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Hydrogen RD&D Collaboration Opportunities: China

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Contents

Executive summary: China **1**

1 Country analysis: China **5**

1.1 Introduction 5

1.2 China's hydrogen drivers, strategy and RD&D priorities 5

1.2.1 China's key drivers 5

1.2.2 China's strategic hydrogen industry priorities 6

1.2.3 China's hydrogen RD&D priorities 13

1.3 China's hydrogen RD&D ecosystem 17

1.3.1 Public bodies and policy ecosystem 17

1.3.2 Hydrogen consortia 25

1.3.3 Funding mechanisms 26

1.3.4 Other key hydrogen policies, regulation and legislation 28

1.4 China's domestic hydrogen RD&D projects 30

1.4.1 Major domestic hydrogen RD&D projects 30

1.4.2 Major domestic commercial hydrogen projects 31

1.4.3 China's hydrogen RD&D clusters 31

1.5 International collaboration and joint RD&D projects 35

1.5.1 Overview of China's approach to international collaboration 35

1.5.2 China's bilateral hydrogen relationships 36

1.5.3 China's joint international RD&D projects 36

1.5.4 China's joint international commercial projects 39

1.6 Data insights: China's hydrogen RD&D activity 39

1.6.1 Research publication data 39

1.6.2 Patent data 40

1.6.3 Project data 45

Executive summary: China

China has been undertaking hydrogen research, development and demonstration (RD&D) since the late 1990s and has been particularly active in the hydrogen fuel cell vehicles space. The *Hydrogen RD&D Collaboration Opportunities: China* chapter aims to enhance country-to-country engagement by providing an overview of China's hydrogen priorities and ecosystem. This report also includes a publication and intellectual property (IP) scan, identifying the key stakeholders in China actively undertaking hydrogen RD&D, both at the early research and commercialisation stage.

China's hydrogen strategy

While China has published an *Energy-saving and New Energy Vehicles Technology Roadmap*, China is yet to publish a hydrogen strategy document covering the entire hydrogen economy. Pending an official strategy document, the China Hydrogen Association (CHA) developed the 2019 *CHA White Paper* with buy-in from government stakeholders, which serves as a guiding document. China also has developed several policy documents covering hydrogen at the national and the provincial level which have in effect created a national hydrogen strategy. China's focus on hydrogen is driven by three factors: emissions reduction, economic and social development, and being a global leader in hydrogen and hydrogen-related areas. China's strategic industry priorities, which have been inferred from several documents, include: transportation (light and heavy-duty vehicles RD&D, competitive vehicle manufacturing, fuel cells, refuelling infrastructure); future industry incubation to accelerate emerging technologies; and hydrogen storage.

China's targets and RD&D priorities

China has several targets articulated in its *14th Five Year Plan* (FYP) (2021-2025), namely an 18% reduction in carbon dioxide (CO_2) intensity per unit of GDP and to reach a 20% share of non-fossil fuels in total primary energy demand. To achieve this, China has set a goal to have half of China's vehicles be electric or fuel-cell powered and the remaining half hybrid, by 2035. Other goals include the growth of over 5,000 hydrogen refuelling stations, over 1 million fuel cell vehicles, and greater than 50% of hydrogen production coming from renewables by 2030.

To achieve these goals, China is investing in RD&D in the following areas. Additional RD&D priorities are anticipated with the release of China's hydrogen strategy in the near future.

Production
Electrolysis: PEM, alkaline, solid oxide, emerging
Fossil fuel conversion: SMR, coal gasification, CCS/CCUS
Photochemical and photocatalytic

Storage and distribution
Compression and liquefaction: pressurised storage, pipelines
Chemical: ammonia, liquid organic hydrogen carriers, synthetic fuels, ammonia, hydrides, physisorption
Other: tanker trucks, shipping

Utilisation
Gas blending: pipelines
Transport: fuel cells, refuelling stations, aviation
Electricity generation: hydrogen turbines, fuel cells
Industrial processes: steel processing, combustion
Other: cement kilns

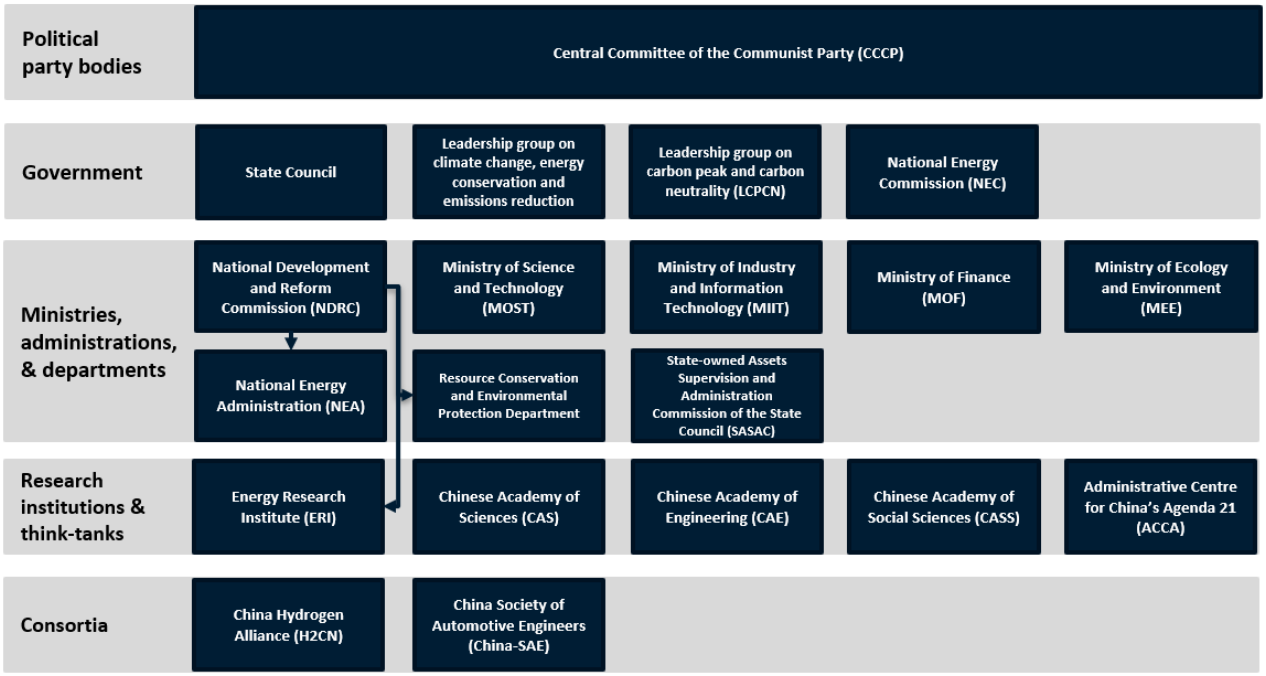
Cross-cutting
Safety

China's domestic hydrogen landscape

China maintains a top-down approach to science, technology and innovation policy. Hydrogen policy and implementation is driven by the Five-Year-Plans. Thirty provinces and cities have produced hydrogen-specific development strategies aligned to the overarching FYP, which are then implemented at a local level. Policy direction is set by the State Council, Central Committee of the Communist Party, Ministerial bodies, or the National People's Congress, with specific Ministries then drafting policies. During the drafting process, advice and input is sourced from various stakeholders, including research institutions (e.g. Chinese Academy of Sciences) and government think-tanks (e.g. Energy Research Institute (ERI) and the National Centre for Climate Change Strategy and International Cooperation (NCCCSIC)). The State Council may then approve the policy, and if passed the relevant ministry is responsible for its implementation alongside provincial governments. Further, State-Owned Enterprises (SOEs), play a key role in hydrogen RD&D and commercialisation by undertaking commercial activities and promoting infrastructure development.

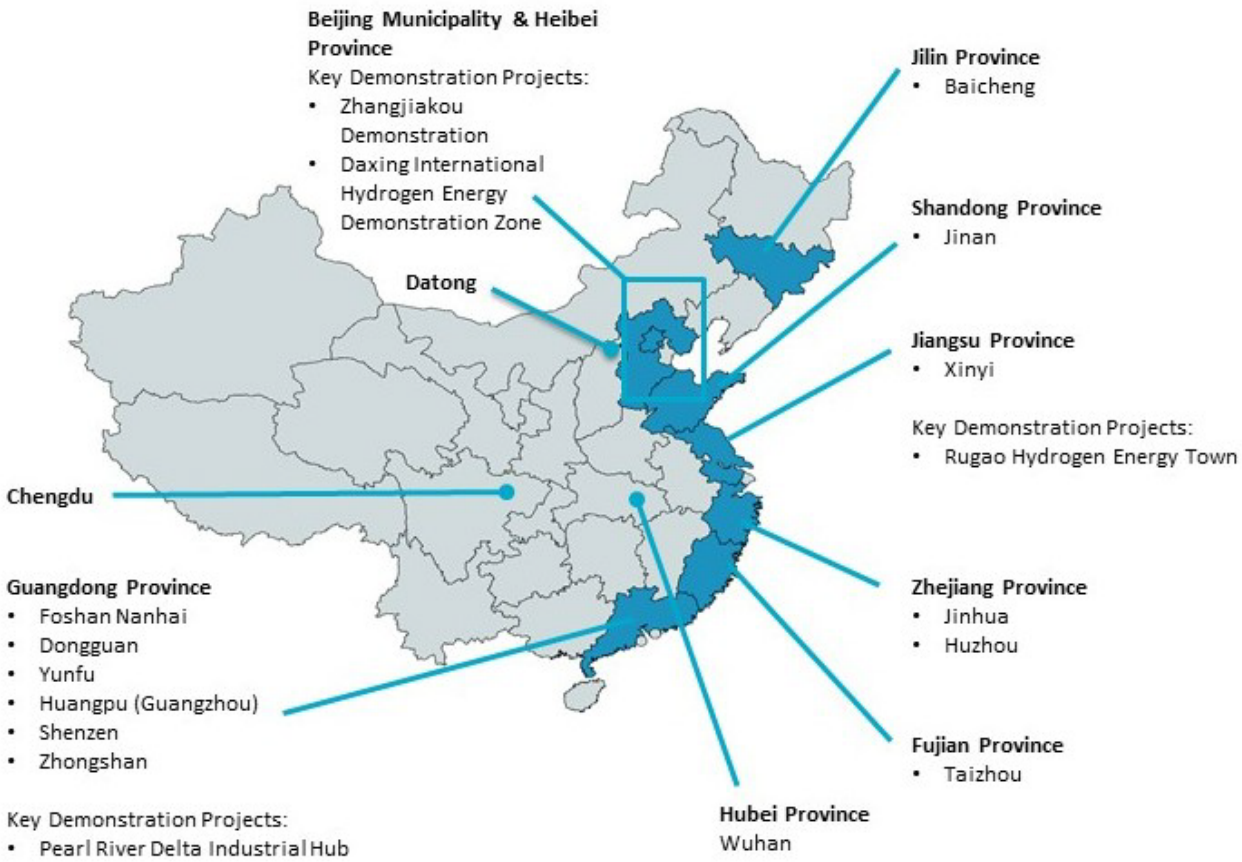
While no hydrogen-specific public funding program has been publicised, initiatives are currently being funded through existing mechanisms set out in the FYP such as the China Energy Investment Corp (CEIC). Subnational governments also allocate funding to provincial-level initiatives and priorities. Private companies, research institutions and SOEs also heavily fund hydrogen RD&D activities.

Figure 1: China's hydrogen RD&D ecosystem



Industry, academia and government are collaborating to bring about hydrogen clusters (also known as hydrogen valleys or ecosystems). These are hydrogen value chain demonstrations and pilot projects that cut across sector applications. With the support of SOEs and local government, China has established 'hydrogen towns', and there are several emerging 'hydrogen valleys':

Figure 2: China's hydrogen clusters



IP and publications scan

Several universities, public research institutions and private companies are highly active in early-stage hydrogen research and late-stage technology commercialisation. This is reflected in hydrogen research publication output and patent output data.

Table 1: Top organisations active in early-stage and late-stage hydrogen RD&D

Rank	Top organisations (Research publication output)	Top organisations (Hydrogen patent output)
1	Chinese Academy of Sciences	China Petroleum & Chemical
2	University of Science and Technology of China (CAS)	SINOPEC
3	Tsinghua University	Wuhan Grove Hydrogen Energy Automobile
4	Tianjin University	SINOPEC Research Institute of Petroleum Processing
5	Xi'an Jiaotong University	Dalian Institute of Chemical Physics, Chinese Academy of Sciences (DICP CAS)

International collaboration

China is active in several international forums, including the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) and the Clean Hydrogen Mission under Mission Innovation. In 2021, China signed a Memorandum of Understanding (MoU) with the International Renewable Energy Agency (IRENA) to promote carbon neutrality through renewables. China has also launched several international initiatives for hydrogen RD&D, including the International Hydrogen Fuel Cell Association (IHFCA) which is focussed on facilitating collaboration to promote fuel cell RD&D and commercialisation, and the International Hydrogen Energy Centre (IHEC) which is co-funded by the People's Government of Beijing Municipality and the United Nations Industrial Development Organization's Global Programme for Green Hydrogen in Industry. Large Chinese industry stakeholders are also members of the Hydrogen Council. Bilaterally, China has several joint RD&D projects with other countries, realised via industry and public-private partnerships. Finally, the Daxing International Hydrogen Energy Demonstration Zone has signed agreements with international partners such as the Green Hydrogen Organisation.

Activity levels for hydrogen and net-zero initiatives is high. While effort has been made to capture major announcements and key information as at 28 January 2022, the content is intended to provide a starting point for informing international engagement, particularly when used in conjunction with other reports in the series, and is non-exhaustive.

1 Country analysis: China

1.1 Introduction

China has been undertaking hydrogen research, development and demonstration (RD&D)[1] since the late 1990s. China has now become the largest producer of hydrogen in the world, has deployed more fuel cell vehicles than the rest of the world combined, and has the second-largest refuelling network (expected to become the largest with continued support from government).[2]

While the fuel cell vehicle and refuelling network space has been highly active, and a clear strategy and technical roadmap for this area exists, an economy-wide hydrogen strategy covering other sectors is expected. Nevertheless, China's industry consortia and international organisations have already mapped out areas of strong potential for hydrogen, with support of the government. Further, several provinces have included hydrogen in their Five-Year Plans (FYPs), tailored to their comparative advantages. This is driven by China's ambition to peak carbon emissions by 2030, grow economic and social development using clean energy, and to invest in developing clean energy technologies.

While energy-related RD&D policy is driven from the top, local governments, research institutes, and state-owned enterprises have played a significant role in RD&D implementation. This is supported by an increase in RD&D funding, with a strong focus on experimental development and demonstration. While China had already established 'hydrogen towns' several years ago, there are several emerging hydrogen valleys. These include ambitious hydrogen industrial hubs, hydrogen cities, and demonstration zones.

The *Hydrogen RD&D Collaboration Opportunities: China* chapter presents an overview of the hydrogen RD&D landscape in China, starting from the national strategy level, down to activity in specific hydrogen technology areas.

1.2 China's hydrogen drivers, strategy and RD&D priorities

1.2.1 China's key drivers

China's hydrogen push can be credited to three main drivers: their desire to reduce emissions, to accelerate economic and social development, and to obtain technological leadership within hydrogen and fuel cell technology.

- **Emissions reduction and environment**: In September 2020, President Xi Jinping announced that China will reach their emissions peak by 2030 and be carbon neutral by 2060.[3] Despite being the largest energy consumer and carbon emitter, this emissions reduction goal is significant. A key policy instrument in this context is China's 14th FYP for 2021-2025, which has binding targets of a 13.5% reduction in energy intensity, a 18% reduction in carbon dioxide (CO_2) intensity, and a non-binding target to reach a 20% share of non-fossil fuel in primary energy use by 2025.[4] China's pathway to net

[1] As defined by the IEA Guide to Reporting Energy RD&D Budget/Expenditure Statistics, 2011

[2] IEA (2021) An Energy Sector Roadmap to Carbon Neutrality in China https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf

[3] IEA (2021) An Energy Sector Roadmap to Carbon Neutrality in China https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf

[4] IEA (2021) An Energy Sector Roadmap to Carbon Neutrality in China https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf

neutrality covers all sectors from energy to industrial processes. Further, there is a domestic push for emissions reduction, as evidenced by the 'Blue Sky War', a three-year action plan for cleaner air.[5]

- **Economic and social development**: Transitioning economic development towards lower carbon intensity is seen as a catalyst for shifting towards higher quality and more sustainable growth. China sees the transition to clean energy as a way to raise GDP per capita, reduce urban-rural and regional inequality, improve technological and innovation capability, and to protect the health of the population.[6]
- **Technological leadership**: China sees higher value-added technologies, green manufacturing, and services as a central element to the low-carbon transition.[7] China's most recent goals include increasing public spending on research and development (R&D), increasing patent output, and boosting the share of scientific and technological contribution to economic growth.[8] Among several technology areas, China sees new energy vehicles (including fuel cell electric vehicles (FCEVs) and new energy equipment as key.[9]

1.2.2 China's strategic hydrogen industry priorities

China has released a number of documents pertaining to its strategy in the areas of fuel cell vehicles and refuelling infrastructure. However, China has not yet released a comprehensive hydrogen roadmap or strategy that covers other end uses and the specifics of hydrogen production, distribution and storage. Such a strategy or roadmap is expected in the near future.[10] The plan is expected to establish hydrogen R&D priorities, targets and the technical standards necessary to facilitate the commercial scale-up of a hydrogen economy.[11] Given China's size and the economic diversity of its provinces, hydrogen priorities are likely to differ across different regions.

