China and the Geopolitics of Hydrogen: An Awakening Giant?

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Abstract Over the past decade, China has emerged as a pivotal player in the energy transition, leading the global deployment of renewable energy and assuming an increasingly dominant role in clean energy supply chains. In the hydrogen sector, it was not among the initial frontrunners and continues to take a cautious approach. While developments have started accelerating, these are still primarily driven by sub-national actors. Against this background, the chapter explores Chinese developments in the hydrogen sector from a geopolitical perspective. It begins with a brief overview of China's broader energy foreign policy. This is followed by a review of its domestic hydrogen strategy and key developments in the Chinese hydrogen sector. Building on this, the paper provides an overview of China's international hydrogen-related policy, including engagement in technology cooperation, supply chain development and international standard-setting and bilateral cooperation with key partners. It concludes with a synthesis of China's emerging role within the nascent hydrogen economy. It highlights the country's key assets and potentials as well as the main concerns and priorities of its evolving policy approach.

1 Introduction

China has emerged as a key player in the global energy market since the turn of the century. This has coincided with its rapid increase in energy demand, turning it into a net energy importer in the late 90s (Meidan, 2023). To confront its increasing dependence on fossil fuel imports, its energy companies, most of them state-owned

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enterprises (SOEs), have actively invested in foreign oil and gas fields and initiated oil and gas trade to secure its external energy supply (Gong, 2022). This has resulted in a growing presence in the Middle East and Central Asia as well as a number of African oil-producing countries, increasing Chinese influence but also vulnerability to developments in these regions (Meidan, 2023). In more recent years, the electricity sector has become a second important dimension of China's outward-oriented energy engagement, covering investments in traditional power generation, power grids as well as renewable energy (Chen et al., 2020).

These foreign engagements are driven by a combination of commercial and political objectives. Energy companies have invested to exploit economic opportunities in foreign energy markets and to engage in technology-related cooperation to boost their competitiveness on international markets. At the same time, these investments can be viewed as tools for realizing strategic objectives, like securing access to energy resources, exerting influence on strategically important countries, and becoming a leader in strategic energy technologies (Kenderdine & Lan, 2018; Tolipov, 2018). Indeed, against the background of growing geoeconomic rivalry, China's increasing dominance of green energy supply chains, most notably in the sphere of lithium-ion batteries and solar photovoltaics, has become a central concern of Western governments (Bond et al., 2024). At the same time, Chinese policymakers are concerned that constraints on access to international technological know-how could pose as a new threat to its energy security within the context of a transition to net zero, replacing dependence on energy imports as its main vulnerability (State Council, 2020; NDRC & NEA, 2017).

It is against this background that hydrogen is emerging as an increasingly influential factor in the evolving geopolitics of China's energy transition. The development of an international hydrogen economy comes with a host of geopolitical implications as countries vie for leadership in a net-zero economy (IRENA, 2022). In this vein, China's hydrogen development and its international hydrogen cooperation add an important new dimension to the discussion on China's increasing role in the international political economy of energy (de Blasio & Pflugmann, 2021). Hydrogen development will influence its existing energy relations and may influence the global distribution of power. This includes questions related to international hydrogen production and trade as well as the geoeconomics of emerging hydrogen technologies and supply chains (Nakono, 2022).

To shed light on these ongoing developments, this chapter provides an overview of China's international hydrogen policy and its related initiatives abroad. The chapter begins with a brief overview of China's broader energy foreign policy. This is followed by a review of its domestic hydrogen strategy and key developments in the Chinese hydrogen sector. Building on this, the paper provides an overview of China's international hydrogen-related policy, including engagement in technology cooperation, supply chain development, and international standard-setting. Section 5 discusses bilateral cooperation with key partners, including leading industrialized countries and a number of strategic energy partners. Section 6 sums up and discusses implications.

2 China's Evolving External Energy Strategy

Diversifying energy supply, expanding China's role in global energy value chains to enhance its influence, and fostering international technology cooperation are key dimensions of China's external energy strategy. Diversifying its supply of oil and gas remains a major goal of China's energy strategy, given its heavy reliance on imports (NDRC & NEA, 2016b). Policymakers have stressed the importance of diversifying oil and gas suppliers and transportation routes through investments in hydrocarbon extraction and the construction of pipelines (NDRC & NEA, 2017; NEA, 2022). A series of policy documents have called for expanding pipeline capacity and for ensuring its safe operation by collaboratively working with countries within its Belt and Road Initiative (BRI) (NDRC, 2016; NDRC & NEA, 2017).

Furthermore, China is increasingly pursuing a strategy aimed at enhancing its influence on the global energy sector by expanding its role in global energy value chains (NEA, 2014). To achieve this, China is trying to go beyond securing energy imports to developing stakes further upstream in the oil and gas sector as well as power generation. In this vein, China's energy SOEs have established their presence in the oil and gas industry of the Middle East, from exploration, transport, and refining to engineering services and equipment sales (Kenderdine & Lan, 2018). Chinese companies have also pursued overseas investments in various types of power generation, including coal-based power generation (especially in South and Southeast Asia), hydropower (especially Africa and Southeast Asia) as well as wind and solar (especially in Europe and Latin America) (Chen & Springer, 2021; Liedtke, 2017). While hydropower and coal-fired power generation have dominated overall, China has recently bowed to international pressure, announcing in 2021 that it would no longer invest in overseas coal projects. While Chinese-backed investments in the sector have not been halted entirely, there are now clear signs that the government has substantially reduced its support, giving an important boost to projects in the renewable energy sector (Wang et al., 2024).

As Kenderdine and Lan (2018) have argued, China's outward-oriented investment policy is part of a broader geoeconomic strategy. In an effort to graduate to an innovation-centered model of industrial development, the government is seeking to wind down excess industrial capacity in sectors like steel and cement making and promote the relocation of manufacturing industries to countries within the BRI. This provides its firms with new investment opportunities, while exporting Chinese standards (Xu & Miao, 2019). It is also an entry-point for positioning low-cost Chinese technology in developing country markets, especially in those sectors where China has found it difficult to compete with higher-quality Western products (Oh, 2021).

