beijing, Shanghai, Foshan) (MOF, MIIT, MOST, NDRC & NEA, 2020).

China Development Bank (CDB), China's largest policy bank, has not issued any hydrogen-specific policies. However, CDB has declared its intention of supporting green transport, namely increasing the use of NEVs (China Development Bank, 2020). Therefore, promoting the application of hydrogen fuel cell vehicles could be supported by CDB. Following a meeting on August 6th, 2020, the Party Secretary of SPIC and the head of CDB announced that CDB would enhance its support to hydrogen projects of SPIC (SPIC, 2020c). In 2021, CDB issued the *Working Plan of Supporting the Achievement of the Objectives of 'Carbon Peaking and Carbon Neutrality' in the Energy Sector* (2021), pledging subsidized loans of CNY 500 billion (around US$75.1 billion) for various applications in the green energy sector, including hydrogen. Table 2 on the following page provides a summary of major central government entities and their role in governing China's hydrogen sector.

Supported and supervised by NDRC, MOST, MIIT, MOF, MOT, NEA and SASAC, the China Hydrogen Alliance was established in 2018 as 'a high-end communicational and cooperative platform' (China Hydrogen Alliance). The establishment of this alliance was led by China Energy Corporation

[2] The draft of the National Plan of Mid-and-Long Term Science and Technology Development (2021-2035) is still being processed by the Ministry of Science and Technology of the People's Republic of China (MOST).

Table 2: Major central government entities governing China's hydrogen sector

Government entity	Main responsibilities
State Council	▪ Sets the broad goals for hydrogen development, as manifested in various five-year plans
National Development and Reform Commission (NDRC)	▪ Formulates energy development plans (e.g. the national hydrogen development plan) with NEA ▪ Formulates industry guidance or catalogues that list the hydrogen industry as a green or 'encouraged' industry
National Energy Administration (NEA)	▪ Subordinated to NDRC and assists NDRC in governing the energy sector ▪ Drafts laws and regulations related to the energy sector, including hydrogen
State-Owned Assets Supervision and Administration Commission (SASAC) of the State Council	▪ Supervises the management of energy SOEs
Ministry of Industry and Information Technology (MIIT)	▪ Promotes the use of new energy vehicles, including hydrogen fuel cell vehicles ▪ Participates in setting the technical standards for hydrogen infrastructure ▪ Leads interdepartmental coordination mechanism for developing the new energy automobile industry, including fuel cell vehicles
Ministry of Science and Technology (MOST)	▪ Promotes hydrogen-related technologies
Ministry of Finance (MOF)	▪ Grants subsidies and rewards for the use of hydrogen fuel cell vehicles
Ministry of Housing and Urban-Rural Development (MHURD)	▪ Formulates regulation for hydrogen infrastructure
Ministry of Transportation (MOT)	▪ Promotes the use of hydrogen fuel cell vehicles
China Development Bank (CDB)	▪ Provides financing for green transport and new energy vehicles, including fuel cell vehicles
Standardization Administration of the People's Republic of China (SAC)	▪ Develops technical standards for hydrogen infrastructure

Source: Authors' own.

and its daily operation is supported by other leading energy companies, universities and research institutes (China Hydrogen Alliance).[3] The alliance aims to facilitate communication, cooperation and resources pooling in China's hydrogen sector. More specifically, the alliance focuses on advancing the R&D of hydrogen energy and hydrogen fuel cells, the manufacturing and standard-setting of key equipment, the support to hydrogen investments or demonstration projects, and fostering a favorable social environment for hydrogen development (China Hydrogen Alliance). It issued the *Standard and Evaluation of Low-carbon Hydrogen, Clean Hydrogen and Renewable Hydrogen* in 2020 (discussed in section 4) (China Hydrogen Alliance, 2020), which defines benchmarks for the carbon intensity of different types of hydrogen (China Hydrogen Alliance, 2021a). In addition, according to the national hydrogen development plan, the government intends to create an inter-ministerial coordinating mechanism for hydrogen industrial development. It will be established to address challenges of hydrogen development and to formulate hydrogen policies and regulations, according to the national hydrogen development plan (NDRC, 2022). What ministries will be involved in this mechanism and how they are going to design the policy and regulatory framework remains open.

3.2 Local hydrogen governance

Local governments have been crucial players at the early stage of developing hydrogen in China, enabling the central government to 'test the waters' in the hydrogen sector (Yang & Gao, 2020). The provincial or municipal governments, or sometimes the local branches of the NDRC, are responsible for formulating hydrogen development plans for their geographical areas (Qingdao DRC, 2020; Beijing Municipal Bureau of Economy and Information Technology, 2021). They also help central ministries with the implementation of hydrogen-related policies (e.g. the rewards for pilot cities developing fuel cell vehicles). More specifically, the local administration of NDRC shoulders the mission of developing a diversified hydrogen supply system, with the support from the local administration of MIIT (Tianjin Government, 2020; Guangdong Government, 2018; Dalian Government, 2018). To minimize the cost of hydrogen production, in Guangdong Province (located in Pearl River Delta), Chengdu (located in South-West China) and Inner Mongolia (located in North China), the local branches of NDRC are also responsible for offering discounted electricity rates to hydrogen production based on renewable energy (see section 5.4) (Chengdu Government, 2020; Guangdong Government, 2018; Inner Mongolia Government, 2022) . This support mechanism is largely arranged by local branches themselves at this stage, as NEA is still drafting related policies (BJX, 2022a).

By coordinating with the local administration of NDRC and NEA (NDRC and NEA, 2016), the local administrations of MOST are tasked with advancing technology innovation in the fields of hydrogen production, storage, transport and application, with a particular focus on fuel cells (Chengdu Government, 2020; Tianjin Government, 2020; Guangdong Government, 2018; Jiaxing Government, 2021; Dalian Government, 2018). For example, the Guangdong branch of NDRC works with the provincial branches of MOST to promote technological advancement in hydrogen fuel cell vehicles (Guangdong Government, 2018). The local administrations of MIIT focus on establishing industrial clusters around hydrogen fuel cells, encourages companies to strengthen their manufacturing capacities and promotes the use of hydrogen fuel cell vehicles (Tianjin Government, 2020; Jiaxing Government, 2021). The

[3] The leading energy companies include Sinopec, State Grid, China Three Gorges Corporation, China Iron & Steel Research Institute Group., China Shipbuilding Industry Corporation, BP China. The Universities and research institutes include Tongji University, Harbin Institute of Technology, North China Electric Power University, Tsinghua University, etc. include Universities and research institutes include Tongji University, Harbin Institute of Technology, North China Electric Power University, Tsinghua University, etc.

local traffic management administrations are also involved in facilitating hydrogen use in automobiles. They handle the registration of hydrogen-based fuel cell vehicles and encourage the purchase of these vehicles (Chengdu Government, 2020; Tianjin Government, 2020; Guangdong Government, 2018).

The local finance administrations play crucial roles in granting subsidies to or providing various funds for hydrogen storage, technology innovation, the construction of hydrogen refueling stations, and the manufacturing of hydrogen fuel cells (Chengdu Government, 2020; Tianjin Government, 2020; Guangdong DRC, 2016; Foshan DRC, 2020a; Jiaxing Government, 2021; Shanghai Government, 2021). For instance, the municipal finance bureau of Chengdu has invested in industrial funds to support the development of hydrogen value chains. The local finance administration of Guangzhou, with the support from the administrations of NDRC, MOST and MIIT, should help companies to diversify funding sources (Guangzhou Government, 2020).

Several local administrative departments jointly govern the construction of hydrogen infrastructure. As there has so far been no national regulation that governs hydrogen refueling stations, the local governance of hydrogen refueling stations varies. Investors need to turn to different local administrative departments to undergo various administrative procedures. These local administrative departments usually include the local planning and natural resources administration, the local branches of MHURD, the local gas administration, the local branches of the Ministry of Ecology and Environment (MEE), and the local branches of SAC. These departments work together to review the application for land permits for hydrogen-related infrastructure (Zhangjiakou Government, 2020; Guangdong Government, 2018; Foshan Housing and Urban Design Administration, 2018; Fuzhou Government, 2020; Shanghai Government, 2021; Weifang Government, 2019). Typically, the local emergency management administration, the local branches of MHURD, NDRC, MEE and SAC are responsible for the final approval of hydrogen refueling stations (Zhangjiakou Government, 2020; Foshan Housing and Urban Design Administration, 2018; Fuzhou Government, 2020; Suzhou Government, 2021). The local emergency management administration is also responsible for drafting the safety rules of and standards for hydrogen refueling stations (Zhangjiakou Government, 2020).

3.3 The enabling environment for SOEs' engagement in the hydrogen sector

The potential promotion in the political career incentivizes the top management of SOEs to comply with the Party's policies (State Council, 2017; Lin & Milhaupt, 2013; Chen et al., 2020). This includes the development of the hydrogen economy as well as promoting carbon neutrality and reducing China's reliance on foreign oil and gas supply by developing renewable-based hydrogen. To minimize the cost of green hydrogen production, the local branches of State Grid or China South Power Grid are expected to work with the local branches of NDRC to develop supportive electricity prices for hydrogen production, as stipulated in, for example, the *Guidance on Promoting the High-Quality Development of the Hydrogen Industry in Chengdu* (2020) (Chengdu Government, 2020).

SOEs also cooperate with local administrations to implement their hydrogen development plans (KAS, 2022). According to *the Implementation Plans of the Hydrogen Development Plan in Beijing (2021-2025)*, electricity and energy SOEs will produce hydrogen at a large scale, build hydrogen infrastructure, and promote cross-region hydrogen transport in the Beijing-Tianjin-Hebei Region (Beijing Municipal Bureau of Economy and Information Technology, 2021). This is embedded in the strategic cooperation agreements of central electricity and energy SOEs with the governments of Hebei Province, Beijing, and Tianjin (Beijing Municipal Bureau of Economy and Information Technology, 2021).

The municipal government of Zhangjiakou worked with various SOEs, including China Energy Investment Group Co., Hebei Construction and Investment Group Co. and Sinopec, to accelerate the construction of hydrogen refueling infrastructure ahead of the Beijing Winter Olympics 2022 (Zhangjiakou Government, 2020; the District Government of Chongli in Zhangjiakou, 2021; Zhangjiakou Government, 2020; NEA, 2021). *Tianjin’s Hydrogen Development Plan (2020 – 2022)* states that SOEs should support the replacement of existing vehicles with hydrogen fuel cell vehicles (Tianjin Government, 2020; Dalian Government, 2018; Guangdong DRC, 2016). Local governments in Dalian, Tianjin and Guangdong Province provide SOEs with incentives for developing hydrogen fuel cell vehicles (Dalian Government, 2018; Guangdong DRC, 2016; Tianjin Government, 2020). In Guangdong Province in the Pearl River Delta, the operation of fuel cell vehicles is exempted from the evaluation of SOEs’ business performance (Guangdong DRC, 2016) to give executives the ability to take on riskier projects without endangering their career prospects (SASAC, 2016). Furthermore, local branches of SASAC have encouraged SOEs to create industrial funds to attract private capital in areas such as NEVs (Guangdong DRC, 2016; Jiaxing Government, 2021). Accordingly, similar to their roles in the traditional energy sector, energy SOEs contribute to the implementation of hydrogen policies.

4 Hydrogen-related policy objectives

Promotion of the hydrogen sector in China dates back to 1986 and has strongly focused on fuel cells and related refueling infrastructure. Policymaking at the local level is more advanced than that at the central level. Before the issuance of the Mid-and-Long-Term Hydrogen Industrial Development Plan in March 2022, local governments had already issued hydrogen development plans, mainly focused on fuel cell vehicles. The national hydrogen development plan identifies hydrogen's broader role in decarbonizing energy consumption and contributing to achieving carbon neutrality in hard-to-abate sectors, including the steel, transport and chemical industry. It aims to produce 100,000 to 200,000 tons of renewable hydrogen per year by 2025 and aims to thereby reduce 1 to 2 million tons of CO_2 *emissions annually. Despite these ambitions to promote hydrogen production from renewable power, the PRC Energy Law (Draft) does not distinguish different forms of producing hydrogen. Hydrogen development plans adopted by local governments include both ambitious goals to expand renewable hydrogen and plans to scale up conventional hydrogen production in the chemical sector.*

The plan also reconfirms China's longstanding aim to promote fuel cell vehicles and related technologies. By 2025, the central government is targeting 50,000 fuel cell vehicles. Building hydrogen refueling stations has figured in local hydrogen development plans since at least 2015. The role of hydrogen for the decarbonization of industry has only recently been addressed by Chinese policy makers. The national hydrogen development plan includes the aim to use renewable hydrogen as a source of industrial heat and to replace fossil fuels in ammonia production, methanol production and the refinery sector.