National level hydrogen priorities

The priorities related to hydrogen and hydrogen technologies can be gleaned from several strategy documents including:

- **White Paper on China's Hydrogen and Fuel Cell Industry:**[12] In 2019 the China Hydrogen Alliance, with support from the National Energy Administration (NEA) released the *White Paper on China's Hydrogen Energy and Fuel Cell Industry*. The document recommends development goals and initiatives for hydrogen energy and fuel cell technology in China over the medium and long term. While these are not mandated by the government, the China Hydrogen Alliance's leadership and steering committee is

[5] IEA (2021) Three-year action plan for cleaner air (also called the Blue Sky War). IEA/IRENA Renewables Policies Database. https://www.iea.org/policies/8508-three-year-action-plan-for-cleaner-air-also-called-the-blue-sky-war

[6] IEA (2021) An Energy Sector Roadmap to Carbon Neutrality in China https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf

[7] IEA (2021) An Energy Sector Roadmap to Carbon Neutrality in China https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf

[8] IEA (2021) An Energy Sector Roadmap to Carbon Neutrality in China https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf

[9] State Council (2015) Made in China 2025. English Translation, IoT ONE http://www.cittadellascienza.it/cina/wp-content/uploads/2017/02/IoT-ONE-Made-in-China-2025.pdf

[10] Bloomberg News (2021) China is Formulating a Hydrogen Plan But Its Timing is Uncertain. Viewed at https://www.bloomberg.com/news/articles/2021-04-23/china-is-formulating-a-hydrogen-plan-but-its-timing-is-uncertain

[11] Bloomberg News (2021) China is Formulating a Hydrogen Plan But Its Timing is Uncertain. Viewed at https://www.bloomberg.com/news/articles/2021-04-23/china-is-formulating-a-hydrogen-plan-but-its-timing-is-uncertain

[12] Summary of China Hydrogen Alliance White Paper on China Hydrogen and Fuel Cell Industry [English Translation] derived from CHA (2019) White Paper on China Hydrogen and Fuel Cell Industry.

made up of former ministers and senior academics of considerable influence, and industry representatives from major State-Owned Enterprises (SOEs).

- **The Hydrogen Fuel Cell Vehicle Technology Roadmap:** [13] In 2016 the Society of Automotive Engineers of China released a *Hydrogen Fuel Cell Vehicle Technology Roadmap*, which is based off of the *Made in China 2025*[14] plan. The roadmap outlines detailed technical progress and milestones for key fuel cell technologies, fuel cell vehicles, and refuelling infrastructure.
- **Energy-saving and New Energy Vehicles Technology Roadmap 2.0:**[15] In 2020 the Society of Automotive Engineers of China released the *Energy-saving and New Energy Vehicles Technology Roadmap 2.0*¸ which was commissioned by the Ministry of Industry and Information Technology of China. This Roadmap outlines targets for fuel cell vehicles and outlines the development strategy of China's automotive industry up until 2035.
- **The New Energy Vehicle Industry Development Plan (2021-2035):**[16] In 2021 China released the industry development plan setting targets for new energy vehicles (including fuel cells) as well as other development targets to grow an internationally competitive clean vehicle market.
- **China's 14th Five Year Plan (2021-2025):**[17] Passed by the Chinese parliament in 2021, this document prioritises organising and implementing future industry incubation and acceleration plans for emerging technologies, including hydrogen energy and industrial transformations.
- **China's 14th Five-Year Plan for Industrial Green Development (2021-2025):** This plan, released by the Ministry of Industry and Information Technology in December 2021, details a comprehensive set of measures and projects to improve the energy consumption and decrease carbon emissions across core industrial sectors. Also promoted in the plan is resource utilisation and recycling practices, green manufacturing, and transformations to clean production practices.[18]
- **The Energy Development Technology Discipline Development Action Plan (2020-2024):** Published in 2020, the plan calls for several measures including the integration of skills, industrial development and innovation. Within this measure, hydrogen storage and fuel cells are mentioned as a core technology.[19]
- **China's 2020 Dual Circulation Strategy:** Published in response to COVID-19, the core objective of this strategy is to enhance innovation and position China as a global manufacturing power in high-value

[13] Society of Automotive Engineers of China (2016) Hydrogen Fuel Cell Vehicle Technology Roadmap. English Version, translation sponsored by Anglo American https://docs.wixstatic.com/ugd/45185a_e975e82743f3496ca41fe3ccc94c6228.pdf

[14] State Council (2015) Made in China 2025. English Translation, IoT ONE http://www.cittadellascienza.it/cina/wp-content/uploads/2017/02/IoT-ONE-Made-in-China-2025.pdf

[15] China-SAE (2020) Energy saving and new energy vehicles Technology Roadmap 2.0. English Translation by DeepL.

[16] ICCT (2021) China's New Energy Vehicle Industrial Development Plan for 2021-2035. Policy Update. https://theicct.org/sites/default/files/publications/China-new-vehicle-industrial-dev-plan-jun2021.pdf

[17] Xinhua News Agency (2021) Outline of the People's Republic of China 14th Five-Year Plan for National Economic and Social Development and Long-Range Objectives for 2035. Translation sponsored by the Center for Security and Emerging Technology https://cset.georgetown.edu/wp-content/uploads/t0284_14th_Five_Year_Plan_EN.pdf

[18] MIIT (2021) Notice of the Ministry of Industry and Information Technology on Printing and Distributing the "14th Five-Year Plan for Industrial Green Development". https://wap.miit.gov.cn/zwgk/zcwj/wjfb/tz/art/2021/art_4ac49eddca6f43d68ed17465109b6001.html

[19] MOE (2020) Notice of the National Development and Reform Commission and the National Energy Administration of the Ministry of Education on Issuing the Action Plan for the Development of Energy Storage Technology Professional Disciplines (2020-2024). http://www.moe.gov.cn/srcsite/A08/s7056/202002/t20200210_419693.html

added products.[20] This document builds on the 2015 **"Made in China 2025"**[21] strategy which outlines a number of priority areas. One of these areas is new energy vehicles (which includes fuel cell vehicles), and the development of a complete industrial system, manufacturing of essential parts, and independent brands to match advanced international stakeholders.

Hydrogen strategy at the province level

Provinces in China develop their own five-year plans in line with the national five-year plan. These implement the national five-year plan tailored to provincial circumstances and comparative advantages. As such, hydrogen priorities are likely to differ between provinces subject to several factors including resource endowment, and the types of industrial activities undertaken there.

Thirty provinces and cities have launched their own five-year plans mentioning hydrogen. Of these 11 have listed hydrogen as a key priority, including Shanghai, Shandong, Hebei, Jilin, Liaoning, Guizhou, Guangdong, Shaanxi, Gansu, Guangxi and Inner Mongolia.[22] While hydrogen is not mentioned in the five-year plans of Beijing, Zhejiang and Sichuan, these provinces will likely incorporate hydrogen in their strategic energy planning.[23] It should be noted that Beijing, Zhejiang and Sichuan have released hydrogen specific plans and guidelines: Beijing and Sichuan each released a *Hydrogen Industry 14th Five Year Plan* aiming to become hydrogen cities, and Zhejiang released hydrogen industry development guidelines committing to building a 'hydrogen industry highland'.[24]

Strategic priorities for eight key areas are outlined in Table 2 below:[25]

[20] CSIS (2021) Will the Dual Circulation Strategy enable China to Compete in a Post-Pandemic World? China Power, Centre for Strategic and International Studies. https://chinapower.csis.org/china-covid-dual-circulation-economic-strategy/

[21] State Council (2015) Made in China 2025. English Translation, IoT ONE http://www.cittadellascienza.it/cina/wp-content/uploads/2017/02/IoT-ONE-Made-in-China-2025.pdf

[22] Energy Iceberg (2021) China's Hydrogen Market in 14th Five-Year Plan: Provincial Strategy Breakdown. https://energyiceberg.com/hydrogen-14th-fyp-provincial-strategy/#Provinces_Prioritizing_Hydrogen

[23] Energy Iceberg (2021) China's Hydrogen Market in 14th Five-Year Plan: Provincial Strategy Breakdown. https://energyiceberg.com/hydrogen-14th-fyp-provincial-strategy/#Provinces_Prioritizing_Hydrogen

[24] Consultation with in-country stakeholders

[25] Energy Iceberg (2021) China's Hydrogen Market in 14th Five-Year Plan: Provincial Strategy Breakdown. https://energyiceberg.com/hydrogen-14th-fyp-provincial-strategy/#Provinces_Prioritizing_Hydrogen

Table 2: Provincial-level hydrogen priorities

Province	Hydrogen priorities
Inner Mongolia	• Hydrogen production (renewables – wind) • Fuel cell vehicles • Power and heating
Jilin	• Hydrogen production (renewables – wind) • Hydrogen supply (export) to other regions in China • Gas networks
Hebei	• Hydrogen production (renewables – wind) • Fuel cell vehicles • Iron and steel production • Petrochemical production • Applications in coal harbours
Shandong	• Fuel cell vehicles • Gas networks • By-product hydrogen (refineries)
Sichuan	• Fuel cell vehicles & refuelling stations • Fuel cell manufacturing • Power co-generation • Hydrogen storage
Zhejiang	• Fuel cell component manufacturing • Power and heating • Fuel cell vehicles (public transport and harbour logistics)
Shanghai	• Fuel cell vehicles
Beijing	• Fuel cell vehicles

China's hydrogen targets

China has set several important targets with respect to clean energy in its *14th Five Year Plan* (2021-2025), namely an 18% reduction of CO_2 intensity per unit of GDP, and increase to roughly 20% non-fossil fuels in total primary energy demand.[26] The 2016 *Hydrogen Fuel Cell Vehicle Technology Roadmap* also aims at turning half the vehicles in China to be electric or fuel-cell powered, and the other half to be hybrid by 2035.[27] The 2020 *Energy-saving and New Energy Vehicles Technology Roadmap 2.0* updates these targets, with the target for hydrogen fuel cell vehicles in 2035 being extended to 1 million vehicles (with a 2025 target of 100,000 vehicles), and the addition of fuel consumption targets for energy-saving and new energy

[26] IEA (2021) An Energy Sector Roadmap to Carbon Neutrality in China https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf

[27] Xinhua News Agency (2021) Outline of the People's Republic of China 14th Five-Year Plan for National Economic and Social Development and Long-Range Objectives for 2035. Translation sponsored by the Center for Security and Emerging Technology https://cset.georgetown.edu/wp-content/uploads/t0284_14th_Five_Year_Plan_EN.pdf

vehicles.[28] China's new fuel cell vehicle subsidy policy has also laid out a target to reduce the cost of hydrogen at refuelling stations to CNY 35 per kilogram.[29]

Further, in August 2021, the Beijing Municipal Bureau of Economy and Information Technology reportedly released a plan outlining the development of China's hydrogen energy industry for the 2021-2025 period. Reported targets in this plan include the development of 5-8 leading industrial enterprises with the scale exceeding CNY 50 billion before 2023; the construction of 74 hydrogen refuelling stations and 10,000 hydrogen fuel cell vehicles by 2025; and the establishment of 10-15 leading industrial chain enterprises and 3-4 leading industrial R&D platforms post-2025.[30]

The Society of Automotive Engineers of China, a non-governmental organisation formed by Chinese automotive scientists and guided by the Chinese Association of Science and Technology (a government science organisation) has set the following targets for fuel cell vehicles and refuelling infrastructure in the 2016 *Hydrogen Fuel Cell Vehicle Technology Roadmap,*[31] the 2020 *Energy-saving and New Energy Vehicles Technology Roadmap 2.0*[32] target updates*, and the 2019 CHA White Paper*[33] as follows:

[28] China-SAE (2020) Energy-saving and New Energy Vehicles Technology Roadmap 2.0.

[29] ChinaPolicy (2021) Hydrogen and FCV policy in the PRC: major developments since September 2020.

[30] The State Council of The People's Republic of China (2021) Beijing releases plan on hydrogen energy industry development. Viewed at http://english.www.gov.cn/news/topnews/202108/17/content_WS611bbd06c6d0df57f98de93f.html

[31] China-SAE (2016) Hydrogen Fuel Cell Vehicle Technology Roadmap. English Version, translation sponsored by Anglo American https://docs.wixstatic.com/ugd/45185a_e975e82743f3496ca41fe3ccc94c6228.pdf; NOW GmBh (2020) Factsheet: Hydrogen and Fuel Cell Technology in China https://www.now-gmbh.de/wp-content/uploads/2020/09/Factsheet-China-FC-EN.pdf; Society of Automotive Engineers (2020) Energy-saving and New Energy Vehicles Technology Roadmap 2.0, English Translation by DeepL.

[32] China-SAE (2020) Energy saving and new energy vehicles Technology Roadmap 2.0. English Translation by DeepL.

[33] Summary of China Hydrogen Alliance White Paper on China Hydrogen and Fuel Cell Industry [English Translation] derived from CHA (2019) White Paper on China Hydrogen and Fuel Cell Industry.

Table 3: China's hydrogen targets

	Current state (2019)	2025	2030	2035	2050
	2016 Technology Roadmap 1.0 and 2020 Technology Roadmap 2.0 (updated target denoted *)				
H_2 production			>50% hydrogen production from renewables		
Number of fuel cell vehicles		100,000*	1 million*		
Vehicle type		Commercial 20% Passenger 80%			
Cost (commercial vehicle)		RMB <1 million	RMB <600,000		
H_2 refuelling stations		1,000*		5,000*	
	2019 CHA Industry White Paper recommendations[34]				
H_2 demand (tonnes)	25 million (current production)	30 million	35 million	40 million	60 million tonnes (+export 10 million 'green'[35] H_2)
% of energy mix	2.7%	4%	5%	6%	10%
H_2 from fossil fuels	67%		60%		20%
H_2 from industrial by-product	30%		23%		-
H_2 from renewables	3%		15%		70%
H_2 from biomass	-		2%		10%
H_2 Cost	20 RMB/kg	<20 RMB/kg		<15 RMB/kg	<10 RMB/kg
FCEV production capacity	2000 p.a.	50,000 p.a.		1.3 million p.a.	5.2 million p.a.

[34] Although the CHA White Paper recommendations are not mandated government targets, prior to the release of a national hydrogen strategy, the paper provides useful guidance around hydrogen's potential development in China.

[35] 'Green' refers to hydrogen production from renewables

Economy-wide analysis

Some of China's priorities (other than fuel cells vehicles and refuelling infrastructure) can be inferred from China's activity in the hydrogen economy, and from the International Energy Agency's (IEA) report *An Energy Sector Roadmap to Carbon Neutrality.*[36] The IEA was invited by the Chinese government to co-operate on long-term strategies for China for reaching carbon neutrality, and its modelling is based on China's pledge of peaking CO_2 emissions before 2030, and reaching net zero by 2060. The dominant production, storage and utilisation pathways identified are as follows:[37]

- **Production:** Hydrogen production from fossil fuels will continue to contribute to hydrogen production in the short term. After 2030, this is expected to be retrofitted with carbon capture, utilisation and storage (CCUS), or replaced by electrolytic hydrogen. By 2060, hydrogen production from fossil fuels with CCUS is expected to contribute to roughly 15% of hydrogen production. Almost all hydrogen produced in 2060 will be low-carbon, of which roughly 80% will be electrolytic hydrogen.[38] This will require approximately 300 TWh of electricity (one fifth of China's total electricity output). Alkaline electrolysis is likely to remain the dominant electrolyser technology in China given its three biggest electrolyser manufacturers are all producing alkaline electrolysers. Capacity in 2020 was 18MW (a fourfold increase and quarter of global additional capacity). This is expected to increase ninefold in 2021. Electrolyser capacity could expand to 25GW by 2030 (15% of global capacity), and 750 GW by 2060 (40% of global capacity).
- **Storage and Distribution:** Current activity in China with respect to storage and distribution (other than in the fuel cell vehicle refuelling network) is quite limited, and future development will likely depend on hydrogen demand growth across each province. There is currently 100km of dedicated hydrogen pipelines owned by industry stakeholders. Future options include tanker trucks, shipping, hydrogen pipelines and repurposing of high-pressure gas pipelines. This will require significant planning, as energy infrastructure across China is still developing. The predominant storage medium is unclear, however by 2060, 20% of hydrogen demand is expected to be in the form of ammonia and synthetic hydrocarbon fuels.
- **Utilisation:** Total hydrogen demand (including hydrogen derived fuels) is expected to increase to 31 Mt by 2030, and 90 Mt by 2060, making up 6% of total energy demand in 2060. Demand for hydrogen from 2020 through to 2060 comes predominantly from the industry sector. Hydrogen is expected to provide 10% of energy needs in industry generally, 20% of energy needs in steel production, and 15% of energy needs in chemicals production. From 2040 onwards, demand from the transport sector is expected to grow and become the second greatest demand sector in 2060. Despite battery electric vehicles dominating road transport, hydrogen is expected to feature strongly in heavy road transport, shipping and aviation (a quarter of total transport energy needs by 2060). Modelling shows there could be 750,000 FCEVs deployed by 2030 and 48 million by 2060. The building and power sector is expected to make up a small portion of demand.

[36] IEA (2021) An Energy Sector Roadmap to Carbon Neutrality in China https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf

[37] IEA (2021) An Energy Sector Roadmap to Carbon Neutrality in China https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf

[38] China refers to low-carbon hydrogen as hydrogen that is produced with below 14.51kgCO_2-e/kgH_2. China refers to clean hydrogen as hydrogen produced from renewables and fossil fuel conversion with CCS with below 4.90kgCo_2-e/kgH_2. See Wei Liu, Yanming Wan, and Pengbo Gao (2021) 'Green Hydrogen Standard in China: Standard and Evaluation of Low-Carbon Hydrogen, Clean Hydrogen, and Renewable Hydrogen', Hydrogen Sourced from Renewables and Clean Energy: A Feasibility Study of Achieving Large-Scale Demonstration. Jakarta: ERIA. https://www.eria.org/uploads/media/Research-Project-Report/RPR-2021-19/15_Chapter-9-Green-Hydrogen-Standard-in-China_Standard-and-Evaluation-of-Low-Carbon-Hydrogen%2C-Clean-Hydrogen%2C-and-Renewable-Hydrogen.pdf

According to the IEA report, China may choose to pursue technologies which represent the most significant abatement of CO_2 emissions. The technologies with the biggest potential for CO_2 abatement in the Chinese economy are:

- Electrolysis using renewables for methanol and ammonia production;
- Ammonia fuelled ships;
- FCEVs (cars, trucks and buses); and
- Hydrogen for the direct reduction of iron/production of steel.