In addition, technology cooperation plays a critical role in boosting the competitiveness of the domestic energy industry (Zhao & Wu, 2012). Since 2007, Chinese energy policymakers have attached increasing importance to this dimension of its international energy policy (NDRC & NEA, 2016a, 2017). By engaging in technology cooperation, energy companies can enhance their innovation capacity and acquire advanced know-how for domestic use. The government's Opinions on Promoting Green Development under the Belt and Road Initiative (2022) and the 14th Five-Year Plan of Renewable Energy Development (2022) promoted international technology cooperation in the areas of cost-effective power generation by renewable energy, smart grids, hydrogen energy, energy storage and carbon, capture, use, and storage (CCUS) (NDRC et al., 2022).

SOEs are leading players in carrying out China's external energy strategy (Gong, 2022). SOEs are expected to improve the capacity of securing energy supply and lead the development of new energy (State Council, 2016a). To this end, the State-owned Assets Supervision and Administration Commission of the State Council (SASAC) engages with SOEs to develop company-specific five-year plans in support of national five-year plans (SASAC, 2016). The evaluation of energy SOEs also explicitly includes the appraisal of the contribution of overseas energy investments to the security of oil supply (NDRC, 2016). In this vein, China's national oil companies (NOCs) have helped its government to achieve policy objectives of diversifying foreign oil and gas supply. They have pioneered oil exploration in countries like Sudan and have invested in import infrastructure, like LNG terminals and pipeline projects, connecting China to supplies of natural gas in Russia and Central Asia (NDRC, 2013). In the electricity sector, State Grid has actively pursued acquisitions in foreign electricity transmission and distribution grid infrastructure projects (Zhang, 2023), including the Philippines, Portugal, and Brazil. More broadly, the Chinese government has encouraged electricity SOEs to pursue international cooperation in energy R&D, export energy services, and participate in standard-setting (NDRC & NEA, 2016a). China's energy-related five-year plans highlighted that electricity companies should introduce technology standards to foreign electricity projects (NDRC & NEA, 2016b; NEA, 2016).

3 Hydrogen Development in China

Despite being the world's largest producer and consumer of hydrogen, China's clean hydrogen policy is still at an early stage compared to global frontrunners like Germany or Japan (Gong et al., 2023). A clear policy agenda is only beginning to emerge. Nevertheless, China's hydrogen economy can build on a significant policy legacy, most notably in the area of fuel cell electric vehicles (FCEVs), as well as an increasingly dynamic investment agenda driven by a number of provinces seeking to capitalize on global trends in the sector. Before turning to China's international hydrogen activities, this section provides an overview of key developments in China's domestic hydrogen sector.

3.1 The State of China's Hydrogen Economy

China is the largest hydrogen producer in the world, accounting for approximately one-third of global output. Its production volume reached 37.81 million tons in 2022 (NEA, 2023), of which currently only a small fraction (approximately 2%) is based on renewable energy-based electrolysis (see Fig. 1). Nevertheless, given its abundant solar and wind resources in the North of the country and major hydropower resources in the Southwest, China is expected to significantly increase production of renewable electricity-based hydrogen (Gong et al., 2023). By 2030, the China Hydrogen Alliance predicts a share of 15% of national production. Currently, the Beijing-Tianjin-Hebei Region, the Yangtze River Delta, the Pearl River Delta, and Ningdong Energy and Chemical Base (located in Ningxia Province) are the most important areas of hydrogen development in China (China Center for International Economic Exchanges, 2021).

China is emerging as a global frontrunner in electrolysis-based hydrogen production (Xu & Yu, 2021). It accounted for two-thirds of both operational and announced electrolysis capacity in 2024 (Hydrogen Council & McKinsey, 2024). According to the IEA Hydrogen Production and Infrastructure Database, China had over 10 GW of electrolysis capacity either in operation or under construction in October 2024, more than double that of the EU (see Fig. 2). Deployment in China has been dominated by investments in alkaline electrolyzers, where the country has emerged as a cost leader. The productivity of alkaline electrolyzers in China is estimated at 1000–1200 m^3 per hour (Wen et al., 2019), and they are estimated to cost as little as $200 per kW (Guotai Junan Securities Co., Ltd, 2024), significantly below estimated costs in Europe (approximately $1200 per kW) (PV Magazine, 2024). As for storage and transportation infrastructure, an increasing number of demonstration projects

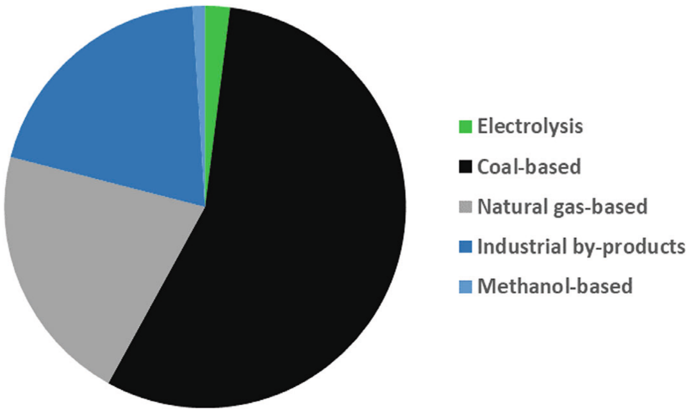

Fig. 1 China's hydrogen production in 2022. *Source* Authors, based on Securities Times China News (STCN) (2024)

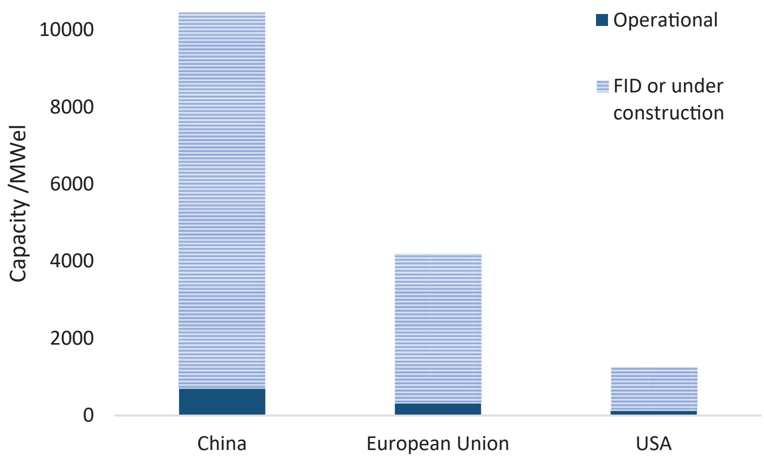

Fig. 2 Electrolyzer capacity in China, the European Union, and the US, operational and under construction, October 2023. *Source* Authors, based on the IEA Hydrogen Production and Infrastructure Database, October 2024

have emerged in the past years, including hydrogen refueling stations, short-distance hydrogen pipelines, and liquid hydrogen storage.