The hydrogen economy is also seen as an area with important potential for innovation and industrial development. While the government has emphasized fuel cells and fuel cell vehicles in the past, it has recently increased its attention to other segments of the hydrogen value chain. The national hydrogen development plan aims to improve the efficiency of hydrogen production based on renewable energy and to scale up and increase the productivity of related production equipment. The plan also stresses the importance of developing materials for hydrogen storage, which is viewed as a potential bottleneck for the development of China's hydrogen sector.

Finally, the hydrogen development plan has identified the development of technical standards as an important priority. In 2020, the China Hydrogen Alliance had already issued the Standard and Evaluation of Low-carbon Hydrogen, Clean Hydrogen and Renewable Hydrogen (2020), which defines different types of hydrogen based on their production process and their CO_2 *emissions. The* CO_2 *benchmarks for clean and renewable hydrogen are equivalent to those of European schemes, while the benchmark for low-carbon hydrogen is significantly above the estimated* CO_2 *emission intensity of hydrogen based on natural gas. These standards do not serve as the reference for any government communication at this stage.*

The following section highlights China's policy objectives and their evolution over time as they relate to different segments of the hydrogen value chain as well as broader policies to decarbonize its energy system, to diversify its energy mix, and to boost industrial development. To achieve carbon neutrality, China aims to boost renewable hydrogen production and to utilize hydrogen for energy storage and in fuel cell vehicles. The establishment of such hydrogen value chains also represents another economic growth point and the chance of reforming China's industrial structure.

4.1 General objectives for hydrogen development in China's Five-Year Plans

The promotion of developing fuel cells by the government dates back to 1986. In the past 15 years, the hydrogen sector, with a particular emphasis on fuel cells and related refueling infrastructure, has received increasing attention. In a first step in 2006, the State Council listed hydrogen storage and transport as an emerging technology, according to the *National Mid-and-Long Term Development Plan of Science and Technology* (2006-2020). The *Planning for the Development of the Energy-Saving and New Energy Automobile Industry* (2012-2020) identified the importance of hydrogen production, refueling, storage and transport as the basis for the development of fuel cell vehicles.

In a second major step, the *13th Industrial Development Plan of Strategic Emerging Industries* (2016) identified hydrogen production and storage and hydrogen refueling stations as strategic emerging industries, demonstrating the central government's aim to pursue industrial leadership in the sector (State Council, 2016). In this vein, the *Action Plans of Energy Technological Revolution and Innovation (2016-2030)* adopted by NEA and MOST pointed out priority areas for the promotion of innovation in the hydrogen sector (NDRC & NEA, 2016). The *13th Specific Plan of Scientific and Technological Innovation in Transportation* (2017) identified hydrogen fuel cell vehicles (MOST and MOT, 2017) as well as hydrogen storage and refueling, both of which are important for the use of hydrogen fuel cell vehicles, as policy priorities (MOST and MOT, 2017). The *Governmental Work Report on National Economic Development* presented by State Council in 2019 promoted the construction of hydrogen refueling stations (State Council, 2019), attracting increasing attention from local governments.

In 2021, the *Outline of the People's Republic of China 14th Five-Year Plan for National Economic and Social Development and Long-Range Objectives for 2035* (2021) highlighted the hydrogen industry as a 'future' emerging industry and encouraged R&D in the field of hydrogen energy (The CPC Central Committee & State Council, 2021a). In the same year, the *14th Five-Year Plan of Energy Technology Innovation* (2021) adopted by NEA and MOST updated the priority areas of hydrogen technology innovation (NEA and MOST, 2021).

In addition to the active promotion of innovation in hydrogen technology, China has also shifted its perception of hydrogen as a dangerous chemical to hydrogen as a form of energy for the reduction of fossil-fuel use and for meeting carbon neutrality targets. Hydrogen will be officially recognized as an energy carrier if the *Energy Law of PRC (2020 Draft)* comes into effect (NEA, 2020b). According to the *Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy* (2021), developing hydrogen value chains will help achieve the goal of accelerating the establishment of a clean, efficient, low-carbon and safe energy system and will increase the supply of non-fossil fuels (The CPC Central Committee & State Council, 2021b). In the *Notice by the State Council of the Action Plan for Carbon Dioxide Peaking Before 2030* (State Council, 2021), the State Council disclosed the goal of piloting the application of hydrogen in the chemical, metallurgy, transport and construction industry to reduce carbon emissions.

Figure 5 Hydrogen-related Five-Year Plans and relevant targets since 2016

The 13th Industrial Development Plan of Strategic Emerging Industries (2016)

- Promote the development of the technology of on-board hydrogen storage, hydrogen production and hydrogen refueling
- Advance the construction of hydrogen refueling stations
- Promote R&D for the hydrogen fuel engine

The 13th Specific Plan of Scientific and Technological Innovation in Transportation (2017)

- Accelerate R&D for key equipment of fuel cell vehicles
- Advance the construction of hydrogen refueling facilities
- Promote R&D for hydrogen refueling and storage

Outline of the People's Republic of China 14th Five-Year Plan for National Economic and Social Development and Long-Range Objectives for 2035 (2021)

- Recognize the hydrogen energy industry as a 'future industry' and focus on the R&D for hydrogen energy

The 14th Five-Year Plan of Modern Energy System (2022)

- Significantly improve innovation in hydrogen technology
- Formulate safety standards for hydrogen energy
- Overcome the technological difficulties of hydrogen production based on renewable energy, hydrogen storage, hydrogen use including hydrogen fuel cells
- Promote the demonstration of hydrogen production based on solar and wind power
- Encourage hydrogen use in stabilizing the use of renewable energy power

The 14th Five-Year Plan of Renewable Energy Development (2022)

- Promote green hydrogen production as a way of using renewable energy on a large scale
- Promote green hydrogen use in transportation, the chemical industry and metallurgy
- Strengthen the technology innovation for electrolyzers

Source: Authors' own, based on hydrogen-related five-year plans.

The 14th Five-Year Plan of Modern Energy System (2022) provides additional details of hydrogen development. It articulates the need for drafting safety standards for hydrogen as an energy carrier. It also emphasizes the importance of producing hydrogen from renewable energy resources and of hydrogen as a storage medium in an energy system dominated by renewables (NDRC & NEA, 2022a). This was reconfirmed in the *Notice on the Implementation Plan of Developing New Energy Storage During the 14th Five-Year Period* (2022) and *14th Five-Year Plan of Renewable Energy Development* (NDRC et al., 2022) (see Figure 5 on the previous page for an overview of hydrogen-related targets in China's Five-Year Plans since 2016).

Finally, the *Mid-and-Long-Term Hydrogen Industrial Development Plan* published in March 2022 highlights the importance of hydrogen for developing a safe and climate-neutral energy supply and its potential contribution to national economic development. According to the plan, hydrogen will help decarbonize energy consumption and contribute to achieving carbon neutrality in hard-to-abate sectors, including the steel, transport and chemical industry. Overcoming remaining technological barriers in hydrogen value chains is seen as an opportunity to foster economic growth and low-carbon industrial development. It further stresses the importance of international cooperation within the Belt and Road Initiative (BRI) to foster hydrogen development and the advancement of technology and safety standards in the sector (NDRC, 2022) (see Figure 6 on the following page for an overview of the main goals of the plan).

4.2 Objectives for the development of hydrogen supply

China aims to increase the percentage of renewable hydrogen in its future energy system. In *the 14th Five Year Plan for a Modern Energy System* (2022), NDRC and NEA announced that hydrogen production from solar and wind power represented an important avenue for establishing a low-carbon energy system (NDRC & NEA, 2022a). By 2025, China seeks to establish a hydrogen supply system based on hydrogen from industrial by-products and renewable hydrogen to reduce 1 to 2 million tons of CO_2 emissions annually (NDRC, 2022). The *Mid-and-Long-Term Hydrogen Industrial Development Plan* explicitly advances renewable hydrogen, aiming to produce 100,000 to 200,000 tons of renewable hydrogen per year by 2025 (NDRC, 2022). The plan does not make any reference to CCUS technologies to reduce the carbon footprint of hydrogen production. According to the China Hydrogen Alliance, China's demand for hydrogen is predicted to reach 30 million tons by 2025, while the Beijing municipal government anticipates that China's demand for hydrogen could reach up to 60 million tons. Therefore, renewable hydrogen can hardly meet a large portion of demand for hydrogen by 2025. By 2030, according to this national hydrogen development plan, China aims to establish a comprehensive renewable hydrogen production and supply system (NDRC, 2022). After 2030, securities analyst predicts that renewable hydrogen industry will develop rapidly with corresponding cost reductions (Everbright Securities, 2022a). By 2035, China's hydrogen value chains are targeted to meet the increased demand for climate-neutral hydrogen in transport, energy storage and industrial development (NDRC, 2022). According to the China Hydrogen Alliance, renewable hydrogen will represent 15 and 70 percent of hydrogen supply, respectively by 2030 and 2050 (Everbright Securities, 2022b).

Before issuing the national hydrogen development plan, the Chinese government had already supported pilot city clusters for the promotion of fuel cell vehicles to explore options for renewable hydrogen production and to increase renewable hydrogen use in fueling automobiles (MOF et al., 2020a; Chongqing Economic and Information Commission, 2020). *The 14th Five-Year Plan of Renewable Energy Development* (2022) further explains that renewable hydrogen production will be established in places where the cost of generating renewable electricity is low and where there have been pilot applications of hydrogen storage, transport and use (NDRC et al., 2022).

Figure 6 The Mid-and-Long-Term Hydrogen Industrial Development Plan (2021-2035)

Recognizes hydrogen energy as a crucial source of China's future energy supply

Hydrogen use to decarbonize final energy consumption

- Development of renewable electricity-based hydrogen
  - 100,000-200,000 tons per year by 2025
- Ensure the safe use of hydrogen
- Use of hydrogen fuel cell vehicles
  - 50,000 hydrogen fuel cell vehicles by 2025
- Expansion of hydrogen use in the refinery and chemical industry and exploration of hydrogen use in metallurgy
- Support hydrogen as storage for solar/wind power and hydrogen fuel cells

Hydrogen infrastructure

- Explore the demonstration of hydrogen blending in gas pipelines or hydrogen pipelines
- Refurbish the current petrol-/gas-refueling stations into hydrogen refueling stations

Hydrogen industry as a strategic emerging industry

- Improve technology innovation, such as R&D for PEM fuel cells and increase the efficiency of storing high-pressure gaseous hydrogen
- Formulate quality and safety standards for hydrogen production and use, standards for key equipment, hydrogen refueling stations, hydrogen as energy carriers and fuel cell vehicles

International collaboration

- International cooperation for equipment, technology and the formulation of global standards
- Strengthen cooperation in the Belt and Road Initiative

Source: Authors' own, based on NDRC, *The Mid-and-Long-Term Hydrogen Industrial Development Plan (2021-2035)* (《氢能产业发展中长期规划（2021-2035 年）》) (2022).

Despite these ambitions to promote hydrogen production from renewable power, the *PRC Energy Law (Draft)* does not distinguish different forms of producing hydrogen. Moreover, both the central government and local governments refer to 'hydrogen' and 'green hydrogen' without explicitly defining the terms. When referring to the use of hydrogen as a medium for storing renewable energy power, it is implicitly clear that this translates into support for the development of renewable hydrogen production. However, China's hydrogen policy has yet to establish mechanisms to regulate the sources or carbon footprint of hydrogen. This ambiguity is mirrored in plans at the local level.

Hydrogen development plans adopted by local governments include both ambitious goals to expand renewable hydrogen and plans to scale up conventional hydrogen production in the chemical sector. The shares of renewable hydrogen production and production of hydrogen from other sources vary in different regions. Renewables-rich provinces such as Sichuan Province emphasize the development of renewable hydrogen. Coal-rich provinces or provinces that have mature chemical industries such as Shandong Province and Shanxi Province still mainly pursue the production of hydrogen from coal or industrial by-products. Provinces with both rich renewables and coal are developing hydrogen from all sources, such as Ningxia Province and Autonomous Region of Inner Mongolia.

