Australian National University

China's hydrogen plans

Near-term policy challenges & Australia-China links in decarbonization

Policy Brief

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1. Introduction

Many countries are rolling out hydrogen strategies, given the potential of hydrogen energy to decarbonize 'hard to abate' processes. Hydrogen use could cover applications in multiple sectors such as steel and other metals production, transportation, synthetic fuels, ammonia or fertilizer, chemical production, building heating, and distributed energy (Figure 1). Projections or national strategies see greatly varying breakdown of hydrogen demand in different sectors, but the current focus of hydrogen end-product development appears to be in the industrial, transportation, and energy sectors, with significant uncertainty surrounding the use of hydrogen in buildings (World Energy Council, 2021).

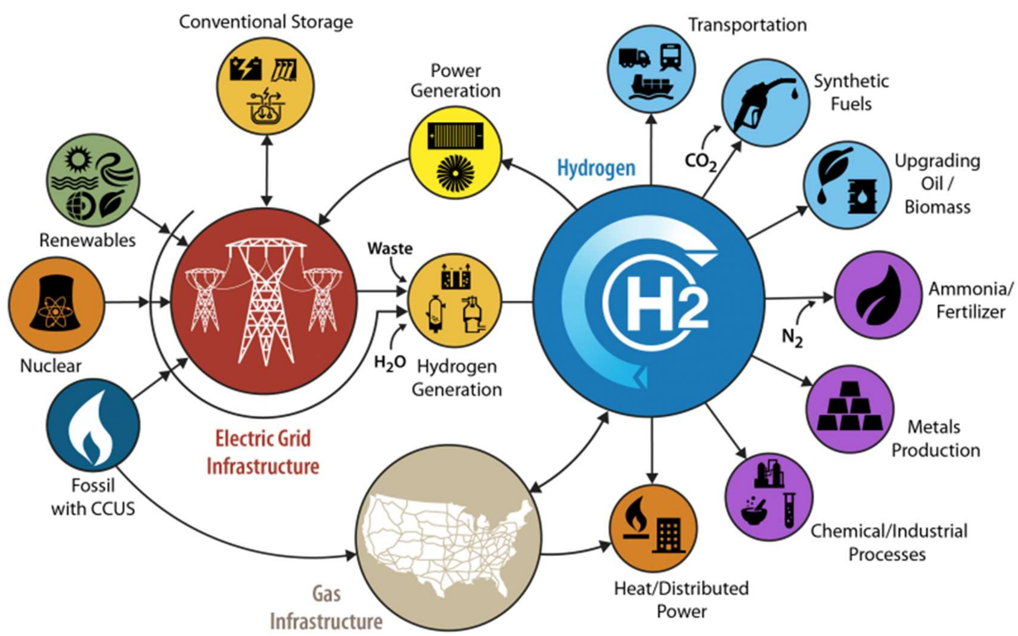

Figure 1. Potential sources and uses of hydrogen by sector. Source: (Office of Energy Efficiency & Renewable Energy, 2017)

There are a number of different chemical or physical methods to produce hydrogen (Figure 2), with a key distinction between hydrogen produced from fossil fuels, and hydrogen produced through electrolysis of water. Hydrogen is classified as grey hydrogen when it is produced from fossil energy sources, industrial by-products, etc., and as blue hydrogen when the process is accompanied by carbon capture, utilization and sequestration (CCUS) (Bartlett & Krupnick, 2020). Green hydrogen is produced through electrolysis of water using renewable energy. Other classifications also include purple hydrogen, produced through thermochemical cycles or high-temperature steam electrolysis using nuclear energy, and other colours (Teng, Wang, & Huang, 2022).

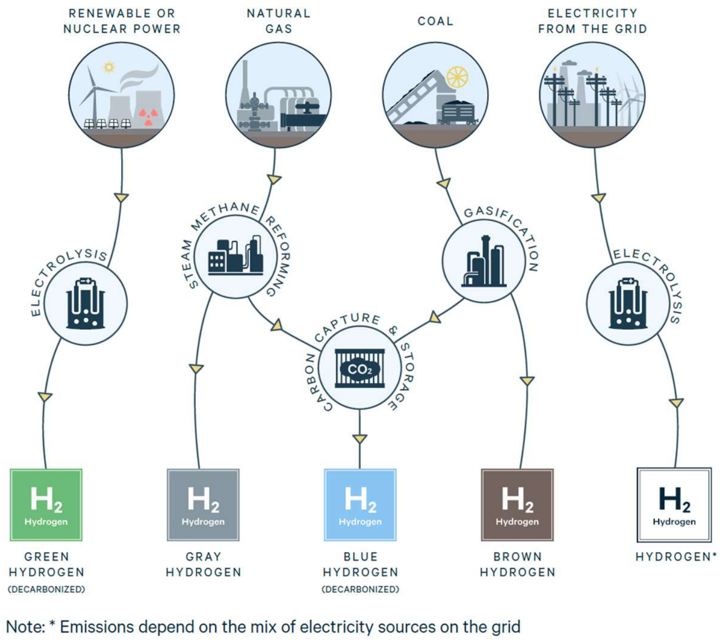

Figure 2. Hydrogen Production Process, Source: Bartlett & Krupnick (2020).

At present, the majority of global hydrogen production is from fossil fuel production routes. Steam methane reforming (SMR) is currently the most common hydrogen production technology, accounting for roughly half of production globally. Black and brown coal are also commonly used as feedstock in coal gasification (CG) (Longden et al., 2022). Emission reduction strategies and the continuing rapidly decreasing costs of renewable energy applications will likely mean the proportion of green hydrogen will rapidly grow, and act as one of the most effective ways to build a clean, low-carbon, safe and efficient energy system.