Outside the petrochemical sector, the most well-established application is the use of hydrogen in heavy-duty, commercial FCEVs. The development of fuel cells has been identified as a critical energy-related project in the state's high-technology development plan (Yi et al., 2018). China also promotes R&D and industrialization of polymer electrolyte membrane (PEM) fuel cells and solid oxide (SO) fuel cells (China Hydrogen Alliance, 2019). Since 2017, fuel cells have been gradually introduced in ships, buses, and commercial vehicles (Sun & Yang, 2021). FCEVs account for just 0.4% of new energy vehicles (NEVs) in China (Haitong Securities, 2021). Nevertheless, China accounted for over 50% of global FCEV sales in 2024 (up to end of October) (Collins, 2024a), and it is predicted that the number of FCEVs in China will reach around 2 million by 2035 and around 11 million by 2060 (S&P Global Commodity Insights, 2022), exceeding current policy objectives (see Sect. 3.3).

Chinese state-owned energy companies have played a major role in large-scale and capital-intensive hydrogen projects, including the construction of hydrogen refueling stations and pipelines. China National Petroleum Corporation (CNPC) and PipeChina are positioned to play a significant role in hydrogen transport (Tu, 2020), while China Petrochemical Corporation (Sinopec) has engaged broadly in the hydrogen business including launching renewable hydrogen production in Xinjiang and Inner Mongolia, building short-distance hydrogen pipelines, and repurposing petrol-/gas-refueling stations. The State Power Investment Corporation (SPIC), an important electricity SOE in China, is building on existing capacities in the power sector to explore opportunities in the field of electricity-based hydrogen production.

The development of China's hydrogen value chain still lags behind advanced economies and remains dependent on technology imports in a number of areas such as core elements of fuel cells (Tu, 2020; Xu & Yu, 2021). For instance, Chinese firms lack the capacity for large-scale manufacturing of platinum catalysts, needed for PEM fuel cell stacks (Haitong Securities, 2021). China also depends on imports of key parts of PEM electrolyzers (Wallstreet News, 2022a), which are more suitable for running on intermittent renewables than traditional alkaline systems. Similarly, China lacks capacities in important storage and transport technologies (Gong et al., 2023).

3.2 The Role of Hydrogen in China's Future Energy Supply System

China aims to increase the percentage of renewable hydrogen in its future energy system. According to the Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy (2021), developing hydrogen value chains will help achieve the goal of accelerating the establishment of a clean, efficient, low-carbon, and safe energy system and will increase the supply of non-fossil fuels (The CPC Central Committee & State Council, 2021). The National Hydrogen Development Plan, launched in March 2022, identifies hydrogen's broader role in decarbonizing energy consumption and contributing to achieving carbon neutrality in hard-to-abate sectors, including the steel, transport, and chemical industries. By 2025, China seeks to establish a hydrogen supply system from industrial by-products and renewable hydrogen to reduce 1–2 million tons of CO_2 emissions annually (NDRC, 2022). In an effort to facilitate the sector's development, the government adopted the country's Energy Law in 2024, officially classifying hydrogen as an energy source rather than a hazardous chemical (PRC Energy Law, 2024). This will have important implications for the regulation and promotion of hydrogen within Chinese energy policy (Collins, 2024b).

The National Hydrogen Development Plan explicitly advances renewable hydrogen, although its initial goals have remained relatively modest. It aims to produce 100,000–200,000 tons of renewable hydrogen per year by 2025 (NDRC, 2022). The plan does not make any reference to CCUS technologies to reduce the carbon footprint of fossil-based hydrogen production. Before issuing the National Hydrogen Development Plan, the central government had already supported pilot city clusters for the promotion of FCEVs, especially those supported by renewable hydrogen (MOF et al., 2020a). The 14th Five-Year Plan of Renewable Energy Development (2022) further explains that renewable hydrogen production will be established in places where the cost of generating renewable electricity is low and where there have been pilot applications of hydrogen storage, transport, and use (NDRC et al., 2022). There are also strong signals that the Chinese government will continue supporting its hydrogen ambitions in the upcoming 15th Five Year Plan period from 2026 to 2030, building on the objectives and actions set-out in the National Hydrogen Development Plan. It has also clearly signalled that it wants to prioritize renewable hydrogen, but it has stopped short of announcing plans for a broader subidy scheme that goes beyond the scale of industrial pilot projects (Collins, 2025a). Instead, in its Guiding Opinions on Energy Work in 2025, the National Energy Administration has called on sub-national governments to "steadily develop renewable hydrogen production and sustainable fuel industries" (Collins, 2025b).

Hydrogen development plans adopted by sub-national governments include both plans to scale up conventional hydrogen production in the chemical sector and ambitious goals to expand renewable hydrogen, in some cases exceeding national goals. The role of different hydrogen production pathways varies from region to region. Coal-rich provinces and those with mature chemical industries, such as Shandong Province and Shanxi Province, still mainly pursue the production of hydrogen from coal or industrial by-products. Provinces rich in renewables are seeking to exploit these resources for electricity-based hydrogen production. Here Ningxia Province and the Autonomous Region of Inner Mongolia stand out, targeting 300,000 and 480,000 tons of renewable hydrogen by 2030, respectively. Given the lack of central-level guidance, renewable hydrogen production is not the main focus across the country. Rather, Chinese local and provincial governments are promoting a mix of hydrogen production pathways in an effort to boost overall supply (Gong et al., 2024).