In terms of renewable hydrogen production, Beijing aims to launch demonstration projects for coupling hydrogen and renewable energy production (Beijing Municipal Bureau of Economy and Information Technology, 2021). Tianjin plans to produce hydrogen from renewable energy in an effort to diversify hydrogen supply (Tianjin Government, 2020). Hebei provincial government has the goal of establishing Zhangjiakou as a renewable hydrogen production base to integrate renewable energy power into the power supply system (Hebei DRC, 2019; Zhangjiakou Government, 2019). In the Yangtze River Delta, the Municipal People's Government of Suzhou and the Municipal People's Government of Shanghai have stated that they seek to produce hydrogen via wind or solar power (Suzhou Government, 2018; Shanghai DRC, Shanghai Science and Technology Commission & Shanghai Economic and Information Commission, 2017). In North China, Shandong Province aims to develop renewable hydrogen through PEM electrolysis and SO electrolysis powered by solar or wind power (Shandong Government, 2020). Ningxia Province, where Ningdong base is located, promotes the use of wind or solar power in hydrogen production (Ningxia Government, 2020). According to Ningxia Provincial People's Government, the base aims to produce 300,000 tons of renewable hydrogen during the 14th five-year period, to facilitate its transformation from a coal-chemical industrial base to a low-carbon energy base (Ningxia Government, 2021). The Autonomous Region of Inner Mongolia aims to produce more than 480,000 tons of green hydrogen per year by 2025 (Inner Mongolia Energy Bureau, 2022). This would represent 25 to 50 percent of the central government's target for 2025. In the Pearl River Delta, Foshan aimed to produce hydrogen from renewable energy (Foshan DRC, 2015). It will launch solar-powered demonstration projects during the 14th five-year period (Foshan Government, 2021). Shenzhen disclosed its objectives of producing hydrogen from PEM electrolysis and SO electrolysis in its hydrogen development plan (2021-2025) (Shenzhen DRC, 2021). More specifically, it seeks to produce hydrogen from offshore wind power plants in its special cooperative zone with Shantou (Shenzhen DRC, 2021).

Despite these plans to expand the production of hydrogen from renewable power, local governments identify hydrogen derived from industrial by-products as the primary source of hydrogen supply at the current stage of developing hydrogen (Foshan DRC, 2020b; Changshu Government, 2021a). In line with the national hydrogen development plan, local governments will continue to promote hydrogen production from industrial by-products until at least 2025. The local governments of Yangtze River Delta (e.g. Zhejiang Province and Jiangsu Province) (Changshu Government, 2021b; Zhejiang DRC, Zhejiang Economic and Information Administration and Zhejiang Science and Technology Administration, 2019), Jiaxing located in Zhejiang Province (Jiaxing Government, 2021), Beijing and Hebei provinces (Beijing Municipal Bureau of Economy and Information Technology, 2021; Hebei DRC, 2019) as well as Shandong Province and Ningxia Province (Shandong Government, 2020; Ningxia Government, 2020) seek to increase their production of hydrogen from chemical by-products. Tianjin plans to supply hydrogen from chlor-alkali (Tianjin Government, 2018; Shandong Government, 2020; Ningxia Government, 2020), while, in the Pearl River Delta, Foshan aims to increase production of hydrogen from polypropylene (Foshan DRC, 2020b). Although the national hydrogen development plan does not highlight the use of CCUS in hydrogen production, Shandong Province and Shenzhen disclosed their targets of developing CCUS technology for hydrogen production (Shandong Government, 2020; Shenzhen DRC, 2021). Additionally, Shandong Province, Shenzhen and Foshan also aim to produce hydrogen from nuclear power, given existing nuclear capacities in the province (e.g. Guangdong Daya Bay Nuclear Power Plant in Shenzhen).

4.3 Developing hydrogen transport and storage infrastructure

As outlined in the previous section, China has a longstanding policy aimed at promoting hydrogen refueling infrastructure and related technological innovation to support the development of fuel cell vehicles. In 2016, the Society of Automotive Engineers of China stated that China aimed to establish 300 hydrogen refueling stations by 2025 and 1000 hydrogen refueling stations by 2030 (China Society of Automotive Engineers, 2017). In 2020, the Society of Automotive Engineers of China was more ambitious about the construction of hydrogen refueling stations, aiming at 1000 and 5000 hydrogen refueling stations in service by 2025 and 2050, respectively (China Society of Automotive Engineers, 2020). NDRC and NEA have recently reemphasized the aim to promote construction of hydrogen refueling facilities (NDRC & NEA, 2022b). The national hydrogen development plan also promotes the conversion of existing petrol and gas-refueling stations and explores the possibility of building hydrogen refueling stations with on-site hydrogen production (NDRC, 2022).

Recent policy documents have also articulated broader policy objectives, encompassing additional dimensions of hydrogen storage and transport, though still focused primarily on enabling hydrogen use in the transport sector. The *Industrial Development Plans of New Energy Vehicles (2021-2035)* and the national hydrogen development plan aim to promote the pilot application of storing and transporting solid hydrogen, high-temperature gaseous hydrogen, cryogenic gaseous hydrogen, and low-temperature liquid hydrogen (State Council, 2020a). The national hydrogen development plan also promotes the use of existing oil and gas transport pipelines for hydrogen transport, i.e. via blending in gas pipelines or conversion of oil and gas pipelines for hydrogen transport (NDRC & NEA, 2022b; NDRC, 2022).

Building hydrogen refueling stations has also figured in local hydrogen development plans since at least 2015 (Ling et al., 2019; Foshan DRC, 2015). Table 3 on the following page provides an overview of targets for the construction of hydrogen refueling stations in Chinese cities and provinces. To lower the cost of building and operating hydrogen refueling stations, local governments have promoted the repurposing of existing petrol and gas stations and encouraged combined services of petrol, gas, hydrogen and electricity supply (Zhejiang DRC, Zhejiang Economic and Information Administration & Zhejiang Science and Technology Administration, 2019; Shandong Government, 2020; Chongqing Economic and Information Commission, 2020; Hebei DRC, 2019; Guangdong Government, 2018). The city cluster of the Yangtze River Delta (including Shanghai, Suzhou and Changshu) propose the refurbishment of oil and gas refueling stations owned by CNPC and Sinopec into hydrogen refueling stations (Suzhou Government, 2018; Changshu Government, 2021a; Shanghai DRC, Shanghai Science and Technology Commission & Shanghai Economic and Information Commission, 2021). In the Pearl River Delta, almost 70 percent of the total volume of hydrogen refueling stations in Foshan will be repurposed from petrol-refueling stations (Foshan DRC, 2020b).

Table 3 Local-level targets for the expansion of hydrogen refueling stations

Industrial Clusters	Provinces/Cities	Target for building hydrogen refueling stations (by 2025)
Yangtze River Delta	Changshu	4
	Ningbo	10 – 15
	Jiaxing	20
	Shanghai	70
Beijing-Tianjin-Hebei Region	Beijing	37
	Hebei province	50
Pearl River Delta	Foshan	30
	Guangzhou	>50
	Shenzhen	10
	Maoming	>10
Hydrogen Corridor in Henan province	Henan province	>80
Ningdong Energy and Chemical Base	Ningxia province	1 – 2

Source: Authors' own, based on hydrogen development plans issued by local governments.

A number of provincial or municipal governments have also been promoting various storage and transport solutions, including high-temperature gaseous hydrogen, solid hydrogen and low-temperature liquid hydrogen storage (Beijing Municipal Bureau of Economy and Information Technology, 2021; Changshu Government, 2021b; Jiaxing Government, 2021; Shanghai DRC, Shanghai Science and Technology Commission & Shanghai Economic and Information Commission, 2021; Shandong Government, 2020; Hebei DRC, 2019). While the national hydrogen development plan does not address questions of hydrogen trade in China, the municipal governments of Qingdao (a coastal city in Shandong Province near Beijing-Tianjin-Hebei region), Ningxia and Foshan stated that, in the long term, they seek to build networks to enable the trade of hydrogen both within and across regions in China (Qingdao DRC, 2020; Foshan Government, 2021; Ningxia Government, 2021). Qingdao also articulated the objective of creating a trading platform and developing a regime for hydrogen transactions and pricing (Qingdao DRC, 2020). However, these cities have not given details of potential domestic hydrogen trade (e.g. a certification regime). Similarly, the Changshu municipal government aims to collaborate with the municipal governments of Nanjing, Ningbo and Shanghai to develop a hydrogen network in the Yangtze River Delta (Changshu Government, 2021a). Overall, local governments appear to be more advanced in their efforts to promote domestic hydrogen trade than the central government.

4.4 Expanding hydrogen use

According to the national hydrogen development plan, hydrogen energy plays an important role in decarbonizing energy end-use, and its use should be promoted in transport, the power sector and industrial production (NDRC, 2022). In the following, specific goals are detailed for these various subsectors.

4.4.1 Transport

The State Council's strategy for the new energy automotive industry from 2012 to 2020 formulated the aim of developing a China's hydrogen-fueled vehicle industry in tandem with developments in the rest of the world (State Council, 2012). In 2020, the central government launched pilot applications of mid- to long-distance commercial fuel cell vehicles in hydrogen industrial clusters (e.g., Beijing and Shanghai) (MOF et al., 2020a). *The Mid-and-Long-Term Hydrogen Industrial Development Plan (2021-2035)* (2022) highlights that in the transport sector, hydrogen will first be used to fuel hydrogen fuel cell commercial heavy vehicles and will then be gradually used to fuel hydrogen fuel cell passenger vehicles. By 2025, the number of hydrogen fuel cell vehicles should reach around 50,000 (NDRC, 2022). The Society of Automotive Engineers of China stated in 2016 that the production capacity for commercial hydrogen fuel cell vehicles should reach approximately 100,000 units and the deployment should reach 1 million units by 2030 (China Society of Automotive Engineers, 2017). In 2020, the deployment target for commercial fuel cell vehicles was postponed to 2035 (China Society of Automotive Engineers, 2020).

In addition, the national hydrogen development plan articulates the aim to expand hydrogen use in shipping or aviation (China Society of Automotive Engineers, 2017). Although there are no further details of developing hydrogen-fueled shipping, in May 2022, China's first hydrogen-fueled ship 'Three Gorges Hydrogen Boat 1' started its inspection process with China Classification Society (FuelCellsWorks, 2022). Similarly, in 2017, China tested its first hydrogen-fueled aircraft (Sohu, 2017).

As already indicated above, local governments have been active players in the promotion of hydrogen fuel cell vehicles (Maoming Government, 2020; Beijing Municipal Bureau of Economy and Information Technology, 2021). Before the national policy for the pilot application of fuel cell vehicles was launched in 2020, the provincial government of Guangdong and Zhejiang, and the municipal government of Suzhou had already formulated targets for the development of fuel cell vehicles (Guangdong Government, 2018; Zhejiang DRC, Zhejiang Economic and Information Administration & Zhejiang Science and Technology Administration, 2019; Suzhou Government, 2018). The municipal governments of Chongqing, Shanghai and Changshu, and the provincial governments of Ningxia and Henan joined them after the launch of the central government's initiative, focusing on buses and heavy trucks for logistics (Chongqing Economic and Information Commission, 2020; Ningxia Government, 2021; Shanghai DRC, Shanghai Science and Technology Commission and Shanghai Economic and Information Commission, 2021; Changshu Government, 2021b; Foshan DRC, 2020b; China Center for International Economic Exchanges, 2021). Table 4 on the following page presents the number of hydrogen fuel cell vehicles the relevant cities aim to use by 2025.

Table 4: Local government targets for the promotion of hydrogen fuel cell vehicles

Industrial Clusters	Cities	Target volume for hydrogen fuel cell vehicles (by 2025)
Yangtze River Delta	Ningbo	600 –800 (by 2022)
	Jiaxing	1,500
	Shanghai	More than 10,000
Beijing-Tianjin-Hebei Region	Beijing	More than 10,000
	Hebei province	10,000
Hydrogen Corridor in Henan province	Henan Province	More than 5,000
Pearl River Delta	Foshan	30,000
	Maoming	600

Source: Authors' own, based on hydrogen development plans issued by local governments.

4.4.2 Renewable hydrogen use in the power system

Stabilizing variable renewable power through hydrogen storage is an important area of application, due to its role in decarbonizing energy consumption. According to *the 14th Five-Year Plan of Modern Energy System* (2022), hydrogen is envisioned to help increase the share of renewable energy in China's power system (NDRC & NEA, 2022a). The *Mid-and-Long-Term Hydrogen Industrial Development Plan (2021-2035)* (2022) states that China will explore and foster 'energy storage via hydrogen energy and wind or solar power.' (NDRC, 2022). The national hydrogen development plan also promotes hydrogen fuel cells as back-up power supply in areas such as data centers or communication stations. Hydrogen energy is also planned for use in distributed power and heat supply in residential areas, industrial parks, mining areas and ports (NDRC, 2022). NDRC and NEA further introduce that there will be demonstration projects for the use of hydrogen-based storage for balancing variable renewable power generation (NDRC & NEA, 2022a; Yang et al., 2021; Li et al., 2021). According to the *Notice on the Implementation Plan of Developing New Energy Storage During the 14th Five-Year Period* (2022), NDRC and NEA aim to establish Zhangjiakou, located in Hebei Province, as a pilot region for this purpose (NDRC & NEA, 2022c).