In June 2022, 34 countries had issued national-level hydrogen energy strategies and policies (HyResource, 2022). Among them, the United States, the United Kingdom, Canada, Germany, and China have prioritized hydrogen energy development in regional pilot policy schemes. China is amongst the countries actively developing renewable energy to produce hydrogen, and reducing the cost of renewable energy electricity and electrolyser is the key to realize large-scale production of green hydrogen in China. The market for electrolysers for hydrogen energy reached 458 MW in 2021, and BNEF expects shipments to at least quadruple over 2022. China is expected to account for roughly two-thirds of total global demand, largely driven by state-owned companies that are spearheading the country's decarbonization goals (BloombergNEF, 2022). While China is still in a development phase of industrialization and urbanization, and remains focused on reducing the intensity of CO_2 emissions per unit of GDP production, the development of the hydrogen industry is seen as a key transitionary step between fossil and renewable energy sources in the decarbonisation of its energy system (He, 2021; Meng, et al., 2022)

2. Hydrogen costs and emissions comparisons

2.1 Global costs and emissions of hydrogen

Costs and emissions from hydrogen production vary greatly depending on the feedstock and process used. A key barrier to the development of low-carbon hydrogen is the current cost gap with fossil fuel-based hydrogen production.

An ANU review of cost estimates in the scientific literature shows production costs of green hydrogen are currently about two to three times that of fossil fuel-based production routes (Figure 3, see also Longden et al., 2022). Applying Carbon Capture and Storage (CCS) technology would add significantly to production cost and help to close the cost cap.

More importantly, the study notes that many proponents of such blue hydrogen are overly optimistic about carbon capture costs. They note that many national strategies and major reports assume capture rates of circa 90%, which have not yet been achieved in large-scale commercial projects. An exception is the Tomakomai CCS demonstration project, where such high capture rates were achieved at a largely prohibitive cost of $127/t CO_2. The study concludes that the substantial further cost reductions in renewable electricity and equipment cost associated with green hydrogen production as foreseen for the near future will likely make green hydrogen cost-competitive with fossil fuel-based hydrogen, given carbon emission costs of around $50/t CO_2 (Figure 3).

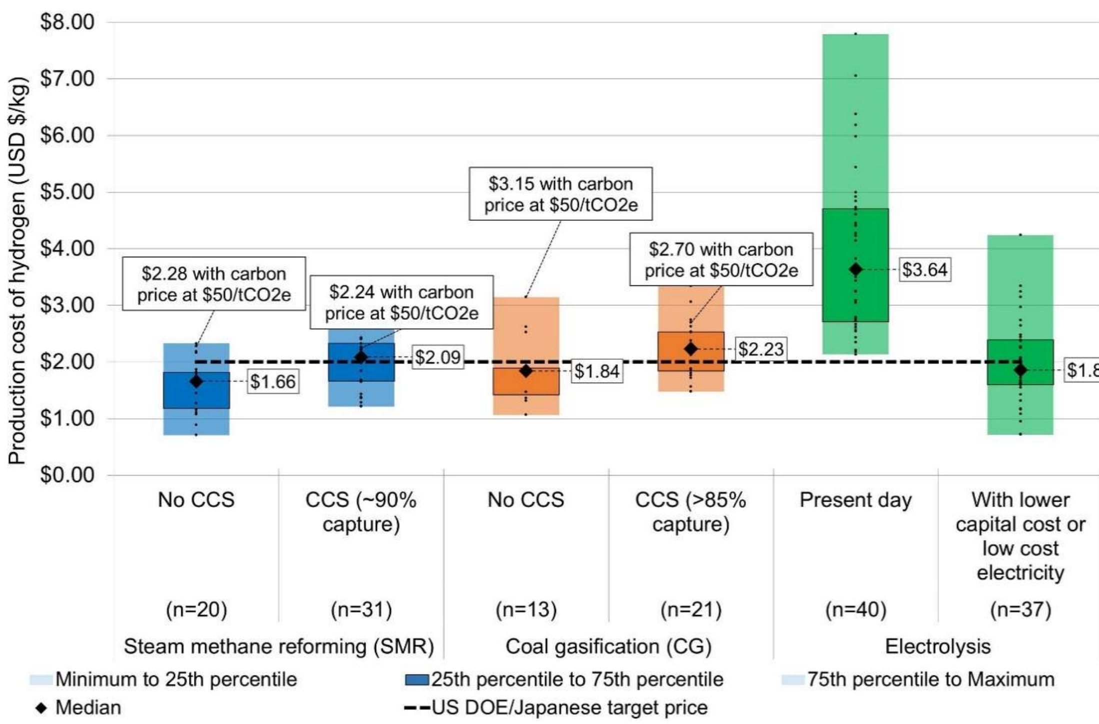

Figure 3. Cost estimates for key hydrogen production routes, with averages and spread based on a review of 16 scientific reports. Source: (Longden et al., 2022).

The same ANU study compared the intensity of emissions from hydrogen production processes using black coal, brown coal, and natural gas, with or without CCS technology. The study found that hydrogen produced with black or brown, without CCS, would even result in emissions higher even than direct combustion of black or brown coal, per unit of useful energy created (Figure 4). It also notes substantial fugitive emissions from hydrogen produced with black coal (of ca. 26 kg CO_2/GJ), or natural gas (of ca. 13 kg CO_2/GJ).

