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Energy Cooperation Platform

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Opportunities in LNG, CCUS and Green Hydrogen sector in China for EU Business: enabling policies and financing needs

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This report was prepared by:

ISSARD François, Senior International Energy Consultant
John Z SONG, Senior Consultant (LNG)
LI Yanzhong, Lead Climate Consultant, ICF (CCUS)
TIAN Zepu, Senior Consultant (Green H2)

EU-China Energy Cooperation Platform (ECECP)
Website: http://www.ececp.eu
E-Mail: info@ececp.eu

EU-China Energy Cooperation Platform was launched on 15 May 2019, to support the implementation of activities announced in the 'Joint Statement on the Implementation of EU-China Energy Cooperation'. The overall objective of ECECP is to enhance EU-China cooperation on energy. In line with the EU's Green Deal, Energy Union, the Clean Energy for All European initiative, the Paris Agreement on Climate Change and the EU's Global Strategy, this enhanced cooperation will help increase mutual trust and understanding between EU and China and contribute to a global transition towards clean energy on the basis of a common vision of a sustainable, reliable and secure energy system. Phase II of ECECP is implemented by a consortium led by ICF, and with National Development and Reform Commission- Energy Research Institute.

English editing: Helen Farrell, Chinese editing: Daisy Chi

Preface

The EU China Energy Cooperation Platform (ECECP) is committed to supporting the energy transition in both the European Union and China. In 2023, the ECECP published two reports that are highly relevant to the business opportunities in the green hydrogen, CCUS, and LNG sectors in China: Joint Statement report 'Presenting the Conditions and Outlining Priorities for Joint Cooperation on Flexible and Efficient Global Energy Markets for LNG' and ECECP II Flagship project 'Investment and Technologies for Net-Zero Carbon Infrastructure'.

These reports identified several key areas for collaboration, including: deep gas exploration; enhanced access to gas and LNG storage and infrastructure; gas value chain regulatory development; alternative forms of energy commodity transportation, such as hydrogen pipelines; Power-to-X (P2X) infrastructure; CO_2 capture, utilisation, and storage (CCUS).

This report, 'Business opportunities in LNG, Green hydrogen, and CCUS sectors in China', follows up on the findings of the above two reports and explores specific cooperation opportunities in these sectors between the EU and China.

The green hydrogen sector is a particularly promising area for cooperation, as both the EU and China have set ambitious targets for developing this sector. Green hydrogen can be produced using renewable energy, such as solar and wind power, and can be used to decarbonize a wide range of industries, including transportation, manufacturing, and power generation.

CCUS is another important technology for reducing greenhouse gas emissions. CCUS captures CO_2 from industrial processes and power plants, and transports it to storage sites where it is permanently stored underground. CCUS can play a vital role in decarbonising China's heavy industries, such as steel and cement production. The LNG sector is also important for both the EU and China. LNG is a clean and efficient way to transport natural gas, and it can help to diversify energy supplies and improve energy security.

The report also highlights the importance of cross-border infrastructure in supporting cooperation in these sectors. For example, pipelines are needed to transport green hydrogen and CO_2, while LNG terminals are needed to import and export LNG. Cooperation on infrastructure development could help to reduce the cost of transporting these energy resources and make it easier for businesses to invest in these sectors. The EU and China have a long history of cooperation on energy issues. By working together, the two sides can accelerate the development of the green hydrogen, CCUS, and LNG sectors in China, and make significant progress towards their shared climate goals.

I hope that this report will be a valuable resource for businesses and policymakers in both the EU and China who are interested in pursuing cooperation opportunities in the green hydrogen, CCUS, and LNG sectors.

Dr Flora Kan
Team Leader
EU China Energy Cooperation Platform

Executive Summary

The use of fossil fuels is driving up global temperatures, evidenced by catastrophic weather events and extreme temperatures. It is imperative for the move away from oil and gas to accelerate, in order to avoid the worst consequences of global warming.