At the local level, Shandong Province aims to launch pilot projects for storing surplus renewable power in the form of hydrogen and to establish combined renewable energy power and hydrogen energy storage systems (Shandong Government, 2020). Tianjin also aims to use hydrogen as seasonal energy storage in the renewable energy power system (Tianjin Government, 2020). Guangzhou aims to a pilot renewable-hydrogen peak-shaving power station by 2022 (Guangzhou DRC, 2020a). Furthermore, dating back to 2018, Beijing, Suzhou and Foshan have already disclosed their objectives of accelerating the application of distributed hydrogen energy storage systems in buildings or industrial parks to enable the increasing use of renewable power (Beijing Municipal Bureau of Economy and Information Technology, 2021; Suzhou Government, 2018; Foshan DRC, 2020b; Shenzhen DRC, 2021). More specifically, Beijing aims to build a distributed power supply system (>= 10MW) by 2025 (Beijing Municipal Bureau of Economy and Information Technology, 2021). Suzhou aims to broaden hydrogen use in power supply for residential use (Suzhou Government, 2018). Zhejiang Province and Foshan located in Guangdong Province also explore the ways of using hydrogen fuel cells as back-up power for communication stations (Zhejiang DRC, Zhejiang Economic and Information Administration & Zhejiang Science and Technology Administration, 2019; Foshan DRC, 2020b).

4.4.3 Hydrogen for the decarbonization of industry

The role of hydrogen for the decarbonization of industry has only recently been addressed by Chinese policy makers. Beginning in 2021, China has formulated goals to use hydrogen to decarbonize the steel industry and the chemical industry (Zhao et al., 2015). According to the *Notice by the State Council of the Action Plan for Carbon Dioxide Peaking Before 2030* (2021) and the *Mid-and-Long-Term Hydrogen Industrial Development Plan* (2021-2035), steel companies are expected to explore the use of renewable hydrogen to reduce carbon dioxide emissions. Since 2022, NDRC and NEA aim to support the coupling of the coal-chemical industry and green hydrogen development and to promote the use for renewable hydrogen as raw materials in chemicals production (NDRC & NEA, 2022a). The *Implementation Plan of Carbon Peaking of Industry* (2022) recognizes hydrogen as low-carbon energy or a low-carbon raw material in decarbonizing the steel industry, the construction industry and the transport industry (MIIT et al., 2022).

According to the *Mid-and-Long-Term Hydrogen Industrial Development Plan* (2021-2035), the Chinese government aims to use renewable hydrogen as a source of industrial heat and to replace fossil fuels in ammonia production, methanol production and refinery. Prior to the encouragement given by the national hydrogen development plan, there have been pilot projects for the use of renewable hydrogen in the chemical industry. For instance, Ningxia Baofeng Energy at Ningxia Energy and Chemical Base produced 13,000 tons of methanol using renewable-based electricity in 2021 (Li et al., 2022). Additionally, according to the *Implementation Plan of Carbon Peaking of Industry* (2022), MIIT, NDRC and MEE aim to develop the technology to enable the use of hydrogen for the decarbonization of the cement industry (MIIT et al., 2022).

At the local level, Shandong and Ningxia provinces have articulated plans for hydrogen use for the decarbonization of industry. Shandong Province aims to use hydrogen fuels to power mining machinery (Shandong Government, 2020). The *14th Five-Year Plan* of Ningxia Province highlights that renewable hydrogen will increasingly be used in the production of chemical products, such as methanol, and for the upgrading of the coking industry in the Ningdong Energy and Industrial Base (Ningxia Government, 2021). Hydrogen will be used as a feedstock in the refining of coking crude benzol and coal tar hydrogenation, thus helping to increase the rate of resource conversion and to enhance the competitiveness of the coking industry (Ningxia Government, 2021).

4.5 Promotion of innovation and industrial development in the hydrogen sector

The hydrogen economy is also seen as an area with important potential for economic growth (Sun & Yang, 2021); Yang & Gao, 2020). Overcoming technological bottlenecks of related core technology and key manufacturing equipment is considered important for its economic development (NDRC, 2022). The following section provides an overview of key objectives and priority areas for promoting innovation and industrial development in China's hydrogen sector, first at the central and then at the local level.

4.5.1 At the central level

The Chinese government first started to promote hydrogen-related technologies in its *State Plan of High Technology Research and Development*, issued in 1986 (The CPC Central Committee & State Council, 1986; MOST, 2010; Li & Song, 2021). It stepped up its efforts in the *National Mid-and-Long Term Development Plan of Science and Technology* of 2005 (State Council, 2005). An important priority at this stage was the promotion of R&D and manufacturing of hydrogen fuel cells. Therefore, in 2017 and 2020, the State Council, together with MOST and MOT, reiterated the need for R&D in fuel cells (MOST & MOT, 2017; State Council, 2020b). In 2021, the central government advanced the innovation and manufacturing of key elements of hydrogen fuel cells (NDRC, 2021). The national hydrogen development plan encourages the development of PEM fuel cells, specifically.

China is also increasingly focusing on R&D in the field of electricity-based hydrogen production to achieve corresponding supply targets. Initially, the *National Mid-and-Long Term Development Plan of Science and Technology* (2005) highlighted the importance of advancing the technology for producing hydrogen from both renewable energy and fossil fuels (including coal gasification) in an efficient and cost-effective manner. The *Action Plans of Energy Technological Revolution and Innovation (2016-2030)* promoted innovation in the field of hydrogen purification for its production from industrial by-products. With the State Council's strategy document, *Energy in China's New Era* (2020), the focus shifted to advancing technologies for producing hydrogen from electricity (State Council, 2020b). The *Mid-and-Long-Term Hydrogen Industrial Development Plan (2021-2035)* (2022) aims to improve the efficiency of hydrogen production based on renewable energy and to scale up and increase the productivity of related production equipment (NDRC, 2022). NDRC also aims to advance R&D in various electrolyzer technologies, including SO electrolysis, hydrogen production from sea water and hydrogen production from nuclear energy (NDRC, 2022; NDRC et al., 2022). In its 2022 working plan, NEA aims to advance the demonstration of renewable hydrogen production and to support the commercial application of hydrogen technology (NEA, 2022).

Over time, hydrogen storage and transport has been recognized as another important technological bottleneck for China's hydrogen development. Therefore, the national hydrogen development plan stresses the importance of developing materials for hydrogen storage. As stated by the *Action Plans of Energy Technological Revolution and Innovation (2016-2030)*, hydrogen refueling stations are considered a crucial element in this field, as they can enable distributed hydrogen production and thus reduce the need for transport over longer distances. The *13th Specific Plan of Scientific and Technological Innovation in Transportation* (2020) promotes the manufacturing of equipment for high-pressure hydrogen storage and refueling (i.e. at 70 MPa)(MOST & MOT, 2017). The *14th Five-Year Plan of Energy Technology Innovation* seeks to advance the innovation and manufacturing of hydrogen pipelines and hydrogen refueling stations with varying levels of compression (e.g. 70MPa hydrogen dispenser, 45MPa/90MPa compressor and the key element of 35MPa/70MPa hydrogen refueling equipment). It also supports R&D in the fields of hydrogen cracking, low-temperature absorption, hydrogen leakage and hydrogen deflagration in storage and transport (NDRC & NEA, 2022c; NDRC & NEA, 2022a).

In addition to the R&D initiated by China's domestic energy companies, since 2019, NDRC and the Ministry of Commerce (MOFCOM) have encouraged foreign companies to manufacture hydrogen-related technology and equipment in China (NDRC & MOFCOM, 2019; NDRC & MOFCOM, 2020).

This means that foreign companies receive preferential treatment when developing related projects, such as financial rewards in the case of Guangdong Province or simplified administrative procedures (Gong & Boute, 2021). This has facilitated agreements, such as the MoU signed by Sinopec and French Air Liquide for the joint construction of the West Shanghai petrol-hydrogen refueling station (Reuters, 2019b). In this venture, the French company is contributing its expertise in the construction of hydrogen refueling stations (Reuters, 2019b). Finally, hydrogen-related innovation and industrial development is also considered a promising field for economic development in West China, given its abundant renewable energy resources. The *Catalogue of Encouraged Industries in West China* issued in 2020 encouraged the manufacturing of hydrogen-related equipment, including key equipment for hydrogen refueling stations and fuel cells.

Figure 7 on the following page provides an overview of hydrogen-related targets in the realm of technology and innovation at the central level.

4.5.2 At the local level

Local governments are engaging in the promotion of innovation and the manufacturing of hydrogen fuel cells as well as electrolyzers, with a particular emphasis on the former (Ling et al., 2019; Foshan DRC, 2015; Ningxia Government, 2020). Cities located in the Yangtze River Delta aim to establish a world-class fuel cells manufacturing cluster (Zhu et al., 2021). For instance, Changshu Municipal People's Government has issued a specific development plan for hydrogen fuel cells (Changshu Government, 2021b). These cities have focused on manufacturing electric pile, bipolar plates, PEM fuel cell engines, fuel cell stacks and membrane electrodes and other key elements of fuel cells (Changshu Government, 2021b; Shanghai DRC, Shanghai Science and Technology Commission & Shanghai Economic and Information Commission, 2021; Ningbo Government, 2019; Jiaxing Government, 2021)). Since 2019, Zhejiang Province aims to develop the technology of fuel cell stacks, on-board hydrogen supply systems, PEM, and fuel-cell power generation plants (Zhejiang DRC, Zhejiang Economic and Information Administration & Zhejiang Science and Technology Administration, 2019; Tianjin Government, 2018). In the Beijing-Tianjin-Hebei Region, Beijing and Tianjin both aim to advance the technological development of fuel cells (Beijing Municipal Bureau of Economy and Information Technology, 2021; Tianjin Government, 2018). In the Pearl River Delta, Foshan aims to become a leading R&D and manufacturing base for hydrogen fuel cells (e.g., PEM and bipolar plate) and hydrogen fuel cell vehicles (Foshan DRC, 2015). Guangzhou aims to overcome technological bottlenecks in the field of low-platinum catalysts, PEM, carbon paper for use in fuel cells, metal bipolar plates, membrane electrodes and equipment for hydrogen storage (Guangzhou DRC, 2020b). In North China, Weifang in Shandong Province has also explored the development of on-board hydrogen storage systems since 2019 (Weifang Government, 2019).

In the sphere of hydrogen production, Beijing supports technology development in the field of PEM electrolysis and SO electrolysis systems and seek to improve the efficiency of alkaline electrolysis (Beijing Municipal Bureau of Economy and Information Technology, 2021). In the Yangtze River Delta, Changshu has the objective of improving the efficiency of water electrolysis powered by solar power (e.g. SO electrolysis systems) (Changshu Government, 2021b). It also seeks to promote research on reversible hydrogen electrolysis (Changshu Government, 2021b). Jiaxing aims to support R&D of electrolysis, solar photocatalytic electrolysis and pyrolysis (Jiaxing Government, 2021). Similarly, in its hydrogen development plan, Ningbo states that it will support the manufacturing of equipment for purifying hydrogen from industrial by-products and for electrolysis (Ningbo Government, 2019).

Figure 7 Central-level targets for hydrogen-related technology and innovation (according to the 14th Five-Year Plan of Energy Technology Innovation)

Source: Authors' own, based on NEA and MOST, *The 14th Five-Year Plan of Energy Technology Innovation* (《"十四五"能源领域科技创新规划》) (2021).

4.6 Advancing the formulation of hydrogen standards

In 2020, the China Hydrogen Alliance issued the *Standard and Evaluation of Low-carbon Hydrogen, Clean Hydrogen and Renewable Hydrogen* (2020). The standards are likely to determine the future eligibility of hydrogen projects for receiving financial support (discussed further in section 5), although the government has not officially referred to the standard in any of its recent policy documents. The drafting parties include crucial energy companies, such as the hydrogen technology subsidiary of China Energy, the sales subsidiary of Sinopec, State Grid, important manufacturing companies such as the Chinese branch of Air Liquide, and certification institutions or companies, such as Shanghai Environment and Energy Trade Center and Shenzhen CTI International Certification Co.

