Hydrogen Factsheet - China

Prepared by

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Table of Contents

Summary Table

Political and economic environment	
Main export partners[1]	• USA (17.4%) • EU (15,1%) • Japan (5.5%)
Main export goods[2]	• Broadcasting equipment ($208B) • Computers ($141B) • Integrated circuits ($108B)
Most relevant free trade agreements with	• ASEAN • Australia • EU • Korea • New Zealand • Pakistan
Socio economics	• Unemployment rate: 5%[3] • Poverty rate: 0.6%[4] • GINI index: 38.5%[5]
Hydrogen strategy and economy	
Current annual hydrogen production (by source)	33 MT (62% coal gasification, 19% steam methane reforming (SMR), 18% as a by-product of industrial processes, 1% electrolysis)[6]
Largest hydrogen consumers (by sector/industry)	• Ammonia production (10 MT) • Methanol production (8 MT) • Refining (4,5 MT)[7]
Existing hydrogen strategy	No long-term mid-century national hydrogen strategy, but a 2021-2035 hydrogen development plan has been released in March 2022
Existing hydrogen production projects (incl. blue hydrogen) [8]	9 operational projects (6 small/medium electorlyser plants (in total circa 20 MW) with dedicated renewables; 2 coal with CCUS plants; and 1 oil with CCUS plant (for chemical industry)
Planned hydrogen production projects [up to 2030 [9] (incl. blue hydrogen)	53 announced projects (7 large scale industrial usage,3 integrated hydrogen economy, 28 Transport, 4 infrasture projects, 9 production projects without announced end use)
Hydrogen policy and strategy	High momentum for hydrogen with the 14th Five Year Plan and carbon peaking and neutrality policy framework released, defining it as one of the key strategic sectors. Hydrogen is mentioned as a key strategic sector in most high-level documents related to the 14th Five-Year Plan (2021-2025) and China's pathway to carbon peaking and neutrality. Most recently, China released a 2021-2035 hydrogen development plan, with the following targets:

[1] European Commission 2021
[2] OEC 2021.
[3] World Bank 2021e.
[4] World Bank 2021c.
[5] World Population Review 2021.
[6] IFRI 2020; Carbon Pulse 2021; Carbon Brief 2021.
[7] IFRI 2020.
[8] IEA 2021c.
[9] Hydrogen Council 2021.

<table>
<tr><td></td><td>• By 2025, to produce 100,000-200,000 tons of renewable hydrogen annually and achieve about 50,000 fuel cell vehicles;
• By 2030, to form a more complete hydrogen technology innovation system, renewable hydrogen production and supply system, and to achieve wide usage of renewable energy hydrogen production;
• By 2035, to establish a comprehensive hydrogen industry spanning transportation, energy storage and industrial sectors and significantly improve the portion of renewable hydrogen in the energy consumption
A detailed definition of “renewable hydrogen” was not published yet.
Many regional governments have also set up their own hydrogen strategies and development plans (details see Chapter 5.2).</td></tr>
<tr><td>Support schemes or funding facilities for clean hydrogen</td><td>• Public funding for R&D from central government (details see Chapter 5.1)
• Local government subsidies especially related to fuel cells</td></tr>
<tr><td>Potential branches for domestic hydrogen demand</td><td>• Transport (fuel cell passenger vehicles, busses, trucks, , ships, aviation)
• Stationary fuel cells (as backup power)
• Energy storage
• Industry decarbonization (especially steel and chemical industries)
• Power generation</td></tr>
<tr><td>Exporting potential in strategy [TWh per year]</td><td>As of now, China does not plan to export H_2 (according to the official policy documents published until April 2022).</td></tr>
<tr><td>Main hydrogen production technology in focus</td><td>Currently, China produces mainly grey hydrogen. In the future, more focus will also be given to “renewable hydrogen”, while a diversification strategy is expected to be adopted.</td></tr>
<tr><td>Primary focus with regards to the international level</td><td>The recently published 2021-2035 hydrogen development plan states that international cooperation on hydrogen technology development, supply chain buildup, and standardization activities is planned.</td></tr>
<tr><td>Estimated costs of hydrogen production [LCOH in USD/kgH2] [10]</td><td><table><tr><td>Year</td><td>2020</td><td>2030</td><td>2040</td><td>2050</td></tr><tr><td>baseline</td><td>2.9 - 4.5</td><td>2.1 - 3.4</td><td>1.8 - 2.9</td><td>1.6 - 2.6</td></tr><tr><td>optimistic</td><td>2.2 - 3.2</td><td>1.8 - 2.9</td><td>1.4 - 2.4</td><td>1.0 - 2.0</td></tr></table></td></tr>
<tr><td colspan="2">Main sustainability challenges</td></tr>
<tr><td>Water stress level</td><td>China’s economic centers suffer from water scarcity. Renewable H_2 needs to be imported from southwestern and northern regions with abundant renewable and water resources. This requires large infrastructure investments.</td></tr>
<tr><td>Existing energy system & decarbonisation strategy</td><td>2019[11]</td></tr>
<tr><td>Total gross electricity production [TWh]</td><td>7504</td></tr>
<tr><td>RES share in electricity generation [%]</td><td>27%</td></tr>
</table>

[10] Data based on Brändle et. al. 2020 (EWI H2-Tool): low temperature electrolysis.
[11] IEA 2021b.

CO_2 intensity of electricity generation [gCO_2/kWh]	672
Largest fossil fuel-based electricity generation (share in total generation)]	Coal: 65%
CO_2 emissions from electricity production [$MtCO_2$]	5238
Goals decarbonisation for 2060 (NDC discussion)	Dual climate goals: Emissions peaking in 2030 and carbon neutrality in 2060

Opportunities for cooperation and trade on hydrogen between China and the EU

Table 1: Strengths and weaknesses (as a partner for EU)

Strengths	Weaknesses
Common interest in research and development collaboration	No opportunity for hydrogen trade with the EU due to high domestic energy and hydrogen demand
Opportunity to set common hydrogen standards	Long distance for potential seaborne transport (compared to e.g., MENA region)
Strong domestic government targets for renewables	No existing long-term hydrogen strategy
Chinese ability to make rapid cost reductions	
Potential opportunity of joint projects in third countries	

Source: own

Table 2: Convergence & Divergence with EU strategy

Convergence	Divergence
Strong interest in hydrogen development and existence of mid-term plan	No national mid-century hydrogen strategy
High ambitions for climate change mitigation	China highlights the diversificaiton of hydrogen usage across many sectors while the EU focuses on the industrial and heavy transport sectors
Mutual interest in developing green hydrogen	Strong focus on grey hydrogen in current capacity buildup; ‘all-in’ approach for future development, rather than focusing on green hydrogen
	No sustainability criteria for hydrogen yet

Source: own

Executive Summary

China is the largest producer and consumer of hydrogen in the world. Since 2010, China has increased its hydrogen production by 6.8% per year to reach 33 million tons in 2020. Today, hydrogen produced by coal gasification makes up more than 60% of the supply, hydrogen produced from SMR represents 20% of the supply, 18% as a by-product of industrial processes, while less than 1% is “green”. In Chinese, hydrogen produced from fossil fuels, including from coal, is referred to as grey hydrogen (“灰氢 “).

Hydrogen has been integrated into a number of top-level national energy and technology development strategies, a process which has gathered speed since 2020. In March 2022, China’s top economic planner released a hydrogen development plan for the 2021-2035 period, futher advancing the hydrogen momentum in China. The central government’s R&D program is a key funding scheme for hydrogen technology. The National Key Research and Development Program managed by the Ministry of of Science and Technology has a dedicated funding stream for accelerating renewable energy and hydrogen energy technology. In the future, central government plans to strengthen the financial support including via central budget investment. In addition, many regional governments have set up their own hydrogen strategies with local subsidy provisions. To date, hydrogen in China is mainly used as industrial feedstock to produce ammonia, methanol, and for petroleum refining. Government strategies aim to expand the use of hydrogen to the light and heavy duty transport sector, amongst others, by supporting the uptake of hydrogen fuel cell vehicles, primarily subsidizing the producers. The 2022 Winter Olympics in Beijing were presented as symbolic of China’s hydrogen technology readiness, with up to 1000 buses powered by domestically made hydrogen fuel cells deployed for the event.

Until recently, the shift from grey to green hydrogen has not been at the center of China’s energy agenda. This changed with President Xi Jinping's announcement on 22 September 2020 that China would peak its emissions by 2030 and reach carbon neutrality by 2060 and develop a 1+N framework to support achieving them. The transition to green and blue hydrogen production has since been high on China’s policy agenda. Several green hydrogen projects are currently being developed, in particular in Inner Mongolia and Xinjiang, supported by major state-owned energy enterprises such as Sinopec. In the newly released 2021-2035 hydrogen plan, China aims to produce 0.1-0.2 MT green hydrogen annually by 2025 and to significantly improve the portion of green hydrogen in its energy consumption by 2025. Blue hydrogen techonologies, i.e., fossil-based hydrogen production with CCUS, are still in the early stages of development, but are expected to mature by 2030 and play an important role in China's path to carbon neutrality.

According to the IEA’s Energy Sector Roadmap to Carbon Neutrality in China published in 2021, hydrogen will play a growing role in China’s energy transition between 2021 and 2060, with a sharp increase after 2030. By 2060, hydrogen demand could increase to 90 Mt. China sees a broad application of hydrogen across different sectors such as the light and heavy transport, industry, power generation and electricity storage .

Given China’s vast domestic energy demand, the constraints to long-distance transport of hydrogen, and the sheer distance between the EU and China, the opportunities for establishing trade connections in hydrogen between the two economies are limited. However, other opportunities for collaboration exist, such as in R&D, standard-setting, trade of low-carbon hydrogen technology and equipment and joint projects in third countries. Such engagements would help accelerate the transition to green hydrogen in both regions and facilitate alignment on sustainability criteria.

Detailed country analysis

1 Political system & economy

1.1 Political system

As one of the world's most populated countries and second largest economy, China's current political system and governance structure has evolved since the founding of the People's Repubic of China in 1949. It is is a one-party unitary state, governed by the Communist Party of China (CPC), with the system of so-called multiparty cooperation and political consultation under its leadership.

Regarding energy governance, the development of China's strategic energy policy has been highly centralized, but its formulation engages a broad spectrum of actors. Various ministries and departments take on roles at key stages. The result is that energy governance is becoming increasingly fragmented. Central-provincial political dynamics have also shaped the energy policy process and its outcomes (KAPSARC 2019).

1.2 Economy and Trade connections

With 14.7 trillion USD in 2020, China has the second highest nominal GDP in the world, behind the US with 20.9 trillion USD (World Bank 2021a). Since introducing its economic reform and opening up in 1978, China's GDP growth has averaged almost 10 % a year, though this has slowed in the last decade to 6-8% (U.S. Energy Information Administration 2020; National Bureau of Statistics of China 2021). The 2020 COVID-19 pandemic and resulting economic effects have adversely affected China's economic activity, pushing GDP growth down to 2.3% that year (World Bank 2021b). In 2021, China's growth rate has significantly increased and reached of 8,1% (Reuters 2022).