3.3 Expanding Hydrogen Use

The National Hydrogen Development Plan also reconfirms China's longstanding aim to promote FCEVs and related technologies. The development of China's hydrogen-fueled vehicle industry dates back to 2012 (State Council, 2012). The 13th Specific Plan of Scientific and Technological Innovation in Transportation (2017) identified hydrogen FCEVs (MOST & MOT, 2017) as well as hydrogen storage and refueling as policy priorities (MOST & MOT, 2017). In 2020, the central government launched pilot applications of mid- to long-distance commercial FCEVs in hydrogen industrial clusters (e.g., Beijing and Shanghai) (MOF et al., 2020a). The National Hydrogen Development Plan (2022) highlights that in the transport sector, hydrogen will first be used to fuel hydrogen fuel cell commercial heavy vehicles and will then be gradually used to fuel hydrogen fuel cell passenger vehicles. By 2025, the number of hydrogen FCEVs should reach around 50,000 (NDRC, 2022). It is also a leader in the deployment of hydrogen refueling stations, accounting for approximately 40 percent of global installations at the end of 2024 (Collins, 2025c).

Stabilizing variable renewable power through hydrogen storage is another important area of projected hydrogen use. According to the 14th Five-Year Plan of a Modern Energy System (2022), hydrogen is envisioned to help increase the share of renewable energy in China's power system (NDRC & NEA, 2022a). Also, the National Hydrogen Development Plan states that China will explore and foster 'energy storage via hydrogen energy and wind or solar power.' (NDRC, 2022). NDRC and NEA further introduce that there will be demonstration projects for the use of hydrogen-based storage for balancing variable renewable power generation (NDRC & NEA, 2022a). Local governments such as Tianjin aim to use hydrogen as seasonal energy storage in the renewable power system (Tianjin Government, 2020).

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

3.4 Promotion of Innovation and Industrial Development in the Hydrogen Sector

The 13th Industrial Development Plan of Strategic Emerging Industries (2016) identified hydrogen production and storage and hydrogen refueling stations as strategic emerging industries, demonstrating the central government's aim to pursue industrial leadership in the sector (State Council, 2016b). Overcoming technological bottlenecks of related core technology and key manufacturing equipment is considered important for its economic development (NDRC, 2022). While the government has emphasized fuel cells and FCEVs in the past, it has recently increased its attention to other segments of the hydrogen value chain including scaling-up the manufacturing of related production equipment and developing materials for hydrogen storage. Furthermore, the National Hydrogen Development Plan has identified the development of technical standards as an important priority.

The Chinese government first started to promote hydrogen-related technologies in its State Plan of High Technology Research and Development, issued in 1986 (The CPC Central Committee & State Council, 1986). An important priority at this stage was the promotion of R&D and manufacturing of hydrogen fuel cells, which was reiterated in 2021 (NDRC, 2021). The National Hydrogen Development Plan encourages the development of PEM fuel cells, specifically. More recently, China is also promoting R&D in the field of electricity-based hydrogen production. Initially, the National Mid-and-Long Term Development Plan of Science and Technology (2005) highlighted the importance of advancing the technology for producing hydrogen from both renewable energy and fossil fuels (including coal gasification) in an efficient and cost-effective manner. The Action Plans of Energy Technological Revolution and Innovation (2016–2030) promoted innovation in the field of hydrogen purification for its production from industrial by-products. With the State Council's strategy document, Energy in China's New Era (2020), the focus shifted to advancing technologies for producing hydrogen from electricity (State Council, 2020). The National

Hydrogen Development Plan aims to improve the efficiency of hydrogen production based on renewable energy and to increase the productivity of related production equipment (NDRC, 2022).

Over time, hydrogen storage and transport have been recognized as another important technological bottleneck for China's hydrogen development. Therefore, the National Hydrogen Development Plan stresses the importance of developing materials for hydrogen storage. The 13th Specific Plan of Scientific and Technological Innovation in Transportation (2020) promotes the manufacturing of equipment for high-pressure hydrogen storage and refueling (MOST & MOT, 2017). The 14th Five-Year Plan of Energy Technology Innovation seeks to advance the innovation and manufacturing of the equipment for hydrogen pipelines and hydrogen refueling stations with varying levels of compression.

A major development in the promotion of innovation in the hydrogen sector has come with the launch of the Central Enterprises Green Hydrogen Production, Storage, and Transportation Innovation Joint Venture. Initiated by SASAC and jointly led by CNPC and Sinopec, the initiative brings together major SOEs, technology providers, and academia in an effort to promote innovation and technology development in the fields of green hydrogen production and conversion, storage and distribution, hydrogen-based raw materials and power as well as safety and testing (China Hydrogen Alliance, 2024).

3.5 Advancing the Formulation of Hydrogen Standards

In 2020, the China Hydrogen Alliance issued the Standard and Evaluation of Low-carbon Hydrogen, Clean Hydrogen, and Renewable Hydrogen (2020). According to the document, low-carbon hydrogen should not exceed 14.51 kg of CO_2 emissions per kg of hydrogen, while clean and renewable hydrogen should not exceed 4.9 kg of CO_2 emissions per kg of hydrogen (see Table 1). The standard for clean hydrogen roughly equates to the benchmark of 36.4 g of CO_2 per MJ for low-carbon hydrogen set by the European CertifHy scheme (assuming an energy density of 120–140 MJ per kg of hydrogen). The Chinese benchmark for low-carbon hydrogen exceeds even the estimated emissions of hydrogen produced from natural gas via steam methane reforming (referred to as gray hydrogen). The emissions benchmarks should be quantified using a lifecycle approach, which takes into account the raw material acquisition phase, the transport phase of raw materials, the phase of production, on-site storage, and transport of hydrogen energy. For coal- and natural gas-based hydrogen, this includes the stage of coal and gas extraction and transport, respectively. For electricity-based hydrogen, the assessment begins with the production of electricity. Neither low-carbon nor clean hydrogen is subject to any restrictions in terms of the process of hydrogen production and may in principle include hydrogen production from any source. Renewable hydrogen is considered a sub-category of clean hydrogen with the added requirement that the hydrogen should be produced

Table 1 CO_2 emissions standards for low-carbon, clean, and renewable hydrogen issued by China's Hydrogen Alliance

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

Source Gong et al. (2023)

via electrolysis with renewable energy. The latter may be produced on-site or may be purchased via an eligible certificate program.