According to the document, low-carbon hydrogen should not exceed 14,51 kilograms of CO_2 emissions per kg of hydrogen, while clean and renewable hydrogen should not exceed 4,9 kilograms of CO_2 emissions per kilogram of hydrogen (see Table 5 below). The standard for clean hydrogen roughly equates to the benchmark of 36,4g of CO_2 per MJ for low-carbon hydrogen set by the European CertifHy scheme (assuming an energy density of 120 to 140 MJ per kilogram of hydrogen). The Chinese benchmark for low-carbon hydrogen exceeds even the estimated emissions of hydrogen produced from natural gas via steam methane reforming (referred to as gray hydrogen). The emissions benchmarks should be quantified using a lifecycle approach, which takes into account the raw material acquisition phase, the transport phase of raw materials, the phase of production, on-site storage and transport of hydrogen energy. For coal- and natural gas-based hydrogen this includes the stage of coal and gas extraction and transport, respectively. For electricity-based hydrogen, the assessment begins with the production of electricity. Neither low-carbon nor clean hydrogen is subject to any restrictions in terms of the process of hydrogen production and may in principle include hydrogen production from any source. Renewable hydrogen is considered a sub-category of clean hydrogen with the added requirement that the hydrogen should be produced via electrolysis with renewable energy. The latter may be produced on-site or may be purchased via an eligible certificate program.

Table 5 CO_2 emissions standards for low-carbon, clean and renewable hydrogen issued by China's Hydrogen Alliance

	Low-carbon hydrogen	Clean hydrogen	Renewable hydrogen
Maximum CO_2 emissions per kilogram of hydrogen	14.51 kg	4.9 kg	4.9 kg
Hydrogen production from renewable energy	Not required	Not required	Required

Source: Authors' own, based on China Hydrogen Alliance, *Standard and Evaluation of Low-carbon Hydrogen, Clean Hydrogen and Renewable Hydrogen* (《低碳氢、清洁氢与可再生能源氢的标准与评价》) (2020)

In addition, the central government aims to gradually establish a system of hydrogen technology and safety standards. *The Mid-and-Long-Term Hydrogen Industrial Development Plan (2021-2035)* (2022) highlights the importance of establishing a system of hydrogen industrial standards for different segments of the hydrogen value chain from production to different areas of application (NDRC, 2022). Dated back to 2005, SAC issued national standards for hydrogen production from electrolysis (SAC, 2005). The formulation of standards for storage and applications mainly focused on fuel cells at this stage (China National Institute of Standardization, 2022). Since 2020, MIIT has already initiated the formulation of standards for on-board hydrogen supply systems, hydrogen refueling nozzles, refueling receptacles, air compression and communication protocols for refueling of fuel cell vehicles (MIIT, 2020c; MIIT, 2021). MIIT published the *Standard of fuel cell electric vehicles-Hydrogen refueling nozzle* in 2020 (SAC, 2020) and its draft of *Compressed hydrogen dispenser for vehicles* for collecting public opinions in 2021 (China National Institute of Standardization, 2021). In 2021, to regulate the design and the construction of hydrogen refueling stations, MHURD revised the technical regulations for hydrogen refueling station, regarding location and equipment, issued in 2010 (MHURD, 2021). In the same year, SAC issued the *Fuel Specification for Hydrogen Powered Vehicles—Liquid Hydrogen* (SAC, 2021a), the *Technical Specification for Liquid Hydrogen Production Systems* (SAC, 2021b), and *Technical Requirements for Storage and Transportation of Liquid Hydrogen* (SAC, 2021c).

The Chinese government has also formulated goals for engaging in international cooperation on hydrogen standards, mainly in the sphere of technological standards at this stage (NDRC & NEA, 2022a). In 2020, MIIT announced its intention to work with international organizations to formulate the rules governing fuel cell vehicles and to design related standards (MIIT, 2020a). MIIT also aims to deepen collaboration with the EU, Germany, France, Japan and APEC on formulating standards for fuel cell vehicles (MIIT, 2020a). In *the Mid-and-Long-Term Hydrogen Industrial Development Plan (2021-2035)* (2022), NDRC emphasizes the importance of advancing international cooperation on standards for core hydrogen technology, equipment and materials (NDRC, 2022) At the local level, the government of Qingdao has encouraged companies and research institutes to join the Hydrogen Council, the International Hydrogen Fuel Cell Association (IHFCA) or other international hydrogen organizations to participate in the formulation of standards and rules (Qingdao DRC, 2020). Hydrogen cooperation may also figure more prominently in the BRI in the future (China Center for International Economic Exchanges, 2021). Via the BRI, MIIT aims to promote China's standards for NEVs, including hydrogen fuel cell vehicles, among Association of Southeast Asian Nations (ASEAN) and Central Asian states (MIIT, 2020a).

5 Support policies for hydrogen development

The Mid-and-Long-Term Hydrogen Industrial Development Plan (2021-2035) encourages investment in the hydrogen sector. The Green Industry Guidance (2019) and the Notice of Issuing the Catalogue of Projects Supported by Green Bonds (2021) specify the following hydrogen projects as eligible for financial support: clean hydrogen production; hydrogen refueling stations; hydrogen storage facilities; hydrogen fuel cells; hydrogen fuel cell vehicles; and gaseous hydrogen blending into gas pipelines. This implies that investments in these areas may receive support via support schemes, like preferential loans, subsidies, industrial funds, preferential tax treatment, green bonds and potential financial incentives via the carbon trading market. A number of local governments have actively encouraged the establishment of industrial funds to finance hydrogen projects. The national hydrogen development plan also proposes 'supportive electricity prices' for hydrogen production based on renewable energy, which have already been in place in a number of localities.

Beyond the general investment support for hydrogen-related technologies, the Chinese government has implemented a range of instruments to support the manufacturing and deployment of fuel cell vehicles as well as related infrastructure, i.e. hydrogen refueling stations. To create demand for hydrogen fuel cell vehicles, the central government has granted subsidies to consumers who purchase hydrogen fuel cell vehicles. In addition, the central government announced a pilot city rewards scheme in 2020, which is intended to replace consumer subsidies in selected jurisdictions. Such pilot city schemes have been in place for the promotion of hydrogen refueling stations since 2014. Participating cities receive funding to support the manufacturing of equipment for refueling stations. The funds cannot be provided as direct subsidies for the construction of refueling stations. However, the participating cities provide local resources for this purpose. In addition to direct consumer subsidies and pilot city schemes, the central government has supported fuel cell vehicles via its Dual Credit Policy for new energy vehicles (NEVs). This provides automakers with credits when they exceed production targets for NEVs, which can compensate for deficits in meeting fleet-based fuel consumption targets.

Finally, China's emission trading scheme (ETS) is designed to decarbonize the carbon-intensive sectors of the national economy by pricing related carbon emissions According to the Industrial Development Plans of New Energy Vehicles (2021-2035), the State Council aims to stimulate automobile companies to develop NEVs, including hydrogen fuel cell vehicles, by expanding the ETS to fuel consumption in the transport sector. Similarly, the development of hydrogen in other sectors could benefit from the possible expansion of the ETS to the refinery, petrol-chemical, steel, paper, and cement industry. In addition, the ETS can contribute to the development of renewable hydrogen under the Chinese Certified Emissions Reductions scheme (CCER). The CCER regime is a supplement to the national ETS, consisting in the creation of offset allowances based on emission reduction projects (e.g. in the field of renewable energy).

This section provides a detailed review of various policy instruments in support of the hydrogen sector and their application to date. It begins with a review of R&D funding and different forms of investment support. This is followed by an overview of rewards and subsidies for fuel cell vehicles and refueling stations, the most significant area of support to date.

5.1 R&D support for hydrogen technologies from the central government

Although the national hydrogen development plan clearly articulates the aim of building and improving hydrogen-related technological capacities, it does not establish specific support mechanisms for hydrogen R&D. Nevertheless, hydrogen R&D benefits from a range of more general R&D funding regimes. According to the *14th Five-Year Plan of Energy Technology Innovation* (2021), the central government will support a range of hydrogen-related technologies (see Figure 7 on page 46). While the plan does not define any particular financial allocation, this implies that major funding programs like the National High-tech R&D program (863 Program) and the National Key Technologies R&D program may include support for hydrogen-related technologies (State Council, 2014b). In this vein, the National Natural Science Foundation of China (NSFC) issued a specific funding regime (2023-2025) for efficient hydrogen production from fossil fuels, off-grid renewable hydrogen production and underground hydrogen storage (BJX, 2022b). The central government has also created a special program for supporting the development of hydrogen-related technologies (State Council, 2014b). In 2021, the key program for 'Hydrogen Technology' supported seventeen projects focusing on fuel cells, renewable hydrogen production and electrolyzers, hydrogen storage and hydrogen pipelines and hydrogen blending in gas pipelines (MOST, 2021b). Secondly, the central government may incentivize companies to invest in hydrogen-related technology innovation through different mechanisms, including investments in venture capital funds for emerging industries, the National S&T Achievements Dissemination Program and the TORCH Program (State Council, 2014b). Finally, in the pilot city reward regimes for fuel cell vehicles (as introduced below), the central government allocates funds to selected local governments, for the purpose of commercializing and industrializing the key technologies relevant for fuel cells and fuel cell vehicles.

5.2 Investment support via green corporate bonds, industrial funds, preferential tax treatment and reduced electricity prices

The *Mid-and-Long-Term Hydrogen Industrial Development Plan (2021-2035)* (2022) encourages investment in the hydrogen sector. It indicates its support for banks to grant loans without damaging their financial viability, encourages industrial funds to invest in emerging hydrogen companies and encourages hydrogen companies to raise financing from capital markets. The national hydrogen development plan does not provide specific guidance on which specific parts of the sector should be eligible for support (NDRC, 2022). However, according to the *Green Industry Guidance* (2019) and *Notice of Issuing the Catalogue of Projects Supported by Green Bonds 2021* (2021), the following hydrogen projects are eligible for financial support (NDRC et al., 2019; NDRC et al., 2021): clean hydrogen production; hydrogen refueling stations; hydrogen storage facilities; hydrogen fuel cells;

hydrogen fuel cell vehicles; and gaseous hydrogen blending into gas pipelines.[4] This implies that investments in these areas may receive support via preferential loans, subsidies, industrial funds, preferential tax treatment, green corporate bonds and potential financial incentives via the carbon trading market. Many of these measures are then deployed locally with or without direct funding from the central government. The following section provides further details on each of these mechanisms and their status of implementation. This includes the implementation of support schemes at the local level (see also the overview of local support schemes in Table 6 on page 53).

5.2.1 Green bonds

Issuing green corporate bonds[5] to banks, funds, insurance companies or general public investors offers a low-cost way of financing investments in low-carbon technologies. The interest rates of green corporate bonds are usually below those of other corporate bonds at the same grade and the same payback period. PBOC, NDRC, CSRC and MOF have developed China's green bond mechanism which clarifies the requirements of issuing green corporate bonds, as set out in the *Guiding Opinions on Supporting the Development of Green Bonds* (2017). When applying for issuing green corporate bonds, companies are required to disclose project details, environmental objectives, and the management rules of the capital raised. Seventy percent or more of the capital raised from issuing green corporate bonds must be allocated to operate eligible projects, acquire eligible projects or repay loans to banks, according to the Guidelines issued by Shenzhen Securities Exchange and Shanghai Securities Exchange. An example from the hydrogen sector is the Guangzhou fuel cell manufacturer HTWO, a subsidiary of Hyundai Motor Group, which gained the qualification for issuing green corporate bonds to finance its hydrogen fuel cells projects. Similarly, in 2022, the subsidiary of BAOWU, a steel SOE, issued its green corporate bonds to finance its hydrogen-enriched carbon-recycling blast furnaces.

5.2.2 Local industrial funds and reward schemes

A number of local governments have actively encouraged the establishment of industrial funds to finance hydrogen projects. In China, industrial funds blend public and private finance to support investment in strategic emerging industries (China Financial News, 2020), including the hydrogen industry. Despite their public purpose, they seek to generate returns for investors (Future Services; 21 News, 2021). It implies that local governments encourage private actors to play a role in promoting hydrogen development. Jiaxing municipal government aims to seek financial support from the automobile fund set up by Zhejiang Province to develop the industry of hydrogen fuel cell vehicles (Jiaxing Government, 2021). Shanxi Province established a government-led hydrogen industrial fund to finance hydrogen production, hydrogen purification, hydrogen storage, hydrogen transport and hydrogen fuel cells (e.g. promoting the use of hydrogen fuel cell heavy trucks) (Xinhua, 2021b). The limited partners of this fund include Shanxi Provincial Fund Management Co., the hydrogen production company of Shanxi – Pengfei Group Company and a local hydrogen fuel cell enterprise (Shanxi Daily News, 2021). In Hebei Province, Tianjin, Qingdao, Shenzhen and Chengdu, local governments are seeking to attract private co-financing for their hydrogen-related industrial funds as well as hydrogen-related projects, such as hydrogen refueling stations, fuel cells for energy storage and fuel cell vehicles

[4] While the document does not define the term 'clean hydrogen', it is likely that the government will follow the definitions developed by the China Hydrogen Alliance (see section 4.6 above).