The next best technologies with significant potential for CO_2 abatement are:

- Hydrogen-fired cement kilns; and
- Synthetic hydrocarbon fuel production.

1.2.3 China's hydrogen RD&D priorities

China's RD&D priorities for hydrogen vehicles and fuel cells have been articulated in the 2016 *Hydrogen Fuel Cell Vehicle Technology Roadmap*[39] and the 2020 *Energy-saving and New Energy Vehicles Technology Roadmap 2.0*[40]. These are summarised in Table 4 below.

Table 4: China's hydrogen RD&D priorities relating to new energy vehicles

Supply chain area	Sub-technology areas	China's key RD&D priorities
Production	Electrolysis	Distributed hydrogen production from renewable sources.
Storage and distribution	Liquid hydrogen	Liquid hydrogen transportation at low temperature.
	Chemical carriers	High density liquid organic hydrogen carriers (LOHCs) for hydrogen storage and transportation at normal pressure.
Utilisation	Fuel cell stack	Performance: Novel electrode materials and fuel cell stack structures. Durability: Efficient fuel stack water management and new material applications. Environmental adaptability: Fuel cell stack development for cold start, and integrated thermal management of power systems. Cost control: Key material development (composite proton exchange membranes, new catalysts), batch production of metal and graphite bipolar plates, and production cost reduction.
	Passenger car fuel cell systems and engines	Low temperature start-up, reliability, durability and service life improvements. High pressure cathodes (220 kPa) operation, pressure and flow optimisation. Water management technology without membrane humidification, and closed-loop water content control without humidification.

[39] China-SAE (2016) Hydrogen Fuel Cell Vehicle Technology Roadmap. English Version, translation sponsored by Anglo American https://docs.wixstatic.com/ugd/45185a_e975e82743f3496ca41fe3ccc94c6228.pdf

[40] Society of Automotive Engineers of China (2020) Energy saving and new energy vehicles Technology Roadmap 2.0. English Translation by DeepL

Supply chain area	Sub-technology areas	China's key RD&D priorities
		Anode hydrogen recirculation, and hydrogen pressure injection control. Energy efficient quick-start at -30 to -40 degrees Celsius. Mass production of air compressors, compression ratio >2.5, and flow rate increase to >150g/s. Recirculation pump, inlet/outlet pressure ratio >2.0, increased standard recirculation quantity to >60m^3/h. Improved power density 60-100 kilowatts (kW) fuel cell systems. Low cost 70MPa hydrogen cylinders, and novel on-board hydrogen storage technology. Fuel cell vehicle systems, and vehicle integration. Pilot FCEV demonstration projects within pilot hydrogen cities.
	Commercial vehicle fuel cell systems and engines	Low temperature start-up, reliability, durability and service life improvements. Medium to high pressure cathode gas supply, and high-efficiency air compressors. Cathode water management without humidifier. Anode hydrogen recirculation pumps, and anode ejector. Lifespan improvement: Fuel cell stack status estimation, water and thermal management technology, operating control systems for durability improvements. Operation at both low and high temperatures, and integrated fuel cell energy management systems. Hybrid fuel cell and battery power: Integrated hybrid control technology, hybrid power systems, thermal management systems. 100,000-unit production capacity. Fuel cell vehicle systems, and vehicle integration. Pilot FCEV demonstration projects within pilot hydrogen cities.
	On-board Storage	Tank storage density of 8.0 wt%, volume density >70g/L, system cost < RMB 2,000/kg. Mass production of 70MPa cylinders and novel high density hydrogen storage. Integrated high pressure cylinder valves, and multifunctional integrated valves.
Cross-cutting	Enabling activities	Though not mentioned as an RD&D activity, the 2020 *Energy-saving and New Energy Vehicles Technology Roadmap 2.0* identifies the need for enabling activities. These include infrastructure development, advanced manufacturing, smart connectivity and digital networks, cross-cutting innovation service platforms, safety, quality assurance and skills development.

While China's RD&D priorities are set out in technical detail for fuel cells and FCEVs, China has yet to articulate the same level of technical detail for other areas of the hydrogen value chain. However, some detailed RD&D priorities can be inferred from the research projects funded by China's 2021 *National Key R&D Program*[41] as well as the IEA's report *An Energy Sector Roadmap to Carbon Neutrality.*[42] The IEA was invited by the Chinese government to co-operate on long-term strategies for China to reach carbon neutrality, and points to several ways hydrogen could be developed in China in the coming years. These include technology areas with high market activity in China, and technology areas expected to be prioritised given China's pledges towards carbon neutrality by 2060 (Table 5). [43]

Table 5: Expected hydrogen RD&D priorities for China in 2022

Supply chain area	Sub-technology areas	China's key RD&D priorities
Production	Electrolysis	**R&D** Electrolysis (anion exchange membranes). Novel fluorine PEM Catalysts (novel materials, reduction of platinum, integration of novel catalysts into electrolysis systems) Reduction of platinum use in catalysts Seawater electrolysis **Demonstration** Electrolysis (solid oxide electrolysis) **Deployment and scale-up** Electrolysis (PEM, alkaline) – Alkaline electrolysis is a particularly active area in China and expected to remain the dominant technology in the market.
	Fossil fuels with CCS	**Demonstration** Natural gas reforming or coal gasification with CCS.
	Alternative production methods	**R&D** Photocatalytic hydrogen production. Rare earth metal catalysts for production hydrogen from hydrogen-containing molecules.
Storage & distribution	Compression and Liquefaction	**R&D** Liquefaction (minimising boil off and reducing costs). Hydrogen compression. Storage tanks and related materials.

[41] Polaris Hydrogen Energy Network (2021) 31 Hydrogen Energy Technologies: Announcement of the proposed projects of the National Key R&D Program in 2021. Polaris Power News Network. https://news.bjx.com.cn/html/20211215/1193855.shtml

[42] IEA (2021) An Energy Sector Roadmap to Carbon Neutrality in China https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf

[43] IEA (2021) An Energy Sector Roadmap to Carbon Neutrality in China https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf

Supply chain area	Sub-technology areas	China's key RD&D priorities
	Hydrogen carriers	**Deployment and scale-up** Production of ammonia and methanol from electrolytic hydrogen.
	Solid Storage	Solid storage materials and improved absorption and release of hydrogen. Metal hydrides (e.g. metal borohydrides).
	Pipelines and gas grids	**Demonstration** Hydrogen blending in natural gas grids. **Deployment and Scale-up** Hydrogen pipelines.
	Transport	**Demonstration** Long distance hydrogen transport by ship. **Deployment and scale-up** Tanker trucks.
	Refuelling infrastructure	**Deployment and scale-up** Hydrogen refuelling stations. Refuelling stations have significant market activity in China.
Utilisation	Gas turbines	**R&D** Gas turbines (100% pure hydrogen). **Deployment and scale-up** Gas turbines (hydrogen-rich gases).
	Transport fuels	**R&D** Synthetic aviation fuels (lowering production costs to a viable level). **Demonstration** Ammonia as shipping fuel (reducing toxicity, NOx emissions).
	Industry	**R&D** Hydrogen-fired cement kilns. **Demonstration** Blending of hydrogen for iron ore reduction. Use of electrolytic hydrogen in heavy industrial processes.
	Fuel cells	**R&D** Cost and lifetime improvements for alkaline membrane fuel cell stacks. Automotive solid oxide fuel cells. Onboard storage of hydrogen and key components.

Supply chain area	Sub-technology areas	China's key RD&D priorities
		Improved cost and performance of fuel cell manufacturing. **Demonstration** Fuel cell heavy vehicles. **Deployment and scale-up** Fuel cell light vehicles (cars and buses). Fuel cell vehicles (buses and trucks) has significant market activity in China.
	Electricity generation	**R&D** Improved efficiency and lifetime of membrane electrodes for power generation. **Deployment and scale-up** Stationary fuel cells for electricity generation, including residential systems. Hydrogen boilers for electricity generation.
Cross-cutting	**Safety**	Hydrogen leakage, combustion and explosion analysis.

1.3 China's hydrogen RD&D ecosystem

1.3.1 Public bodies and policy ecosystem

Overview of China's STI policy landscape

The following section describes the understood structure of the science, technology and innovation (STI) landscape in China. It should be noted, however, that this indicative and may not be fully reflected in practice, as there is considerable interplay between government and other bodies with respect to direction setting, policy setting and consultation.

China maintains a centralised, top-down approach to STI policy. The Central Committee of the Communist Party of China is the highest political body in China and establishes the strategic direction of the Communist Party of China and by extension, China. The State Council (also known as the Central People's Government) is the central governmental administrative authority that makes decisions which give effect to the strategic direction set by the Central Committee of the Communist Party of China. These decisions are then actioned by various bodies, including the National People's Congress (lawmaking body), ministries, academies and research institutes within China at a national and provincial level. The development of policy may be influenced by advice from a range of stakeholders such as the Chinese Academy of Science, Chinese Academy of Engineering, the National Natural Science Foundation (which has an advisory role to the Ministry of Science and Technology) and non-government organisations including the Chinese Association for Science and Technology. Further, industrial associations and industry experts have significant influence in policy setting.

There are various policies and plans which guide China's STI ambitions from the national to provincial level. At a high-level, China's strategic priorities have been established in the *National Medium and Long-Term Plan for the Development of Science and Technology (2006-2020)* (MLP). The MLP established specific quantitative targets for China to achieve by 2020, such as 'increasing the contribution of science and

technology progress to economic growth to 60%.[44] From here, China's 5-Year Plans (FYPs) are considered to be a vehicle for implementing the MLP.[45] The FYPs contain high-level socio-economic targets, and their implementation is supported by sector- and technology-specific plans, including the *Energy Development Five-Year Plan,* the *Matters Concerning the Preparation of the 14th Five-Year Plan for Renewable Energy Development*, and the *Environmental Protection Five-Year Plan* developed by the relevant ministries.[46] These sector-specific FYPs outline detailed targets and implementation plans.

From these plans, provincial level FYPs are tailored to adapt the national and sector-specific FYPs to local conditions.[47] Local governments have responsibility for developing, implementing, and monitoring the progress of provincial-level FYPs.[48] In addition, sector and ministry-specific laws, national strategies and action plans are developed in parallel which complement the MLP and FYPs.[49] As an example, the *Energy Supply and Consumption Revolution Strategy* (2016-2030) guides various aspects of China's energy policy, including consumption, supply and energy security.[50]

Against the backdrop of this government top-down approach exists a number of research institutions and think tanks that play roles of varying influence in the formulation, evaluation, and implementation of STI policy within China. Research universities and institutions are largely academic in nature and participate broadly in R&D activities within their areas of study. In recognising the importance of public research and innovation the Chinese government has been incentivising R&D by increasing research funding across the science and technology sector. It is worth noting that the ratio of funding between basic and applied research versus experimental development has increasingly moved toward the latter in recent years.[51]

The most influential think tanks and research institutes in China tend to be those that are government or SOE-affiliated. These include the Chinese Academies of Science, Engineering and Social Sciences (CAS, CAE, and CASS respectively), the Development Research Centre of the State Council, and the Energy Research Institute of the National Development and Reform Commission (NDRC), who provide academic and quality input and advise government on STI developments that can then inform governmental policy.[52]

Overview of China's hydrogen policy landscape

China's energy-specific policy-making process mirrors that of the STI system explained in the above section. During the policy drafting process, advice and input is sourced from various stakeholders, including research institutions (such as the Chinese Academy of Science) and Minister level think-tanks (such as the Energy Research Institute (ERI) and the National Centre for Climate Change Strategy and International

[44] Sun Y, Cao C (2021) Planning for science: China's "grand experiment" and global implications, Humanities &Social Sciences Communications. DOI: 10.1057/s41599-021-00895-7

[45] Sun Y, Cao C (2021) Planning for science: China's "grand experiment" and global implications, Humanities &Social Sciences Communications. DOI: 10.1057/s41599-021-00895-7

[46] IEA (2021) An Energy Sector Roadmap to Carbon Neutrality in China https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf

[47] IEA (2021) An Energy Sector Roadmap to Carbon Neutrality in China https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf

[48] IEA (2021) An Energy Sector Roadmap to Carbon Neutrality in China https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf

[49] IEA (2021) An Energy Sector Roadmap to Carbon Neutrality in China https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf

[50] IEA (2021) An Energy Sector Roadmap to Carbon Neutrality in China https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf

[51] Mallapaty S (2021) China's five-year plan focuses on scientific self-reliance. Nature. Viewed 29 November 2021 https://www.nature.com/articles/d41586-021-00638-3; Sun Y, Cao C (2021) Planning for science: China's "grand experiment" and global implications, Humanities &Social Sciences Communications. DOI: 10.1057/s41599-021-00895-7

[52] Jianjun Tu K (2020). Prospects of a hydrogen economy with Chinese characteristics. French Institute of International Relations, Center for Energy & Climate. Viewed at https://www.ifri.org/sites/default/files/atoms/files/tu_china_hydrogen_economy_2020_1.pdf

Cooperation (NCCCSIC)). The State Council then approves new policy, and if the policy is of note, then the NPC. From here, the relevant Ministry has responsibility for implementing the policy alongside provincial-level governments. Further information on relevant government ministries, regulatory bodies and government think tanks can be found in Table 6. However, it has been noted that hydrogen governance is fragmented between these various government authorities.[53]

Current policy regarding hydrogen is driven by the *Made in China 2025* strategy, and the 14th FYP (2021-2025). It is reported that the National Development and Reform Commission is currently drafting a hydrogen-specific industry strategy.[54] More specifically, the plan is expected to establish hydrogen R&D priorities, targets and the technical standards necessary to facilitate the commercial scale-up of a hydrogen economy.[55] It is expected that, similar to the MLP and FYPs, implementation of the NDRC's hydrogen-specific plan will remain decentralised. This means various research institutions, ministries and provincial-level governments will have responsibility for implementing the plan at various scales.[56] However, in the absence of a centralised hydrogen strategy, approximately 30 provinces and cities have developed hydrogen-specific development strategies.[57] These are individualised strategies which take advantage of the specific capabilities of each province to facilitate R&D and more recently, commercialisation.[58]

The key bodies involved in hydrogen RD&D and the overall hydrogen policy ecosystem are depicted below in Figure 3. A more detailed description of their roles in China's STI ecosystem and hydrogen policy landscape are summarised in Table 6.

[53] Jianjun Tu K (2020). Prospects of a hydrogen economy with Chinese characteristics. French Institute of International Relations, Center for Energy & Climate. Viewed at https://www.ifri.org/sites/default/files/atoms/files/tu_china_hydrogen_economy_2020_1.pdf

[54] Bloomberg News (2021) China is Formulating a Hydrogen Plan But Its Timing is Uncertain. Viewed at https://www.bloomberg.com/news/articles/2021-04-23/china-is-formulating-a-hydrogen-plan-but-its-timing-is-uncertain

[55] Bloomberg News (2021) China is Formulating a Hydrogen Plan But Its Timing is Uncertain. Viewed at https://www.bloomberg.com/news/articles/2021-04-23/china-is-formulating-a-hydrogen-plan-but-its-timing-is-uncertain

[56] IEA (2021) An Energy Sector Roadmap to Carbon Neutrality in China https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf

[57] Consultation with in-country stakeholders.