In addition, the central government aims to gradually establish a system of hydrogen technology and safety standards. Dating back to 2005, the Standardization Administration of China (SAC) issued national standards for hydrogen production from electrolysis (SAC, 2005). The National Hydrogen Development Plan highlights the importance of establishing a system of hydrogen industrial standards for different segments of the hydrogen value chain from production to different areas of application (NDRC, 2022). Currently, the formulation of technological standards focuses on fuel cells and FCEVs (China National Institute of Standardization, 2022). The government has already initiated a series of standards for the use of hydrogen refueling equipment as well as the transport and production of liquid hydrogen (SAC, 2021a, 2021b, 2021c). It has announced that it intends to continue its promotion of hydrogen standards in the 15th Five Year Plan period (Collins, 2025a).

4 China's External Hydrogen Policy

As outlined in the previous section, China's emerging domestic hydrogen policy agenda remains at a relatively early stage. The government has begun to formulate modest supply-side targets, and, despite an emphasis on the importance of renewable hydrogen in a future, carbon–neutral energy system, it has not discouraged investment in fossil-based hydrogen. Instead, the policy remains centered on developing hydrogen-related industries and acquiring related technological know-how. Its external hydrogen engagement clearly reflects this nascent domestic hydrogen policy. It focuses on traditional industrial policy goals and follows patterns of its existing energy foreign policy rather than a distinctive hydrogen foreign policy.

This section provides an overview of China's emerging international hydrogen policy agenda. It begins with an overview of key policy goals. It then describes China's inward-oriented engagement with foreign partners as a vehicle for acquiring key technological know-how. This is followed by an overview of its multilateral hydrogen initiatives and activities in the field of international standard-setting. Bilateral cooperation with a number of strategic partners is covered in the subsequent section.

4.1 Policy Goals and Approaches to International Hydrogen Cooperation

The National Hydrogen Development Plan stated the objective of seeking technology cooperation on core hydrogen technology, equipment, and materials (NDRC, 2022) and actively engaging in international hydrogen standardization processes (NDRC, 2022). The Chinese government aims for both inward-oriented and outward-oriented hydrogen technology cooperation to boost domestic hydrogen technology innovation and participate in the development of global hydrogen value chains (State Council, 2021; NDRC, 2022; NDRC & NEA, 2022a). The National Hydrogen Development Plan stressed that China would work with states who own advanced hydrogen technologies to expand market shares in third states (NDRC, 2022). More specifically, NEA has indicated the intention to strengthen cooperation with Europe on hydrogen technology (NEA, 2021). The Mid-and-Long Term Development Plan of the Automobile Industry (2017) and Key Working Points of Standardizing New Energy Vehicles in 2020 (2020) have also highlighted China's intention of establishing cooperation on hydrogen technology and related standards.

Energy cooperation is also a dimension of China's efforts to 'green' the BRI (NDRC & NEA, 2017; NDRC et al., 2022). The government plans to initiate joint research and development of hydrogen energy, promote cooperation on green energy equipment, including hydrogen, and pursue training and communication activities with BRI states (NDRC et al., 2022). More specifically, BRI-related policy documents emphasize cooperation on hydrogen FCEVs. According to the Mid-and-Long Term Development Plan of Automobile Industry (2017), the government seeks to expand market shares in the fuel cell vehicle sector within the BRI and gradually integrate into global value chains (MOST et al., 2017). Additionally, the Key Working Dimensions of Standardizing New Energy Vehicles in 2020 (2020) stressed the importance of exporting the standards of China's new energy vehicles within the BRI, especially to ASEAN states and Central Asian states (MIIT, 2020).

The National Hydrogen Development Plan also stated that China would explore cooperation on hydrogen trade, the construction of hydrogen infrastructure, and the development of hydrogen-related products within the BRI (NDRC, 2022). Hydrogen trade might offer an opportunity for exports from Chinese provinces with rich solar, wind and hydro-resources in Northwest or Southwest China that are far from China's economic heartland. However, other hydrogen-related policies at the central level have so far rarely discussed hydrogen trade or plans for building international hydrogen infrastructure. It is likely that the Chinese government wants to prioritize the development of domestic production to avoid foreign dependencies. Given the large potential domestic demand, significant Chinese exports of hydrogen are also unlikely. Nevertheless, the hydrogen development plan of Shanghai, adopted in 2022, disclosed the aim to build a shipping terminal for hydrogen imports by 2035 to establish a center for hydrogen trade in East Asia (Shanghai DRC, 2022). Such a marketplace would give China a vehicle for participating in and influencing regional hydrogen markets.

4.2 China's Inward-Oriented Cooperation in Hydrogen Technology and Supply Chains

A key avenue for China's pursuit of hydrogen-related technological know-how is its inward-oriented international hydrogen cooperation. The Catalogue of Industries for Encouraging Foreign Investment 2022 highlights China's different focus areas of inward-oriented international hydrogen cooperation and encourages foreign hydrogen companies to build supply chains in China, including the manufacturing of equipment for hydrogen production and storage, hydrogen fuel cells, and FCEVs (NDRC & MOFCOM, 2022).

Renewable hydrogen production represents one important dimension of China's inward-oriented technology cooperation, including joint ventures and cooperation agreements with a number of European companies (Shell Global, 2022). There has also been some collaboration in the field of steam methane reforming in combination with CCUS, including with South Korea's green energy company SK E&S and state-owned Beijing Gas (Pekic, 2022). Foreign companies have also sought to expand shares in the sector of hydrogen storage and transport. French Air Liquide and Germany's Linde, for instance, have both engaged in the development of China's hydrogen refueling networks (Reuters, 2019). In line with China's traditional focus on fuel cells and FCEVs, technology cooperation in the field of hydrogen use also emphasizes this sector. Hyundai Motor is a central player in promoting the development of FCEV in China.