China's largest export partners in 2019 were the United States (17%), the European Union (15%), and Japan (6%), The main export products were broadcasting equipment, computers and integrated circuits, (CIA 2021). The biggest import partners were the EU27 (12.6%), Japan (8.5%), and South Korea (8.4%), and the most important import products were crude petroleum, integrated circuits, iron, natural gas, cars, and gold (CIA 2021; European Commission 2021).

China's strong growth, built on resource-intensive manufacturing, exports and low-wage labor, has reached its limits to a large extent and has resulted in economic, social and environmental imbalances (World Bank 2021d). This economic model and the corresponding levels of input energy also led the country to become one the world's largest energy importers. In this regard, energy security has been on top of the country's agenda – more recently this has been further strengthened given the domestic power shortages in the second half 2021, rising energy prices globally, and geopolitical developments. It is being addressed through the diversification of energy sources, and building it into a global energy supply chain system by importing energy sources from other countries. China's strategy to address the dual challenge of maintaining energy security while meeting environmental objectives involves the development of a robust hydrogen strategy (see chapter 5.1).

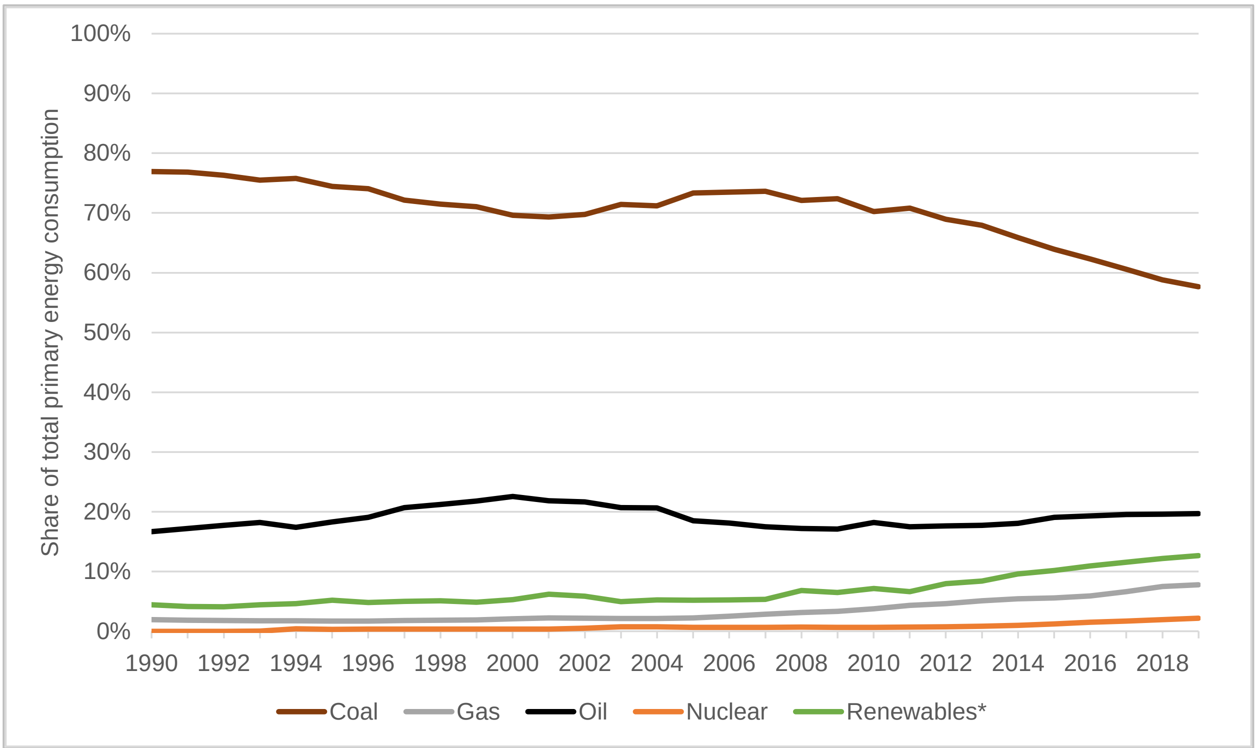
2 Energy and Electricity

2.1 Demand, production, and capacity factors

2.1.1 Primary energy sources

China accounted for 26% of global primary energy consumption in 2020, more than 2.5 times the share of the EU (BP 2021). Its total primary energy supply (TPES) has tripled since 2000, reaching 3.2 gigatonnes of oil equivalent (Gtoe) in 2018. Per capita levels more than doubled over 2000-2018 to 2.3 toe — surpassing the world average on a path of convergence with levels seen in the EU whose per capita supply decreased to 3.1 ktoe the same year (IEA 2021b). Coal is the dominant fuel source in China making up 62% of total energy supply, followed by oil (19%), natural gas (7%), biofuels and waste (4%), hydropower (3%), variable renewables (3%), and nuclear energy (2%) (IEA 2021b).

Figure 1: China's total energy supply (TES) by source, 1990-2019



* Renewables include Solar, Hydro, Wind, Geothermal, Biomass and Biofuels

Source: Own illustration based on (BP 2021); IEA 2021b)

2.1.1.1. Coal

China is the world's largest producer of coal with a global market share of 50.7% in 2020. Despite being the dominant market player, its production capacity mostly serves to meet domestic energy needs. It has over 143 billion tonnes in reserves[12] (13% of global proven reserves), the majority anthracite and bituminous coal, which are projected to last 37 years at current production levels. China's heavy reliance

[12] Definition: Reserves = Proven volumes of energy commodities economically exploitable at today's prices and using today's technology. Resources = Proven amounts of energy resources which cannot currently be exploited for technical and/or economic reasons, as well as unproven but geologically possible energy resources which may be exploitable in future.

on coal has rendered it the number one consumer (82.3 EJ out of the 151.4 EJ world total, or 54%, in 2020) and biggest import market (20.8% of total imports) (BP 2021).

Its steadfast position as global coal leader stands in contrast to recent trends: amidst a historic drop in global coal demand during 2019-2020, China was one of the few countries to record an increase in coal consumption, fuelled by energy demand from power generation and industry (BP 2021; IEA 2020). Current market predictions yield that China's coal demand would level off around 2025, a necessary trend to meet the NDC target of peaking overall emissions before 2030 (IEA 2020). Domestic financial institutions by and large finance China's coal sector with overseas investors accounting for one-tenth of the total (China Dialogue 2021).

2.1.1.2. Oil

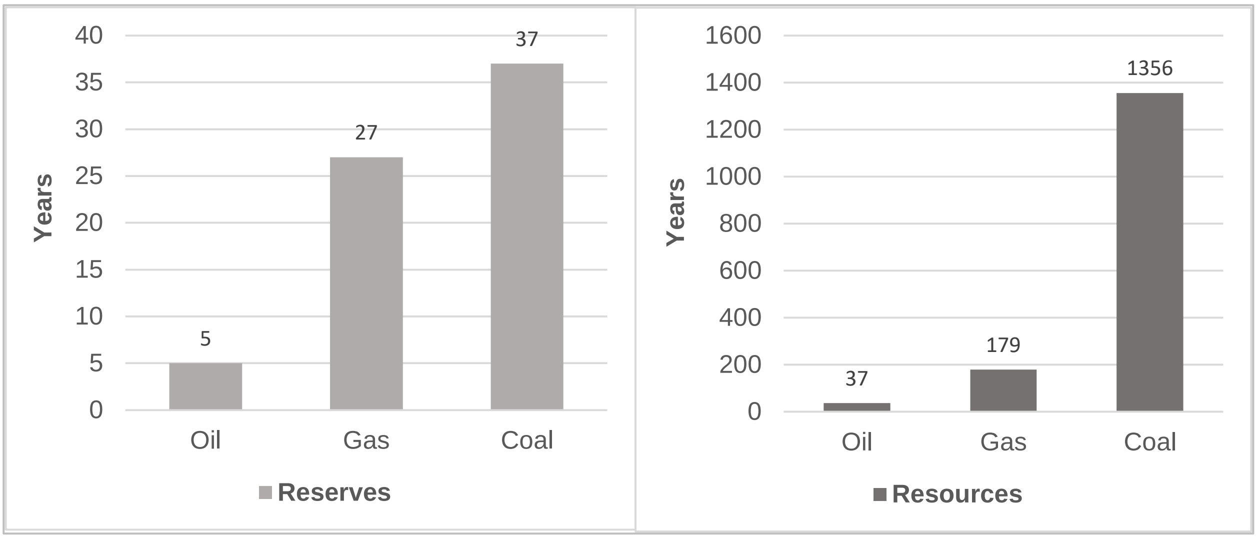
Crude oil is the second primary energy source for the Chinese economy. China is a relatively small player in oil production, extracting 3.9 million barrels per day on average in 2020, or 4.4% of world production in that year.[13] With proved reserves amounting to 26 billion barrels towards the end of 2020, its reserves-to-production ratio is about 18 years. Concurrently, China consumed more oil in 2020 than any other country except for the US. At 14.2 million barrels per day (16% of the world total), China's oil consumption was more than triple its domestic production level signifying the country's high import dependency. China became the largest net importer of oil in 2016, and has since outpaced import demand of the other major economies (Enerdata 2021). Saudi Arabia and Russia were its single largest suppliers in 2020, with China's imports overall being diversified across key export regions such as the Americas, the Middle East and West Africa (BP 2021). The country's oil demand would have to peak before 2030 to remain in line with NDC targets. An influential report coordinated by the Natural Resources Defense Council (NRDC) and Energy Foundation (EF) China released in 2019 projects that target to be reached by 2025 if a concrete set of energy-saving and transition measures are implemented across the demand sectors (transportation, petrochemicals, and other) (NRDC and EF China 2019). However, current market trends do not point in that direction. In 2020, China was the only economy to post an increase in oil consumption (1.6%) while it is projected to lead global demand growth towards 2026 along with India and other Asian economies (IEA 2021d).

2.1.1.3. Natural gas

Natural gas in China has evolved from a marginal fuel to the fastest growing hydrocarbon source in the economy. While accounting for roughly 7% of TPES in 2018, it is set to play an increasingly prominent role by replacing coal in heat and electricity production and heavy industry as the government seeks to peak emissions before 2030. China produced about 5% of the world's gas supplies in 2020, its production levels having doubled over the preceding decade to 194 billion cubic metres that year. China's proven natural gas reserves totalled 8.4 trillion cubic meters at the end of 2020, which would last 43 years at current production levels. These metrics are far from static however, with proven reserves having increased by factor 6 since 2000 (BP 2021), while domestic production is expected to be ramped up in the years ahead to meet increasing domestic demand. Gas demand in China more than tripled between 2010-2020. It reached 330.6 billion cubic metres in 2020, leaving a shortfall in domestic production of 41% met through imports, the majority of which in the form of LNG. Australia supplied nearly half of China's LNG imports in 2020, followed by Qatar, the US, and Indonesia (BP 2021). Wood MacKenzie forecasts China's current gas demand to double towards 2050, with the largest increases coming about before 2030 (Wood Mackenzie 2021).

[13] Including shale oil, oil sands, and condensates.