More importantly, the study notes that many proponents of blue or brown hydrogen are overly optimistic about feasible carbon capture rates. They assess that only hydrogen produced from natural gas with a high capture rate of 90% is below the emission threshold set out by the European CertifHy Guarantee of Origin scheme. Again, such high capture rates are regularly assumed in national strategies and major reports, but have not yet been achieved in a large-scale commercial project. Similarly, these strategies and reports tend to ignore fugitive emissions, which are typically at 3% in operational USA gas fields; a rate, which would also not allow this production method to remain within the emissions intensities specified by the CertifHy scheme.

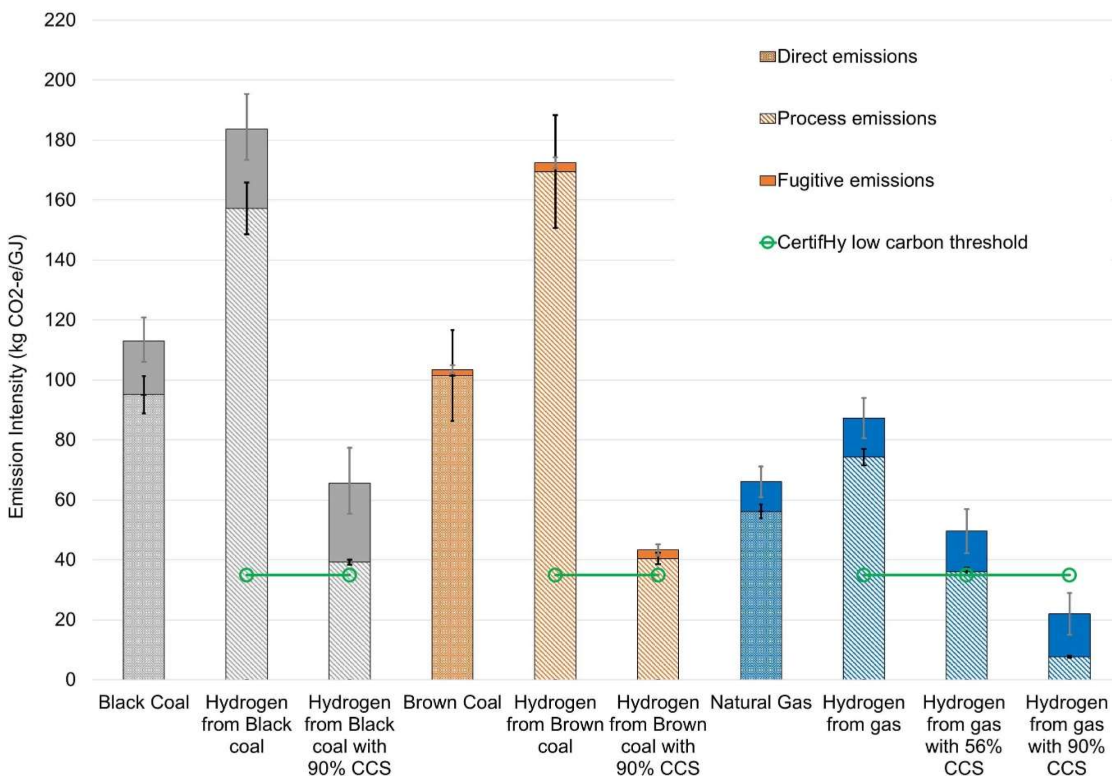

Figure 4. Emission estimates, using IPCC default emission factors, for key hydrogen production routes. Source: (Longden et al., 2022).

Note that the transport of hydrogen energy will be another component of costs and emissions. Currently, about 85% of hydrogen is produced and consumed on-site (IEA, 2019). Over time, hydrogen could become an internationally traded commodity, offering demand centres the possibility of benefitting from distant abundant renewable energy resources (IRENA, 2022). Researchers at the ANU estimate that long distance transport emissions, including possible conversion or compression of hydrogen, could add in the order of 2 to 3 kg CO_2-e/kg H_2, compared with 10 to 13 kg CO_2-e/kg H_2 in production process and fugitive emissions for conventional SMR based hydrogen (White, et al., 2021).

2.2 Chinese estimates of hydrogen cost and emission

Scholars at Tsinghua University have estimated the production costs through to 2060, the year that China aims to achieve net-zero emissions. Their estimates are that production of hydrogen with conventional, fossil fuel-based production methods are about 10 to 15 CNY/kg H_2. The study further assess cost and cost developments for a large variety of hydrogen production processes, both excluding and including an assumed increasing carbon price over time, and rapidly falling technology costs for green production alternatives (Wang, Ou, & Zhou, 2022). Note that Chinese discuss hydrogen generated with nuclear energy on an equal footing with renewable electricity processes. Such nuclear hydrogen is either with electrolysis with nuclear power, or through thermo-chemical water splitting in the high-temperature reactor environment. These renewable and nuclear hydrogen production processes are assessed to have comparable costs, with both currently being roughly 2 to 3 times more expensive than hydrogen produced with fossil fuels, but attaining cost parity even without carbon pricing between 2030 and 2040 (Figure 4).