[5] Companies and financial institutions can issue green bonds. Here we refer only to green corporate bonds.

(Qingdao DRC, 2020; Chengdu Government, 2020; Tianjin Government, 2018; Shenzhen DRC, 2021).

To attract investments and thus build hydrogen value chains, by coordinating with local investment promotion administrations and the local branches of NDRC, the local finance administrations of Chengdu, Tianjin and Jiaxing reward competitive hydrogen companies with cash awards (Chengdu Government, 2020; Tianjin Government, 2020; Jiaxing Government, 2021). The amount of the awards varies depending on the amount of the invested capital. For example, companies that registered in Chengdu will be rewarded 5 percent of the volume of their fixed assets, if their hydrogen business is listed in the Fortune Global 500 for the first time.

5.2.3 Preferential tax treatment

NEVs are eligible for preferential tax treatment, according to the Central Committee of the Communist Party of China (CPC) and the State Council (The CPC Central Committee & State Council, 2021b). The owners or managers of NEVs are exempted from vehicle tax, according to the Vehicle and Vessel Tax Law of the People's Republic of China (National People's Congress, Article 4). Since 2014, consumers of NEVs are also exempted from the vehicle purchase tax (MOF,ChinaTax and MIIT, 2022). The implementation of the preferential treatment of vehicle purchase tax will be extended to the end of 2023 (Xinhua News, 2022). At the local level, the municipal government of Shanghai also grants preferential tax treatment specifically to enterprises engaged in the manufacturing of fuel cell vehicles. They are entitled to tax breaks of 15 percent for 5 years after their registration date in Shanghai (Shanghai DRC, Shanghai Science and Technology Commission and Shanghai Economic and Information Commission, 2021).

5.2.4 Reduced renewable power prices for green hydrogen production

To advance the development of green hydrogen, the central government and local governments offer lower electricity rates for hydrogen production based on renewable energy. The *Mid-and-Long-Term Hydrogen Industrial Development Plan (2021-2035) (2022)* proposes 'supportive electricity prices' for hydrogen production based on renewable energy. Before issuing the plan, renewable hydrogen production already benefited from cheaper electricity rates in a number of cities or provinces. In Foshan, off-peak electricity to produce hydrogen costs investors 0.26 yuan/kwh (around US$ 0.041) since 2017. From 2020 to 2023, in Chengdu, renewable hydrogen companies pay a transmission price of US $0.015/kwh and a distribution price of US $0.043/kwh. In 2020, the regular transmission and distribution price in Chengdu was US $0.034/kwh, and US $0.086/kwh, respectively. Since 2019, hydrogen production from water electrolysis in Zhangjiakou has also been subject to lower electricity rates of 0.36 yuan/kwh (around US$ 0.056).

Table 6 Local hydrogen-related support schemes

Industrial Clusters	City/Province	Support Mechanisms
Beijing-Tianjin-Hebei Region	Hebei province	▪ Hydrogen industrial fund to finance the development of hydrogen value chains
	Zhangjiakou, Hebei province	▪ Subsidies for the construction of hydrogen refueling stations ▪ Discounted electricity rates for the production of renewable electricity based hydrogen
	Tianjin, centrally-administered	▪ Subsidies for the construction of hydrogen refueling stations ▪ Hydrogen industrial fund to finance the development of hydrogen value chains
Yangtze River Delta	Shanghai, centrally-administered	▪ Preferential tax treatment specifically for enterprises engaged in the manufacturing of fuel cell vehicles
	Zhejiang province	▪ Automobile industrial fund to support the development of fuel cell vehicles
	Jiaxing, Zhejiang province	▪ Subsidies for the operation of hydrogen refueling stations
Pearl River Delta	Guangzhou, Guangdong province	▪ Subsidies for the manufacturing of key fuel cell components and for the operation of hydrogen refueling stations
	Foshan, Guangdong province	▪ Discounted electricity rates for the production of renewable electricity based hydrogen ▪ Subsidies for the purchase of hydrogen fuel cell vehicles and for the construction of hydrogen refueling stations
Emerging Hydrogen Corridor in Henan Province	Zhengzhou, Henan province	▪ Subsidies for the development of fuel cell vehicles
	Puyang, Henan province	▪ Subsidies for the construction and operation of hydrogen refueling stations
Other cities	Chengdu, Sichuan province	▪ Discounted electricity rates for the production of renewable electricity based hydrogen ▪ Hydrogen industrial fund to finance the development of hydrogen value chains ▪ Subsidies for the production of fuel cell equipment and for the construction and operation of hydrogen refueling stations
	Qingdao, Shandong province	▪ Hydrogen industrial fund to finance the development of hydrogen value chains
	Shanxi province	▪ Hydrogen industrial fund to finance the development of hydrogen value chains

Source: Authors' own, based on hydrogen development plans issued by local governments.

5.3 Support for fuel cell vehicles and refueling stations

Beyond the general investment support for hydrogen-related technologies, the Chinese government has implemented a range of instruments to support the manufacturing and deployment of fuel cell vehicles as well as related infrastructure, i.e. hydrogen refueling stations. These encompass direct subsidies, pilot city schemes and a credit system aimed at promoting NEVs more generally.

5.3.1 Direct subsidies in support of fuel cell vehicles and refueling stations

To create demand for hydrogen fuel cell vehicles, the central government has granted subsidies to consumers who purchase hydrogen fuel cell vehicles (Tu, 2020). Consumers purchase the cars at discounted prices, while automobile companies are compensated for the price difference from the central government. It is expected that subsidies will play an important role in promoting hydrogen fuel cell vehicles up to 2035, with subsidy rates declining over time (Wallstreet News, 2022a). Since their introduction, rates have been reduced several times (see Table 7 below). In addition, the central government announced a pilot city rewards scheme in 2020 (see section 5.3.2), which is intended to replace consumer subsidies in selected jurisdictions.

Table 7 Consumer subsidies for the purchase of fuel cell vehicles between 2016 and 2022 (granted by central government)

<table>
<tr><th>Types of fuel cell vehicles</th><th>Subsidies to each vehicle in 2016 (CNY)</th><th>Reduction in 2017 (base year: 2016)</th><th>Reduction in 2019 (base year: 2016)</th><th>Reduction in 2021 (base year 2019)</th><th>Reduction in 2022 (base year: 2021)</th></tr>
<tr><td>Passenger vehicles</td><td>20,000</td><td rowspan="3">20 %</td><td rowspan="3">40 %</td><td rowspan="2">20 % (private use)</td><td rowspan="2">30 % (private use)</td></tr>
<tr><td>Light vehicles</td><td>30,000</td></tr>
<tr><td>Heavy/ medium-size bus or vans</td><td>50,000</td><td>10 % (public use)</td><td>20 % (public use)</td></tr>
</table>

Source: MOF et al. 2015; MOF et al. 2020b; MOF et al., 2021

At the local level, Foshan municipal government has been subsidizing the purchase of hydrogen fuel cell vehicles since 2020 (Foshan DRC, 2022a). The level of the subsidies varies depending on the price of the vehicles (Foshan DRC, 2022a). Guangzhou municipal government has also been granting subsidies of up to 10 billion yuan (around US$ 1.57 million) to companies that manufacture key fuel cell components (Guangzhou DRC, 2020b). Chengdu municipal government has planned to provide a reward of up to 1 million yuan (around US$ 156,742) to companies that produce fuel cell equipment (Chengdu Government, 2020).

The central government has not promoted hydrogen refueling stations via direct subsidies but has been operating a pilot city reward scheme since 2014 (see section 5.3.2). However, pilot cities within the scheme have utilized their local resources to provide subsidies, either for the construction of refueling stations or the operation of the stations (see Table 8 on the following page). In 2018, the municipal

Table 8 Subsidies for the construction or operation of hydrogen refueling stations (granted by local governments)

Industrial Clusters	City	Subsidies to companies
Yangtze River Delta	Jiaxing, Zhejiang province	▪ 20 yuan/kg (around US$ 3.13/kg) for operation
		▪ Annual decrease of 5 yuan/kg (around US$ 0.78)
Beijing-Tianjin-Hebei Region	Tianjin, centrally-administered city	▪ Up to 5 million yuan (around US$ 783,712) for construction
	Zhangjiakou, Hebei province	▪ Up to 8 million yuan (around US$ 1.25 million) for construction
Pearl River Delta	Foshan, Guangdong province	▪ Up to 5 million yuan (around US$ 783,712) for construction
	Guangzhou, Guangdong province	▪ Up to 2.5 million yuan (around US$ 391,856) for operation
Hydrogen Corridor in Henan Province	Puyang, Henan province	▪ Up to 10 million yuan (around US$ 1,500,000) for construction
		▪ 2022–2023: 15 yuan/kg (around US$ 2.14/kg) for operation
		▪ 2024–2025: 10 yuan/kg (around US$ 1.43/kg) for operation
Others	Chengdu, Sichuan province	▪ Up to 5 million yuan (around US$ 783,712) for construction
		▪ 20 yuan/kg (around US$ 3.13/kg) for operation

Source: Authors' own, based on hydrogen development plans issued by local governments.

Note: Unless otherwise stated, these subsidy rates were effective in 2022.

government of Foshan started to grant subsidies for the construction of hydrogen refueling stations depending on their daily capacities of hydrogen refueling (Foshan DRC, 2020c). Hydrogen refueling stations with the daily capacity of hydrogen refueling (>=500 kg) received subsidies of 5 million yuan (Foshan DRC, 2020c). After 2018, Foshan subsidized the very first petrol-hydrogen refueling station in Foshan developed by Sinopec (PEIAG, 2019). In 2020, the municipal government of Zhangjiakou also began to offer subsidies for the construction of hydrogen refueling stations (Zhangjiakou Government, 2020). Hydrogen refueling stations with the daily capacity of hydrogen refueling (>=500kg) receive subsidies of 8 million yuan (Zhangjiakou Government, 2020). Hydrogen refueling stations with the daily capacity of hydrogen refueling (200~500kg) receive 4 million yuan (Zhangjiakou Government, 2020). Starting from 2020, companies received subsidies (up to 5 million yuan) for the construction of hydrogen refueling stations from the municipal government of Tianjin (Tianjin Government, 2020). In 2020, the municipal government of Jiaxing decided to subsidize the operation (rather than the construction) of hydrogen refueling stations with 20 yuan per kg, decreasing annually by 5 yuan per kg (Jiaxing Government, 2021). Guangzhou also offers subsidies to hydrogen purchases. However, the level depends on the price of hydrogen. The subsidy is 20 yuan per kg (around US$ 3.13) if the sales price is not more than 35 yuan per kg (around US$ 5.49) (Jiaxing Government, 2021). The subsidy is 15 yuan per kg (around US$ 2.35) if the sales price is not more than 30 yuan/kg (around US$ 4.70) (Jiaxing Government, 2021).

5.3.2 Pilot city schemes for hydrogen refueling stations and fuel cell vehicles

When advancing the implementation of new policies, China frequently selects pilot cities to test the effectiveness of new policies and to detect implementation problems (e.g. the establishment of emission trading schemes in China). The governance of hydrogen refueling stations and fuel cell vehicles is no exception. In this vein, the central government has provided rewards for pilot cities or city clusters to promote the construction of hydrogen refueling stations since 2014. Rewards granted to cities or city clusters are intended for the industrialization of key hydrogen technologies, for the development of human resources and for pilot applications of new hydrogen technology. They are not intended as subsidies for direct investments in increasing the number of hydrogen refueling stations or as consumer subsidies for fuel cell vehicles (The Central Government of PRC, 2020). Instead, participating local governments should invest the rewards in the promotion of technology relevant for hydrogen refueling and fuel cells. Pilot cities or city clusters in Beijing-Hebei-Tianjin region, Yangtze River Delta and Pearl River Delta were rewarded 4 million yuan (around US$ 626,969) per hydrogen refueling station for this purpose (MOF et al., 2014). After 2016, the central government adjusted the rewards in view of the cost of building hydrogen refueling facilities (MOF et al, 2014). It has allocated the rewards from the central budget and has granted them to local governments who are required to make use of the rewards to deploy innovative technologies within the refueling stations (MOF et al., 2014). In contrast to the national regime, local governments, including those participating in the pilot schemes, have utilized their local resources to grant subsidies to companies that build or operate hydrogen refueling stations, while reducing them over time (see section 5.3.1 above).