Figure 2: Fossil fuel reserves and resources in China



Data source: IEA 2021b

2.1.1.3. Uranium

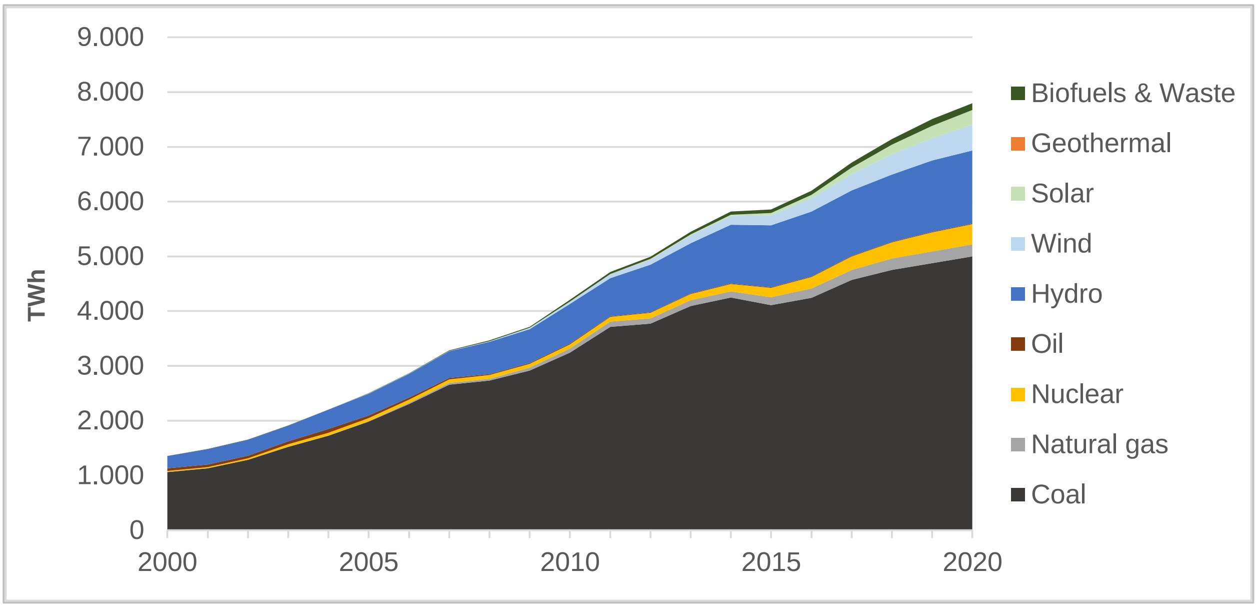
China produced roughly 1,885 tonnes of uranium in 2020, up from 885 in 2011 and just below 4% of the world total (World Nuclear Association 2021b). On par with China's growing nuclear power fleet, one of the world's largest, uranium consumption is expected to rise from 11 thousand tonnes in 2021 to about 24 thousand tonnes by the end of the decade. The government aspires to reach self-sufficiency in the entire fuel cycle and has stated the near-term objectives to increase domestic production to one-third of its annual consumption, import one-third through foreign direct investments (FDI) and joint ventures overseas, and procure the remaining one-third on the market (World Nuclear Association 2021a).

2.1.2 Electricity

Electricity *consumption* in China has risen drastically since the turn of the century, mostly driven by massive increases in industry demand. Overall consumption reached 7,154 TWh in 2019 representing a near sixfold increase since 2000, and twice the consumption level of the EU-28 in 2019 (2,930 TWh) (IEA 2021b). Electricity consumption per capita rose from 1.0 MWh/cap to 5.1 MWh/cap during this period, and may soon surpass the EU average of 5.9 MWh/cap. Looking ahead, electricity demand is expected to reach 10,000-12,000 TWh by 2030 (Cao et al. 2021). This translates into a compound annual growth rate (CAGR) of 3.1% to 4.8% per annum.

Electricity *generation* quadrupled during 2000-2019, increasing from 1,356 TWh to 7,798 TWh. Coal has been the dominant fuel for power generation in China with a fivefold increase in output over the past two decades to reach 5,001 TWh in 2019. This corresponds to an overall generation share of 64%, down from 78% in 2000. While the output from coal-fired power plants has dwarfed other generation sources, the largest growth came from solar PV, wind power, biofuels, natural gas, and nuclear, in that order. Total emissions from heat and power generation amounted to 5,238 $MtCO_2$ in 2019 (IEA 2021b), translating into an average electricity emissions intensity of 672 gCO_2/kWh (EU average: 255 gCO_2/kWh) (EEA 2021).

Figure 3. Electricity generation in China by source, 2000-2020



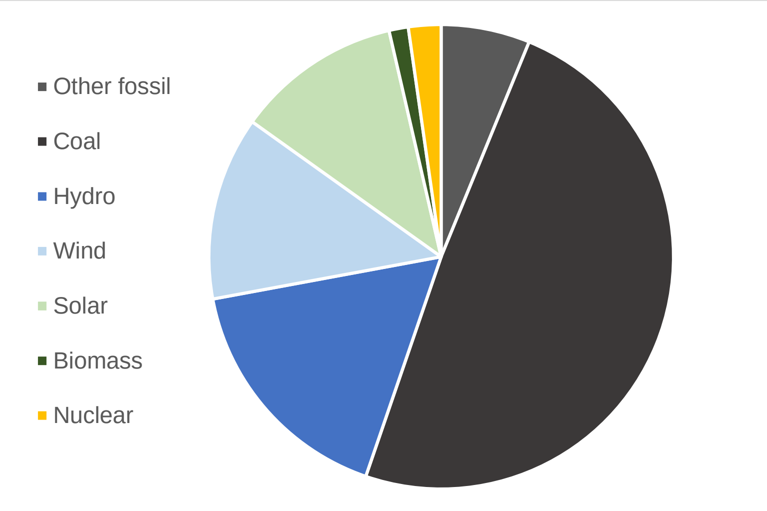
Data source: IEA 2021b

Table 3. Installed generation capacity in China (GW)

	2018	*Share*	2019	*Share*	2020	*Share*
Coal	1,008.4	53.1%	1,040.6	51.8%	1,080.0	49.1%
Other fossil	116.30	6,1%	125.80	6.3%	136.10	6.2%
Hydro	352.6	18.6%	358.0	17.8%	370.2	16.8%
Wind	184.3	9.7%	209.2	10.4%	281.5	12.8%
Solar	174.3	9.2%	204.2	10.2%	253.4	11.5%
Biomass	19.5	1.0%	23.6	1.2%	29.5	1.3%
Nuclear	44.7	2.4%	48.7	2.4%	49.9	2.3%
Total	**1,900.1**		**2,010.1**		**2,200.6**	

Source: China Electricity Council, China National Energy Administration in REF (Argus 2021)

Figure 4. China's generation capacity mix by source (2020)



Source: China Electricity Council, China National Energy Administration in REF (Argus 2021)

China operates the world's largest coal fleet good for half of the global total. Domestically, coal plants account for about half of installed generation capacity, a share which has gradually declined despite substantial net capacity additions. China decommissioned 51 GW of its coal power capacity during 2015-2020 (Global Energy Monitor 2021). On balance, it commissioned 72 GW during 2018-2020 (Table 3), which is roughly equal in size to the coal fleets of South Africa and South Korea combined. Another 159 GW of coal-fired generation capacity was in the pre-construction phase in 2020 (Global Energy Monitor et al. 2021). According to the 14th FYP, coal power is expected to peak by 2025 and decline thereafter. The positioning of coal in the power system will also change from being baseload to providing flexibility and ensuring energy security.

2.2 Imports and exports

China became a net importer of energy in 1993. It has since become the largest energy import market after the EU, and is the largest importer of coal and oil with gross totals of 6.8 TJ and 22.7 million EJ respectively in 2019 (IEA 2021b). In that year, the Chinese economy depended on imports for 27% of its coal consumption, 56% of its natural gas consumption, and 93% of its oil consumption.[14] The government has set maxima on import dependencies for primary energy resources, but domestic production has not kept up with demand. Given continued energy demand growth and limited availability of domestic energy resources, China's import dependency will likely increase further in the coming years until peak emission levels are reached. In response, China has built up its strategic reserves over the past decades, strengthened ties with major exporters, and ventured into new markets through FDIs implemented by its state-owned energy companies. The dependence on natural gas in particular is set to become greater as industry demand increases with the gradual transition away from coal.

Cross-border electricity trade to and from China has increased over the past decades, but remains small compared to the size of the domestic market. Mainland China is a net exporter of electricity. Forecasts

The government of China announced new climate targets in 2020. The country is to peak CO_2 emissions by the end of the decade, and reach carbon neutrality by 2060, to be driven by a range of sub-targets and policies across all energy sectors.

[14] Based on Import/export, and consumption data from IEA 2021b.

The IEA has modelled a pathway for the energy sector to reach these targets (IEA 2021a). In this carbon-neutrality scenario, primary energy demand peaks at 173 EJ towards the end of the decade (up from 147 EJ in 2020) and decreases to 129 EJ by 2060. The share of non-fossil energies increases from 15% in 2020, to 23% in 2030, and 74% by 2060. The share of renewables in total primary energy demand surges from 12% in 2020 to 60% by 2060. Over the same timeframe, the share of nuclear power output increases fivefold from 3% to 15%. Coal consumption drops by more than 80% and the emissions of the remaining coal-fired power plants are captured and stored. Demand for natural gas rises modestly and declines after having peaked around 2035, its role largely reserved for flexible power supply alongside battery and hydrogen storage. Hydrogen becomes a critical clean fuel for transport and heavy industry alongside significant improvements in energy and material efficiency, and far reaching electrification across the demand sectors. Overall, energy demand drops by 26% compared to peak levels, while economic activity more than doubles resulting in a 75% drop in primary energy intensity.

3 Decarbonization and renewable energy support

3.1 Decarbonization goals (including RES targets)

China is the world's largest energy consumer and carbon dioxide emitter in absolute terms, accounting **for 26% of global GHG emissions in 2018** (World Resources Institute 2020). Thus, reaching the objective of the Paris Agreement to keep the increase of global warming to "well below" 2 degrees – or even 1.5 degrees – will largely depend on the success of China's decarbonization strategy.

In September 2020, before the United Nations General Assembly, China's President Xi Jinping pledged to accelerate China's decarbonization trajectory, to **peak emissions by 2030 and reach carbon neutrality before 2060**. In December 2020, at the Climate Ambition Summit, Xi Jinping further announced an increased emissions intensity target for 2030 (**reduction of CO_2 emissions per unit of GDP by over 65%** from the 2005 level compared to the previously announced 60-65%). Additionally, the government pledged that it will increase the share of non-fossil fuels in primary energy consumption to around 25% and bring its total installed capacity of wind and solar power to over 1,200 gigawatts by 2030 (Ministry of Foreign Affairs of China 2020). Following these annoucments, on 28 October 2021, China submitted its **updated nationally determined contributions** (NDC) and its **Mid-Century Long-Term Low Greenhouse Gas Emission Development Strategy** to the UNFCCC, which reaffirmed the key targets.

These targets are firmly embedded in the domestic policy framework of China. In March 2021, China published its **14th Five-Year Plan Period** (FYP) covering the period between 2021 to 2025 in which it set a binding 18% reduction objective for emissions intensity of GDP and 13.5% reduction objective for energy intensity (Carbon Brief 2021).