[58] Yuki (2020) China Hydrogen Policy: A Summary of Provincial Plans. Energy Iceberg. Viewed at https://energyiceberg.com/china-hydrogen-policy-provincial-summary/

Figure 3: Summary of China's hydrogen policy ecosystem

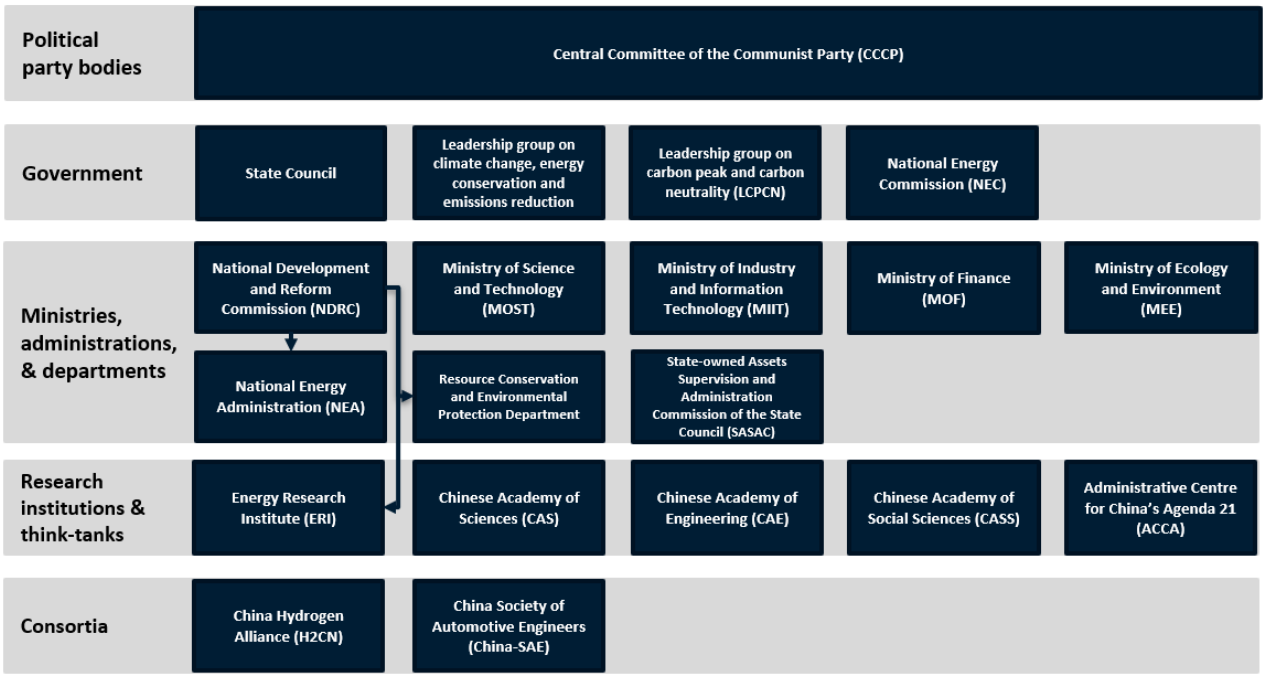


Table 6: Summary of key public bodies[59]

Body	Role in RD&D ecosystem	Hydrogen initiatives
Central Committee of the Communist Party of China	The Central Committee is considered the highest political body in China and establishes China's key strategic direction, priorities, and policy objectives.	The Central Committee of the Communist Party of China establishes China's strategic direction and priorities with respect to hydrogen, and defines policy direction.[60]
State Council	The State Council is the central governmental administrative authority in China and makes decisions to implement the strategic direction and policy objectives set by the Central Committee.[61]	The State Council, in collaboration with the Central Committee, is expected to establish China's strategic and policy direction and priorities with respect to hydrogen.
State Council and Central Committee of the Communist Party	The State Council is the central administrative and planning authority in China.[62] The Central Committee is considered the Chinese Communist Party's highest body of	The State Council and Central Committee of the Communist Party are expected to establish China's strategic direction with respect to hydrogen, and to identify suitable policy options to be developed by the relevant bodies and ministries.[63]

[59]Jianjun Tu K (2020). Prospects of a hydrogen economy with Chinese characteristics. French Institute of International Relations, Center for Energy & Climate. Viewed at https://www.ifri.org/sites/default/files/atoms/files/tu_china_hydrogen_economy_2020_1.pdf

[60] Jianjun Tu K (2020). Prospects of a hydrogen economy with Chinese characteristics. French Institute of International Relations, Center for Energy & Climate. https://www.ifri.org/sites/default/files/atoms/files/tu_china_hydrogen_economy_2020_1.pdf

[61] Jianjun Tu K (2020). Prospects of a hydrogen economy with Chinese characteristics. French Institute of International Relations, Center for Energy & Climate. Viewed at https://www.ifri.org/sites/default/files/atoms/files/tu_china_hydrogen_economy_2020_1.pdf

[62] Jianjun Tu K (2020). Prospects of a hydrogen economy with Chinese characteristics. French Institute of International Relations, Center for Energy & Climate. Viewed at https://www.ifri.org/sites/default/files/atoms/files/tu_china_hydrogen_economy_2020_1.pdf

[63] Jianjun Tu K (2020). Prospects of a hydrogen economy with Chinese characteristics. French Institute of International Relations, Center for Energy & Climate. Viewed at https://www.ifri.org/sites/default/files/atoms/files/tu_china_hydrogen_economy_2020_1.pdf

Body	Role in RD&D ecosystem	Hydrogen initiatives
	authority, overseeing the work of executive bodies of the party. These two bodies are tightly related. Members of the State Council are also members of the Central Committee, and set China's strategic direction.	
NDRC *National Development and Reform Committee*	The NDRC is a ministerial-level department of State Council which has a broad policy remit. At a high-level, the NDRC's role is to develop socio-economic policy and coordinate the implementation of strategies and projects identified in MLPs and FYPs, with a particular focus on social and defence infrastructure.[64]	The NDRC is developing China's hydrogen-specific industry strategy, which is expected to be completed by 2022. Once developed, the NDRC is expected to have overarching responsibility for coordinating the hydrogen strategy's implementation.[65]
NEC *National Energy Commission*	The NEC – sitting under the State Council – has responsibility for developing China's energy development policy, reviewing energy security issues and managing international energy cooperation.[66]	The NEC's specific role regarding hydrogen is unclear. It is expected the NEC will support the State Council and NEA in developing hydrogen-specific plans.
NEA *National Energy Administration*	Managed by the NDRC, the NEA has broad policy remit. This includes drafting and coordinating the implementation of industry-specific development strategies; drafting laws and regulations with respect of energy development; promoting R&D and scientific programs related to the energy industry; and coordinating RD&D projects.	The NEA will have responsibility for hydrogen production, transport, and fuel cell utilisation.[67]
Leadership Group on Climate Change, Energy Conservation and Emissions Reduction	Made up of twenty-six ministries and commissions and chaired by the Premier, the role of this leadership group is to develop climate change strategies and policies, review international cooperation and negotiations, and organise the implementation of the State Councils policies on conservation and emissions reduction.[68]	Leadership Group on Climate Change, Energy Conservation and Emissions Reduction's specific role regarding hydrogen is unclear. However, given the emissions targets as stated earlier, it is expected that hydrogen will be within scope.
LCPCN	The LCPCN, which comprises members of key national ministries, has the role of	The LCPCN's specific role regarding hydrogen is uncertain.

[64] NDRC (n.d.) Main Functions of the NDRC. Viewed at https://en.ndrc.gov.cn/aboutndrc/mainfunctions/

[65] Jianjun Tu K (2020). Prospects of a hydrogen economy with Chinese characteristics. French Institute of International Relations, Center for Energy & Climate. Viewed 16 November 2021, https://www.ifri.org/sites/default/files/atoms/files/tu_china_hydrogen_economy_2020_1.pdf

[66] Zhiyue B (2010) China's New National Energy Commission: Policy Implications. Understanding China's Landscape. Viewed at https://www.understandchinaenergy.org/chinas-new-national-energy-commission-policy-implications/

[67] Jianjun Tu K (2020). Prospects of a hydrogen economy with Chinese characteristics. French Institute of International Relations, Center for Energy & Climate. Viewed 16 November 2021, https://www.ifri.org/sites/default/files/atoms/files/tu_china_hydrogen_economy_2020_1.pdf

[68] Sandalow D (2019) Guide to Chinese Climate Policy, Columbia Center on Global Energy Policy. Viewed at https://energypolicy.columbia.edu/sites/default/files/file-uploads/Guide%20to%20Chinese%20Climate%20Policy_2019.pdf

Body	Role in RD&D ecosystem	Hydrogen initiatives
Leadership group on carbon peak and carbon neutrality	coordinating urgent cross-governmental issues with the view to achieving carbon neutrality.[69]	
MOST *Ministry of Science and Technology*	The MOST develops and coordinates the implementation of science and technology related R&D strategies and plans.	In November 2020, MOST announced plans to increase R&D into hydrogen energy and fuel cell technology, aligned with the FYPs. In addition, the Ministry coordinated the implementation of key 'new energy' FCEV and renewable energy RD&D programs.[70]
MIIT *Ministry of Industry and Information Technology*	MIIT has broad responsibility for policy making, regulation and development with respect of the internet, digital communications, broadcasting, and the national knowledge economy.[71]	The MIIT's specific hydrogen-related role is uncertain. However, it is expected that MIIT will facilitate the development of a hydrogen supply-chain network.[72] In December 2021, the MIIT released the *14th Five Year Plan for Industrial Green Development*, which highlights the utilisation of hydrogen.
MOF *Ministry of Finance*	MOF has responsibility for macroeconomic policy, government expenditure and annual budgets.	The MOF will facilitate the allocation of centralised funding for hydrogen RD&D, working with provinces to support development of a hydrogen economy. The MOF will also coordinate state subsidy programs.[73]
MEE *Ministry of Ecology and Environment*	Broadly, the MEE is China's environmental protection department. The MEE oversees the National Centre for Climate Change Strategy and International cooperation (NCSC).[74]	The MEE's specific role regarding hydrogen is uncertain. However, the MEE has declared mandates pertaining to the attainment of national emission reduction targets and enforcing ecological and environmental regulations which include organising key scientific research projects for environmental technologies.[75]
Department of Resource Conservation and	The Department of Resource Conservation and Environmental Protection is positioned under the NDRC and is responsible for the	In their *Action Plan for Carbon Dioxide Peaking Before 2030,*[77] the department announced plans to integrate trials on

[69] You X (2021) Explainer: China creates new 'leaders group' to help deliver its climate goals. CarbonBrief. Viewed at https://www.carbonbrief.org/explainer-china-creates-new-leaders-group-to-help-deliver-its-climate-goals

[70] China.org.cn (2020) MOST to Strengthen research on Hydrogen and Fuel Cell Technology. Viewed at http://www.china.org.cn/business/2020-11/17/content_76919339.htm

[71] Jianjun Tu K (2020). Prospects of a hydrogen economy with Chinese characteristics. French Institute of International Relations, Center for Energy & Climate. Viewed at https://www.ifri.org/sites/default/files/atoms/files/tu_china_hydrogen_economy_2020_1.pdf

[72] Jianjun Tu K (2020). Prospects of a hydrogen economy with Chinese characteristics. French Institute of International Relations, Center for Energy & Climate. Viewed at https://www.ifri.org/sites/default/files/atoms/files/tu_china_hydrogen_economy_2020_1.pdf

[73] Jianjun Tu K (2020). Prospects of a hydrogen economy with Chinese characteristics. French Institute of International Relations, Center for Energy & Climate. Viewed at https://www.ifri.org/sites/default/files/atoms/files/tu_china_hydrogen_economy_2020_1.pdf

[74] MEE. MANDATES. The People's Republic of China. Viewed 29 November https://english.mee.gov.cn/About_MEE/Mandates/

[75]MEE. MANDATES. The People's Republic of China. Viewed 29 November https://english.mee.gov.cn/About_MEE/Mandates/

[77] NDRC (n.d.) ACTION PLAN FOR CARBON DIOXIDE PEAKING BEFORE 2030. Viewed 29 November 2021, https://en.ndrc.gov.cn/policies/202110/t20211027_1301020.html

Body	Role in RD&D ecosystem	Hydrogen initiatives
Environmental Protection	formulation and implementation of policies relating to green and sustainable development - including policy plans for the utilisation of energy resources and a circular economy. The department also has a hand in coordinating demonstration projects and application of new technologies.[76]	hydrogen metallurgy within the steel industry, expand the application of clean energy in transportation including hydrogen power, and accelerate the RD&D of low-cost hydrogen production and storage.
SASAC *State-owned Assets Supervision and Administration Commission of the State Council*	SASAC, a ministerial level commission, has responsibility for managing SOEs and the drafting of related regulation and laws.	Given hydrogen RD&D activities are undertaken by various SOEs, it is expected SASAC will therefore have a tangential management role in developing China's hydrogen economy.[78]
CAS *Chinese Academy of Sciences*	The CAS is a ministerial level organisation and is the strongest research body in China. It has over 100 institutes across China, covering various research areas including energy.[79] It also functions academic governing body, but also as an advisory capacity.	Given the signal sent by the MOST, it is expected policy and funding will favour hydrogen relevant research, and CAS will contribute a large share of that research. Alongside Shanghai Electric, the Dalian Institute of Chemical Physics of the CAS have inaugurated the PEM Hydrogen Production Technology R&D Centre. The two parties are working to develop high efficiency proton exchange membrane hydrogen generation products.[80]
CAE *Chinese Academy of Engineering*	The CAE is the chief advisory academic institution in the field of engineering sciences and technology in China. The CAE plays an active role in providing consultation for national decision-making and in facilitating strategic research across institutes.[81]	The CAE, alongside other partners (CISRI, Northeast University, and HBIS), established the Hydrogen Technology & Innovation Centre to support their hydrogen project efforts. This includes the construction of a pilot hydrogen station.[82] The CAE also conducts research within the hydrogen sphere.[83]

[76] NDRC (n.d.) Department of Resource Conservation and Environmental Protection. Viewed at https://en.ndrc.gov.cn/policies/202110/t20211027_1301020.html.cn/aboutndrc/BandD/202105/t20210526_1280928.html

[78] Jianjun Tu K (2020). Prospects of a hydrogen economy with Chinese characteristics. French Institute of International Relations, Center for Energy & Climate. Viewed 16 November 2021, https://www.ifri.org/sites/default/files/atoms/files/tu_china_hydrogen_economy_2020_1.pdf

[79] CAS (2014) CAS INSTITUTES. Viewed 29 November 2021, <https://english.cas.cn/cl/>; Chinese Academy of Sciences. ABOUT US. Viewed at https://english.cas.cn/about_us/

[80] Ali S (2021) China Opens PEM Electrolyser R&D Centre, H2 Bulletin. Viewed 29 November 2021, https://www.h2bulletin.com/china-opens-pem-electrolyser-rd-centre/

[81] CAE (2021) About Us. http://en.cae.cn/AboutUs.html

[82] HBIS Group (2020) First HBIS Pilot Hydrogen Station Is In Operation. Viewed at https://www.hbisco.com/site/en/groupnewssub/info/2020/15733.html

[83] CAE (2021) Research & Activities. http://en.cae.cn/All.html?topIndex=0

Body	Role in RD&D ecosystem	Hydrogen initiatives
CASS *Chinese Academy of Social Sciences*	The CASS is an academic organisation and research centre which is made up of 31 research institutes and 45 research centres.[84] CASS is supported/approved by the State Council.	As a state think tank, CASS' studies are highly relevant to any future national strategy. It is expected that CASS will conduct a number of cross-cutting research projects on the impact of carbon neutrality and the hydrogen industry to China's economy.
ACCA21 *Administrative Centre for China's Agenda 21*	The ACCA21 sits under the MOST with its chief role being to facilitate the implementation of China's Agenda 21. This includes conducting sustainability policy/strategy research and providing policy support, fostering international cooperation, and building a national information sharing network for sustainable development.[85]	The ACCA21 participates in research, promotes the *Carbon Neutral Technology Development Roadmap*, [86] and hosts a series of expert seminars to promote cooperation in the transfer of renewable energy technology and the development strategy for the hydrogen energy industry.
ERI *Energy Research Institute*	The ERI sits under the NDRC and is one of China's leading national energy research institutes (alongside the China National Renewable Energy Centre (CNREC)). ERI conducts research and provides policy recommendations to ministerial, provincial, and city governments on all matters pertaining to energy (production, distribution and consumption).[87]	Recent reports from the ERI have shown interest in using hydrogen technologies to reduce China's CO_2 emissions and reach their global emissions reduction targets. Current research topics include hydrogen fuel cells, space heating, and employing hydrogen to expand the use of renewable electricity, in areas of efficacy, feasibility, cost projections, and impact.[88]
Local Governments	In China, there are five levels of local government: the provincial, prefecture, county, township and village. Within every central government ministry, there is an equivalent agency at the local government prefecture level – for example, in Shanxi province the Shanxi Development and Reform Commission is similar to the NDRC. These bodies develop local-level socio-economic policy.[89]	In relation to hydrogen, it is expected these prefecture-level bodies will have remit to manage resources and design and implement prefecture-specific hydrogen plans.

[84] ISC (n.d.) China, Chinese Academy of Social Sciences (CASS). https://council.science/member/china-chinese-academy-of-social-sciences-cass/

[85] ACCA21 (2008) The Administrative Centre for China's Agenda 21: Introduction. Viewed 1 December 2021 http://www.sinoitaenvironment.org/ReadNewsex1.asp?NewsID=2209

[86] ACCA21 (2021) The 21st Century Center parallel session of "The Road to Carbon Neutrality: Emerging Green, Low-Carbon, and Zero-Carbon Technologies". Viewed 1 December 2021 http://www.acca21.org.cn/trs/zlyj/kjzctzhzlyj/gongzuojinzhan/16200.html

[87] IRENA (2021) RENEWABLE ENERGY POLICIES FOR CITIES: EXPERIENCES IN CHINA, UGANDA AND COSTA RICA. Viewed December 1 2021, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/May/IRENA_Policies_for_Cities_2021-V2.pdf

[88] CNREC and NDRC (2019) China Renewable Energy Outlook 2019. https://www.thinkchina.ku.dk/documents/CREO-2019-EN-Final-0316.pdf

[89] Jianjun Tu K (2020). Prospects of a hydrogen economy with Chinese characteristics. French Institute of International Relations, Center for Energy & Climate. Viewed 16 November 2021, https://www.ifri.org/sites/default/files/atoms/files/tu_china_hydrogen_economy_2020_1.pdf

1.3.2 Hydrogen consortia

SOEs play a central role in hydrogen RD&D and commercialisation.[90] There are two key types of SOEs in China:

- **Central SOEs:** Are legal entities which undertake commercial activities on behalf of the central Chinese government. For example, China Energy Investment Group – which formed following the merger of Shenhua and Guodian – has expressed a desire to develop hydrogen production capability. In addition, central SOEs such as the China FAW Group and Dongfeng Motor Group – both of which are car manufacturers – are expected to commence FCEV RD&D, with commercialisation following.[91]
- **Local SOEs:** Are legal entities which undertake commercial activities on behalf of local Chinese governments. Of note, local SOEs may have public policy objectives. As an example, the Shandong Heavy Industry Group and Shandong Port Group have partnered to promote hydrogen infrastructure development at local ports in Shandong.[92]

Central and local SOEs participate in hydrogen consortia involving industry, government and research members. Key hydrogen consortia in China are listed in Table 7.