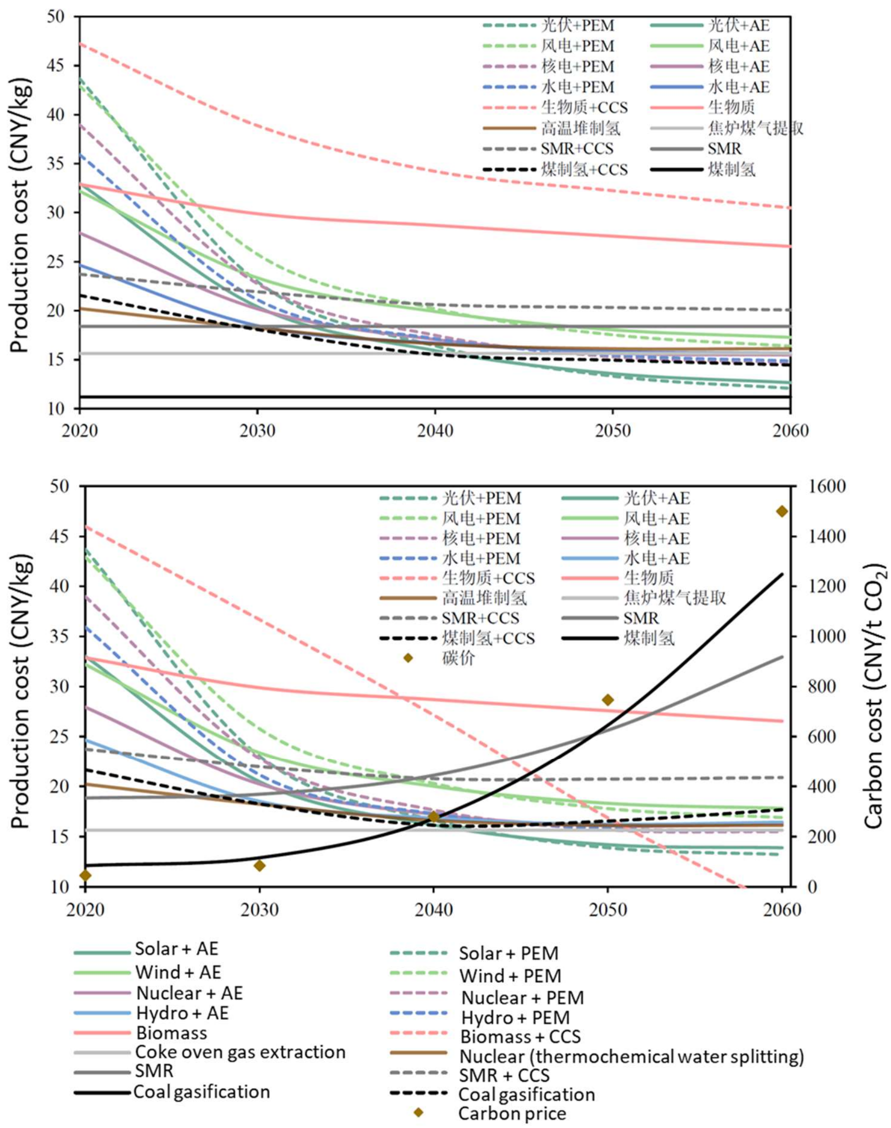

Figure 5. Levelized cost of hydrogen without (top) and with carbon pricing (bottom). Note: AE: alkalyne electrolysis, PEM: polymer electrolyte membrane, two competing methods for generating hydrogen through electrolysis. Source: (Wang, Ou, & Zhou, 2022)

3. China's hydrogen policies

3.1 Historical policy development

The development of hydrogen energy in China started late, but has been rapidly developing in recent years.

In October 2006, the 11th Five-Year Plan for Science and Technology Development proposed to include hydrogen and fuel cell technology as a frontier technology to be deployed ahead of schedule and to carry out key research. During the 12th Five-Year Plan period (2011-2015), China did not have a specific policy on hydrogen, but hydrogen energy was included in policies supporting technological development and innovation. They issued several guidance documents to promote development of fuel and battery vehicles for businesses, including the "Made in China 2025" strategy, released in 2015 (State Council, 2015; MIIT D. , 2016).

During the 13th Five-Year Plan period (2016-2020), China demonstrated its determination to develop new energy vehicles. Policies targeted the research and development and application promotion of hydrogen fuel cell catalyst materials, set standards for the use of fuel cell electric vehicles and provide subsidies for vehicle purchases (NDRC, 2019). The central government also enacted policies to support hydrogen storage and transport (IEA, 2022). Specially, they issued the “New Energy Vehicle Industry Development Plan (2021-2035), which requires the industry to focus on hydrogen storage, hydrogen refuelling stations, on-board hydrogen storage, and to develop industrial by-product hydrogen and renewable energy hydrogen production technologies in regional industrial clusters (State Council, 2020). In 2016, the "Innovation Action Plan for Energy Technology Revolution (2016-2030)" identified technological innovation in hydrogen production with renewable energy, and hydrogen fuel cell technologies, as key areas for development for the first time (NDRC & NEA, 2016).

Furthermore, China has a long history in developing technology for high-temperature gas-cooled reactors (HTGR), under development since the 1970s, with a high-temperature gas-cooled experimental reactor (HTR-10) built at the Institute of Nuclear and New Energy Technologies (INET) at Tsinghua University in 2001 (El-Emam & Khamis, 2019). This same institute has initiated R&D activities for nuclear hydrogen production, coupling a hydrogen facility with the pilot reactor HTR-10 in December 2021 (China Atomic Energy Authority, 2021).