On 24 October 2021, the CPC and the State Council (the chief administrative authority of China) published a guideline specifying its goal of peaking its emissions by 2030 and achieving carbon neutrality by 2060 - providing highest level political support for the deep decarbonization process domestically. Beside reaffirming the 2030 targets announced previously, it calls for an increase in the use of non-fossil fuels to over 80% of total energy consumption by 2060 To achieve this roadmap, the government is in the process of developing sector-specific peaking plans such as for coal-fired power generation, iron and steel, electrolytic aluminum, cement, and petroleum chemistry (Central Committee of the Communist Party of China and State Council 2021). Two days later, the State Council released the "**Action Plan for Peak Carbon by 2030**", which outlines key tasks in ten areas and 43 points for achieving carbon peaking by 2030 covering electricity, industry, building, transport, circular economy, carbon sinks, etc. **Figure 5** below summarizes China's key mitigation targets.

Figure 5: Ovierview of the key mitigation targets of China for 2025, 2030 and 2060

	2025	2030	2060
Overarching		Carbon peaking	Carbon neutrality
Coal	*Peaking*		
Carbon intensiy	- 18% from 2020 level (energy intensiy -13.5%)	- Over 65% from 2005 level	
Non fossil fuels in total energy consumption	c.a. 20%	c.a. 25%	Increase to 80% (fully establish a clean, low-carbon, safe and efficient energy system)
Solar and wind installed capacity		Over 1200 Gigawatts	
Forest (coverage rate)	18 bllion m³ (24.1%)	19 billion m³ (25%)	

Source: Own illustration based on the policy documents mentioned in this chapter.

Besides the domentic climate mitigation targets, China has also recently shifted its stance regarding financing overseas coal projects. In September 2021 at the 76th UN General Assembly, President Xi Jinping promised to halt overseas coal investments (Zack Colmann 2021).

3.2 RES support schemes

China's renewable energy **support schemes** have undergone a rapid and complex restructuring in the past two years.

Since 2009, China has gradually introduced **feed-in tariff (FIT)** mechanisms for onshore wind (2009), solar PV (2011), distributed solar (2013) and offshore wind (2014). Until 2019, renewable projects enjoyed a fixed 20-year FIT (Yuki 2020).

In 2019, China kicked off a renewable subsidy reshuffle which significantly **reduced state subsidies** for renewable energies. Between 2019 and 2021, renewable energy projects have received increasingly less public support as they start to compete with coal-fired plants and achieve grid price parity. In January 2020, the Ministry of Finance (MoF), the National Development and Reform Commission (NDRC), and the National Energy Administration (NEA) specified the new support schemes for renewable energies. **Offshore wind and solar photovoltaic** projects approved before 2019 are still eligible for the national subsidy if "all their units" can be connected to the grid by the end of 2021. For these projects, the renewable energy project grants will be paid out annually; an annual limit will be set for the total grant payment. The grid companies are now responsible for selecting and registering projects eligible for the national subsidy (Yuki 2020).

As of August 2021, China no longer provides subsidies for new solar power plants, solar projects distributed by commercial users or onshore wind projects from the central government budget (Reuters 2021b). A support measure in the form of green certificates and additional trading measures has been put in place to help renewable energy producers increase their revenues (Yuki 2020).

Following these reforms, subsidies to wind farm operators have been reduced by 24.3% to 2.31 billion yuan (CNY) in 2021 and subsidies to biomass generators have been reduced by 18.5% to 59.78 million CNY (Reuters 2021c).

4 The existing hydrogen economy

4.1 Current hydrogen demand and production (ammonia, refinery)

China is the largest producer and consumer of hydrogen in the world, which is currently dominated by hydrogen from coal gasification (IFRI 2020). Its hydrogen production increased by 6.8% annually since 2010 and **reached 33 Mt in 2020** (Carbon Pulse 2021) . In 2020, about 62% of the hydrogen produced in China came from coal, 19% from natural gas, 1% from electrolyzers, and the remaining share from by-products of industrial processes (Carbon Pulse 2021). China has nearly 1,000 coal gasifiers in operation, accounting for 5% of the country's total coal consumption (Cleantech group 2019).

Over **90% of hydrogen is currently used as industrial feedstock** to produce ammonia, methanol and for petroleum refining (Carbon Pulse 2021).

Ammonia synthesis is the largest source of hydrogen consumption in China, with a domestic production of 57,6 Mt in 2019 and a hydrogen consumption of over 10 Mt. In contrast to the rest of the world where steam methane reforming (SMR) is the main route for ammonia production, the most common feedstock in China is coal, via a partial oxidation process. About 76.7% of China's ammonia production comes from coal, 20.8% from natural gas, 2.1% from coke oven gas and 0.5% from other sources (IFRI 2020).

Methanol synthesis is the second largest source of hydrogen consumption. In 2019, China produced 62.2 million tons of methanol which implied an annual hydrogen consumption of about 8 million tons. Around 76% of the domestic methanol production is derived from coal, 17% from coke oven gas and 7% from natural gas (IFRI 2020).

Petroleum refining is also a major source of hydrogen consumption, amounting to approximately 4.5 Mt in 2019 (IFRI 2020).

Although China is showing a growing interest in the development of hydrogen in the **transport sector**, it represents only a small share of today's hydrogen demand (IEA 2021a).

4.2 Stakeholders

The stakeholders involved in the development of hydrogen in China can be divided into four main groups.

Tier 1 institutions provide political guidance and strategic direction. At the highest political level, the Communist Party of China (CPC) — together with its Politburo Standing Committee (PSC) — is the country's highest political decision-making body. Its informal bodies, so-called **Leading Groups/Commissions,** provide assistance on policy development and cross agency implementation. Amongst these are several powerful commissions such as the Central Comprehensively Deepening Reforms Commission and Central Foreign Affairs Commission who influence energy policy. In this respect, the **National Energy Commission (NEC)** is especially relevant. The NEC is responsible for drafting the national energy development strategy, discussing energy security related issues and potential policy responses, and coordinating national energy development and international cooperation. The National People's Congress (NPC), a supreme legislative body, enacts laws and regulations and reviews and approves the government's budget and annual work report. Every five years, the NPC, together with Chinese People's Political Consultative Conference (CPPCC) also reviews and approves the country's top level economic and social development -the Five Year Plans.

Tier 2 institutions are responsible for the development of specific policies at central and local government levels. At the central government level, the commissions and ministries under the State Council are located in separate chains of authority. The National Development and Reform Commission (NDRC) and the National Energy Administration (NEA) under it manage the majority of energy issues, for example, investment approval, pricing, market supervision and market reform (KAPSARC 2019). Besides the NDRC and NEA, the Ministry of Science and Technology (MOST), the Ministry of Industry and Information Technology (MIIT), the Ministry of Finance (MoF), and the Ministry of Transport (MOT) are also heavily involved in hydrogen. Table 4 provides an overview of their roles.

Table 4: List of key central government ministries and their roles

Key Stakeholder	Role
NDRC	Most powerful ministry with broad mandate on economic planning, permitting and pricing; supervising NEA
NEA	Deputy ministerial agency under NDRC in charge of energy sector development
MOST	Funding R&D of technology innovations in China
MIIT	Industrial sector planning, promote innovation of key industry equipment
MoF	State subsidies
MOT	Planning, regulation and enforcement of transport, especially road and waterway

Source: IFRI 2020

It is worth noting that China's government administration just went through a major reorganization in 2018 – reducing the number of ministries from 34 to 26. Newly created are the Ministry of Ecology and Environment (MEE) replacing the previous Ministry of Environmental Protection (MEP) and taking over several mandates from others including climate change from the NDRC. The Ministry of Natural Resources (MNR), International Development Cooperation Agency and National Market Supervision Administration. At the local government level, the provincial and municipal people's governments further play a key role in developing specific policies to promote energy development including hydrogen. Important local actors are the Local Development and Reform Commissions, Economic and Information Technology Commission/Bureaus, Science and Technology Departments, and Energy Bureaus.

In addition to the governmental ministries and agencies, **State-owned enterprises (SOEs**) are well represented in policy discussions and yield significant influence on government decisions pertaining to the energy sector. SOEs have a significant weight in Chinese political and economic systems. Given their political weight and industrial expertise, SOEs are closely involved in the policymaking process in the energy sector (KAPSARC 2019). The so-called central SOEs (*Yangqi*) are directly under the authority of the central governmentand rank high in the administrative order (*Xingzheng jibie*). CEOs of influential SOEs often enjoy a full ministerial rank and thereby have superior authority compared to regional government officials.

Among the major SOEs in the field of hydrogen figures the Chinese Petroleum and Chemical Corporation Sinopec. According to experts interviewed for this analysis, Sinopec aims to produce more than 1 million tons of green hydrogen from renewable energy sources and add 400 MW of solar power generation capacity to provide electricity for charging cars between 2021 and 2025. In the next five years, Sinopec plans to invest a total of more than 30 billion CNY, mainly in hydrogen refueling station construction, high-purity hydrogen purification units, hydrogen storage and transportation, and key materials research and development. Other major SOEs active in hydrogen (in energy, automotive, and renewable sectors epseically) are the China National Petroleum Corporation (CNPC), the National Energy Construction Group, China Huaneng, Hubei Iron and Steel, BaoWu Steel, State Grid, Datang, Great Wall Motor, Dongfang Electric, and China FAW (Automotive) Group.

Local SOEs, owned locally by provincial or city governments, are less privileged than the central SOEs but are influential actors in the policymaking cycle at the subnational level.

Quasi-public industry associations in China – such as the China Electricity Council (CEC) for the electricity sector – play a dual role. On the one hand, they represent the SOEs' interests and interact with the government on their behalf. On the other hand, they provide policy advisory services to the government upon request and inform policymaking. For the hydrogen sector, key relevant associations are the China Hydrogen Energy Alliance, the Hydrogen Energy Industry Promotion Association, and the Energy Investment Professional Committee of the Investment Association of China.

Certain privately-owned renewable energy companies including Baofeng Energy, LONGi Green Energy Technology, and Sunshine Power are also active in the hydrogen economy.

Given the emerging momentum of low-carbon hydrogen in China, some international companies such as Shell and Air Liquid are also trying to expand their hydrogen portfolio in the country, partnering with domestic players and local govenrments.

Besides industrial players, some financial institutions such as Sinopec Capital, Chalco Capital, China Merchants Capital, and Three Gorges Capital actively engage in funneling capital to hydrogen technology development and demonstration projects.