While the central government has provided direct consumer subsidies for fuel cell vehicle purchases (see section 5.3.1 above), in 2020, it announced a shift to a reward regime for pilot city clusters, similar to refueling stations (MOF et al., 2020a). This shift aims to facilitate the commercialization of the technology of fuel cells, support the development of industrial value chains and avoid overinvestments in fuel cell vehicles (BJX, 2021d). In the pilot cities, selected in 2021,[6] consumer subsidies will no longer be available. In these pilot cities local governments will be rewarded 300,000 yuan (around US$ 47,023) per 100 tons of clean or renewable hydrogen used for refueling vehicles (MOF et al., 2020a).

[6] In 2021, the MOF, MIIT, MOST, NDRC and NEA approved the application of Beijing, Shanghai, Guangzhou, Zibo and other cities for being pilot cities.

5.3.3 The new energy vehicles (NEVs) credit system

In addition to the consumer subsidy scheme and the pilot city scheme aimed at fuel cell vehicles specifically, the so-called Dual Credit Policy promotes NEVs more generally, which includes fuel cell vehicles. The regulation was introduced in 2017 by MIIT, with support from MOF and MOFCOM, and updated in 2020 (MIIT, 2020b). The regulation consists of two sets of credit rules, the Corporate Average Fuel Consumption (CAFC) credits and the New Energy Vehicle (NEV) credits. The former sets targets for the production-weighted average fuel consumption for vehicle manufacturers, while the latter obliges manufacturers to meet production quotas for NEVs. The Dual Credit policy provides automakers with credits when they exceed production targets for NEVs, which can compensate for deficits in meeting CAFC credit rules. The system incentives both the production of more efficient internal combustion engine vehicles and the production of NEVs. In addition, NEV credits can be sold to other manufacturers, providing a source of additional income to producers of NEVs.

5.4 The emission trading scheme as a potential support instrument

Finally, China's emission trading scheme (ETS) is designed to decarbonize the carbon-intensive sectors of the national economy by pricing related carbon emissions (Boute & Zhang, 2018; Zhang, 2016). After several years of implementing pilot regimes in different cities (e.g. Beijing), the national emission trading system was launched in July 2021 (Central Government, 2021). Although at this stage most of the participants in the national ETS are power generation companies (e.g. China Huadian) (Central Government, 2021), analysts expect China's ETS to play a role in facilitating clean or renewable hydrogen use in carbon-intensive sectors (SinoHytec, 2021; CICC Research & CICC Global Institute, 2022; CarbonBrief, 2020). Under the ETS, large GHG emitters are required to cover their GHG emissions in a given year with a corresponding number of carbon allowances (Huabao Securities, 2021). The provincial ecological and environmental administration allocates carbon allowances free of charge to emitters that have the right to trade their allowances on the market (MEE, 2021). According to the *Industrial Development Plans of New Energy Vehicles (2021-2035)* (2020), the State Council aims to stimulate automobile companies to develop NEVs, including hydrogen fuel cell vehicles, by expanding the ETS to fuel consumption in the transport sector (State Council, 2020a). Similarly, the development of hydrogen in other sectors could benefit from the possible expansion of the ETS to the refinery, petrol-chemical, steel, paper, and cement industry (Central Government, 2021) (Qin & Lin, 2022). The expectation is that renewable hydrogen use and hydrogen fuel cells would become cost-competitive at carbon prices of 100-200 yuan per ton of CO_2 (around US$16~31/ton of CO_2) (Li, Shi, & Phoumin, 2021).

In addition, the ETS can contribute to the development of renewable hydrogen under the Chinese Certified Emissions Reductions scheme (CCER). The CCER regime is a supplement to the national ETS, consisting in the creation of offset allowances based on emission reduction projects (e.g. in the field of renewable energy) (Beijing Municipal Bureau of Economy and Information Technology, 2021). It might be possible for producers of renewable hydrogen to receive economic benefits by selling their offset allowances to other emitters. For instance, the Beijing municipal government aims to design a hydrogen-related transaction regime within the existing CCER system by recognizing the emission reductions achieved by clean hydrogen under the Beijing Green Transaction Center (Beijing Municipal Bureau of Economy and Information Technology, 2021).

6 Conclusion

China’s promotion of the hydrogen sector is emblematic of its broader efforts to promote greenhouse gas reductions, while pursuing ambitious industrial development goals and promoting energy security. To date, industrial policy goals have clearly taken center stage in its policies, however. It builds on long-standing efforts to promote fuel cell technologies and in particular fuel cell vehicles, which is part of its broader efforts to obtain technological and industrial leadership in New Energy Vehicles. A key aim in this context will be to overcome remaining insufficiencies in selected segments of the hydrogen sectors. To this end, the Chinese government is providing encouragement to foreign firms to invest in hydrogen-related projects in China in cooperation with Chinese partners. If perceived insufficiencies of China’s domestic innovation system in the sector persist, this may represent an obstacle for more ambitious efforts to promote the sector. Indeed, China’s measures to support the demand for hydrogen remains rather limited, still focusing primarily on applications in the transport sector, i.e. commercial fuel cell vehicles. Nevertheless, with the launch of its pilot city scheme for fuel cell vehicles in 2020 and emerging hydrogen-based industrial clusters in various parts of the country, there appears to be increased policy momentum in support of the sector. This builds on important developments at the sub-national level. Indeed, combined local targets for fuel cell vehicles surpass central-level tar-gets. Quantitative targets for refueling station remain exclusively local.

The link between China’s industrial policy ambitions and decarbonization remains uncertain. Short-term ambitions to promote renewable hydrogen are fairly modest compared to other major economies. Moreover, China is currently pursuing a diversified strategy in support of hydrogen supply, which includes all different types of hydrogen production, including coal-based hydrogen. Correspondingly, the unofficial standards for hydrogen production promoted by China Hydrogen Alliance also consider low-carbon based hydrogen production based on coal. Nevertheless, policy documents increasingly emphasize the potential of renewable hydrogen as a vehicle for stabilizing an electricity system based on variable renewable energy as well as broader decarbonization efforts. They also increasingly highlight the need to transition to an exclusively renewable hydrogen supply in the future. Similarly, incentives for investments in renewable hydrogen are expanding in a host of localities that see renewable hydrogen and related decarbonization of industry as an opportunity for future industrial growth. In a number of cases, local-level strategies have come out more strongly in support of renewable hydrogen than current central government policies. Ambitious production targets for renewable hydrogen in Inner Mongolia are a case in point. As a region with modest levels of industrialization and abundant renewable energy resources, hydrogen-based development offers a possible opportunity for the region. Central-level policies for hydrogen-based decarbonization of industry are only at a nascent stage, with initial announcements made in 2022.

Similarly, China’s ambitions to promote hydrogen storage and transport remain at a relatively early stage of development with an important emphasis on the promotion of innovation and acquisition of technological know-how. The national hydrogen development plan does not define a clear vision for national infrastructure development for hydrogen trade. Nevertheless, energy SOEs are being encouraged to build on their existing assets to develop projects to support local developments. Most notably, Sinopec has been leveraging its existing network of refueling stations (i.e. petroleum-based) as a platform for its engagement in the construction of hydrogen refueling stations.

Finally, both China's hydrogen strategy and the engagement of its energy SOEs do not appear to be strongly motivated by considerations of geopolitics at this stage. To be sure, Chinese officials are considering increasing opportunities for investment in hydrogen projects around the world. In this vein, the national hydrogen development plan considers the importance of the BRI for promoting hydrogen-related standards and investments. Beyond these geoeconomic considerations, the role of hydrogen as a future energy commodity and its geopolitical implications do not figure prominently in Chinese policy efforts. Indeed, due to China's relative abundance of renewable energy resources, it is does not exhibit major vulnerabilities related to the future provision of hydrogen. Conversely, hydrogen could even offer an opportunity to reduce its energy dependence in the future. This and other efforts to shape global hydrogen trade do not seem to be a significant driver of its policy efforts, however.

Annex 1: Hydrogen-related policy documents issued by the central government

Institution	Policy	Year
State Council	The National Mid-and-Long Term Development Plan of Science and Technology (2006–2020)（《国家中长期科学和技术发展规划纲要(2006–2020年)》）	2005
State Council	The Planning for the Development of the Energy-Saving and New Energy Automobile Industry (2012–2020)（《节能与新能源汽车产业发展规划(2012–2020)》）	2012
MOF, MOST, MIIT and NDRC	Notice of Awarding the Construction of Charging Facilities of New Energy Vehicles（《关于新能源汽车充电设施建设奖励的通知》）	2014
State Council	Made in China 2025（《中国制造2025》）	2015
MOF, MOST, MIIT and NDRC	Notice of the Fiscal Subsidy Policies for the Promotion and Application of New Energy Vehicles (2016–2020)（《关于2016–2020年新能源汽车推广应用财政支持政策的通知》）	2015
State Council	The 13th Industrial Development Plans of Strategic Emerging Industries（《十三五"国家战略性新兴产业发展规划》）	2016
NDRC & NEA	Action Plans of Energy Technological Revolution and Innovation (2016–2030)（《能源技术革命创新行动计划（2016–2030)》）	2016
Society of Automotive Engineers of China	Hydrogen Fuel Cell Vehicle Technology Roadmap（《氢燃料汽车科技路线图》）	2016
MOST, MIIT and NDRC	The Mid-and-Long Term Development Plan of Automobile Industry（《汽车产业中长期发展规划》）	2017
MIIT	Measures for the Parallel Administration of the Average Fuel Consumption and New Energy Vehicle Credits of Passenger Vehicle Enterprises（《乘用车企业平均燃料消耗量与新能源汽车积分并行管理办法》）	2017, amended in 2020
MOST and MOT	The 13th Specific Plan of Scientific and Technological Innovation in Transportation（《十三五交通领域科技创新专项规划》）	2017
MOF, MIIT, MOST and NDRC	Notice of Adjusting and Improving the Policies of Financial Subsidies to the Promotion and Application of New Energy Vehicles（《关于调整完善新能源汽车推广应用财政补贴政策的通知》）	2018
NDRC, MIIT, MNR, MEE, MHURD, PBOC and NEA	Green Industry Guidance (2019 edition)（《绿色产业指导目录(2019年版）》）	2019
NDRC	Catalogue for Guiding Industry Restructuring (2019 Version)（《产业结构调整指导目录（2019年)》）	2019
NDRC and MOFCOM	Catalogue of Industries for Encouraging Foreign Investment（《鼓励外商投资产业目录》）	2019 & 2020
State Council	The Government Work Report（《政府工作报告》）	2019 & 2020
MOF, MIIT, MOST and NDRC	Notice of Improving the Policies on Government Subsidies for Promotion and Application of New Energy Vehicles（《关于完善新能源汽车推广应用财政补贴政策的通知》）	2020