3.2 Synopsis of most recent policies

In the 14th Five-Year Plan period, the domains of hydrogen energy and energy storage are marked as the focus areas for technological development and accelerated industry development. The “14th Five-Year Plan for Industrial Green Development” proposes to promote innovation in hydrogen technology and infrastructure development in the implementation path for industrial decarbonisation, and requires central-owned enterprises and large enterprises to form industrial demonstration applications in green hydrogen, renewable hydrogen production and energy storage (MIIT, 2021).

In March 2022, the “Medium and Long-Term Plan for Hydrogen Energy Industry Development (2021-2035)” was the first document to discuss hydrogen as an energy source, and specifies targets for 2025, 2030 and 2035 for development of the hydrogen industry (NDRC & NEA, 2022). It aims to significantly increase the share of renewable hydrogen in final energy consumption by 2035, to expand the application of hydrogen energy from transport to a wide range of areas such as metal smelting, electricity supply and household end-use applications. This plan builds China’s hydrogen development pathway for the next 10 years, clearly indicating a shift from fossil energy to renewable energy for hydrogen production, but only giving a numerical target for the short term, of 100-200 kt of hydrogen produced from renewable energy by 2025. By the same year, it sets a target for having 50,000 fuel cell vehicles on the road, to deploy an unspecified number of hydrogen-refuelling stations, and achieve CO_2 emission reductions of 1-2 million ton/year.

In order to promote the development of low-carbon and clean hydrogen production industry, the China Hydrogen Energy Alliance has proposed quantitative criteria for ‘low-carbon’, ‘clean’ and ‘renewable hydrogen’ (Table 1). On 31 January 2022, Yanshan Petrochemical, a subsidiary of Sinopec, successfully passed the clean hydrogen certification of this standard and provided clean fuel for hydrogen vehicles for the 2022 Beijing Winter Olympic Games (Nie & Wan, 2022).

Table 1. China Low Carbon Hydrogen, Clean Hydrogen and Renewable Hydrogen Standards

Classification:	Low Carbon Hydrogen	Clean Hydrogen	Renewable hydrogen
Carbon emissions per unit of hydrogen (kg CO_2e/kg H_2)	14.51	4.9	4.9
Requires renewable energy for hydrogen production	No	No	Yes

Source: (China Hydrogen Alliance, 2020).

The 2019 government work report included a first reference to hydrogen energy. Key State-Owned Enterprises quickly followed suit, and developed strategies for hydrogen energy production and infrastructure construction, key technology research and development, and applications of hydrogen energy. In July 2021, Peng Huagang, secretary-general of the State-owned Assets Supervision and Administration Commission of the State Council, stated that more than one-third of central-owned enterprises are already developing a full hydrogen industry chain including production, storage, refuelling, and application (SASAC, 2021). Among them, China National Nuclear Industry Corporation (CNIC) has planned a 600 MW ultra-high temperature gas-cooled reactor nuclear energy hydrogen production project, with a goal of developing mature nuclear energy hydrogen production and pioneering hydrogen storage, hydrogen transportation and hydrogen fuel cells by 2030. In addition, Sinopec has publicly stated that during the 14th Five-Year Plan period, it will accelerate the development of its new energy business, with hydrogen energy at its core, and plans to construct 1,000 hydrogen refuelling stations by 2025 (NEA, 2022; CNNPN, 2020).

With the deployment of hydrogen energy policies and pilots, the Chinese Ministry of Science and Technology (MOST) and the National Energy Administration (NEA) have issued notices on support for hydrogen R&D, and for hydrogen safety requirements. In May 2022, MOST issued a notice on the “National Key R&D Program "Advanced Structures and Composites" and other key special projects in 2022” to provide funding support for a number of hydrogen and other high-tech research projects. These R&D programs connect with previously announced plans for hydrogen, and emphasise green production and large-scale transportation of hydrogen, hydrogen safety and rapid transmission and distribution, efficient power generation with hydrogen, and household end-use energy applications (MOST, 2022). Later in June 2022, the NEA released ‘Twenty-five Key Requirements for the Prevention of Accidents in Electric Power Production (Draft for Comments)’, which include requirements for safety issues relating to hydrogen, such as preventing explosions of hydrogen storage and other systems, and preventing hydrogen leakage from hydrogen-cooled generators (NEA, 2022).

3.3 Sub-national policies

The development of China's hydrogen energy industry will rely on the top-level design of the central government, and special plans and subsidies for the promotion of hydrogen energy at the regional, provincial and county levels. The "Yangtze River Delta" region, the "Pearl River Delta" region around Guangzhou, and the "Beijing-Tianjin-Hebei" region have also determined their own hydrogen development strategies and targets, in accordance with local renewable energy resource endowments.

A number of provinces including Inner Mongolia, Shandong and Beijing have also formulated local hydrogen development plans. These typically start from developing leadership in the use of hydrogen in transportation, and gradually expand industries to hydrogen production, hydrogen storage, hydrogen refuelling, fuel cell manufacturing, metals production, and household energy use. For example, Inner Mongolia has proposed to develop hydrogen production and storage coupled with large wind and solar power bases.