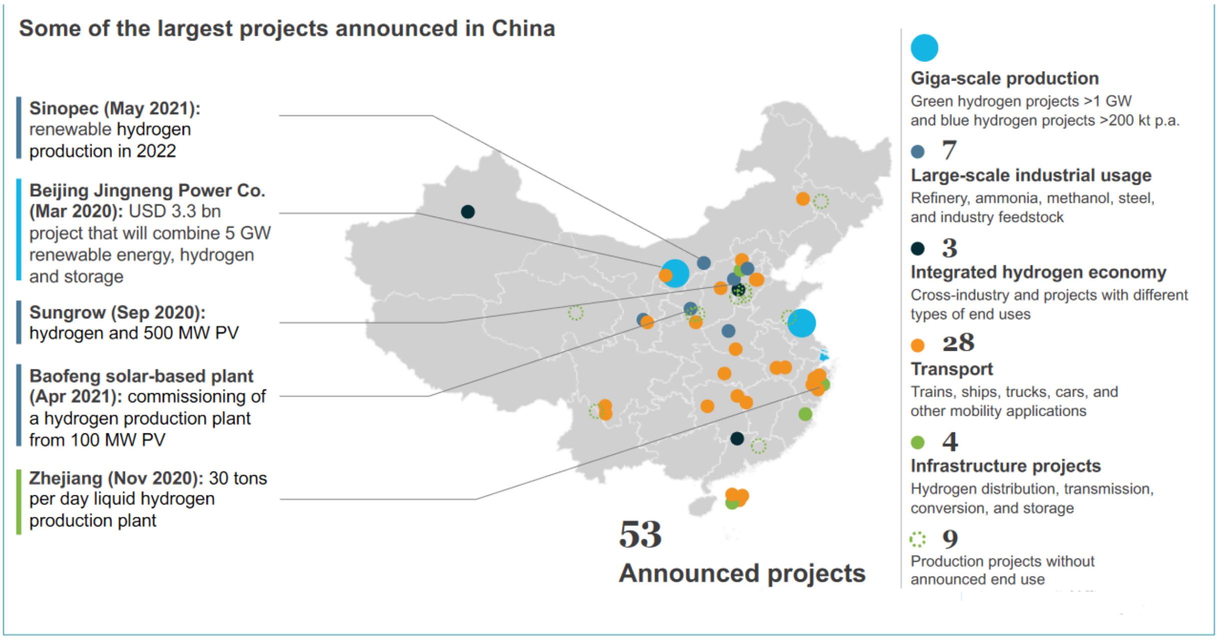
Tier 3 institutions support policymaking. They include **research centers, universities and institutes**. They are also called 'technical support institutes' in the Chinese domestic context. Research entities affiliated with government departments, such as the Energy Research Institute of the NDRC, National Center for Climate Change Strategy, International Cooperation of the MEE, and the Development Research Center of the State Council, each play an active role in analyzing and proposing policies. Other research entities, such as the State Grid Corporation's Energy Research Institute and the CNPC Economic Technology Research Institute, shape energy policymaking in specific areas in which they have strong expertise. (KAPSARC 2019).

Tier 4 institutions include **media, NGOs, and the general public**. They play a limited role in energy policy, although in recent years some NGOs and energy-related media outlets also have policy advocacy functions.

4.3 Major hydrogen projects and investments

As of July 2021, a total of **53 large-scale hydrogen projects** had been announced, out of which 50% are linked to transport applications. According to estimations of the Hydrogen Council, the total number of projects represents over 180 billion USD of investments. The Chinese government has provided 20 billion USD of public investment to hydrogen projects, 75 billion USD of additional investment will be required to meet the government's ambitions, and 85 billion USD of indirect investment will be needed from OEMs and suppliers. (Hydrogen Council 2021).

Figure 6: Main hydrogen projects in China



Source: Hydrogen Council 2021

In the Northern region **Inner Mongolia**, a hydrogen industry worth 100 billion CNY ($15.4 billion) is to be developed by 2025. It will include an annual green hydrogen production capacity of 500,000 tons, 100 hydrogen refueling stations, and more than 10,000 hydrogen fuel cell vehicles (Carbon Pulse 2021). Beijing Jingneng Power Co is building a $3.3 billion green hydrogen plant, which will be powered by 5 GW of solar and wind energy. The plant will have a capacity of 500,000 tons of hydrogen per year (Renewables Now 2020). Also in Inner Mongolia, Sinopec plans to launch a green hydrogen plant with an annual production capacity of 20,000 tonnes and a total investment of $405.58 million (Reuters 2021a).

In Zhangjiakou, located in the Eastern region **Hebei**, the first Chinese Liquid Sunshine Hydrogen Station with a capacity of 50-100 kg of hydrogen produced per day opened in October 2021. This Station supported the use of fuel cell vehicles running during the 2022 Beijing Winter Olympics which will be co-hosted by Zhangjiakou.

In the Northwestern region **Ningxia**, Ningxia Baofeng Energy Group Co Ltd has begun operating a hydrogen production facility powered by a 200MW solar photovoltaic farm in April 2021 (Renewables Now 2021).

In the Eastern region **Zhejiang**, Air Products APD.N is expected to launch a 30-ton-per-day liquid hydrogen production plant in 2022 (Reuters 2020).

4.4 Infrastructure

China's nascent hydrogen infrastructure is in the early stages of development. About **100 km of dedicated hydrogen pipelines** (operating at 1.0-4.0 MPa) have been built to date (IFRI 2020). Most hydrogen is transported by truck, a more expensive and less efficient means of transportation than pipelines. China primarily employs trailers with a capacity of 300 kg of hydrogen, which is less than half the capacity of trailers commonly used in Western countries (Nikkei Asia 2021). The widespread adoption of hydrogen as a low-emission energy carrier in China would require a major expansion of the existing transportation and storage infrastructure. In particular, the development of hydrogen pipelines, large-scale storage facilities, and port terminals must be prioritized. This could include repurposing high-pressure gas transmission pipelines to carry hydrogen (IEA 2021a). As for passenger transport, fuel cell electric vehicles are available on the market (i.e. passenger cars, light commercial vehicles and buses) but further development is needed before fuel cell trucks can be deployed on a larger scale (IEA 2021a).

5 Hydrogen strategies and support schemes

5.1 Existing national hydrogen strategies and support schemes

China has not yet developed a mid-century long-term strategy for hydrogen like other major hydrogen players such as the EU. However, China has seen high momentum for hydrogen with the release of their 14th Five Year Plan and carbon peaking and neutrality policy framework, defining it as one of the key strategic sectors. The most recent development is the release of the Plan on the Development of Hydrogen Energy for the 2021-2035 Period (the Hydrogen Plan) in March 2022. It is the first high-level national policy of its kind focusing exclusively on hydrogen.

Indications on the prospects of hydrogen development in China can be found in a series of top-level documents listed in the Table 5 below, with the Hydrogen Plan being the latest and one that provides a concrete roadmap for 2035.

Hydrogen energy and fuel cells was formally regarded as one strategic direction of energy technology innovation in 2014. The first comprehensive proposal for hydrogen energy development was the **Blue Book on Infrastructure Development of China's Hydrogen Energy Industry** published in 2016 by the China National Institute of Standardization and China Electrical Appliances Industry Association. It provided guidance to accelerate the development of the hydrogen energy industry infrastructure in China. The document proposed that by 2030, the hydrogen energy industry is to reach an output value of at least 10 trillion CNY ($1,4 trillion). Furthermore, it suggests a target for 1,000 hydrogen refueling stations to be installed by the end of the decade.

Several detailed documents have followed, including the **China Hydrogen Energy and Fuel Cell Industry White Paper 2020** published by the China Hydrogen Alliance, a government-supported industry group that explores and supports hydrogen technologies. It predicts that by 2025, the output value of the country's hydrogen industry will grow to 1 trillion CNY ($152.6 billion), and by 2030, hydrogen demand will reach 35 million tons, representing at least 5% of the national energy supply (Nikkei Asia 2021).

Since 2021, the central government government is increasingly focused on the development of the hydrogen industry and will likely drive such efforts going forward. The highest level document mentioning hydrogen as a priority is the **Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality** by the CPC and the State Council published on 24 October 2021. It sets out a plan to develop a complete hydrogen energy chain covering production, storage, transmission, and use, without a specific target year.

The Hydrogen Plan defines the strategic positioning of hydrogen asan important part of the future national energy system, an important viecle for low carbon transofmraiton of multiple energy end-using sectors, and a key strategic emerging industry. It sets the following targets for the coming one and half dacdes:

- By 2025 to produce 0.1-0.2 MT green hydrogen annually and acehive about 50,000 fuel cell vehicles, to achieve preliminary establishment of hydrogen supply chain and industrial system;
- By 2030 to form a more complete hydrogen technology innovation system and clean energy hydrogen production and supply system, and to achieve wide usage of renewable energy hydrogen production;
- By 2035 to establish a comprehensive hydrogen industry spanning transportation, energy storage and industrial sectors and significantly improve the portion of green hydrogen in the energy consumption.

In general, there are several obstacles to advancing the hydrogen economy in China. These include the current classification of hydrogen as a hazardous chemical (rather than an energy commodity), the limitation of hydrogen plants to be located within industrial parks, and the requirement to build hydrogen production and refueling stations separately. These obstacles are expected to be lifted in the future by developing a comprehensive hydrogem policy framework as requested by the Hydrogen Plan and by amending the existing regulations to further booster the hydrogen sector in China.

Besides the planning and policy documents, China has set up **funding schemes for R&D for hydrogen technology** to scale-up domestic production capacity. The National Key Research and Development Programme launched the implementation of the 'Renewable Energy and Hydrogen Energy Technology' project from 2018 to 2020 (Zhu Tong 2021). Through this scheme, the Ministry of Science and Technology has funded 27 R&D projects on hydrogen totalling about 500 million CNY (78 million USD). During 2018-2020, the scheme focused on downstream fuel cell technology (52% of the projects), followed by hydrogen production (19%) and storage technologies (22%), and hydrogen refueling station technology (7%). The funding stream continued in 2021, with a more balanced distribution between upstream production and downstream applications.[15] The National Strategy also states that the central government will strengthen the financial support to promote the hydrogen development, including via central budget investment and by promoting banks and financial institutions, industrial investment funds, and venture capital funds etc.

Table 5: Top-level planning documents for China's hydrogen industry

Year	Document	Key targets or relevance
2014	Energy Development Strategic Action (2014-2020) (by the State Council)	• "Hydrogen energy and fuel cell" formally regarded as one strategic direction of energy technology innovation.
2016	China Energy Technology Innovation Action Plan 2016-2030 (by NDRC and NEA)	• "Hydrogen and fuel cell technology innovation" and "advanced energy storage technology innovation" as one of the 15 key tasks.
2016	Blue Book on China's Hydrogen Energy Industry Infrastructure (by the Resources and Environment Branch of China National Institute of Standardization and the Fuel Cell Branch of China Electrical Appliances Industry Association)	• First comprehensive roadmap proposed for hydrogen energy development. • By 2020: increase the hydrogen production capacity to 72 billion m^3; reach 100 operational hydrogen refueling stations; 100,000 fuel cell vehicles to be deployed; at least 50 hydrogen rail transit vehicles in operation; reach 300 billion CNY in total output value of the industry. • By 2030, the hydrogen energy industry to become a new economic growth point and an important part of China's new energy strategy. The industrial output value is to exceed 1,000 billion CNY; the number of hydrogen refueling stations must reach 1,000; and the deployment of fuel cell vehicles is to reach 2 million.

[15] In the 'Notice on Seeking Comments on the 2021 Project Declaration Guidelines of 18 Key Special Projects including Hydrogen Energy Technology of the 14th Five-Year National Key R&D Program' released on February 1, 2021, the distribution of key special R&D projects in the categories of fuel cell technology, hydrogen production technology and hydrogen storage technology are 32%, 32% and 32% respectively (Zhu Tong 2021).