This report identifies ways of cooperation between the EU and China and between their respective companies, with a view to speeding up the development of substitutes for current primary sources. These include liquefied natural gas (LNG, as a substitute for coal or oil) or alternative carriers such as hydrogen and decarbonisation technologies such as carbon capture, utilisation and storage (CCUS), to mitigate emissions from the most polluting industries that will not be able to turn aside from fossil fuel use during the energy transition and beyond.

To this end, an analysis of the situations in Europe and China is proposed for each of the three topics covered, through a non-exhaustive summary review of the technologies concerned as well as the uncertainties related to their possible inclusion in energy markets.

It should be noted that development of green hydrogen, i.e., hydrogen strictly produced from renewable energy (guaranteed green electricity and/or nuclear electricity), still has a long way to go. Europe and China would benefit from taking that road together; the methods for production and use of hydrogen are complex and varied, while the conditions for creating a large hydrogen market governed by standards, certification methods and regulations are not yet in place.

As a result, the risks for market entry are still very high for potential European industrial players, even if some of them are already well positioned in certain segments of the value chains.

In this sector, China has prioritised the manufacturing approach (production of hydrogen, electrolysers, equipment, etc.), while Europe is keeping its focus on building a coherent regulatory and economic environment, so as to create a functioning market and minimise the possible destruction of capital. This report advocates a 'win-win' approach of sharing the best know-how of the two parties.

CCUS, meanwhile, is at what can be described as a demonstration phase. The initial phases of future major projects are being set up in Europe, with China close behind. This combination of technologies, which consists of recovering CO_2 and either using it or storing it sustainably, is intended to offer a means of rendering carbon neutral those industries that will still be using fossil fuels by 2050-60.

The transition now needs to accelerate from the current pilot phases to full-scale industrial developments, bringing with it a significant reduction in costs, while legislation will soon be needed (particularly related to carbon pricing) that allows fair market conditions as well as harmonisation at regional and inter-regional level.

There is already cooperation on CCUS between Chinese and European companies, and this needs to be amplified and promoted, for example by means of ad-hoc and harmonised institutional supports (financing assistance tools, taxation, etc.) between the EU and China.

At the same time, the use of LNG is evolving in a globalised market model in which powerful partnerships have already been established between Chinese and European companies, and further, with producing countries and their representatives. Further integration can only be achieved through a greater opening of the Chinese gas market to European operators, a step they want to see taken as soon as possible, both to optimise their own operations in China but also to allow for greater integration of their Chinese partners in global energy flows. This in turn would contribute to a form of international stability, and therefore of security for all parties involved, through the creation of shared interests.

Finally, this report argues against the introduction of policies in the EU or China that could inadvertently create barriers to investment. Clear rules on industrial property ownership are also essential to enable new European entrants to invest in emerging energy sectors in China, where innovation and research play a vital role.

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1. LNG Business Status

1.1 Introduction: Global Markets

Tensions in the global gas market eased during 2023, marking some relaxation compared to 2022 and the situation discussed in an ECECP sponsored report dated April 2023 (‘*Presenting the conditions and* outlining *priorities* for *joint cooperation on flexible and efficient global energy markets for LNG’*). However, LNG has continued to act as a buffer between strong global demand and a lagging supply, creating a seller’s market in the short to medium term.