Shandong is currently focusing on building a hydrogen fuel cell-vehicle application city cluster and plans to accelerate the terminal application of transportation, industry and household energy (NDRC, 2021). As an important heavy chemical industrial base in China and a province with a large amount of low-cost industrial by-product hydrogen resources and considerable potential for renewable hydrogen production, Shandong had announced its hydrogen energy development plan for 2020-2030 in June 2020. By the end of 2020, there are more than 120 enterprise and research institutions related to hydrogen industry in Shandong. The complete industrial capacity and research investment will help Shandong to achieve the target of building 100 hydrogen refuelling stations and have 10,000 fuel cell vehicles on the road by 2025. By 2030, Shandong plans to further increase the number of hydrogen refuelling stations to 200, have 50,000 fuel cell vehicles on the road, and increase the total value of the hydrogen industry to 300 billion yuan (Shandong Provincial Government, 2020). Shandong's hydrogen energy goals are similar to those of California, USA, which has been a beacon of success for hydrogen stations and FCEV deployment since 2000. By 2019. The state has 40 retail hydrogen stations and the cost of these large stations has fallen by 40% in the last few years. The state plans to have 250,000 charging points and 200 hydrogen refuelling stations in retail operation by 2025, and 5 million ZEVs, including BEVs and FCEVs, on the road by 2030 (California Independent System Operator, 2019).

Changping District in Beijing has proposed the "Changping District Hydrogen Energy Industry Innovation Development Action Plan (2021-2025)", which seeks to couple of universities and energy industries in the area to build an "Energy Valley", for promoting world-class technology innovation for hydrogen energy technologies. Furthermore, it aims to develop a public service platform for the hydrogen energy industry and a platform for international exchange and cooperation on hydrogen energy (Government of Changping District, 2021). Even some smaller cities like Puyang, with a population of less than one million, has set a goal to reach an annual production capacity of 6,200 fuel cell drivetrains and 2,500 fuel cell vehicles by 2024. In addition, it aims to build 10 hydrogen refuelling stations, open 4 hydrogen fuel cell vehicle bus lines, and increase the share of hydrogen vehicles for commercial and public use to 80% (Puyang Daily News, 2022).

3.4 Comparison with hydrogen policies in major countries

The strategic goals of hydrogen policies and the technological routes chosen for its production vary in different countries, amongst others due to the level of infrastructure development, differences in renewable energy endowment, and the level of technological development in each country (Table 2). According to project pipeline data published by the IEA 2022, the US and the UK's early starter of hydrogen has shown its capacity holding the most hydrogen production projects among countries. Australia and China have an advantage in renewable energy hydrogen production projects, while the US and China lead in nuclear energy hydrogen production facilities (IEA, 2022).

The US was one of the first countries to adopt a hydrogen energy strategy, with the launch of the H2USA programme in 2013. The plan sought to develop a strategy for financing of hydrogen refuelling stations, network planning and market expansion, helping to establish the US as a world leader in hydrogen energy infrastructure (Chen & Chen, 2022). At the end of 2017, the Japanese government released the Basic Strategy for Hydrogen Energy, which set out a vision for Japan's future low-carbon energy society. The plan includes a headline target to reduce the production cost of hydrogen to US$3/kg, develop a commercial hydrogen supply capacity of 300 kt/year, and to build 900 hydrogen refuelling stations, all by 2030.

Overall, the ambition level of China's hydrogen policy seems limited, when assessed on the headline target of 100 to 200 kt of annual green hydrogen production capacity by 2025. A number of other countries have targets in the order of several Mt, though note that comparisons on an exact like-for-like basis are difficult. The EU has a target for 10 Mt of green hydrogen produced and a further 10 Mt imported by 2030. Chile has a production target of 1Mt of green hydrogen by 2027. Japan has a target of 3 Mt/y by 2030, of which at least 420 kt green hydrogen. The US, however, does not have an explicit green hydrogen goal.

China does have a reputation of setting and then over-achieving on moderately ambitious renewable energy targets. The existing pipeline of green hydrogen projects under construction does already exceed this production level, though this very strongly leans on a single 67 kt/y project in Inner Mongolia. The sum of sub-national plans as described in section 3.3 may very well help exceed national headline targets. China's hydrogen plans on the national level in particular stand out for their strong focus on the use of hydrogen in the transport sector, whereas the decarbonization of other industries including China's enormous steelmaking sector are mentioned mostly as medium to long term targets for decarbonization using hydrogen energy. Again, the consideration of nuclear energy as a route to low carbon hydrogen is also a unique feature of China's hydrogen plans.