2019	"Government Work Report" delivered by the Chinese Premier[16]	• First time hydrogen was mentioned in such a report, indicating high-level political endorsement of its importance as an emerging strategic sector.
12/2020	Annual White Paper on Energy Development (by the State Council Information Office)	• Accelerate the development of hydrogen energy industry chain technology and equipment such as green hydrogen production, storage and transportation and application, and promote the development of hydrogen fuel cell technology chain and hydrogen fuel cell vehicle industry chain.
04/2021	14th Five-Year Plan Hydrogen Energy Industry Development Forum	• The NEA statement at the Forum that hydrogen would be one of the focuses of national energy policy and that hydrogen energy and fuel cell technology are included in the list of main directions and tasks of energy technologies.
04/2021	China Hydrogen Energy and Fuel Cell Industry White Paper 2020 (by China Hydrogen Alliance)	• Projects the annual demand for hydrogen to reach 130 million tons by 2060, the majority of which supplied by green hydrogen. • Renewable energy hydrogen production is expected to reach parity by 2030; the scale of renewable energy hydrogen production is expected to reach 100 million tons in 2060. • Predicts 300 and 1,500 hydrogen refuelling stations by 2025 and 2030 will be built respectively. The number of hydrogen refueling stations will reach 10,000 by 2050, and the industry output value is expected to reach 12 trillion CNY.
10/2021	Action Plan for Carbon Dioxide Peaking in 2030 (by the State Council)	• Establish well-conceived standards for the production, storage, transportation and usage of hydrogen; expand the application of new and clean energy in transportation, such as hydrogen power; boost construction of hydrogen fueling stations; expand sources to import hydrogen-rich raw materials. • Develop new approaches in personnel training for example in hydrogen energy; expand green technology cooperation, promote research cooperation and technological exchanges relating inter alia to hydrogen power.
10/2021	Annual White Paper on Climate Actions of China (by the State Council Information Office)	• Improve electric charging and hydrogen fueling infrastructure to facilitate the use of new energy vehicles (NEVs).
10/2021	Updated NDC submitted to the UNFCCC (submitted by MEE)	• Give impetus to constructing hydrogen filling stations. • Push forward with technological breakthroughs in various fields to support green transition, including hydrogen energy.

[16] The government work report is delivered by China's premier, officially the head of the Chinese government, to the delegates of the National People's Congress as part of the annual "two sessions" for their review and approval. The report offers a comprehensive view of the country's economic and social development in the previous year and, more importantly, lays out general guidelines for government policies for the current year.

12/2021	14th Five-Year Plan for Green Industrial Development (by MIIT)	• Accelerate hydrogen energy technology innovation and infrastructure construction, and promote the diversified use of hydrogen energy. • Implement a number of key projects in the field of green hydrogen energy and other areas. • Encourage the application of alternative energy sources such as hydrogen energy in steel, cement, chemical and other industries. • Strengthen the basic research and frontier technology development of green hydrogen and other technologies.
03/2022	14th Five Year Plan for a Modern Energy System (by NDRC and NEA)	• By 2025 improve the hydrogen energy technology innovation capability significantly. • Carry out demonstration of hydrogen production from wind power and photovoltaic power generation, among others.
03/2022	Plan on the Development of Hydrogen Energy for the 2021-2035 Period (the Hydrogen Plan) (by NDRC and NEA)	• Define the strategic positioning of hydrogen in national energy system, low carbon transformation as well as industrial development. • Set qantiative and/or quantitaive targets for 2025, 2030 and 2035. • Outline key policy elements to promote hydrogen development, while mandating a comprehensive policy package to be developed.

Source: Based on public information and interviews

5.2 Existing provincial and municipal hydrogen strategies

Acording to experts interviewed for this analysis, China has issued hydrogen energy plans and guidelines in **23 provinces, municipalities and autonomous regions**, and introduced relevant policies to support the hydrogen energy and fuel cell industries**.** In some regions, hydrogen related targets and policies are included in policy planning documents (Anhui, Hunan, Yunnan, Heilongjiang and Shaanxi provinces). In other regions, special hydrogen policies or plans are issued in addition to the comprehensive top-level planning document (Beijing, Shandong, Hebei, Tianjin, Sichuan, Zhejiang and Ningxia). These regional hydrogen strategies are usually coupled with regional financial subsidies and other measures such as land price concessions.

Nearly all provinces and cities that have issued special hydrogen energy industrial policies have focussed on the development of fuel cell vehicles in the car manufacturing sector. A comprehensive approach to establishing a hydrogen economy has so far been lacking. This is expected to change with the release of the Hydrogen Plan that now informs the regional policies with a view to rapidly expanding up- and midstream hydrogen sectors.

Another shortcoming of the existing regional policy landscape is that an overly rapid local promotion of hydrogen development without a clear focus on the whole industry value chain and quality of that development may lead to waste of government resources – like the ‘renewable bubble’ that occurred at the early stages of solar and wind energy development in China (Zhu Tong 2021). The Hydrogen Plan also recognizes these issues and attaches significance to resolve them. In like manner to what happened shortly after the bubble, a nationally coordinated approach to low-carbon hydrogen development can mitigate such risks.

5.3 International partnerships and dialogues on hydrogen

An increasing number of international players have started collaborating with China on green hydrogen development in recent years. These include GIZ (on behalf of the German Ministry of Economic Affairs and Energy), Agora Energiewende, and the Rocky Mountain Institute (RMI). In November 2021, Agora Energiewende hosted a Europe-China workshop on the green hydrogen economy. The workshop was supported by GIZ and the Federal Ministry for Economic Affairs and Energy (BMWi)'s Sino-German Energy Transition Project, in partnership with the Shanghai Institute for International Studies (SIIS) and the Energy Investment Professional Committee of the Investment Association of China (IAC). In the same month, the RMI organized the Europe-China Clean Hydrogen-based Steel Dialogue and Collaboration Workshop supported by the EU Delegation to China, as well as the embassies of Sweden, the Netherlands, and Norway.

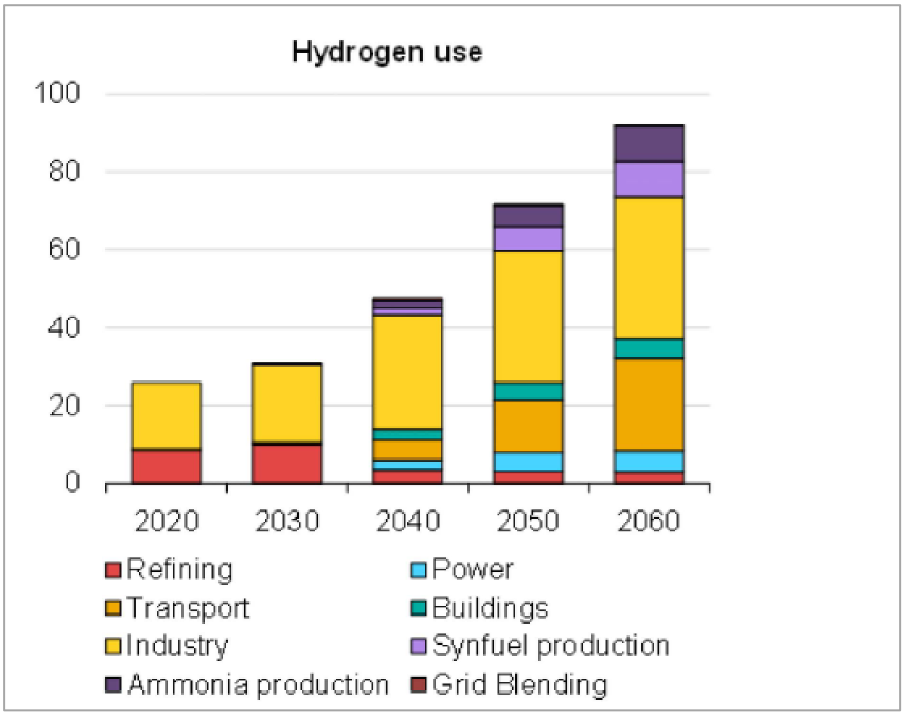
6 Potential for a hydrogen economy

6.1 Hydrogen demand

In June 2021, and in response to the Chinese government's request, the IEA released a comprehensive report on China's roadmap to achieve its dual climate goals for 2030 and 2060 (see section 0). The analysis projects a growing role for hydrogen in China's energy transition. By 2060, hydrogen demand would triple to approx. 90 Mt, representing 6% of China's final energy demand. (IEA 2021a). Hydrogen is expected to become a key energy source for the decarbonization of the transport sector. According to the IEA forecast on China, hydrogen and derived fuels will be widely used in road freight, shipping and aviation. In 2060, hydrogen will meet nearly a quarter of the total energy needs of the transportation sector (IEA 2021a). The contribution of hydrogen to the decarbonization of the chemicals and steel sector will also be determinant, accounting for approx. 15% and 20% of total energy use in those sectors respectively by 2060. In the industry overall, hydrogen would represent approx. 10% of total energy use. In the building sector, hydrogen will account to less than 3% of total energy use, mostly in the form of pure hydrogen (IEA 2021a).

In the power sector, the IEA projects that hydrogen as a storage option will only play a small role, since the cheaper batteries are expected to be dominant in short-term storage and fossil fuels with CCUS will primarily be used as a long-duration storage option (IEA 2021a).

Figure 7: Hydrogen Demand by sector in China (in Mt) (IEA 2021a)



Source: IEA 2021a. All rights reserved. An Energy Sector Roadmap to Carbon Neutrality in China. *CC BY-NC 3.0 IGO.* Available at: https://www.iea.org/reports/an-energy-sector-roadmap-to-carbon-neutrality-in-china. This is an adaptation of an original work by the IEA. Views and opinions expressed in the adaptation are the sole responsibility of the author or authors of the adaptation and do not necessarily reflect the views or policy of the IEA Secretariat, IEA Member countries.

Note: Hydrogen use for “ammonia production” relates to the future use of green ammonia as an energy carrier mainly in shipping, while the hydrogen used as a feedstock for ammonia production already today is included under “industry”.