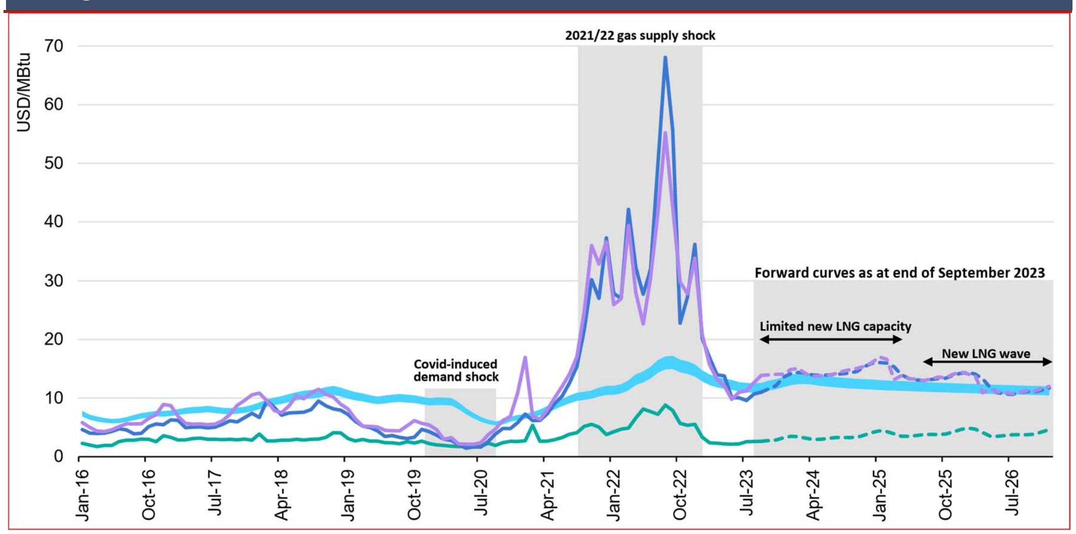
Indeed, gas supplies remain structurally tight in 2023, keeping prices relatively high, above historical averages with relatively high volatility (ref. Figure 1.1), despite a drop in demand in Europe. While not experiencing the panic movements of last year, markets are still reacting to any incident in the value chain as was evident after strikes in Australia or outages in Norway in the summer of 2023.

Europe has managed to significantly lower its gas consumption while increasing its production of electricity from renewables (hydro and solar).

On the demand side Germany is not deviating from its strategy to substitute LNG imports for Russian gas, and has gone on to sign long-term purchase agreements and plan for new LNG terminals. Its decisions will probably make Germany an important LNG importer for decades. Other Eastern Europe countries may follow suit, like Baltic states and Poland.

The Asia Pacific region, where gas production is in decline, is evidencing higher demand for LNG: LNG imports were up 2.6% y-o-y (6.3 bcm) in the three first quarters of 2023. This surge was primarily driven by China (see below).

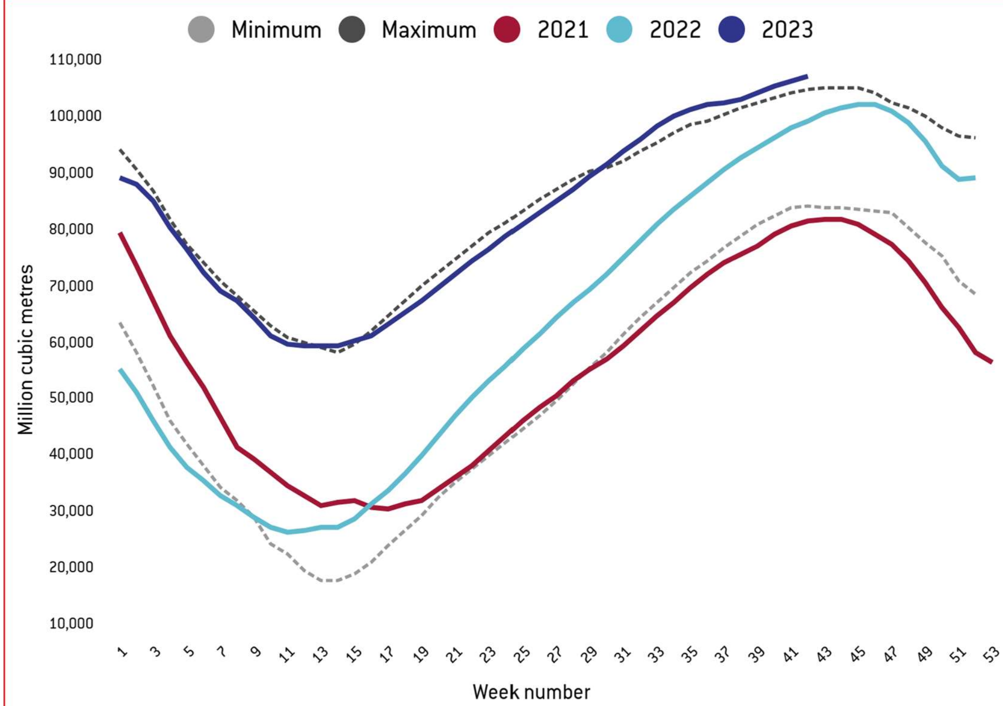
Figure 1.1: Natural gas price assumptions – forward curves point to prices above historical averages in short to medium term