Table 7: Hydrogen consortia

Consortium	Description
H2CN *China Hydrogen Alliance*	Founded in 2018, this consortium of research institutions and companies across the energy and automotive sectors, supported by the government, serves as a stakeholder platform and think-tank for the development of a Chinese hydrogen strategy.[93] Membership of the Alliance includes central and local SOEs, research institutions, private enterprises and foreign entities. These include: Beijing Institute of Technology, CASC, CISRI, Harbin Institute of Technology, North China Electric Power University, Tsinghua University, Tongji University, Zhejiang University, CHN Energy, Baosteel, Chery, China Shipbuilding Industry Corporation, CRRC, Dongfeng Motor Group, China FAW Group, SAIC Motor, Shanghai Electric, and State Grid Corporation.
China-SAE *China Society of Automotive Engineers*	The Society of Automotive Engineers is a national academic organisation and is a member of the China Association for Science and Technology. Their aims are to promote scientific and technical progress in the automotive industry and have more than tens of thousands of individual members and thousands of corporate members.[94]

[90] Jianjun Tu K (2020). Prospects of a hydrogen economy with Chinese characteristics. French Institute of International Relations, Center for Energy & Climate. Viewed 16 November 2021, https://www.ifri.org/sites/default/files/atoms/files/tu_china_hydrogen_economy_2020_1.pdf

[91] Jianjun Tu K (2020). Prospects of a economy with Chinese characteristics. French Institute of International Relations, Center for Energy & Climate. Viewed 16 November 2021, https://www.ifri.org/sites/default/files/atoms/files/tu_china_hydrogen_economy_2020_1.pdf

[92] Jianjun Tu K (2020). Prospects of a hydrogen economy with Chinese characteristics. French Institute of International Relations, Center for Energy & Climate. Viewed 16 November 2021, https://www.ifri.org/sites/default/files/atoms/files/tu_china_hydrogen_economy_2020_1.pdf

[93] NOW GmBh (2020) Factsheet: Hydrogen and Fuel Cell Technology in China https://www.now-gmbh.de/wp-content/uploads/2020/09/Factsheet-China-FC-EN.pdf

[94] China-SAE (n.d.) About Us. http://en.sae-china.org/c301

1.3.3 Funding mechanisms

Overview of China's hydrogen RD&D public budget allocations

China is placing significant emphasis on science and technology and renewable energy RD&D more specifically. Since 2017, investment in hydrogen-related projects has surpassed CNY 250 billion.[95] Total public and private science and technology expenditure increased by 12.5% in 2019 to USD 322 billion.[96] In March 2021, China announced a 7% GDP increase in R&D expenditure between 2021 and 2025, increasing the ratio of R&D spending to GDP.[97] In 2021, China had the second highest growth in R&D input, and is closing the gap with other countries in the OECD.[98]

Hydrogen RD&D activities are funded through existing funding mechanisms established by the FYPs.[99] The Chinese Government also funds hydrogen initiatives under the National Key R&D Program aiming to fund highly qualified research whose areas is of national strategic interest. Sub-national governments also allocate funding subject to provincial-level initiatives and priorities. Key points and examples to note include:

- In 2021, MOST announced several hydrogen grants under the 2021 National Key R&D Program. Projects under this grant range from a duration of three to five years and cover the entire hydrogen value chain and include hydrogen production via electrolysis, novel production methods, catalysis science, storage materials, new energy vehicles, and fuel cell manufacturing.[100]
- China is encouraging and focusing funding for innovation and RD&D around carbon neutrality.[101] Funding for specific RD&D initiatives is aligned to priorities established in FYPs and the MLP – noting hydrogen was prioritised in the most recent 14th Five-Year Plan.[102]
- A New Infrastructure Initiative as part of its COVID-19 recovery package, involving investment in digitalisation, energy and transport infrastructure.[103] It also includes an innovative infrastructure component comprising science, technology and education infrastructure, and industrial technology innovation infrastructure (including innovation-focused industrial parks).[104]
- The People's Bank of China (PBoC) announced it would offer low-interest loans for carbon emissions reduction and projects working toward carbon neutrality, as of November 2021. Financial institutions

[95] CMS Law (2020). Hydrogen Law and Regulation in China. Viewed 16 November 2021, https://cms.law/en/int/expert-guides/cms-expert-guide-to-hydrogen/china

[96] Normile D (2020) China again boosts R&D spending by more than 10%. Science. https://www.science.org/content/article/china-again-boosts-rd-spending-more-10

[97] Kharpal A (2021) China spending on research and development to rise 7% per year in push for major tech breakthroughs, CNBC. Viewed at https://www.cnbc.com/2021/03/05/china-to-boost-research-and-development-spend-in-push-for-tech-breakthroughs.html

[98] Kharpal A (2021) China spending on research and development to rise 7% per year in push for major tech breakthroughs, CNBC. Viewed at https://www.cnbc.com/2021/03/05/china-to-boost-research-and-development-spend-in-push-for-tech-breakthroughs.html

[99] IEA (2021) An Energy Sector Roadmap to Carbon Neutrality in China https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf

[100] Polaris Hydrogen Energy Network (2021) 31 Hydrogen Energy Technologies: Announcement of the proposed projects of the National Key R&D Program in 2021. Polaris Power News Network. https://news.bjx.com.cn/html/20211215/1193855.shtml

[101] IEA (2021) An Energy Sector Roadmap to Carbon Neutrality in China https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf

[102] Reuters Staff (2021) China's CEIC, China Reform set up $1.55 billion new energy fund, Reuters. Viewed at https://www.reuters.com/article/us-china-fund-cleanenergy-idUSKBN29R10U

[103] IEA (2021) An Energy Sector Roadmap to Carbon Neutrality in China https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf

[104] Wong (2020) How can foreign technology investors benefit from China's new infrastructure plan? China Briefing. https://www.china-briefing.com/news/how-foreign-technology-investors-benefit-from-chinas-new-infrastructure-plan/

that offer loans for these projects will receive support from the central bank, with priority given to growth-stage, high-impact projects and industries.[105]

Industry and consortia funding for hydrogen RD&D

Private companies, research institutions and SOEs have begun to heavily fund hydrogen RD&D activities. In China, various mechanisms are used to fund hydrogen RD&D, including industry funds, bonds and private equity. China's political system means private and public investments across SOEs, private companies, research and commercial institutions and local government can be readily combined to establish industry funds and public-private partnerships (PPPs) – both of which are primary funding mechanisms for hydrogen. At a high-level, most hydrogen related RD&D funding has been directed to FCEVs and associated infrastructure, including fuelling stations.[106] Examples of funding sources are as follows:

- The Daxing International Hydrogen Energy Demonstration Zone and Tsinghua University have established a joint fund which has invested UDS 283 million in hydrogen entities, hydrogen-related start ups and hydrogen RD&D.[107]
- In May 2020, China Energy entered into a cooperation agreement with Donghu Development Zone to establish an RMB 1 billion hydrogen industry fund.[108]
- In June 2019, Meijin Energy established the 'Qingdao Meijin Hydrogen Energy Town Cooperation Framework Agreement' with the Qingdao Municipal Bureau of Industry and Information Technology, which will invest CNY 10 billion in hydrogen R&D and technologies, including FCEVs, membrane electrodes and general scientific support.[109]
- In June 2019, Dongfang Electric Group entered into an agreement with Three Gorges Capital and Chengdu Innovation Ventures to establish a RMB 500 million hydrogen industry fund.[110]
- In September 2019, Chengdu municipal government issued RMB 224 million worth of government bonds to develop a hydrogen industrial park. However, government-issued bonds are a less common funding mechanism.[111]
- In 2018, Hyundai Motor signed a Memorandum of Understanding (MoU) with Beijing-Tsinghua Industrial R&D Institute to establish a 'Hydrogen Energy Fund.' The fund sought to raise USD 100 million to facilitate R&D across the hydrogen value chain, and support hydrogen-related start-ups in China and South Korea.[112]

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[105] ChinaPolicy (2021) Hydrogen and FCV policy in the PRC: major developments since September 2020.

[106] Bloomberg (2019). China's Hydrogen Vehicle Dream Chased With $17 Billion of Funding. Viewed 17 November 2021, https://www.bloomberg.com/news/articles/2019-06-27/china-s-hydrogen-vehicle-dream-chased-by-17-billion-of-funding

[107] Consultation with in-country stakeholders

[108] Green Finance and Development Center (2020). Hydrogen: China's Progress and Opportunities for a Green Belt and Road Initiative. Viewed 16 November 2021, https://greenfdc.org/hydrogen-chinas-progress-and-opportunities-for-a-green-belt-and-road-initiative/?cookie-state-change=1637217869997

[109] CMS Law (2020). Hydrogen Law and Regulation in China. Viewed 16 November 2021, https://cms.law/en/int/expert-guides/cms-expert-guide-to-hydrogen/china

[110] Green Finance and Development Center (2020). Hydrogen: China's Progress and Opportunities for a Green Belt and Road Initiative. Viewed 16 November 2021, https://greenfdc.org/hydrogen-chinas-progress-and-opportunities-for-a-green-belt-and-road-initiative/?cookie-state-change=1637217869997

[111] Green Finance and Development Center (2020). Hydrogen: China's Progress and Opportunities for a Green Belt and Road Initiative. Viewed 16 November 2021, https://greenfdc.org/hydrogen-chinas-progress-and-opportunities-for-a-green-belt-and-road-initiative/?cookie-state-change=1637217869997

[112] Hyundai (2018). Hyundai Motor establishes 'Hydrogen Energy Fund'. Viewed 15 November 2021, https://www.hyundai.news/eu/articles/press-releases/hyundai-motor-establishes-hydrogen-energy-fund-with-rd-institute-btirdi.html

- Mingtian Hydrogen plans to invest CNY 2.5 billion to conduct R&D and manufacture fuel cell stacks and components.[113]
- Great Wall Motor has invested CNY 1 billion in hydrogen energy and FCEV RD&D.[114]
- China National Heavy-Duty Truck Group seeks to invest USD 7.6 billion to develop FCEV technology and manufacturing capacity in Shandong.[115]
- Fuel cell technology companies – such as SinoSynergy and Wuhan Tiger FCV – have been invested in by listed companies.[116] This illustrates how private and public equity investments are now becoming more common methods to fund hydrogen RD&D activities.

1.3.4 Other key hydrogen policies, regulation and legislation

In addition to the governance, strategy and funding mechanisms for hydrogen RD&D programs, China has several key policies, regulations and laws to incentivise and regulate the commercial uptake of hydrogen technologies. Notable policies and regulations are outlined below.

Legislation

At present, China does not have hydrogen-specific legislation to facilitate the development of hydrogen technology or commercialisation, at either a national or provincial level. However, China's new draft *Energy Law of the People's Republic of China* classifies hydrogen as an energy fuel. Although, it remains uncertain exactly how this draft legislation will regulate hydrogen R&D and commercialisation activities.[117]

Regulation

Whilst not hydrogen-specific, there are various domestic regulations and standards which tangentially apply to hydrogen R&D, production and utilisation. The China National Institution of Standardization (CNIS) is the central body responsible for standardisation across the China's economy.[118] Regulations cover the following areas relevant to hydrogen:[119]

- **Vehicle Standards:** The National Technical Committee of Auto Standardisation (NTCAS) develops standards and technical specifications for FCEVs, and components. More comprehensive vehicle standards are being developed to ensure International Organisation for Standardisation (ISO) alignment.

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[113] Bloomberg (2019). China's Hydrogen Vehicle Dream Chased With $17 Billion of Funding. Viewed 17 November 2021, https://www.bloomberg.com/news/articles/2019-06-27/china-s-hydrogen-vehicle-dream-chased-by-17-billion-of-funding

[114] China Daily (2019). Great Wall Motor Bets Big on Hydrogen Fuel Cell Vehicles. Viewed 10 November 2021, http://global.chinadaily.com.cn/a/201902/26/WS5c749b98a3106c65c34eb69d.html

[115] De Blasio N and Pflugmann F (2020). Is China's Hydrogen Economy Coming? A Game-Changing Opportunity. Harvard Kennedy School, United States of America. Viewed 15 November 2021, https://www.belfercenter.org/sites/default/files/files/publication/Is%20China%27s%20Hydrogen%20Economy%20Coming%207.28.20.pdf

[116] Green Finance and Development Center (2020). Hydrogen: China's Progress and Opportunities for a Green Belt and Road Initiative. Viewed 16 November 2021, https://greenfdc.org/hydrogen-chinas-progress-and-opportunities-for-a-green-belt-and-road-initiative/?cookie-state-change=1637217869997

[117] S&P Global Platts (2020). Interview: New policies will support use of hydrogen as energy fuel in China. Viewed 16 November 2021, https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/072720-interview-new-policies-will-support-use-of-hydrogen-as-energy-fuel-in-china-air-liquides-h2-director

[118] Jianjun Tu K (2020). Prospects of a hydrogen economy with Chinese characteristics. French Institute of International Relations, Center for Energy & Climate. Viewed 16 November 2021, https://www.ifri.org/sites/default/files/atoms/files/tu_china_hydrogen_economy_2020_1.pdf

[119] Pfautsch J (n.d.) Regulations and standards for hydrogen-based electric mobility in China, NOW GmbH. Viewed at https://www.now-gmbh.de/en/news/pressreleases/regulations-and-standards-for-hydrogen-based-electric-mobility-in-china/

- **Fuel Cell Standards:** The National Technical Committee for the National Standardisation of Fuel Cells and Flow Batteries develops standards for fuel cell and flow batteries. For example, 'GB/T 37244' specifies the minimum hydrogen quality for use in FCEVs, which mirrors the equivalent ISO specifications (ISO/14687:2019).
- **High-pressure storage:** The National Standardisation Technical Committee of Gas Cylinders regulates high-pressure storage systems, such as those to be used for hydrogen storage and distribution. For example, 'TSG R0002-2005 Super-high pressure vessel safety and technical supervision regulation' specifies requirements for the production, utilisation, inspection, and supervision of equipment.[120]

The National Standardisation Technical Committee for Hydrogen Energy, a sub-committee of the CNIS, is currently developing hydrogen-specific standards across the value chain.[121] It is unknown when these standards will be finalised.

In April 2019, the State Council issued an opinion on the *Government Work Report*, recommending a decentralised approach to regulation.[122] Instead of one central hydrogen-specific regulatory body, the State Council recommended that individual ministries should retain responsibility for developing and enforcing hydrogen regulations across the value chain relevant to their portfolio.[123]

Subsidies

Subsidies at a national and provincial-level incentivise the development and commercialisation of hydrogen technology. In 2020, a subsidy scheme was introduced to promote provincial-level hydrogen demonstration projects over a four-year demonstration period. As part of the scheme, CNY 1.7 billion will be allocated to city-level governments to fund FCEVs RD&D (with funding proportional to their success in promoting hydrogen innovation). [124] City-level governments will then award subsidies to manufacturers who specialise in various aspects of FCEVs including fuel cell components, as well as to purchasers of medium- and heavy-duty fuel cell electric buses (FCEBs) subject to minimum technical standards. [125] Selected areas were the Jing-jin-ji region (Beijing-Tianjin-Hebei), Shanghai, and Guangdong. In addition, subsidies will be provided to production, transportation and distribution companies which reduce the consumer and/or commercial price of hydrogen.[126] This scheme also seeks to improve the policy and institutional environment surrounding fuel cell adoption across the entire hydrogen value chain. [127]

[120] Zheng JY, Hua ZL, Ou KS, Chen LX, Wang G, and Zhao YZ (2013) Evolution in Hydrogen Safety Activities, Regulations, and Standards in China Over the Last Decade [Conference Paper]. Viewed at http://www.ichs2013.com/images/papers/155.pdf

[121] Pfautsch J (n.d.) Regulations and standards for hydrogen-based electric mobility in China, NOW GmbH. Viewed at https://www.now-gmbh.de/en/news/pressreleases/regulations-and-standards-for-hydrogen-based-electric-mobility-in-china/

[122] CMS Law (2020). Hydrogen Law and Regulation in China. Viewed 16 November 2021, https://cms.law/en/int/expert-guides/cms-expert-guide-to-hydrogen/china

[123] CMS Law (2020). Hydrogen Law and Regulation in China. Viewed 16 November 2021, https://cms.law/en/int/expert-guides/cms-expert-guide-to-hydrogen/china

[124] IEA (2021) An Energy Sector Roadmap to Carbon Neutrality in China https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf

[125] IEA (2021) An Energy Sector Roadmap to Carbon Neutrality in China https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf

[126] IEA (2021) An Energy Sector Roadmap to Carbon Neutrality in China https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf

[127] IEA (2021) An Energy Sector Roadmap to Carbon Neutrality in China https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf

1.4 China's domestic hydrogen RD&D projects

1.4.1 Major domestic hydrogen RD&D projects

In 2021, 31 hydrogen grants were announced by the MOST covering the hydrogen value chain. The projects are being led by several research institutions across China, including universities.[128] The research areas of focus are covered in *Section 1.2.3 China's hydrogen RD&D priorities.*

Many of China's hydrogen RD&D projects are led by a consortia of research institutions, government bodies and SOEs. State Power Investment Corporation (SPIC) – a large state-owned utility company – has begun to invest heavily in hydrogen RD&D projects. A non-exhaustive list of projects commenced by SPIC is as follows:

- Designed and developed a hydrogen industry park, which includes integrated hydrogen production, storage and fuelling station for 150 FCEVs for utilisation during the 2022 Winter Olympics. The facility also comprises a hydrogen testing and R&D laboratory.[129]
- In October 2019, commenced a hydrogen blending in natural gas network demonstration project in Chaoyang district, Beijing.[130]
- In August 2018, entered into an agreement with a local technology company, Fuhai Cryo, to conduct R&D into electrolysis and liquefied hydrogen devices.