Table 2. Hydrogen Energy Strategy comparison by country

Country	Documents	Main goals	Project pipeline
China	Medium and Long-term Plan for the Development of Hydrogen Energy Industry (2021-2035)	By 2025: 50,000 fuel cell vehicles, deploy hydrogen refuelling stations (HRSs), CO_2 emission reduction of 1-2 Mt/y, and green hydrogen production of 100-200 kt/y. By 2030, build a green hydrogen production and supply system to support carbon peaking target.	48 projects (1st one in 2015), 34 dedicated renewable and 3 nuclear electrolysis. Production capacity of 2,348 kt/y; of which 139 kt/y operational or under construction.
Australia	Australian Hydrogen Strategy	Become a top three exporter of hydrogen to the Asian market by 2030, and a global leader in hydrogen safety, hydrogen economy, and hydrogen certification. NSW: 20% of public heavy-duty vehicles to be hydrogen vehicles by 2030, have approximately 1800 hydrogen heavy-duty vehicles on the road by 2030, creating a hydrogen demand of 10 kt/y.	65 projects (1st one in 2013), 43 dedicated renewable electrolysis projects. 15.3 million. Production capacity of 11,992 kt/y; of which 12.7 kt/y operational or under construction.
Japan	Strategic Roadmap for Hydrogen and Fuel Cells (2014, 2016, 2019); Green Growth Strategy (2020, 2021)	By 2030, total hydrogen use reaches 3 Mt per year, of which 420 kt green hydrogen, 800,000 hydrogen fuel cell vehicles, 1,200 FC buses, 10,000 FC forklifts, 900 hydrogen refuelling stations, 3 million tons of ammonia fuel demand	28 projects (1st one in 2003), 5 dedicated renewable electrolysis projects Production capacity of 2.7 kt/y; of which 2.0 kt/y operational or under construction.
USA	H2 USA (2013); Comprehensive Energy Strategy (2014); Hydrogen Energy Program Development Plan 2021; Road Map to a US Hydrogen Economy (2021)	By 2025, total hydrogen demand reaches 13 Mt, 1000 HRSs, 150,000 light, medium and heavy duty FCVs in total, and 125,000 material handing FC forklifts on the road. California: 250,000 charging stations and 200 hydrogen stations in operation by 2025, and 5 million ZEVs, including BEVs and FCEVs, on the road by 2030.	74 projects (1st one in 1982), 19 dedicated renewable and 4 nuclear. Production capacity of 982 kt/y; of which 194 kt/y operational or under construction.
UK	UK Hydrogen Strategy 2021; Hydrogen Investment Roadmap 2022	Double its 5GW low-carbon hydrogen target to 10GW by 2030, with at least half of this production will come from electrolytic hydrogen.	74 projects (1st one in 2004), 19 dedicated renewable and 3 nuclear, Production capacity of 5,174 kt/y; of which 2.4 kt/y operational or under construction.
Germany	National Hydrogen Energy Strategy 2020	Increase renewable electrolyser capacity by 5 GW in 2030， 400 HRSs by 2023. At least 500 MW of electrolysis capacity in North Germany by 2025 and at least 5 GW of capacity by 2030.	10 projects (1st one in 2006), 3 dedicated renewable, Production capacity of 2,978 kt/y; of which 48.8 kt/y operational or under construction.

Note: the number in this table refers to projects all projects in any stage of planning, or 'operational, under construction, or FID' as included in the IEA project pipeline database (IEA, 2021). Sources: China (NDRC & NEA, 2022); Australia (COAG Energy Council Hydrogen Working Group, 2019); Japan (Nakano, 2021); United States (Road map to a US hydrogen economy, 2020); UK (UK Government, 2022); Others: (HyResource, 2022).

3.5 China's hydrogen market outlook

Globally, current hydrogen demand and production sits at roughly 90 Mt, predominantly produced with fossil fuels. Depending on the level of ambition, decarbonization plans could lead to a three to fivefold increase in production, with about half destined for use in industry and transport (Figure 6). Hydrogen use in gas-fired power plants and stationary fuel cells may help balance the increasing generation of variable renewables, allowing a larger share of solar PV and wind to provide seasonal energy storage. Together with an increased use of hydrogen in buildings, this could increase the flexibility of the grid, and help achieve a clean transition in the power sector (IEA, 2021).

China is already the world's largest producer and consumer of hydrogen, accounting for about 20% of global demand. In 2020, 63.5% of China's hydrogen supply came from coal gasification, 21.2% from industrial processes such as oil refining, 13.8% from natural gas, and only 1.5% from electrolysis, none of which is fully supplied by renewable energy-based electricity. The focus of China's hydrogen development plan is to shift to renewable energy-based hydrogen while increasing control over fossil fuel-based hydrogen. According to a conservative forecast by the China Hydrogen Energy Alliance in 2020, China's annual hydrogen demand will reach 37 Mt in the 2030 carbon peak scenario, representing about 5% of the end-use energy consumption demand, and 97 Mt by 2050, representing 18.3% of the IEA global net zero scenario hydrogen demand (Figure 6). In Tsinghua's 2022 ISCCD report, hydrogen may account for 15.6% end-use energy in the industrial sector, and 18% in the transport sector under 1.5 °C scenario by 2050, though the shares are much lower under a 2°C scenario (He, Li, & Zhang, 2021).

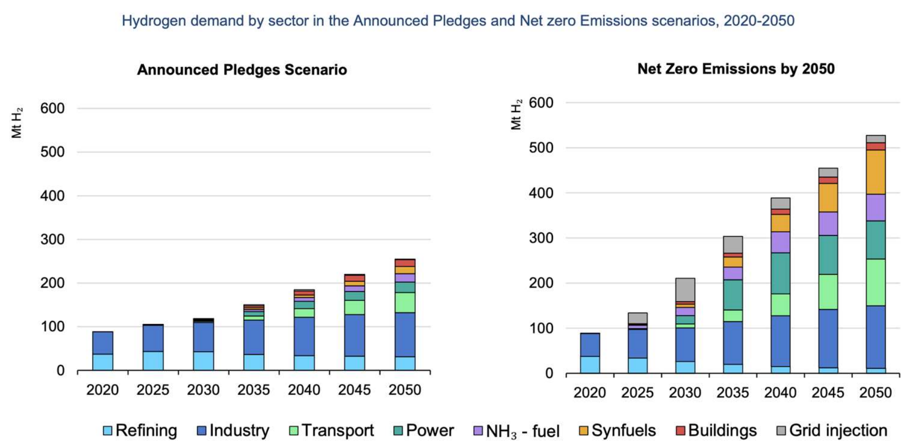

Figure 6. Global hydrogen demand by sector in the Announced Pledges and Net zero Emissions scenarios, 2020-2050 Mt. Source: (IEA, 2021)

Potential consumption in the steel industry, should China choose to make big strides towards hydrogen based steel making, would be enormous. Supposing a steel output of roughly 1,000 Mt (similar to current levels) and roughly half supplied from scrap steel, China would require about 500 Mt of primary steel from hydrogen direct reduction, which would consume roughly 25 Mt of hydrogen. This is also roughly total current production and consumption of conventional fossil-based hydrogen in China's ammonia, methanol and oil refining chemical industry (Zhou, Zhou, & Xu, 2022).