Finally, a number of foreign companies have also invested in research, development, and demonstration projects in the field of industrial hydrogen uses. BHP and China Baowu signed an MoU in 2020 to invest up to USD 35 million in hydrogen injection into blast furnaces and have set up the China Baowu-BHP Low-carbon Metallurgy Knowledge Sharing Center (BHP, 2020). Similarly, IHEC has promoted renewable hydrogen use in the metallurgical and chemical industries by working with the Shuimu Mingtuo Group and Hualu to establish the International Hydrogen Energy Metallurgy and Chemical Demonstration Zone (CSIRO, 2022).

4.3 Multilateral Engagement

According to Opinions on Improving the Regime and Implementation Measures of Energy Green Low-Carbon Transition (NDRC & NEA, 2022c), China also aims to integrate into global hydrogen value chains by engaging in multilateral organizations. The government targets cooperation via IRENA and IEA, the League of Arab States, the African Union, ASEAN, the Sustainable Energy Center of APEC and with Central and Eastern Europe (NDRC & NEA, 2022c) (see Table 2). China has worked closely with IEA and IRENA in the sphere of technology and to promote exchange on policy and best practices. In 2016, China joined the IEA Hydrogen Implementing Agreement to collaborate with other member states in hydrogen R&D and demonstration with the initial focus on hydrogen-based energy storage (IEA HIA, 2016).

More recently, the Administrative Center for China's Agenda 21 (ACCA21) collaborated with IEA in a study on the potential for hydrogen production with CCUS in China (IEA, 2022). Similarly, NEA and IRENA signed an MoU to deepen their cooperation on the production and use of renewable fuels such as hydrogen (IRENA, 2021). For the upcoming Five Year Plan period from 2026 to 2030, the government has articulated its intention to continue promoting international cooperation, in particular under the auspices of the BRI, BRICS and APEC (Collins, 2025a).

China is also a partner country in the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) and is committed to collaborating to accelerate innovation in fuel cell and hydrogen technologies (IPHE, 2023). In particular, it has focused on fuel cell-related cooperation within IPHE in the past. By launching the International Hydrogen Fuel Cell Association (IHFCA), the China Society of Automotive Engineers sought cooperation on fuel cell-related R&D and the development of the hydrogen fuel cell value chain with international organizations and multinational corporations, including the United Nations Development Program (UNDP) and

Table 2 China's multilateral hydrogen cooperation

Multilateral organization or forum	Area of engagement
International Energy Agency (IEA)	Member of IEA Hydrogen Implementing Agreement since 2016 to collaborate with other member states in hydrogen R&D and demonstration with the initial focus on hydrogen-based energy storage
International Renewable Energy Agency (IRENA)	MoU in 2021 on collaboration in the spheres of production and use of renewable fuels, such as hydrogen
International Partnership for the Hydrogen Economy (IPHE)	Collaboration activities focused in particular on fuel cells so far
International Hydrogen Fuel Cell Association	Association initiated by China Society of Automotive Engineers aimed at promoting technology innovation for fuel cells and the development of hydrogen fuel cell value chains
United Nations Industrial Development Organization (UNIDO)	Launch of International Hydrogen Energy Center (IHEC) in 2021 within UNIDO's Global Programme for Green Hydrogen in Industry to attract international R&D funding to China and disseminate knowledge and advance research with international partners
Forum on China-Africa Cooperation	Declaration to promote hydrogen development within Declaration on China-Africa Cooperation on Combating Climate Change (2022)
Association of Southeast Asian Nations (ASEAN)	Commitment to promote R&D and technical exchange in Plan of Action to Implement the ASEAN-China Strategic Partnership for Peace and Prosperity (2021–2025)

Source Author, based on organization's websites and media reports a range of foreign companies (CSIRO, 2022). China has also supported the launch of the International Hydrogen Energy Center (IHEC) by the United Nations Industrial Development Organization (UNIDO). IHEC will promote China's hydrogen development and its international hydrogen cooperation by attracting international R&D funding and disseminating knowledge and advancing research involving China and other states (UNIDO, 2020).

According to the Declaration on China-Africa Cooperation on Combating Climate Change, both China and Africa will provide an investment-friendly environment and financial support for renewable hydrogen development projects. According to the Plan of Action to Implement the ASEAN-China Strategic Partnership for Peace and Prosperity (2021–2025), China and members of ASEAN should carry out joint R&D and technical exchange for hydrogen and fuel cells.

As highlighted above, China has actively promoted the formulation of hydrogen-related standards. In the National Hydrogen Development Plan, NDRC emphasized the importance of advancing international cooperation on standards for core hydrogen technology, equipment, and materials (NDRC, 2022). Moreover, the Notice on the Implementation Plan of Promoting the Development of New Energy in the New Ara (2022) states that increasing the global influence of China's hydrogen standards and participating in global standard-setting would help internationalize the domestic new energy industry (NDRC & NEA, 2022b). In this vein, the China-UK Hydrogen Energy Cooperation Forum as well as the Sino-German Energy Partnership have announced plans to advance international cooperation on hydrogen-related standard-setting (MFA, 2022; Sino-German Energy Partnership, 2022).

Given China's important emphasis on the promotion of fuel cells and FCEVs, it has pursued a particular focus on joint standard-setting in this area. Since 2020, the Ministry of Industry and Information Technology (MIIT) has promoted cooperation with the EU, Germany, France, Japan, and APEC on formulating standards for fuel cell vehicles (MIIT, 2020). As early as 2017, the Vice Chairman of SA attended the 2nd International Conference of the Industrial Development of Hydrogen Energy and Fuel Cells (SAC, 2017) and called for collaboration with foreign companies and scholars to help China to develop its fuel cell industry (SAC, 2017). In its 2022 working plan, SA plans to work with ISO, IEC, and ITU to develop standards relevant for carbon peaking and carbon neutrality, including hydrogen standards (SAC, 2022a, 2022b).