Other Chinese SOEs and private companies have entered into the following R&D agreements or projects:

- In April 2020, China Datang Corporation entered into a cooperation agreement with China Resources Power to conduct R&D into hydrogen energy production.[131]
- In August 2020, China Southern Power Grid established a hydrogen research facility in Guangzhou.[132]
- In January 2019, China National Nuclear Corporation entered into cooperation agreements with Tsinghua University and Baowu Group to conduct R&D into nuclear-powered hydrogen production.[133]
- In January 2019, Shanghai Re-fire Energy Technology Co., Ltd., Foshan City, Nanhai District and Guangdong Province entered into an agreement to develop a hydrogen industry project in Nanhai District. The project will establish research facilities to conduct R&D into FCEVs and related infrastructure.[134]

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[128] Polaris Hydrogen Energy Network (2021) 31 Hydrogen Energy Technologies: Announcement of the proposed projects of the National Key R&D Program in 2021. Polaris Power News Network. https://news.bjx.com.cn/html/20211215/1193855.shtml

[129] Energy Iceberg (2020) Ten Chinese Green Hydrogen Companies Poised to Lead, Viewed at https://energyiceberg.com/ten-chinese-green-hydrogen-companies/

[130] Energy Iceberg (2020), Ten Chinese Green Hydrogen Companies Poised to Lead, https://energyiceberg.com/ten-chinese-green-hydrogen-companies/#CNNC_Nuclear_Giants_Power-to-Gas

[131] Green Finance and Development Center (2020). Hydrogen: China's Progress and Opportunities for a Green Belt and Road Initiative. Viewed 16 November 2021, https://greenfdc.org/hydrogen-chinas-progress-and-opportunities-for-a-green-belt-and-road-initiative/?cookie-state-change=1637217869997

[132] Green Finance and Development Center (2020). Hydrogen: China's Progress and Opportunities for a Green Belt and Road Initiative. Viewed 16 November 2021, https://greenfdc.org/hydrogen-chinas-progress-and-opportunities-for-a-green-belt-and-road-initiative/?cookie-state-change=1637217869997

[133] Green Finance and Development Center (2020). Hydrogen: China's Progress and Opportunities for a Green Belt and Road Initiative. Viewed 16 November 2021, https://greenfdc.org/hydrogen-chinas-progress-and-opportunities-for-a-green-belt-and-road-initiative/?cookie-state-change=1637217869997

[134] Zhang V (2021) Hydrogen Law and Regulation in China, CMS Legal. Viewed at https://cms.law/en/int/expert-guides/cms-expert-guide-to-hydrogen/china

- In 2019, state-owned CEIC launched an R&D program to utilise hydropower for hydrogen production in Sichuan.[135]
- In September 2019, China National Offshore Oil Corporation (CNOOC) commenced techno-economic research projects, the scope of which includes research into optimal electrolysis solutions, hydrogen-wind integration and offshore hydrogen storage and distribution.[136]
- China Sheshua Energy is currently developing heavy-duty FCEVs in collaboration with Weichai, a state-owned R&D and manufacturing enterprise.[137]
- PERIC Hydrogen, a subsidiary of state-owned China State Shipbuilding Corporation (CSSC), currently specialises in fuel cell R&D.[138]

Demonstration projects

- In January 2019, Dalian Institute of Chemical Physics – an arm of the Chinese Academy of Science – successfully tested a manned hydrogen-powered aircraft in Shenyang.[139]
- Multiple demonstration projects are occurring across China's hydrogen clusters. See *Section 1.4.3 China's hydrogen RD&D clusters* for more detail.

1.4.2 Major domestic commercial hydrogen projects

The scope of this report is on research, development and demonstration (RD&D) projects. For information on commercial hydrogen projects, see *HyResource*, an online knowledge sharing platform across the hydrogen community, led by CSIRO, Future Fuels CRC, NERA and the Australian Hydrogen Council.

HyResource provides a directory of publicly available databases and information sources on international projects:

- https://research.csiro.au/hyresource/projects/international/

1.4.3 China's hydrogen RD&D clusters

China has several established and emerging hydrogen clusters (also known as valleys, hubs, or ecosystems) Previously established 'hydrogen towns' include Yunfu (Guangdong), and Taizhou (Fujian). China's emerging

[135] Energy Iceberg (2020) Ten Chinese Green Hydrogen Companies Poised to Lead. Viewed at https://energyiceberg.com/ten-chinese-green-hydrogen-companies/

[136] Energy Iceberg (2020) Ten Chinese Green Hydrogen Companies Poised to Lead. Viewed at https://energyiceberg.com/ten-chinese-green-hydrogen-companies/

[137] Green Finance and Development Center (2020). Hydrogen: China's Progress and Opportunities for a Green Belt and Road Initiative. Viewed 16 November 2021, https://greenfdc.org/hydrogen-chinas-progress-and-opportunities-for-a-green-belt-and-road-initiative/?cookie-state-change=1637217869997

[138] Green Finance and Development Center (2020). Hydrogen: China's Progress and Opportunities for a Green Belt and Road Initiative. Viewed 16 November 2021, https://greenfdc.org/hydrogen-chinas-progress-and-opportunities-for-a-green-belt-and-road-initiative/?cookie-state-change=1637217869997

[139] Green Finance and Development Center (2020). Hydrogen: China's Progress and Opportunities for a Green Belt and Road Initiative. Viewed 16 November 2021, https://greenfdc.org/hydrogen-chinas-progress-and-opportunities-for-a-green-belt-and-road-initiative/?cookie-state-change=1637217869997

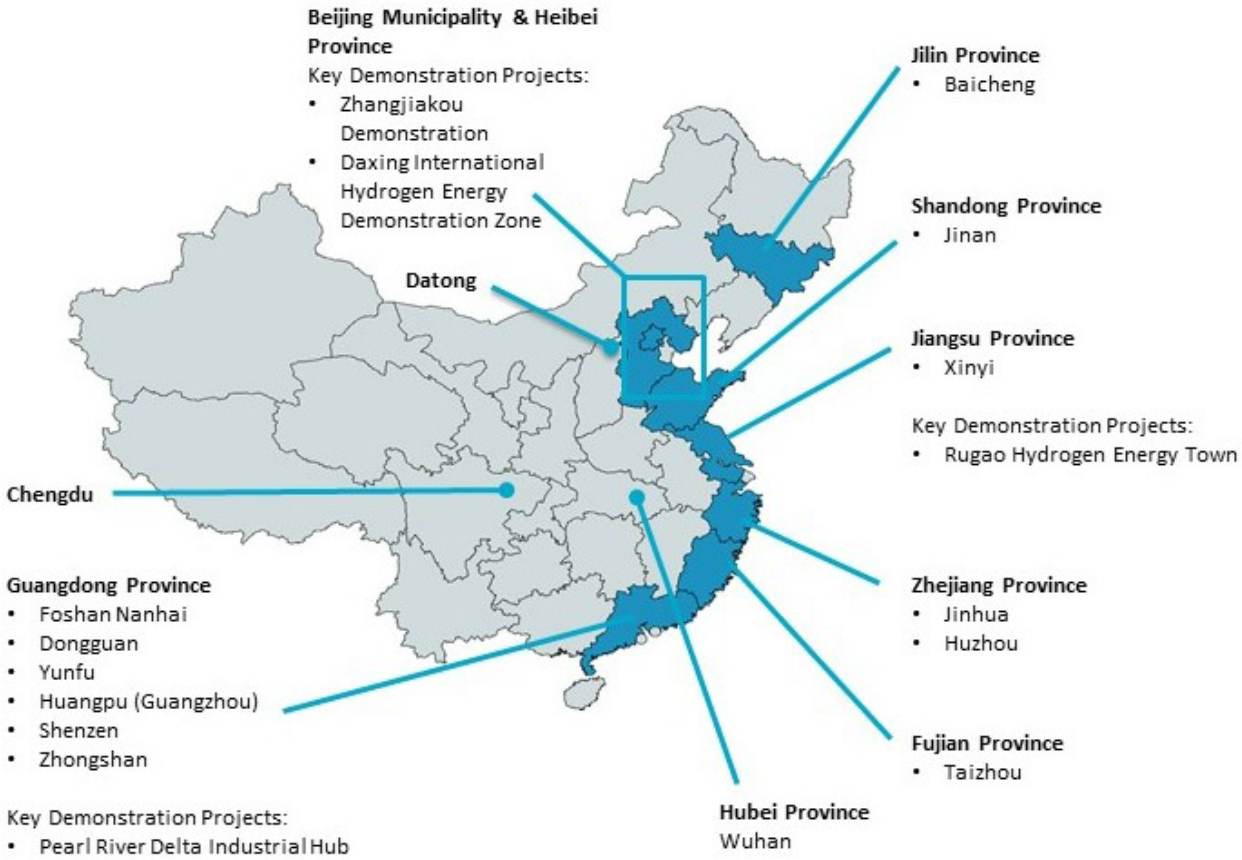
hydrogen clusters have put forward ambitious projects which include integrated value chains with the support of state-owned energy companies and local government:[140]

- Jinan (Shandong)
- Baicheng (Jilin)
- Huangpu, Guangzhou (Guangdong)
- Foshan Nanhai (Guangdong)
- Dongguan (Guangdong)
- Jinhua (Zhejiang)
- Huzhou (Zhejiang)
- Xinyi (Jiangsu)

Further, some capital cities are developing hydrogen cities. These are:

- Chengdu (Sichuan)
- Datong (Shanxi)
- Wuhan (Hubei)

Figure 4: China's hydrogen clusters



[140] Energy Iceberg (2019) China's Hydrogen Push: Sizzling Market Fueled by Local Subsidy Schemes. https://energyiceberg.com/china-hydrogen-provincial-subsidy/

Guangdong Province

The Guangdong is considered one of the largest clusters in terms of hydrogen industrial development. The Ministry of Finance and four other governmental departments approved Guangdong as a fuel cell demonstration zone in September 2021.[141] Major FCEV technology hubs include Foshan Nanhai, Huangpu (Guangzhou), and Shenzhen. Key material, technology and equipment R&D bases include Dongguan, Zhongshan and Yunfu. Designated hydrogen source supply bases include Zhuhai and Yangjiang.

- **Pearl River Delta Area industrial hub:** This area is considered China's most active area in hydrogen innovation, as most companies leading FCEV development are based here and supply roughly 40% of China's total fuel cell demand. Fuel cell manufacturers include CEMT, Refire and Synergy Technology. Guangdong also has the largest FCEV market and an extensive refuelling network.[142]
- **Foshan Nanhai Xianhu Lake Hydrogen Valley Town:** Located within the Guangdong province, this city is founded upon the automobile industry cluster, and is predominantly a centre for hydrogen fuel cell vehicle and innovation. On December 30th, 2019, the world's first hydrogen tram started commercial service in Foshan, covering 6.57km with 10 stations.[143] In 2021, Foshan was selected for a "Hydrogen Energy into Ten Thousand Homes" demonstration community, led in collaboration with Japan and South Korea in the "China, Japan, South Korea Intelligent Energy Industrial Basement Project".[144] Plans include increasing renewable energy interconnectivity, and promoting the implementation of national standards and codes for hydrogen buildings. This project will have a total investment of CNY 8 million; the first phase focused on fuel cell combined heat and power (CHP) application, and the second phase focused on the integration of upstream and downstream value chains for CHP. The city also plans to complete a multi-energy intelligent micro-grid.[145]

Beijing Municipality and Hebei Province

Major demonstration and commercialisation projects are ongoing in the region. The Beijing municipality announced a hydrogen development plan in August 2025 which outlined regional hydrogen targets. The Hebei province is a leader in renewable electrolysis projects, and 10 projects are currently operational with a further seven to begin operation by 2022.[146] Separately, in preparation for the Winter Olympics, Hebei province has a fleet of over 300 FCEVs, which is expected to reach 2,500 one the Olympics begin.[147]

- **Daxing International Hydrogen Energy Demonstration Zone (Daxing Park):** is a world-leading hydrogen energy demonstration zone, which focuses on the utilisation of hydrogen in the transport sector. While currently under construction, Daxing Park will include a Hydrogen Refueling Demonstration Station and a Hydrogen Energy Exchange Center. Daxing Park is expected to be a

[141] ChinaPolicy (2021) Hydrogen and FCV policy in the PRC: major developments since September 2020.

[142] IEA (2021) An Energy Sector Roadmap to Carbon Neutrality in China <https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf>

[143] IPHE (2020) International Partnership for Hydrogen and Fuel Cells in the Economy: China. <https://www.iphe.net/china>

[144] FuelCellsWorks (2021) China's First "Hydrogen Energy into Ten Thousand Homes" Demo Community to be in Nanhai District, Foshan. < https://fuelcellsworks.com/subscribers/chinas-first-hydrogen-energy-into-ten-thousand-homes-demo-community-to-be-in-nanhai-district-foshan/>

[145] Fuel Cell China (2021) Hydrogen Powered House – Foshan Will Build China's First Hydrogen Powered Intelligent Energy Demonstration Community http://www.fuelcellchina.com/cnt_151.html

[146] IEA (2021) An Energy Sector Roadmap to Carbon Neutrality in China https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf

[147] IEA (2021) An Energy Sector Roadmap to Carbon Neutrality in China https://iea.blob.core.windows.net/assets/6689062e-43fc-40c8-9659-01cf96150318/AnenergysectorroadmaptocarbonneutralityinChina.pdf

hydrogen RD&D hub and will support research into the commercial utilisation of hydrogen FCEVs and related technologies.[148]

- **Zhangjiakou Demonstration Project:**[149] Led by the Zhangjiakou Municipal People's Government, this is a designated national-level renewable energy demonstration zone. Hydrogen activity in the area includes hydrogen production using PEM electrolysis, hydrogen storage, and transport via compressed gas (pipeline and trucking), and liquid hydrogen (trucking), and end use in mobility, stationary fuel cells and gas-fired power plants. Partners of the project include Zhangjiakou Development and Reform Commission, and the Zhangjiakou Hydrogen and Renewable Energy Research Institute.

Shandong Province

The Shandong province is home to major chemical, metallurgical and energy industries, and has the largest provincial capacity of photovoltaic power and fourth largest capacity of wind power.[150] This provides Shandong with significant capabilities to participate in large-scale demonstration projects. Shandong's *Medium- and Long-term Development Plan for the Hydrogen Energy Industry (2020-2030)*[151] highlights several potential sectors for projects that align with Shandong's provincial strengths: industry, logistics and transportation, energy storage and power generation, and the integration of energy infrastructure into homes and communities.

- **Hydrogen into Ten Thousand Homes:** Announced by the Ministry of Science and Technology and the Shandong Provincial Government, the project aims to promote and demonstrate the various end-use applications of hydrogen – including in industrial parks, homes and community buildings – and will also develop hydrogen-specific road and port transport infrastructure. Additionally, the project will aim to deploy 100 refuelling stations, 10,000 FCEVs and increase hydrogen demand by 50,000 tonnes annually by 2025. The project will receive CNY 30 billion in funding. Further, on June 24th 2020, the Shandong provincial government released *The Medium- and Long-Term Development Plan for the Hydrogen Energy Industry (2020-2030)* which outlines its provincial strategy and broaches areas including: hydrogen development, industrial requirements, development pathways, development goals, safeguarding measures, and environmental impact assessments.[152]

Jiangsu Province

In 2019, the Jiangsu provincial government announced ambitions to become a leading base for hydrogen FCEVs, and has since then supported RD&D efforts to achieve this end. The provincial approach to project development has been to form an industrial chain that links areas of hydrogen production, storage and transportation, FCEV technology R&D, and vehicle and infrastructure development. Key industrial players include Nanjing Golden Dragon, Foresight Energy, Bing Energy, Re-Fire and GUOFUHEE.[153]

- **Rugao Hydrogen Energy Town:** Awarded 'Hydrogen Featured Town' by the government of Jiangsu province and 'Hydrogen Pilot City' by the UNDP China, Rugao is demonstrating an integrated hydrogen

[148] The People's Government of Beijing Municipality (2021) Construction of the "Two Zones" Boosts High Quality Development of Daxing http://english.beijing.gov.cn/investinginbeijing/two_zones/updates/202105/t20210524_2396604.html

[149] Mission Innovation (2021) Zhangjiakou Demonstration Project. Hydrogen Valleys. https://www.h2v.eu/hydrogen-valleys/zhangjiakou-demonstration-project

[150] NBSO Jinan & Qingdao (2020) Opportunity Report: Shandong Hydrogen Industry. https://www.rvo.nl/sites/default/files/2020/08/Report-on-Shandong-Hydrogen-Industry.pdf

[151] Wang Mingyou (2020) Shandong releases 2020-2030 hydrogen energy industry development plan (in Chinese). https://www.d1ev.com/news/zhengce/119279

[152] CSIRO (2021) HyResource: China. Viewed at https://research.csiro.au/hyresource/policy/international/china/

[153] Gasgoo China Automotive News (2019) Jiangsu Province aims to reach China's leading level in hydrogen vehicle industry. https://autonews.gasgoo.com/new_energy/70016317.html

economy.[154] Rugao begun its hydrogen development in 2010 and has become a hub for the fuel cell industry. Currently, Rugao has roughly 30 hydrogen companies operating across the hydrogen value chain. The city also integrates fuel cell R&D, development and manufacturing of fuel cell vehicles, and demonstrations of other end-use applications.[155]

1.5 International collaboration and joint RD&D projects

1.5.1 Overview of China's approach to international collaboration

China has yet to release a hydrogen strategy articulating its approach to international collaboration. However, China is already collaborating internationally across the value chain and in cross-cutting areas. For example, China is active in hydrogen RD&D collaboration across several international forums:

- China is a participant in the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), an international collaboration initiative for the development and deployment of hydrogen and fuel cell technologies.
- China is a member of the Clean Hydrogen Mission under Mission Innovation, a platform that mobilises global RD&D efforts to accelerate the implementation of low emissions technologies.
- Large Chinese multinationals and technology companies are members of the Hydrogen Council, including CHN Energy Investment Group, Great Wall, Sinopec, Weichai Power, Power Assets Holdings Ltd, Sinocat, SinoHytec, and Sinoma Science & Technology Co Ltd.
- The Ministry of Ecology and Environment of China signed an MoU with the International Renewable Energy Agency (IRENA) in 2021 to promote carbon neutrality through renewables. Parties agreed to explore ways and make suggestions to promote the implementation of and exchange knowledge in relation to China's climate actions.[156]

China has also launched a number of international initiatives for hydrogen RD&D collaboration, indicating a desire to collaborate on several technology and cross-cutting areas. This includes the International Hydrogen Fuel Cell Association and the International Hydrogen Energy Centre. Further details on these organisations are contained within this section.