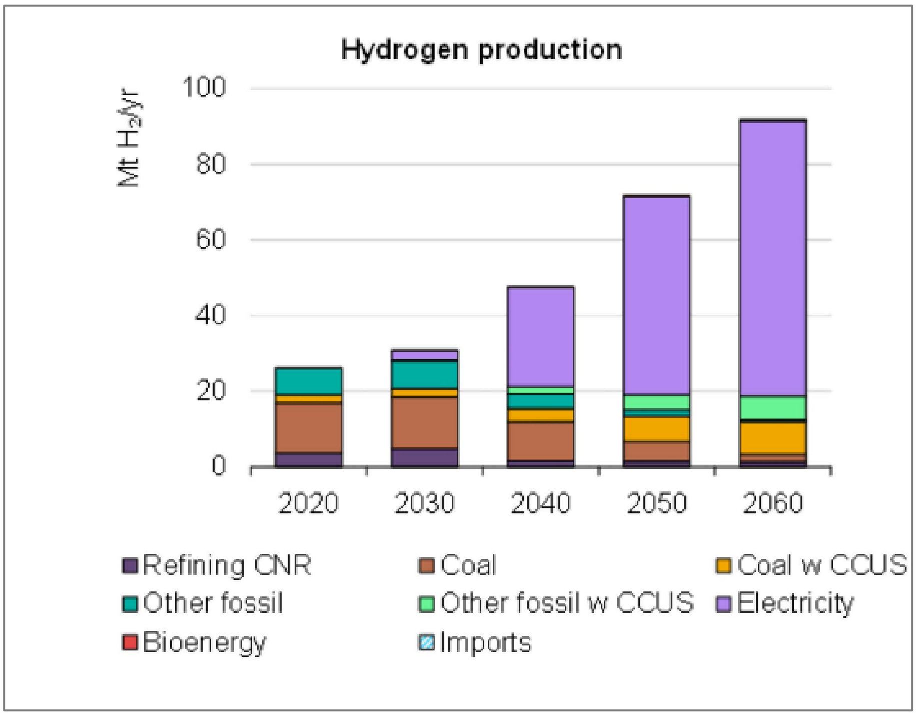
Chinese experts we interviewed in late 2021 have underlined the potential for increased hydrogen demand across the energy spectrum spanning transport, electricity, heavy industry and buildings. This has been confirmed by the newly released Hydrogen Plan.

6.2 Hydrogen production

6.2.1 General overview

Today, China’s hydrogen production relies heavily on fossil fuels — coal-based and gas-based hydrogen constituting most of the output. Today, 62% is produced from coal gasification, 19% from natural gas by steam methane reforming (SMR), 18% as a by-product of industrial processes, while less than 1% is “green” (Recharge 2021). Given the momentum of hydrogen development in China supported by an increasingly streamlined policy framework (see Chapter 5), China’s hydrogen production capacity is expected to enter a quick expansion phase in the coming years. This may include an ‘all-in’ approach covering all types of hydrogen, while also giving a strong focus on green hydrogen. Modelling results from the IEA reveal a pathway for China’s hydrogen economy (Figure 7), and underscore the necessity of ramped-up electrolyzer capacity in the coming years, complemented by blue hydrogen, to remain on track with climate targets.

Figure 8: Hydrogen Production Sources in China (2020-2060)



Source: IEA 2021a. All rights reserved. An Energy Sector Roadmap to Carbon Neutrality in China. CC BY-NC 3.0 IGO. Available at: https://www.iea.org/reports/an-energy-sector-roadmap-to-carbon-neutrality-in-china. This is an adaptation of an original work by the IEA. Views and opinions expressed in the adaptation are the sole responsibility of the author or authors of the adaptation and do not necessarily reflect the views or policy of the IEA Secretariat, IEA Member countries.

6.2.2 Green Hydrogen Production

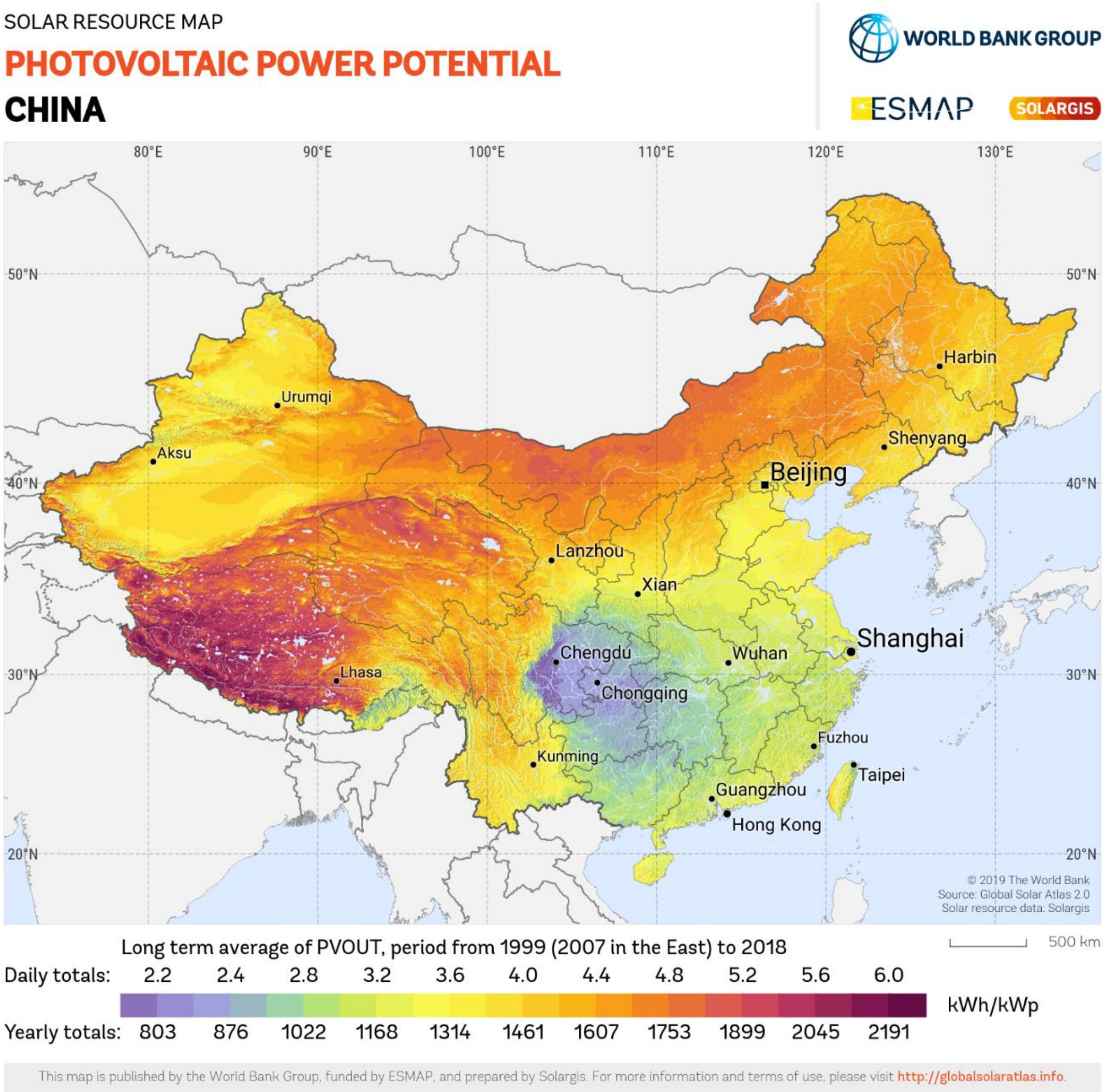
Over the past years, China has shown increased interest in the production of electrolytic hydrogen combined with renewables, mainly from onshore and offshore wind and solar PV. According to the IEA, electrolytic hydrogen capacity has grown fourfold to reach 18 MW in 2020. Another 2 GW of electrolytic hydrogen capacity are currently being developed in China by public and private companies. By 2030, electrolytic hydrogen is expected to meet 7% of total hydrogen production and by 2060, that share might increase to 80% (IEA 2021a). China's Hydrogen Energy and Fuel Cell Industry White Paper 2020 expects that the majority of demand in 2060 will be supplied by green electrolytic hydrogen (100 out of 130 Mt). (China Hydrogen Alliance 2021).

There are currently three types of electrolyser technologies: alkaline, proton exchange membrane (PEM), and solid oxide (SO). China leads the global market on alkaline, the cheapest and most deployed technology. Benefiting from economies of scale, Chinese producers sell alkaline cells for 200 USD/kW, which is 80% cheaper than in Europe. On the other hand, Europeans are leading on the production of "innovative technologies" such as PEM and solid oxide, which are more compact and efficient for producing green hydrogen (Euractiv 2021).

The chemical and metallurgy sectors appear to be the most promising applications for green hydrogen, in particular for ammonia, methanol and steel production. Some projects are already undergoing, as for example the production of methanol powered by solar PV in the Ningxia Province by the Ningxia Baofeng Energy Group (mentioned above). Today, the use of green hydrogen in other sectors, such as the iron and steel industry, are still at the demonstration stage (IEA 2021a).

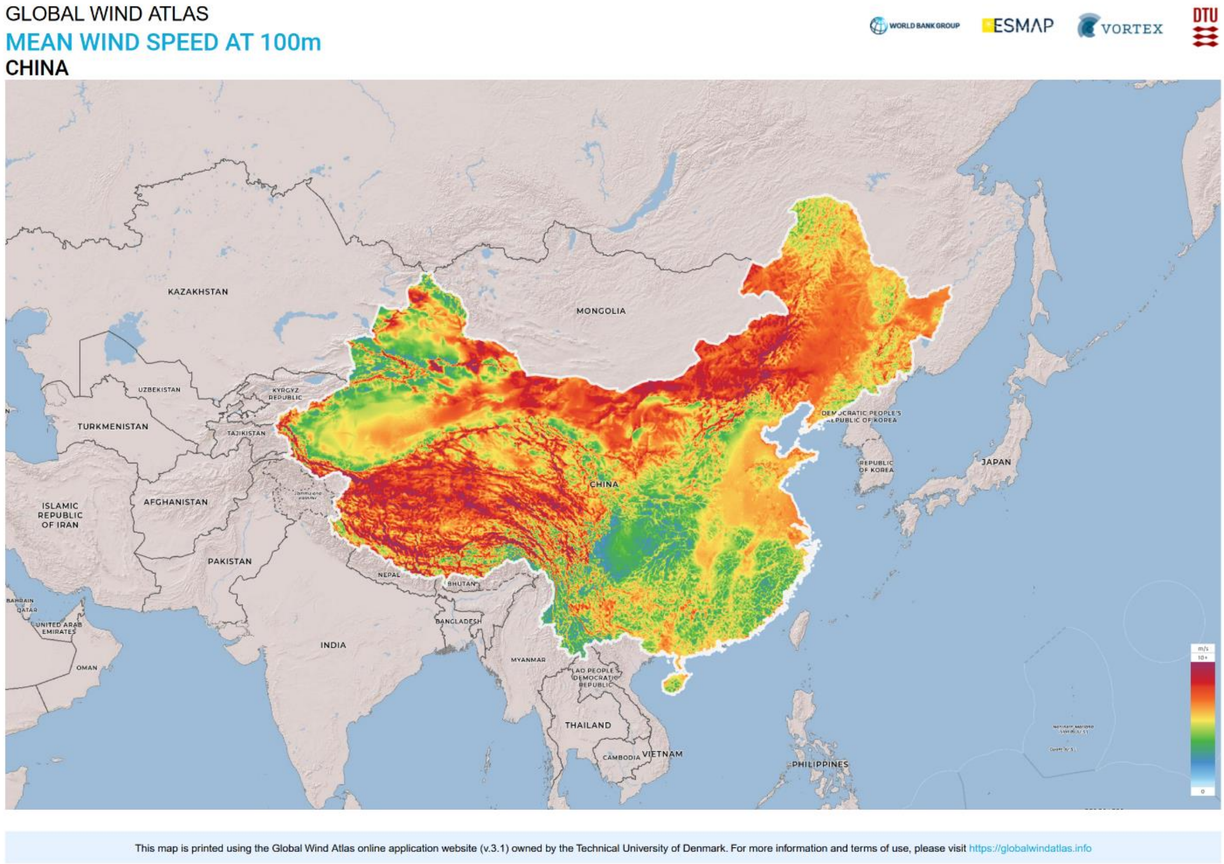
Technology costs are an important hurdle to accelerating green hydrogen uptake. In 2020, production costs for coal-based hydrogen ranged between \$0.95-1.90/kg, grey hydrogen between \$1.27-2.37/kg, and green hydrogen between \$3.95-5.54/kg (Recharge 2021). Economies of scale – backed by increased demand, targeted support policies, and low-cost electricity – will each be key to bringing down costs of electrolytic hydrogen going forward.