5 Bilateral Hydrogen Cooperation

Complementing China's inward-oriented foreign engagement and its multilateral cooperation on hydrogen, it is beginning to engage actively in bilateral cooperation with a number of leading industrialized countries. In the sphere of fuel cell vehicles, cooperation is taking place as part of its broader industrial policy strategy, aimed at internationalizing its automotive sector. Although there is no official policy on the promotion of overseas investment in hydrogen production, a number of SOEs have also started to engage with strategic energy partners in different world regions for the development of green hydrogen projects. For now, these are based in countries where China has strong, pre-existing engagement in the energy sector, notably in Brazil, Pakistan, Egypt, and Saudi Arabia (Quitzow & Gong, 2023). Additionally, there is nascent cooperation with Russian partners on fossil-based hydrogen production with CCUS. This section provides an overview of the main activities that have emerged along these various bilateral avenues for cooperation.

5.1 Technology Cooperation with Major Industrialized Countries

Complementing its inward-oriented technology cooperation, the Chinese government has promoted bilateral cooperation with a host of advanced industrialized countries, including Germany, the UK, the US, and Australia. With Germany, it engages via the Sino-German Energy Partnership and has launched funding lines for joint R&D in the area of FCEVs (NOW, 2022). According to the China-UK Hydrogen Energy Cooperation Forum, both states will jointly promote research and development of hydrogen technology to facilitate the development of their hydrogen value chains (MFA, 2022). The Australia–China Science and Research Fund Joint Research Center has provided funds for hydrogen-related research (ACSRF, 2023). In the 2022 Sino-American Forum on Cooperation in the Hydrogen Energy Industry, Chinese and American public and private bodies had dialogues on the prospects for potential hydrogen cooperation between important hydrogen regions in China, such as the Beijing-Tianjin-Hebei Region, the Yangtze River Delta and the Pearl River Delta, and Californian counterparts (CSIRO, 2022). In the 15th Five Year Plan, the government aims to expand technology cooperation with Europe (Collins, 2025b).

5.2 Industrial Policy for the Automotive Sector: Internationalization of FCEV Supply Chains

Government policies have also stressed the export of equipment and products of fuel cells and FCEVs, as part of a broader policy to promote the internationalization of its automotive industry. Since 2017, China has aimed to initiate bilateral and multilateral framework agreements of automobile industrial cooperation including hydrogen FCEVs. The Mid-and-Long Term Development Plan of Automobile Industry (MOST, MIIT & NDRC, 2017) promoted producers of hydrogen FCEVs to export products, services, technologies, and standards by investing in foreign markets rather than focusing on export sales alone. It targets overseas investments where Chinese firms retain management control and that enable technology cooperation (MOST, MIIT & NDRC, 2017). The Mid-and-Long Term Development

Plan of the Automobile Industry (2017) further explains that the central government will support companies in the automotive sector in their efforts to contribute to the development of overseas industrial parks (MOST, MIIT & NDRC, 2017). Overseas automobile industrial parks have been promoted by the Chinese government in cooperation with host country governments (EY, 2020), for instance in Kazakhstan. Typically, SOEs act as lead investors in cooperation with other state-owned or private firms. These industrial parks may benefit from infrastructure along the 'Maritime Silk Road' to explore the opportunities of incorporating hydrogen logistics in shipping, automobiles, and buses (Yue & Wang, 2022).

5.3 Green Hydrogen Cooperation with Strategic Energy Partners

Although China's hydrogen-related policies do not explicitly promote the export of electrolyzers, China's companies, such as PERIC Hydrogen Technologies, Cockerill Jingli Hydrogen, and Shandong Saikesaisi, have already exported electrolyzers to overseas markets (Brown & Grünberg, 2022), reflecting China's increasing capacity of manufacturing standard alkaline electrolyzers. Also, the hydrogen subsidiary of LONGi has the ambition of exporting alkaline electrolyzers to foreign markets (The Japan Times, 2023). These export ambitions align with China's policy of increasing its influence within the global energy sector by expanding its role in global energy value chains. A number of SOEs are beginning to spearhead cooperation with a number of strategic energy partners across different world regions, including Brazil, Pakistan, Egypt, Saudi Arabia, and Russia (Quitzow & Gong, 2023).

5.3.1 R&D Cooperation as a Precursor to Green Hydrogen Investment in Brazil

China's electricity companies have taken a strong position in the power sector of Brazil since 2010 and now hold over 10% of Brazil's generation, transmission, and distribution infrastructure (Global Development Center, 2021). Building on this, Chinese power sector SOEs are currently establishing R&D on green hydrogen and seeking the possibilities of building hydrogen value chains in Brazil. State Power Investment Corporation (SPIC) has been an active player in the financing of renewable energy projects and started technology cooperation on renewable hydrogen with Brazil prior to the publication of the National Hydrogen Development Plan (SPIC, 2020). In 2021, SPIC and its Brazilian subsidiary signed an MOU for the investment of US$3.5 million in the research and development of renewable hydrogen and smart energy with the Center for Energy Research of Brazil. The renewable hydrogen is expected to be used in energy storage and the production of ammonia and fertilizers in Brazil. Similarly, in 2020, China Three Gorges International Corporation

(CTGIC) was operating 17 hydropower and 11 wind power projects in Brazil. By leveraging its strong position in Brazil, CTGIC launched research and development activities in the field of renewable hydrogen and is collaborating with Brazil's Serviço Nacional de Aprendizagem Industrial (SENAI), a provider of industry-focused technical education and innovation services, to explore opportunities for cooperation in renewable hydrogen. With US$3.2 million, CTGIC and SENAI decided to establish a transaction platform for renewable hydrogen that can guarantee its origin (CTGIC, 2022).