There are further technical and cost barriers to large-scale commercial application of hydrogen in China, as elsewhere. The recent net-zero target has not yet been translated into much concrete sectoral policy, and the industrial chain remains underdeveloped. In future scenarios with large-scale hydrogen consumption, storage and pipeline transportation will need to deal with "hydrogen embrittlement" of steel (Msheik, Rodat, & Abanades, 2021). Special materials such as Monel alloy that can be used for pipelines etc. are currently still very costly, with one estimate of about 5 million CNY/km of pipeline. NIST researchers calculate that, depending on pipe diameter and operating pressure, steel pipelines dedicated to hydrogen could cost 68%

more than natural gas pipelines (Fekete, Sowards, & Amaro, 2015). The price of fuel-cell vehicles is about 2-3 times higher than that of ICE vehicles and 1.5-2 times higher than that of battery electric vehicles, and the construction cost of refuelling infrastructure is also substantial, at about 12-15 million CNY for a hydrogen refuelling station (Zhang, Fan, Wu, & Zheng, 2022). From experience in demonstration projects such as the vehicle fleets used in the Winter Olympic Games, hydrogen fuel cell vehicles are still most suitable in the commercial vehicle segment, whilst costs for the passenger car segment remain largely prohibitive.

There are also reasons for optimism for China's domestic hydrogen market development. China has ample renewable energy potential to become a major producer of green hydrogen. China has a strong track record in green industrial policy, with good potential to drive expansion of the hydrogen industry in production, consumption, and manufacturing of equipment such as electrolysers and fuel cells. The increasing activity of major SOE in this industry space, including a healthy pipeline of green hydrogen production projects, also bodes well for future levels of industry development. The domestic carbon market, whilst still in early stages of development and covering only the electric power industry for now, can be expected to contribute to creating price differentials between fossil and renewable energy resources in a greater range of industries in the near future. This either could happen by including key industries such as steelmaking into this market, or through increased use of national certified voluntary emission reductions (CCERs), which key emitters may use to offset emissions up to 5% under current rules of the “Measures for the Administration of Carbon Emission Trading (Trial Implementation)”.

4. Relevance for Australia

IRENA estimates that more than 30 percent of the world's hydrogen could be traded across borders by 2050. Countries that have not traditionally traded energy are building bilateral energy relationships around hydrogen. Some countries that expect to become importers are already deploying dedicated hydrogen diplomacy, such as Japan and Germany (IRENA, 2022). Fossil fuel exporting countries are increasingly seeing clean hydrogen as an attractive way to diversify their economies. Australia is well placed to be a major producer of clean hydrogen both for domestic use and for export in various forms, and could become a key producer for export of hydrogen to Asian markets.

As the world's largest greenhouse gases emitter, China has demonstrated its support for building low-carbon development sectors such as hydrogen energy, and has shown interest in hydrogen trade. Although the current round-trip efficiency of hydrogen (electricity-hydrogen-electricity) is only about 30%, it has the advantage of transport flexibility because hydrogen can be shipped, either in liquefied form or converted to ammonia prior to transport. Green ammonia can be used directly to decarbonize the $50 billion per year global ammonia fertilizer market and can also be reconverted to hydrogen in the end-use market. Australia has the second largest pipeline of announced green hydrogen projects in the world, and has strong potential to become an exporter of zero-carbon hydrogen energy and derived commodities (Burke et al., 2022).

When considering the size of China's potential demand for green hydrogen, given its net-zero commitments and limited current domestic hydrogen production targets, the potential for exports of green hydrogen to China, and for derived products such as green ammonia, fertilizer, and green iron or steel, would seem enormous. There are however, also reasons to believe China's strategy will not be to position itself as a major importer. First, expectations are that China will overachieve on its existing unambitious hydrogen production target. Second, the recent experience with volatile prices in international energy markets has seen a strong resurgence of commitment to energy security in China's top-level energy and climate policy documents. This has been targeted primarily import dependency levels of coal and fossil gas, but it should not be expected that China would be willing to become highly dependent on foreign sources of hydrogen energy.

Trade in green hydrogen depends on the initial willingness of importers to pay a premium, justified by the ability of importing countries to avoid local pollution costs and make progress towards their GHG reduction targets by importing such products. Carbon pricing and emissions regulations provide a direct incentive to pay this premium. China has implemented a national carbon market in 2021, which may trigger carbon border adjustments for regions that have not yet implemented a carbon tax or an emission trading system to ensure incentives for exporters to pursue zero-carbon processes, and the EU has adopted a carbon border adjustment mechanism scheduled for implementation in 2026 (Qi, Xu, & Yang, 2022). On the other hand, the GHG emissions from different hydrogen production processes are not easily and directly verifiable, and the resulting information asymmetry between buyers and sellers is a market failure reducing efficiency, which will hinder domestic and international trade and will discourage jurisdictions wishing to limit imports of high-embedded emissions products. A reliable, internationally recognized accounting of carbon emissions associated with hydrogen in the marketplace is needed to correct this market asymmetry (White et al., 2021).

In summary, Australia has very good prospects to become a large hydrogen producer and exporter, however it is unclear to what extent China might be an importer of hydrogen.

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