Figure 9: China's annual photovoltaic potential



Source: Map obtained from the Global Solar Atlas 2.0, a free, web-based application is developed and operated by the company Solargis s.r.o. on behalf of the World Bank Group, utilizing Solargis data, with funding provided by the Energy Sector Management Assistance Program (ESMAP). CC BY 4.0. For additional information: https://globalsolaratlas.info

Figure 10: China’s mean annual wind speed



Source: Map obtained from the Global Wind Atlas 3.0, a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU). The Global Wind Atlas 3.0 is released in partnership with the World Bank Group, utilizing data provided by Vortex, using funding provided by the Energy Sector Management Assistance Program (ESMAP). CC BY 4.0. For additional information: https://globalwindatlas.info

6.2.3 Blue Hydrogen Production

While China plans to scale up the production of renewable energy, experts agree that blue hydrogen i.e. natural gas reforming or coal gasification with CCUS will also be a key technology for China to reach its carbon neutrality target in 2060.

Major state-owned energy enterprises such as China Huaneng, China Energy Investment Corp (CEIC), and Sinopec have shown increased interest in the deployment of CCUS. Today, there are 35 undergoing CCUS projects, most of them are still on a demonstration level (Oil and Gas Climate Initative 2021; Energy Iceberg 2021). Among them, two projects are designed to produce blue hydrogen in China today (overall 1.1 Mt CO2 captured per year): the Yanchang Integrated Carbon Capture and Storage Demonstration Project and the Qilu Petrochemical CCS Project in Zibu City (IEA 2021a) .

Table 6: Major CCUS Projects in China

	NAME	SCALE Mt	OPERATION	INDUSTRY
1	CNPC Jilin Project	0.6	2018	Natural gas processing
2	CHNE Jingie	0.1	2021	Power generation
3	CNOOC Enping	0.1	2021	Natural gas processing
4	Sinopec Qilu Project	0.4	2021	Chemical production
5	Yanchang Integrated Project	0.4	2021	Chemical production
6	Sinopec Huadang Project	0.5	2021	Chemical production
7	CHNE Taizhou	0.5	2025	Power generation
8	China Northwest Hub	1.5	2025	Multiple
9	CRP Haifeng Project	1.0	2030	Power generation
10	Huaneng IGCC Project Phase III	2.0	2030	Power generation
11	Shenhua Ningxia Project	2.0	2030	Coal-to-liquids
12	Sinopec Shengli Project	1.0	2030	Power generation
13	CNPC Daqing	3.0	2030	Multiple
14	CNPC Changqing	3.0	2030	Multiple
15	CNPC Dagang	1.0	2030	Multiple
16	Shenzhen Energy	0.5	2030	Power generation

Source: Oil and Gas Climate Initative 2021

At present, natural gas reforming or coal gasification with CCUS has not yet been widely deployed in China mainly due to the higher costs involved. According to the IEA, the growth of blue hydrogen will be progressive between 2021 and 2060, with an acceleration of its deployment after 2030 (IEA 2021a).

Hebei and Shandong provinces are favourable for the development of blue hydrogen. They have a young fleet of plants currently using coal to produce ammonia and methanol, and could consider retrofitting existing plants with CCUS given their proximity to oil and gas reservoirs. Regions such as Jiangsu could also develop blue hydrogen, as they have good access to potential CO2 storage capacity. (IEA 2021a)

6.3 International trade of hydrogen

China has a high theoretical potential for green hydrogen production of 4083 Mt/a by 2030 and 4590 Mt/a by 2050, based on its very large solar and wind energy potential (Brändle et. al. 2020). According to most experts, China will be able to meet its own renewable hydrogen needs and not rely on imports. This would also be in line with its strategic objective of reducing energy import dependency. However, few studies estimate that China will need to import low-carbon hydrogen to meet its overall demand. Some studies indicate that China may consider importing renewable hydrogen from Central Asia, for example (Wood Mackenzie 2021)).

As for the international trade potential between EU and China, given China’s vast domestic energy demand, the constraints to long-distance transport of hydrogen, and the sheer distance between the EU and China, the opportunities for establishing trade connections in hydrogen between the two economies are limited.

7 Potential sustainability issues associated with hydrogen production

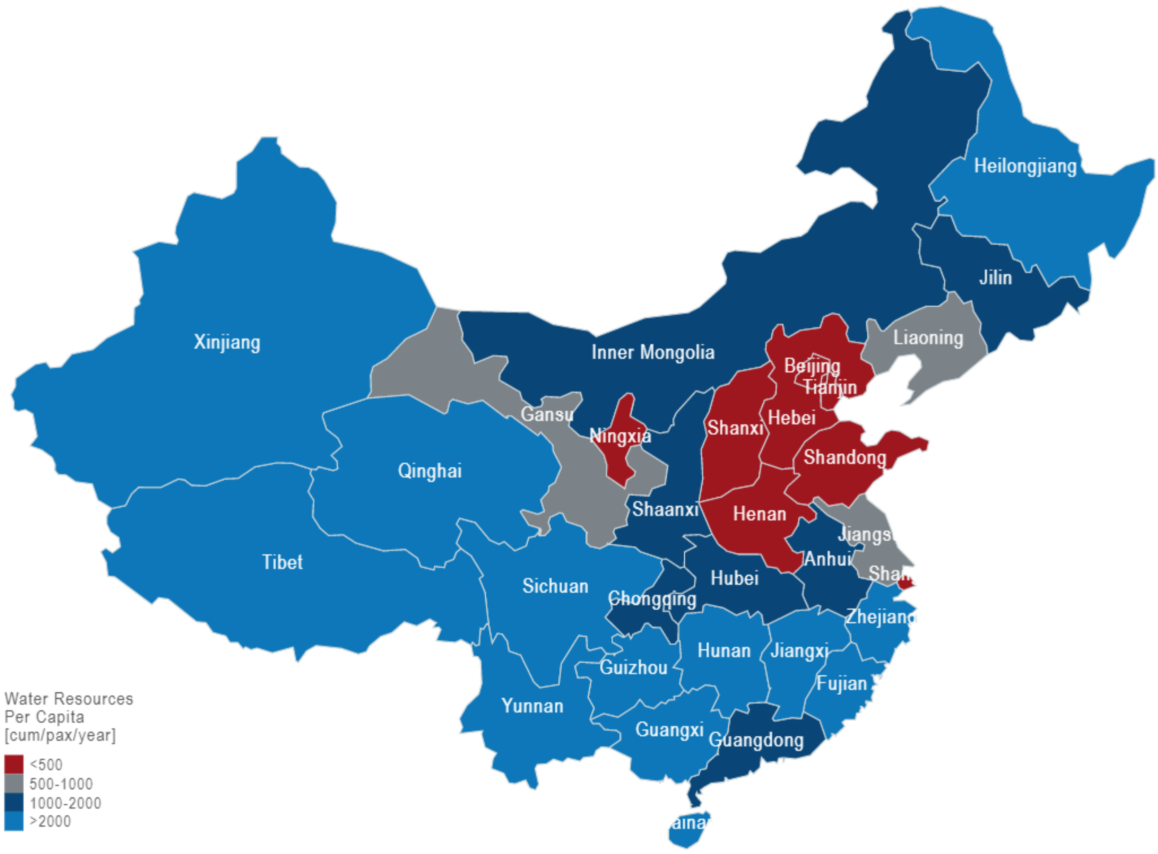
7.1 Water resources

At present, there is no in-depth discussion on sustainbitliy criteria of hydrogen in China. However, water scarcity in China's economic is an important potential sustainability issue.

The availability of water in China varies considerably between regions. Water scarcity is already a serious problem in urban centres and industrial areas of the north. As industrialisation increases, the nation's access to adequate freshwater resources is increasingly threatened, particularly in the economic centre. (Belfer Center for Science and International Affairs 2020) (see figure 11).

Southwestern and northern regions could become the heart of green hydrogen production, as they have abundant renewable resources and do not suffer from water scarcity. For onshore wind and solar PV, Inner Mongolia and Xinjiang present the highest potentials. The coastal regions of Fujian and Guangdong present the highest potential for offshore wind (IEA 2021a). However, these regions are at a considerable distance from China's economic center, which means that large infrastructure investments are required to connect green hydrogen supply and demand (Belfer Center for Science and International Affairs 2020). In particular, China will need to repurpose existing high-pressure gas transmission pipelines and develop new dedicated hydrogen pipelines (IEA 2021a). Building such large infrastructure usually involves considering key sustainbiltiy issues like land use and resettlement of migrants.

Figure 11: Water resources per capita



Source: China Water Risk Project (2017): CWR Big Picture. Who is running dry. Provinces, autonomous regions and municipalities, available at: http://www.chinawaterrisk.org/the-big-picture/whos-running-dry/.

7.2 Sustainability criteria of hydrogen production

Although China does not have an official classification of green, blue and green hydrogen, China's Hydrogen Energy Alliance has published its own voluntary classification "Standard and Assessment for Low-carbon Hydrogen, Clean Hydrogen and Renewable Hydrogen Energy" in December 2020. The standard makes a distinction between low-carbon hydrogen, clean hydrogen and renewable hydrogen based on a well-to-gate life-cycle assessment approach. Low-carbon hydrogen is defined with a threshold of 14.51 kgCO2e/kgH2 and clean and renewable hydrogen with a threshold of 4.9 kgCO2e/kgH2. The difference between clean and renewable hydrogen is that the latter specifically requires to be produced based on renewable energy (including wind, solar, hydro, biomass, geothermal, and ocean energy) (China Electricity Council 2021). Based on these emissions thresholds, not only blue, but also grey hydrogen produced from SMR (without CCS) could be potentially counted as "low-carbon hydrogen", depending on the assessment method and assumptions regarding the rate of fugitive CH4 emissions (Howarth & Jacobson 2021; TERIIN 2020; Bauer et al. 2022). This is because China is currently also producing even more emissions intensive hydrogen based on coal gasification (without CCS), which is here the benchmark (Wei Liu et al. 2021). Overall, China still lacks officially endorsed mandatory sustainability criteria that include both emission as a criteria but other factors such as other enivonrmental and social ones. In relation to this, a robust certification system is also missing. The 2022 Hydrogen Plan puts a strong emphysis of developing a standard system covering production, storage, transmission and usage for the hydrogen industry in China, which offers a good opportuntiy for the country to establish such a mandatory sustainbiltiy criteria. Thre is also opportunity for international cooperation on the hydrogen standardization.

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