The International Hydrogen Fuel Cell Association (IHFCA)

China SAE has initiated the IHFCA for the purpose of collaboration, innovation and reciprocal sharing across the hydrogen fuel cell value chain. Current members are a range of international organisations and multinational corporations including the United Nations Development Programme (UNEP), Toyota Motor, Anglo American, Diamler, Honda Motor, Ballard Power Systems, Air Liquide, Shell, China FAW Group Corp, SAIC Motor Crop, China Petrochemical Corporation and China National Petroleum Corp. The association is concerned with linking resources across the entire fuel cell value chain to promote global technology development, commercialisation and scale-up.[157]

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[154] UNDP China (2021) Hydrogen Economy Pilot in Rugao. https://www.cn.undp.org/content/china/en/home/projects/china_s-hydrogen-economy-pilot-project-in-rugao.html

[155] Information Office of Nantong Municipal People's Government (2019) Rugao hydrogen energy town honored for fast growth. Rugao. http://en.nantong.gov.cn/2019-07/31/c_392312.htm

[156] IRENA Agency (2021) IRENA and China Sign Landmark Co-operation to Address Climate Change. https://www.irena.org/newsroom/pressreleases/2021/Jun/IRENA-and-China-Sign-Landmark-Cooperation-to-Address-Climate-Change

[157] IHFCA (2021) Introduction. http://www.ihfca.org.cn/index.php?m=content&c=index&a=lists&catid=12

International collaboration activities of this group include:[158]

- Collaboration on codes, standards, and policy studies.
- Promotion of demonstrations and commercialisation of hydrogen fuel cell vehicle infrastructure.
- Public education and awareness.
- Consulting services (technical, investment, and policy).
- Global communication and collaboration activities (international seminars, forums, exchanges, and studies).
- Capital investment and financing (connecting industry with financial capital sources).

International Hydrogen Energy Centre (IHEC)[159]

The IHEC was inaugurated in 2021 by the China International Center for Economic and Technical Exchanges (CICETE), the Beijing Municipal Bureau of Economy and Information Technology, the United Nations Industrial Development Organisation, Beijing (UNIDO Beijing), and the Tsinghua Industrial Research and Development Institute. The initiative is jointly funded by the People's Government of Beijing Municipality and UNIDO's Global Programme for Green Hydrogen in Industry. The IHEC is a knowledge partner of the UNIDO Global Programme for Green Hydrogen in Industry, and its primary goal is to achieve technological breakthroughs, and to strategically develop the global hydrogen energy industry. This includes:

- Promoting best practice via south-south, triangular, and regional cooperation, through UNIDO's network.
- Carrying out RD&D
- Supporting capacity building.

1.5.2 China's bilateral hydrogen relationships

The majority of formalised joint hydrogen R&D collaborations pursued by China to date have been with multinational corporations rather than national governments. It is expected that in 2021 and beyond, China will engage bilaterally in joint research funding with other countries prioritising hydrogen, new energy vehicles (hydrogen and electric battery vehicles), and clean energy.[160]

1.5.3 China's joint international RD&D projects

While China's RD&D collaboration projects at the research institution level are less widely publicised, several major industry collaborations on hydrogen RD&D have been announced in recent years. These are summarised in Table 8.

[158] IHFCA (2021) What we do. http://www.ihfca.org.cn/index.php?m=content&c=index&a=lists&catid=14

[159] UNIDO (2021) Launch of the International Hydrogen Energy Centre (IHEC). https://www.unido.org/news/launch-international-hydrogen-energy-centre-ihec

[160] Consultation with DFAT.

Table 8: Joint RD&D projects with other countries

Country	Description
International	Daxing International Hydrogen Energy Demonstration Zone (Daxing Park), is located in Beijing and has a strong focus on the hydrogen transport value chain (including hydrogen production and storage, and the processing and manufacturing of fuel cell components and FCEVs). Similar to other designated zones, Daxing Park aims to develop the local hydrogen economy, but is also focused on promoting international partnerships and collaborations.
Air Products (USA)	In December 2021, Air Products announced it will be contributing to China's 'Hydrogen into Ten Thousand Homes' demonstration project initiated by China's MOST and the Shandong provincial government. Air Products will be commissioning a hydrogen refuelling station in the Shandong Province as part of a broader demonstration of cross-sector hydrogen applications.[161] In 2016 Air Products (a supplier of hydrogen and mobility solutions) and the National Institute of Clean-and-Low-Carbon Energy (NICE), signed an MoU to collaborate on hydrogen refuelling projects. NICE is an R&D institute in China devoted to hydrogen R&D and interested in developing the Chinese refuelling business.[162]
Australia	In January 2022, the Green Hydrogen Organisation, chaired by former prime minister Malcolm Turnbull signed an MoU with Daxing International Hydrogen Energy Demonstration Zone with the aim of enabling acceleration of green hydrogen production and utilisation, establishing international standards, and facilitating collaboration between Chinese and international companies. The Green Hydrogen Organisation is made up of several international organisations, including Australia's Fortescue Future Industries. In 2020, BHP and steel producer China Baowu signed an MoU to invest up to USD 35 million and engage in knowledge sharing for the production of low-carbon steel. This includes a range of low emission technical solutions, including hydrogen injection into blast furnaces. A related initiative is the establishment of the China Baowu-BHP Low-carbon Metallurgy Knowledge Sharing Center.[163] Through China's National Key R&D Program, international entities and researchers may participate in projects alongside Chinese and foreign national project leads. This program also operates 'Intergovernmental Cooperation NKPs' through multilateral programs with international institutions such as the Generation IV International Forum (GIF), through which Australia may participate and potentially co-fund.[164] **The Australia-China Science and Research Fund (ACSRF):** The ACSRF funds virtual Joint Research Centres (JRCs) to conduct research-related activities in a priority area of mutual benefit to Australia and China, including to improve energy security, reduce emissions, and train early-career researchers and professionals. The ACSRF is supported by the DISER, and the MOST. However there is no hydrogen-related JRC currently. • Catalyst design for hydrogen production (electrolysis and steam reforming). • Material and reactor scale-up (catalysts, electrodes, and reaction design).

[161] Air Products (2021) Air Products Supports China's "Hydrogen into Ten Thousand Homes" Demonstration Project. News Center. https://www.airproducts.com/news-center/2021/08/0812-air-products-supports-china-hydrogen-demo-project

[162] Air Products (2016) Air Products and NICE Sign MOU to Work Jointly on Hydrogen Fueling Projects in China. News Center. https://www.airproducts.com/company/news-center/2016/10/1013-air-products-and-nice-sign-mou-for-hydrogen-fueling-project-in-china

[163] BHP (2020) BHP partners with China Baowu to address the challenges of climate change. Media Centre https://www.bhp.com/news/media-centre/releases/2020/11/bhp-partners-with-china-baowu-to-address-the-challenges-of-climate-change

[164] ChinaInnovationFunding (2021) National Key R&D; Programmes. https://chinainnovationfunding.eu/national-key-rd-programmes/

Country	Description
	• Hydrogen utilisation technologies (green ammonia, hydrogen refuelling stations, methane transport, waste oil refining). • Transformation of technologies (roadmapping, market and policy studies).
Japan & Republic of Korea	The 'China, Japan and South Korea Smart Energy Industry Base Project' located in China's Danzao, Nanhai district, was launched in November 2021 and seeks to build the first smart energy demonstration community in China. The project will encompass 100,000m^2 and is currently focused on manufacturing and installing fuel cell cogeneration equipment for commercial and domestic use. The project is supported by Osaka Gas and DOOSAN, industry stakeholders in Japan and Korea respectively, through the sharing of information and experience.[165]
MCE Ventures (Malaysia)	In September 2021, Malaysian MCE Ventures Sdn. Bj (MVSB) and China's Chongqing Beidou Jiean Neo-Energy Technology Ltd (BDJA) signed a MoU to establish a joint venture which will act as a centre for research, dissemination and incubation of hydrogen motorcycles and other electric vehicles.[166]
Siemens (Germany)	In August 2020, Germany's Siemens Energy and China's State Power Investment Corporation (SPIC) signed an agreement to develop a 1MW demonstration project in Beijing to produce hydrogen from renewables for the hydrogen transport value chain.[167] In September 2019, SPIC signed an MoU with Siemens to explore opportunities for collaboration in areas concerning hydrogen produced from renewables.[168]
Linde (UK/EU)	In July 2020 Linde and Beijing Green Hydrogen Technology Development Co. Ltd. signed an MoU to collaborate on hydrogen initiatives, including R&D and implementation of mobility solutions.[169] Also in July 2020, Linde also has signed an MoU with China National Offshore Oil Corporation subsidiary, CNOOC Energy Technology and Services to explore investment in hydrogen production and filling facilities, and utilisation in industrial applications and mobility.[170]
Air Liquide (France)	In November 2019 Air Liquide signed an MoU with Sinopec to study the development of the hydrogen mobility network in China, and the underpinning regulatory framework.[171]

[165] Foshan International (2021) China's first intelligent energy demonstration community in Danzao, Nanhai. http://www.foshan.gov.cn/english/sylbt/content/post_4706662.html

[166] H2 Bulletin (2021) Malaysia-China JV to develop hydrogen-powered 2-wheeler https://www.h2bulletin.com/malaysia-china-jv-to-develop-hydrogen-powered-2-wheeler/?

[167] Siemens (2020) Siemens Energy launches its first megawatt green hydrogen production project in China. https://press.siemens.com/global/en/pressrelease/siemens-energy-launches-its-first-megawatt-green-hydrogen-production-project-china

[168] Energy Iceberg (2020), Ten Chinese Green Hydrogen Companies Poised to Lead, https://energyiceberg.com/ten-chinese-green-hydrogencompanies/#CNNC_Nuclear_Giants_Power-to-Gas

[169] Linde (2020) Linde Signs MoU with China Power to Develop Green Hydrogen Energy in China. Press Releases. https://www.linde.com/news-media/press-releases/2020/linde-signs-mou-with-china-power-to-develop-green-hydrogen-energy-in-china

[170] Linde (2020) Linde Signs MoU with CNOOC to Jointly Develop China's Hydrogen Industry. Press Releases. https://www.linde.com/news-media/press-releases/2020/linde-signs-mou-with-cnooc-to-jointly-develop-china-s-hydrogen-energy-industry

[171] Air Liquide (2019) Air Liquide and Sinopec sign an MoU to accelerate the deployment of hydrogen mobility solutions in China. News. https://www.airliquide.com/mainland-china/air-liquide-and-sinopec-sign-mou-accelerate-deployment-hydrogen-mobility-solutions

1.5.4 China's joint international commercial projects

The scope of this report is on research, development and demonstration (RD&D) projects. For information on commercial hydrogen projects, see *HyResource*, an online knowledge sharing platform across the hydrogen community led by CSIRO, Future Fuels CRC, NERA and the Australian Hydrogen Council.

HyResource provides a directory of publicly available databases and information sources on international projects:

- https://research.csiro.au/hyresource/projects/international/

1.6 Data insights: China's hydrogen RD&D activity

The following section provides data-driven insights on China's RD&D activity in hydrogen technologies. Research publication data, patent data, and commercial project data has been used to understand hydrogen related activity. While limitations exist with such an approach, these data sources do provide an opportunity to consider activity across the innovation spectrum from basic research to demonstration. It also aims to help identify technology areas that have received significant focus in each country and key organisations to support international collaboration efforts.

The data for this section was sourced from CSIRO's publications team, CSIRO's IP team, IP Australia, and the IEA's hydrogen projects database.

Figure 5: Hydrogen innovation activity data

1.6.1 Research publication data

Research publications in hydrogen are an indicator of basic and applied research activity. CSIRO's publications team has conducted a research publication scan to identify Chinese organisations conducting research across the hydrogen value chain. The publications search approach, first developed in 2019 to support the report *Hydrogen Research, Development and Demonstration: Priorities and opportunities for Australia* was applied in 2021 to provide an updated dataset for this report. The details of the search approach can be found in the *National Hydrogen Research, Development and Demonstration (RD&D): Technical Repository*.[172]

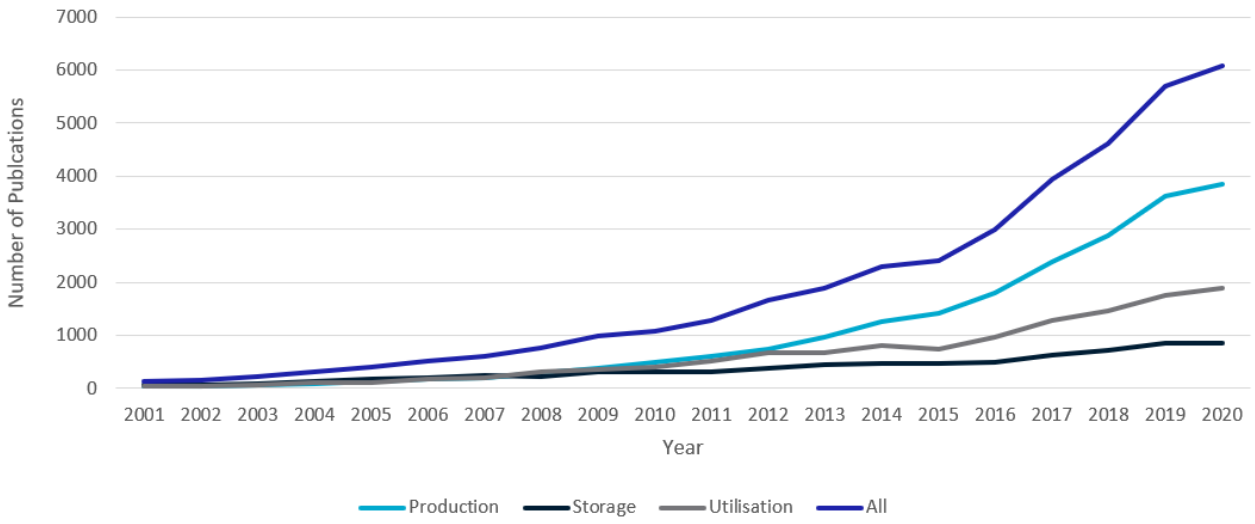
[172] CSIRO (2019) National Hydrogen Research, Development and Demonstration (RD&D): Technical Repository. Available at https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/csiro-futures/futures-reports/hydrogen-research

Figure 6 shows Chinese institutions ranked in terms of publication output across hydrogen production, storage and distribution, and utilisation from 2016-2020. Figure 7 shows China's country-wide research publication output trends across the hydrogen value chain.

Figure 6: Top institutions by publication output (2016-2020)

Domestic Ranking	Production	Storage and Distribution	Utilisation	Overall
	1st Global Rank	*1st Global Rank*	*1st Global Rank*	*1st Global Rank*
1st	Chinese Academy of Sciences (CAS)	Chinese Academy of Sciences (CAS)	Chinese Academy of Sciences (CAS)	Chinese Academy of Sciences (CAS)
2nd	University of Science and Technology of China (USTC)	Zhejiang University	Tsinghua University	University of Science and Technology of China (USTC)
3rd	Tsinghua University	Inner Mongolia University of Technology	Tianjin University	Tsinghua University
4th	Tianjin University	Central Iron and Steel Research Institute	University of Science and Technology of China (USTC)	Tianjin University
5th	Xi'an Jiaotong University	Xi'an Jiaotong University	Zhejiang University	Xi'an Jiaotong University

Figure 7: China's hydrogen-related research publication output (2001-2020)



1.6.2 Patent data

Patent activity in hydrogen is an indicator of applied R&D and innovation occurring across the value chain. This section draws on two different patent analytics approaches. CSIRO developed a search approach in 2019 to support the *Hydrogen Research, Development and Demonstration: Priorities and opportunities for Australia* report. CSIRO applied this approach to provide a patent landscape across the hydrogen value chain for each country. The details of the search approach and any limitations can be found in the *National Hydrogen Research, Development and Demonstration (RD&D): Technical Repository*.[173] The second approach, performed by IP Australia, builds on the hydrogen technology taxonomy developed in CSIRO's 2019 report to provide information on specific hydrogen technologies that sit within production, storage

[173] CSIRO (2019) National Hydrogen Research, Development and Demonstration (RD&D): Technical Repository. Available at https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/csiro-futures/futures-reports/hydrogen-research

and utilisation. The full data visualisations, details of the search approach and any limitations can be found at *Patent analytics of hydrogen technologies: an interactive visualisation.*[174]

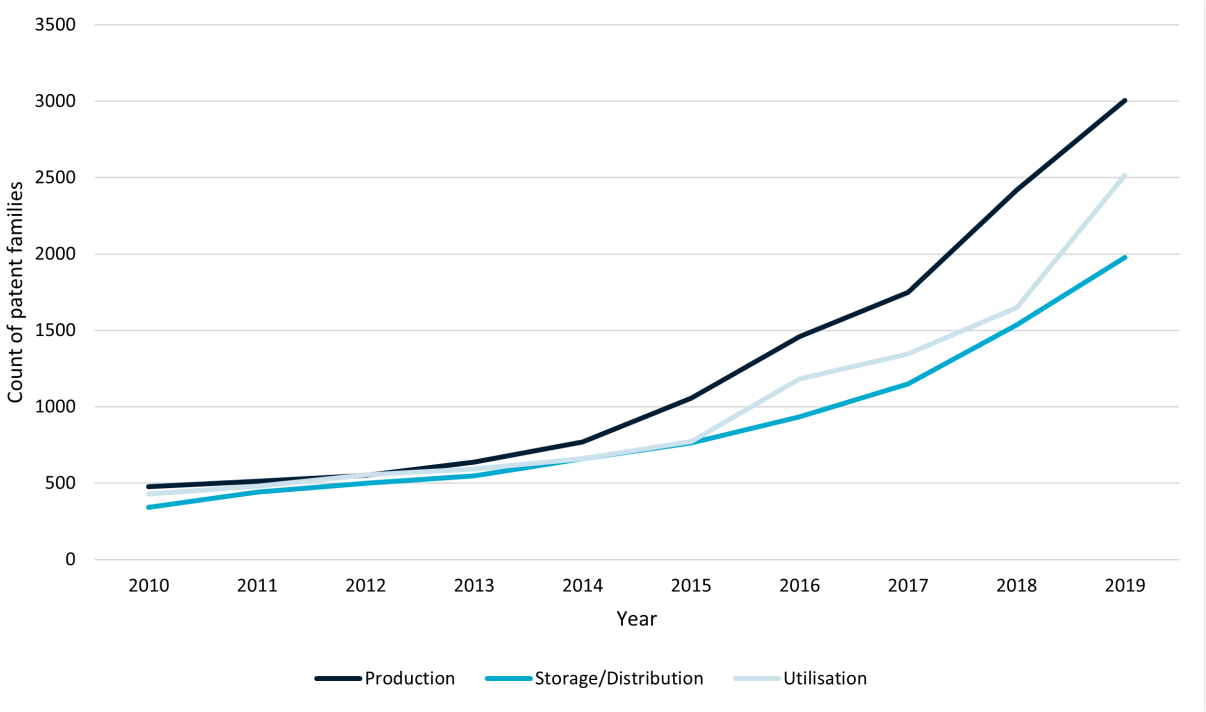
It should be noted that analysis of patent data is not necessarily representative of patent impact. As such, this data should be viewed holistically with the other data presented in this section, particularly project deployment.