5.3.2 Green Hydrogen Investment Within the China–Pakistan Economic Corridor (CPEC)

In October 2021, PowerChina International Group, a subsidiary of Power Construction Corporation of China (PowerChina), signed a cooperation agreement with international natural resources project developer Oracle Power to jointly develop a renewable hydrogen production facility in Pakistan's Sindh province. Building on the region's abundant solar and wind energy resources, it is expected to produce 150,000 kg of hydrogen per day (Whitlock, 2021). PowerChina would provide construction services and act as a joint developer, while Jiangsu Guofu, a privately owned Chinese firm, would provide the equipment. The companies have been assessing the commercial viability of the project and are looking for hydrogen off-takers from Pakistan, China, or third states, indicating the possibility of renewable hydrogen trade between the two countries (Oracle Power PLC, 2021). The investment is in line with the objectives of the longstanding China–Pakistan Economic Corridor (CPEC) initiative and Pakistan's role as a key partner in the BRI. The CPEC includes a series of investments in logistics and energy infrastructure, which provide the enabling environment for investments in hydrogen (Mardell, 2020).

5.3.3 Cooperation in the Middle East: Egypt and Saudi Arabia

After COP27 in Egypt, China Energy Engineering Corporation Limited (CEEC) signed an MoU on jointly developing a renewable hydrogen project with the Egyptian New Energy Authority, the Suez Canal Economic Zone Authority, sovereign wealth funds, and power transmission companies, signaling the start of China's hydrogen cooperation with Egypt. The project is expected to produce 210,000 tons of renewable hydrogen per year upon completion, which would be further converted to approximately 1.2 million tons of green ammonia (Hydrogen Insight, 2023a). CEEC will export the equipment, services, and technologies relevant for the combined development of solar, wind, and renewable hydrogen in this project. The project aligns with China's external energy strategy of exporting energy equipment, services, and technologies, in particular in BRI countries. Egypt serves as a gateway to the African Continent, and its Suez Canal connects the Mediterranean Sea to the Red Sea and the Indian Ocean.

Similarly, China has started to explore hydrogen cooperation with Saudi Arabia, building on its well-established and expanding relationship in the fossil fuel sector. At the Arab States-China Summit held in December 2022, Saudi Arabia and China signed an MoU on hydrogen energy and the encouragement of direct investment between the two states (Reuters, 2022). In 2023, Saudi Arabia's Aramco announced plans to collaborate with Chinese Since Gas to build a plant for the conversion of ammonia to hydrogen (SCMP, 2023). Moreover, Chinese wind-turbine producer Envision will be supplying turbines for the large-scale renewable hydrogen project being developed in Saudi Arabia under its Neom Project (Hydrogen Insight, 2023b).

5.3.4 Cooperation in Fossil-Based Hydrogen and CCUS with Russia

Against the background of the well-established Chinese-Russian gas cooperation, China has also begun cooperation on fossil-based hydrogen production with CCUS technology. In September 2022, Gezhouba Rus, a subsidiary of China Energy Engineering Group in Russia, announced the intention to cooperate with Rusatom for the construction of a plant for the production of hydrogen from natural gas with CCUS. The project includes plans to export low-carbon hydrogen from Sakhalin to China by sea in the form of liquid hydrogen as early as 2025 (Biogradlija, 2022). Given China's abundant potential to produce domestic hydrogen, cooperation with Russia is unlikely to be driven by concerns to secure future hydrogen supply. Rather, it would appear to represent an approach for maintaining active energy cooperation outside the oil and gas sector and good diplomatic relations with Russia.

6 Conclusion

China's hydrogen strategy—both internal and external—is still at an emergent stage (Quitzow & Gong, 2023). With the formulation of the National Hydrogen Development Plan, the government took a major step toward formalizing its policy approach. Nevertheless, the national targets remain modest, and policy remains ambiguous regarding the preferred production pathway. China's long-term vision clearly emphasizes the role of renewable hydrogen to help balance an energy system dominated by wind and solar energy. However, current policy provides ample space for the promotion of other forms of hydrogen production. Rather than a strong, centralized policy approach, local and provincial governments along with SOEs have been driving investment and policy experimentation in the sector, which includes efforts to boost fossil-based hydrogen production (Gong et al., 2024). While the government has reiterated its commitment to the hydrogen economy, in particular renewable hydrogen, in the 15th Five Year period from 2026 to 2030, its announcements have so far stopped short of proclaiming a marked acceleration of its ambitions (Collins, 2025a).

A major priority for the central government is the development and acquisition of technological know-how across the hydrogen value chain as part of a broader industrial policy agenda in emerging, green industries. Building on an important legacy in the promotion of FCEVs, China still places substantial emphasis on promoting this segment of its domestic hydrogen industry. However, in recent years, technology bottlenecks in hydrogen storage, transport as well as PEM fuel cells and electrolyzers have assumed increasing prominence in China's efforts to promote technological leadership in the field. These are pursued actively through inward- and outward-oriented technology cooperation with partners in other leading countries as well as active engagement in the development of hydrogen-related standards. Hydrogen FCEVs are also being promoted as part of a broader policy to support the internationalization of China's automotive industry. This has included the development of industrial parks focused on the automotive sectors in BRI countries.

Hydrogen is also emerging as an element of China's external energy policy, albeit not with a distinctive geopolitical strategy (Quitzow & Gong, 2023). Chinese SOEs are pursuing investments in renewable hydrogen projects in countries with pre-existing energy-related cooperation, including Brazil, Pakistan, Egypt, Saudi Arabia as well as Russia. In this vein, hydrogen-related cooperation can be seen as an extension of China's broader external energy policy, which combines commercial interests with the goal of expanding its influence along international energy value chains. With the exception of Russia, projects are predominantly focused on renewable hydrogen and extend cooperation into this new area of the energy sector. Although cooperation with Pakistan and Russia may involve the export of hydrogen to China, securing hydrogen supply does not appear to be an important driver of China's international involvement in the sector. The development of hydrogen imports as an energy security imperative does not feature as a theme in the National Hydrogen Development Plan, and China is likely to have sufficient renewable resources to supply its domestic economy with renewable hydrogen. Rather, the government has expressed concern that China may not have access to all the required technological know-how, underlining its multidimensional efforts to secure this know-how via engagement with international partners.

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