Institution	Policy	Year
MOF, MIIT, MOST and NDRC	Notice of Further Improving the Fiscal Subsidy Policies for the Promotion and Application of New Energy Vehicles (《关于进一步完善新能源汽车推广应用财政补贴政策的通知》)	2019 & 2020
State Council	Industrial Development Plans of New Energy Vehicles (2021–2035) (《新能源汽车产业发展规划（2021–2035 年）》)	2020
	Energy in China's New Era (《新时代的中国能源发展》)	2020
MOF, MIIT, MOST, NDRC and NEA	Notice of the Pilot Application of Fuel Cell Vehicles (《关于开展燃料电池汽车示范应用的通知》)	2020
NDRC and MOJ	Notice of Issuing the Opinions on Accelerating the Establishment of a System of Regulations and Policies on Green Production and Consumption (《关于加快建立绿色生产和消费法规政策体系的意见》)	2020
MOF	The Interim Measures for the Administration of Subsidy Funds for Energy Conservation and Emission Reduction (《节能减排补助资金管理暂行办法》)	2015, 2020 amendment
PBOC, NDRC and CSRC	Notice of Issuing the Catalogue of Projects Supported by Green Bonds 2021 (《关于印发<绿色债券支持项目目录(2021年版)>的通知》)	2021
MIIT	Key Working Dimensions of Automobile Standardization 2020 (《2020年汽车标准化工作要点》)	2020
NEA	The Guiding Opinions on Energy-related Work in 2020 (《2020年能源工作指导意见》)	2020
	The Guiding Opinions on Energy-related Work in 2021 (《2021年能源工作指导意见》)	2021
Member of the Standing Committee of the Political Bureau of the CPC Central Committee and State Council	Outline of the People's Republic of China 14th Five-Year Plan for National Economic and Social Development and Long-Range Objectives for 2035 (《中华人民共和国国民经济和社会发展第十四个五年规划和2035年远景目标纲要》)	2021
	Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy (《中共中央、国务院关于完整准确全面贯彻新发展理念做好碳达峰碳中和工作的意见》)	2021
State Council	Notice by the State Council of the Action Plan for Carbon Dioxide Peaking Before 2030 (《2030年前碳达峰行动方案》)	2021
NDRC and NEA	The Guiding Opinions on Accelerating the Promotion of Developing New Energy Storage (Draft for Public Opinions) (《关于加快推动新型储能发展的指导意见》)	2021
NEA and MOST	The 14th Five-Year Plan of Energy Technology Innovation (《"十四五"能源领域科技创新规划》)	2021
MOF, MIIT, MOST and NDRC	Notice of the Policies on Fiscal Subsidies for Promotion and Application of New Energy Vehicles in 2022 (《关于2022年新能源汽车推广应用财政补贴政策的通知》)	2021

Institution	Policy	Year
MHURD	Technical Regulation for Hydrogen Refueling Station (《加氢站技术规范》)	2010, amended in 2021
NDRC	Catalogue of Encouraged Industries in West China 2020 (《西部地区鼓励类产业目录 2020》)	2021
MIIT	Key Working Dimensions of Automobile Standardization 2021 (《2021 年汽车标准化工作要点》)	2021
SAC	Fuel specification for Hydrogen Powered Vehicles–Liquid Hydrogen (《氢能汽车用燃料-液氢》) Technical Specification for Liquid Hydrogen Production System (《液氢生产系统技术规范》) Technical Requirements for Storage and Transportation of Liquid Hydrogen (《液氢贮存和运输技术要求》)	2021
NDRC	The Mid-and-Long-Term Hydrogen Industrial Development Plan (2021–2035) (《氢能产业发展中长期规划（2021–2035 年）》)	2022
NEA	Guidelines on Energy Work in 2022 (《2022年能源工作指导意见》)	2022
NDRC and NEA	Notice on the Implementation Plan of Developing New Energy Storage During the 14th Five-Year Period (《十四五新型储能实施方案》) Opinions on Improving the Regime and Implementation Measures of Energy Green Low-Carbon Transition (《关于完善能源绿色低碳转型体制机制和政策措施的意见》) The 14th Five-Year Plan of Modern Energy System (《"十四五"现代能源体系规划》)	2022 2022 2022
NDRC and others	The 14th Five-Year Plan of Renewable Energy Development (《"十四五"可再生能源规划》)	2022
MIIT, NDRC and MEE	Implementation Plan of Carbon Peaking of Industry (《工业领域碳达峰方案》)	2022

Annex 2: Hydrogen-related policy documents issued by sub-national governments

Province/ City	Institution	Policy	Year
Yangtze River Delta			
Jiangsu province	Suzhou Municipal People's Government	Guidance on Hydrogen Development in Suzhou (Trial Implementation) (《苏州市氢能产业发展指导意见（试行）》)	2018
		Interim Regulations on the Safety Management of Hydrogen Refueling Stations (《苏州市加氢站安全管理暂行规定》)	2021
	Changshu Municipal People's Government	Industrial Development Plans of Hydrogen Fuel Cells 2021–2030 (《常熟市氢燃料电池产业发展规划（2021 – 2030年）》)	2021
	Emergency Management Bureau of Nanjing Municipal Government	Interim Measures of Safety Management of Hydrogen Refueling Stations in Nanjing (Draft for Public Opinions) (《南京市加氢站安全管理暂行规定》)(公开征求意见稿)	2022
Zhejiang province	Zhejiang Development and Reform Administration, Zhejiang Economic and Information Administration and Zhejiang Science and Technology Administration	Guiding Opinions of Zhejiang Province on Accelerating Hydrogen Development (《浙江省加快培育氢能产业发展的指导意见》)	2019
	Office of Ningbo Municipal People's Government	Several Opinions on Accelerating Hydrogen Industrial Development (《关于加快氢能产业发展的若干意见》)	2019
	Office of Jiaxing Municipal People's Government	Guidance on Hydrogen Development in Jiaxing (《嘉兴市关于加快氢能产业发展的工作意见》)	2020
Shanghai	Shanghai Development and Reform Commission, Shanghai Science and Technology Commission and Shanghai Economic and Information Commission	Shanghai's Development Plan of Fuel Cell Vehicles (《上海市燃料电池汽车发展规划》)	2017
	Office of Shanghai Municipal People's Government	The Implementation Plan of Quickening the Industrial Development of New Energy Vehicles in Shanghai 2021–2025 (《上海市加快新能源汽车 产业发展实施计划(2021–2025年)》)	2021
		Management Measures of the Construction and Operation of Hydrogen Refueling Stations that Serve Fuel Cell Vehicles in Shanghai (《上海市燃料电池汽车加氢站建设运营管理办法》)	2022

Province/ City	Institution	Policy	Year
Beijing-Tianjin-Hebei Region			
Tianjin	Office of Tianjin Municipal People's Government	The Three-Year Action Plan of Tianjin New Energy Industrial Development (2018–2020) (《天津市新能源产业发展三年行动计划(2018–2020)》)	2018
		The Action Plan of Tianjin Hydrogen Development (2020–2022) (《天津市氢能产业发展行动方案(2020–2022年)》)	2020
Beijing	Beijing Science and Technology Commission	Guiding Opinions of Beijing on Accelerating Technological Innovation and Development of New Energy Smart Automobiles (《北京市加快科技创新培育新能源智能汽车产业的指导意见》)	2017
	Beijing Municipal Bureau of Economy and Information Technology	The Implementation Plans of the Hydrogen Development Plan in Beijing (2021–2025) (《北京市氢能产业发展实施方案(2021–2025 年) 》)	2021
Hebei province	Hebei Development and Reform Commission	Implementation Opinions on Promoting Hydrogen Industry Development in Hebei (《河北省推进氢能产业发展实施意见》)	2019
	Zhangjiakou Development and Reform Commission	Zhangjiakou's Ten Measures of Supporting the Development of Hydrogen Industry (《张家口市支持氢能产业发展的十条措施》)	2019
	Zhangjiakou Municipal People's Government	Development Plan of Zhangjiakou's Hydrogen Energy (2019–2035) (《氢能张家口建设规划(2019–2035年)》)	2019
		Implementation Plan of Phase I Project of Securing Hydrogen Supply to Zhangjiakou (《张家口氢能保障供应体系一期工程建设实施方案》)	2020
Emerging Hydrogen Corridor in Henan province			
Henan province	The provincial government of Henan province	14th Five-Year Development Plan of Strategic Emerging Industries and Future Industries (《河南省"十四五"战略性新兴产业和未来产业发展规划》)	2022
		Action Plans of the Development of Hydrogen Fuel Cells Industry in Henan (《河南省氢燃料电池产业发展行动方案》)	2020
Ningdong Energy and Chemical Base			
The Autonomous Region of Ningxia	The Government of Autonomous Region of Ningxia	Guiding Opinions on Accelerating and Fostering the Development of Hydrogen Industry (《关于加快培育氢能产业发展的指导意见》)	2020
		The 14th Development Plan of Ningdong Energy and Chemical Base (《宁东能源化工基地"十四五"发展规划》)	2021

Province/ City	Institution	Policy	Year
Pearl River Delta			
Guang-dong province	Foshan Development and Reform Commission	Industrial Development Plan of New Energy Vehicles in Nanhai District, Foshan (2015–2025)（《佛山市南海区新能源汽车产业规划2015-2025》）	2015
	Guangdong Development and Reform Commission	Implementation Opinions on Accelerating the Promotion and Application of New Energy Vehicles（《关于加快新能源汽车推广应用的实施意见》）	2016
	Foshan Development and Reform Commission	Implementation Details of Support Measures of the Industrial Development of New Energy Vehicles（《佛山市南海区促进新能源汽车产业发展扶持办法实施细则》）	2020
	Foshan Housing and Urban Design Administration	Interim Measures of Managing Foshan Hydrogen Refueling Stations (Draft for Public Opinions)（《佛山市加氢站管理暂行办法（征求意见稿）》）	2018
	Guangdong Provincial People's Government	The 13th Five-Year Plan of Developing Strategic Emerging Industries in Guangdong（《广东省战略性新兴产业发展"十三五"规划》）	2017
		Opinions on Accelerating the Innovation and Development of the Industry of New Energy Vehicles（《关于加快新能源汽车产业创新发展的意见》）	2018
	Guangzhou Municipal People's Government	Implementation Plans of Promoting the Construction of New Infrastructure (2020–2022)（《广州市推进新型基础设施建设实施方案(2020–2022年)》）	2020
	Foshan Development and Reform Commission	Hydrogen Industrial Development Plan in the Nanhai District of Foshan 2020–2035（《佛山市南海区氢能产业发展规划2020–2035》）	2020
		Management Measures of Financial Subsidies to the Promotion and Application of New Energy Bus and to the Construction of Relevant Infrastructure（《佛山市新能源公交车推广应用和配套基础设施建设财政补贴资金管理办法》）	
	Guangzhou Development and Reform Commission	Implementation Details of the Measures of Promoting Hydrogen Industrial Development of Development Zones of Guangzhou（《广州市黄埔区广州开发区促进氢能产业发展办法实施细则》）	2021
	Foshan Municipal People's Government	Outline of Foshan 14th Five-Year Plan for National Economic and Social Development and Long-Range Objectives for 2035（《佛山市国民经济和社会发展第十四个五年规划和2035年远景目标纲要》）	2021
	Shenzhen Development and Reform Commission	Shenzhen Hydrogen Industrial Development Plan 2021–2025（《深圳市氢能产业发展规划（2021–2025年）》）	2021
	Maoming Municipal Government	The Hydrogen Industrial Development Plan of Maoming（《茂名市氢能产业发展规划》）	2020

Province/ City	Institution	Policy	Year
Other cities/provinces			
Wuhan, Hubei province	Hannan District Government	Interim Provisions for the Approval and Management of Hydrogen Refueling Stations in Wuhan Economic and Technological Development Zone (Hannan District)（《武汉经济技术开发区(汉南区）加氢站审批及管理暂行办法》）	2018
Dalian, Liaoning province	Office of Dalian Municipal People's Government	Guiding Opinions on Accelerating the Innovation and Development of New Energy Vehicles（《关于加快新能源汽车产业创新发展的指导意见》）	2018
Shandong province	Office of Shandong Provincial People's Government	The Mid-and-Long Term Hydrogen Development Plan of Shandong 2020–2030（《山东省氢能中长期发展计划 2020–2030》）	2020
	Weifang Municipal People's Government	Opinions on the Construction and Operation of Hydrogen Refueling Stations（《关于做好全市汽车加氢站规划建设运营管理工作的意见》）	2019
	Qingdao Development and Commission	The Hydrogen Industrial Development Plan of Qingdao (2020–2030)（《青岛市氢能产业发展规划2020–2030》）	2020
Chengdu, Sichuan province	Office of Chengdu Municipal People's Government	Guidance on Promoting the High-Quality Development of the Hydrogen Industry in Chengdu（《成都市人民政府办公厅关于促进氢能产业高质量发展的若干意见》）	2020
Chongqing	Chongqing Economic and Information Commission	Guidance on the Industrial Development of Hydrogen Fuel Cell Vehicles in Chongqing（《重庆市氢燃料电池汽车产业发展指导意见》）	2020
Inner Mongolia	The Government of Autonomous Region of Inner Mongolia	14th Five-Year Plan of Hydrogen Development in Inner Mongolia（《内蒙古自治区"十四五"氢能发展规划》）	2022
Fuzhou, Fujian province	Fuzhou Municipal People's Government	Interim Regulations on Constructing, Operating and Managing Hydrogen Refueling stations in Fuzhou（《福州市加氢站建设及经营管理暂行办法》）	2020
Hainan province	Hainan Housing and Urban Design Administration, Hainan Transportation Administration, Hainan Natural Resources Planning Administration and other Administration	The Approval Process of Constructing Hydrogen Refueling Stations in Hainan (Trial Implementation)（《海南省加氢站建设审批流程（试行）》）	2020

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