Patent landscape of hydrogen value chain

Performed by the CSIRO, this patent landscape analyses patent family[175] filings across the hydrogen value chain. Figure 8 outlines patent filings over time across the areas of hydrogen production, storage/distribution and utilisation. Figure 9 shows the jurisdictions in which Chinese patent applicants are filing patents, outside of China. This provides an indication of which global markets, or manufacturing/commercialisation destinations are of interest to Chinese patent applicants or inventors.

Note that patent databases have a delay of roughly 18 months, therefore 2020 and 2021 have been omitted from the graphs below. Some patent filings may also be counted twice as the categories of production, storage and utilisation may not be mutually exclusive in all instances and some could relate to multiple areas of the hydrogen value chain.

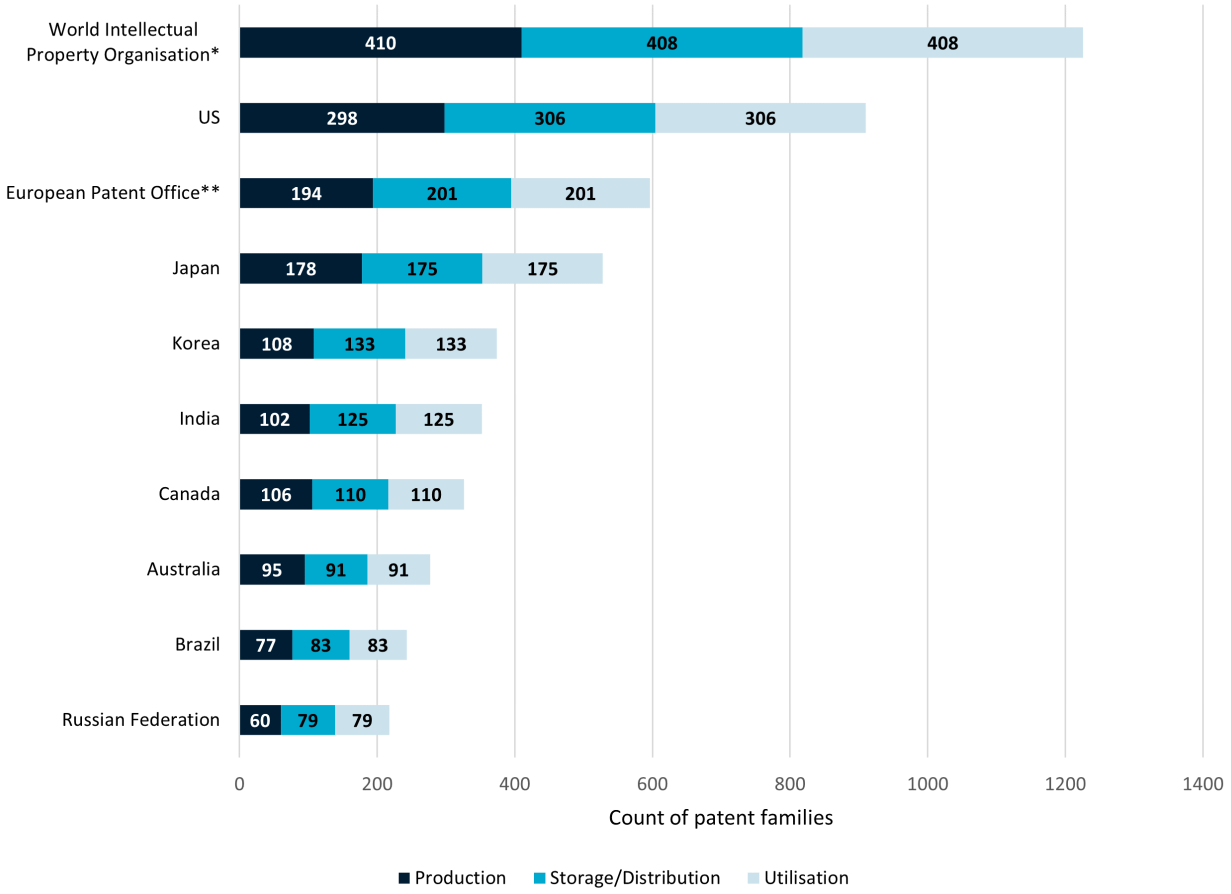
Figure 8: Patent filings over time across production, storage/distribution and utilisation



[174] IP Australia (2021) Patent Analytics on Hydrogen Technology, Australian Government. Available at https://www.ipaustralia.gov.au/tools-resources/publications-reports/patent-analytics-hydrogen-technology

[175] Applications with the same priority, but filed in different jurisdictions, are known as patent families. Patent families enable us to analyse inventive activity regardless of the number of countries in which protection is sought. Patent families are used in analytics to represent a single invention.

Figure 9: Location of patent filings by Chinese patent applicants



*** The World Intellectual Property Organisation (WIPO) is an international organisation that promotes the protection of intellectual property and supervises administrative cooperation amongst the intellectual unions regarding protection of intellectual property. Patents filed in the WIPO enable applicants to obtain protection for their inventions in up to 153 of the parties to the Patent Cooperation Treaty.**

**** The European Patent Office enables investors, researchers and companies to obtain protection for their inventions in up to 44 countries, including all 27 EU member states.**

Patent analytics of specific hydrogen technologies

Data extracted from IP Australia's interactive visualisation provides an in-depth analysis of specific hydrogen technology developments. Figure 10 shows the number of patent families filed since 2010 for specific technology areas by Chinese applicants.

Table 9 shows the number of patent families filed by Chinese applicants since 2010 by sub-technology area, expressed as a percentage of total global patent family filings. Table 9 also shows the top organisations in China filing patents in each technology area. It should be noted that the majority of fuel cell technologies are categorised under the 'electricity generation' category.

Figure 10: China's patent family output by sub-technology area (2010-2020)

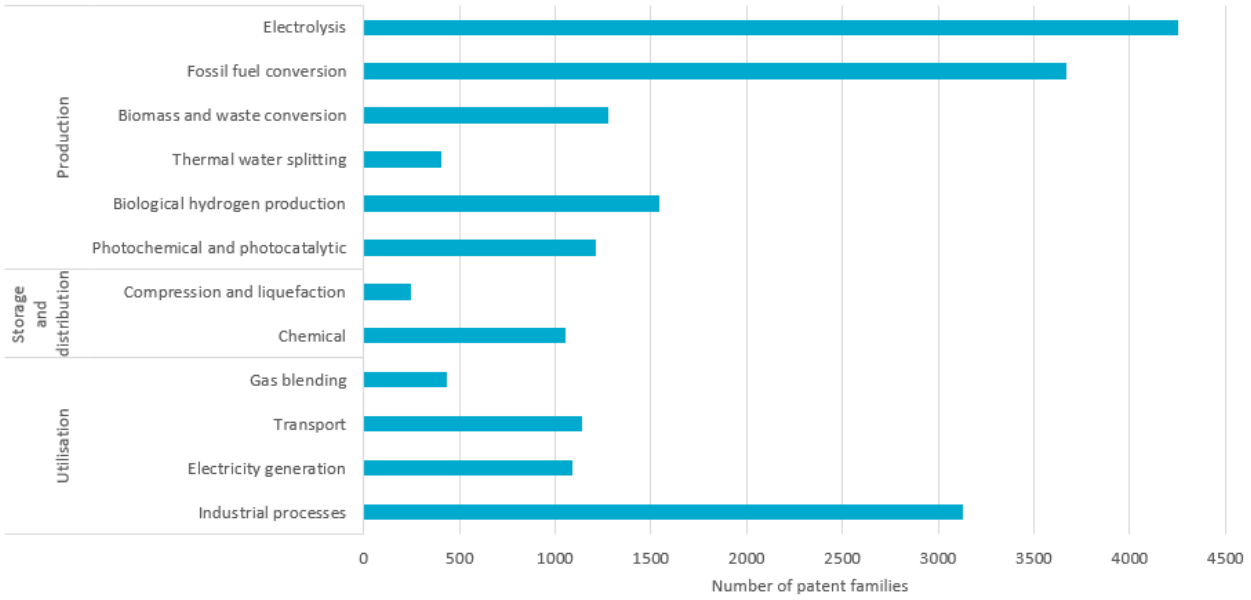


Table 9: China's IP output (number of patent families filed by Chinese applicants) by sub-technology area from 2010-2020

Technology area		IP output (% of global)	Leading companies	Leading non-profits and universities
Production	Electrolysis	52.8%	Huaneng Clean Energy Research Institute, Shenzhen Qing'ai Tianxia Health Technology Holding, Shenzhen Hydrogen Healthy World Health Technology Company, Fuzhou Pinxing Science & Technology Development	Institute of Chemical Material, China Academy of Engineering Physics, National Center for Nanoscience and Technology, China Huaneng Group Cleaning Energy Technology Research Institute
	Fossil fuel conversion	59.4%	China Petrochemical Corporation, China National Petroleum, Beijing Shenwu Environment & Energy Technology, China National Offshore Oil Corporation	Chinese Academy of Sciences, South China University of Technology, Southeast University, China University of Petroleum-Beijing, Taiyuan University of Technology
	Biomass and waste conversion	42.9%	China Petrochemical Corporation, Shanghai Hydrogen Mobile Reformer Instrument Co., Beijing Shenwu Environment & Energy Technology, Guangdong Hydrogen Energy Science & Technology Company	Wuhan Kaidi General Research Institute of Engineering & Technology, Wuhan Kaidi Technology R&D Institute, Eco Environmental Energy Research Institute

Technology area		IP output (% of global)	Leading companies	Leading non-profits and universities
	Photochemical and photocatalytic	63.5%	SGCC, Sungrow Power Supply Company, Huaneng Clean Energy Research Institute, Huadian Electric Power Research Institute, Chengdu New Keli Chemical Science Company	CAS, Tianjin University, Fuzhou University, South China University of Technology, Jiangsu University
	Biological	64.2%	China Petrochemical Corporation, Chengdu Lvke Huatong Technology Company, Guangdong Hydrogen Energy Science and Technology Company, Beijing Sanju Environmental Protection & New Materials Company	Shandong Technical Center of Inspection and Quarantine, Material Institute of China Academy of Engineering Physics, Shandong Institute of Light Industry, International Center for Bamboo and Rattan, Institute of Soil and Fertilizer
	Thermal water splitting	55.1%	Weihai Doyle Electronics Company, China Petrochemical Corporation, Chengdu New Keli Chemical Science Company, Xinjiang Juli Environmental Protection Technology Company	CAS, Fuzhou University, Jilin University, Tianjin University, Shaanxi University of Science and Technology
Storage and distribution	Compression and liquefaction	34.0%	Shanghai Hydrogen Mobile Reformer Instrument, Zhangjiagang Furui Hydrogen Energy Equipment, Shanghai Hejide Dynamic Hydrogen Machinery, Anhui Bohua Hydrogen Energy Technology, Beijing Sinohytec	CAS, Tongji University, Nanjing Xiaozhuang University, Tsinghua University, Chongqing Industry Polytechnic College
	Chemical storage	42.5%	General Research Institute for Nonferrous Metals, Shanghai Huapeng Explosion-Proof Technology, GRINM Engineering Technology Research Institute, Global Hydrogen Power Science & Technology	Tianjin Normal University, Chinese Academy of Sciences, Zhejiang University, Inner Mongolia University of Science & Technology
Utilisation	Gas blending	30.4%	China Petrochemical Corporation, Hangzhou Zhongtai Cryogenic Technology, Chengdu Shenleng Liquefaction Plant, Shanghai Hualin Industrial Gas Company, Kaifeng Air Separation Group	CAS, Tianjin Polytechnic University, Taiyuan University of Technology, Southeast University, KMUST
	Transport	44.9%	Guangdong Hydrogen Energy Science and	Beijing University of Technology, North China

Technology area		IP output (% of global)	Leading companies	Leading non-profits and universities
			Technology Company, Shanghai Hydrogen Mobile Reformer Instrument Company, Wuhan Grove Hydrogen Automobile Company, Wuxi Tongchun New Energy Technology Company	University of Water Resources and Electric Power, Shenyang Aerospace University, Tsinghua University, Jilin University
	Electricity generation	26.0%	Huaneng Clean Energy Research Institute, Guangdong Hydrogen Energy Science and Technology, China Huadian Engineering, Huadian Distributed Energy Engineering & Technology Company, Hubei Shentan Environmental Protection New Material	CAS, Harbin Institute of Technology, Dalian University of Technology, Tianjin University, Tsinghua University
	Industrial processes	71.6%	China Petrochemical Corporation, Hubei Saint Environmental Protection New Material, Beijing Sanju Environmental Protection & New Materials Company, Petrochina, Tongling Pacific Special Materials	CAS, East China University of Science and Technology, Central South University, Beijing Yuji Science & Technology Company, South China University of Technology

IP Australia patent analytics on hydrogen technology

IP Australia has developed an interactive visualisation tool to provide hydrogen insights to researchers

, academics, business and policy sectors. For more hydrogen IP statistics including key destination markets, origin profiles, applicant profiles, collaborations and specific patent searches, refer to IP Australia's Hydrogen Patent Landscape tool:

- https://www.ipaustralia.gov.au/tools-resources/publications-reports/patent-analytics-hydrogen-technology

1.6.3 Project data

Data from the IEA Hydrogen Projects Database (as at October 2021)[176] provides insight on clean hydrogen technology value chains deployed at pilot and commercial scale across China. Note that the following limitations should be taken into account:

- The database does not indicate whether the technologies used are indigenous or purchased from an overseas provider. While many countries often deploy their own technologies at scale, many countries

[176] IEA (2021) Hydrogen Projects Database. Available at https://www.iea.org/data-and-statistics/data-product/hydrogen-projects-database

purchase technologies from overseas to deploy locally. As such the database indicates deployment activity, but not necessarily the ability to translate indigenous R&D into commercial scale-up.

- This dataset counts only low-carbon hydrogen projects and their associated value chains. As such hydrogen production projects from gas, coal and oil without CCS are not included. Similarly, utilisation projects not related to a clean hydrogen project source are not included.
- The dataset reflects only projects occurring domestically, and therefore does not count projects undertaken by Chinese companies outside of China. As such, the table may understate China's activity, particularly its contribution to international supply chain development. This data should therefore be considered holistically with the rest of this report.
- Any limitations stated in the data collection methodology, definitions and assumptions should be taken into account (see IEA Hydrogen Projects Database for details).

For the purposes of this report, the dataset has been filtered to include only projects from 2010 through to projects expected to be operational by 2030 as this timespan best reflects current activities. Projects without a specified date have been excluded from the table below. Further, only projects that are at feasibility study, final investment decision, demonstration, or operational stage are included. Projects at the 'concept' stage are not included. It should be noted that the majority of projects listed span production, storage and multiple end-uses, and as such can be counted in more than one technology category.

Table 10: China's domestic clean hydrogen project data

Technology	Sub-technology		Domestic project count	% of global
Production	Electrolysis	PEM	5	2.7
		Alkaline	4	3.4
		Solid Oxide	-	-
		Other or unspecified	14	5.7
	Fossil fuel conversion	Coal gasification with CCS	4	66.7
		Natural gas with CCS	-	-
		Oil with CCS	1	16.7
		Methane pyrolysis	-	-
	Biomass and waste conversion		-	-
	Photochemical and photocatalytic		-	-
	Biological production		-	-
	Thermal water splitting		-	-
	Compression and liquefaction		24	4.7

Technology	Sub-technology		Domestic project count	% of global
Storage and distribution	Chemical carriers	Ammonia	1	3.6
		Methane	-	-
		Methanol	3	14.3
		Synfuels	-	-
Utilisation	Gas blending		-	-
	Transport		13	5.5
	Electricity generation		2	1.5
	Industrial processes	Refining	-	-
		Ammonia	-	-
		Methane	-	-
		Iron and steel	1	4.8
		Biofuels	-	-
		Synfuel	-	-
		Other industry	4	2.9

IEA Hydrogen Projects Database

The latest version of the IEA Hydrogen Projects Database can be found at:

- https://www.iea.org/data-and-statistics/data-product/hydrogen-projects-database

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