1.2 Gas Storage

As they were in 2022, EU storage levels are high as winter approaches, allowing for cautious optimism ahead of the 2023-24 heating season (see Figure 1.2).

Figure 1.2: Europe gas storage stocks 2021-23 + historical minimum and maximum 2015-20



Source: AGSI: https://agsi.gie.eu/#/

Note: Minimum and Maximum values are calculated from the period 2015-2020.

Source: AGSI

In China, storage levels are also high, Chinese operators having replenished their inventories during the summer months of 2023 (see below).

All other things being equal, the continuing relative stability of the market will be highly dependent on the evolution of the weather this coming winter in the northern hemisphere.

However, the scenario beyond 2024 is full of uncertainty:

- Demand side: How world economies are going to fare moving through recurrent political crises and related instability, high inflation, and high interest rates, energy transition engagements.

- Supply side: how rapidly can new supply (essentially from US) reach the markets, contract expirations, new contract terms (flexibility, optionality).

Based on occasional public announcements, some European energy companies are remaining quite active in China gas markets despite the volatile geopolitical context, reflecting a business environment that remains favourable.

In the next five chapters we shall review in more details recent LNG trends in China after a series of policy and investment decisions.

1.3 China's 2023 LNG Infrastructure Boom

Resuming a pre-pandemic trend, China's appetite for natural gas is once again on the rise (China's net LNG imports started to recover in March 2023 after 13 months of year-on-year decline, and grew by 13% (7.8 bcm) in Q1-Q3 2023 compared to 2022, with three new import terminals coming online in 2023, driving its total import capacity to 120 Mt annually (156 bcm) at 27 import terminals.

The three new terminals are:

- Tangshan City, in Hebei Province, owned by Xintian Green Energy with 5 Mt annual capacity (6.8 bcm).
- Wenzhou LNG in Zhejiang Province (the fourth terminal to be built in this province) owned by Zhejiang Energy Group, with a 3 Mt/year (4 bcm) initial capacity (expandable to 10 Mt).
- Nansha LNG (Guangzhou) for Guangzhou Gas, with 1.1 Mt capacity initially (1.4 bcm), which received its first cargo from Indonesia in August 2023, representing China's 27th terminal[1].

This LNG infrastructure surge confirms the firm establishment of LNG as a major component of China's energy transition strategy. LNG is apparently no longer merely a response to domestic demand growth, but is also being used to help stabilise energy supplies for the nation. The usage of these higher LNG imports (national security storage) also points to the same interpretation. China is prioritising a stable transition.

This rate of expansion confirms China NDRC's current national strategic plan objective for gas demand to peak at 550-650 bcm annually by 2040 or around 12% to 15% of the country's energy mix at this time.

As a result, LNG imports have increased 7% during 2022 to 46.1 bcm (33.4 Mt) in the first half of 2023 (79.3 Mt and 64.1 Mt for the whole of 2021 and 2022, respectively). As stated above, most of these imports have apparently not reached China's consumer market (only 5.4 Mt) but have instead been directed to strategic storage reserves (28 Mt).

Additionally, reflecting both the national objective of self-sufficiency and the resilience of domestic niche markets, domestically-produced LNG increased 7.6 % year-on-year to 9.6

[1] China's strategic energy planning calls for ninety-two (92) LNG terminals in the coming 5 years. Twenty-seven (27) already operational, eighteen (18) under construction and forty-seven (47) in planning stage.

Mt, despite the fact that effective overall natural gas demand was depleting at the same time.

As far as global LNG flow is concerned, unlike in 2022 when geopolitical conditions generated the opportunity for profitable arbitrage between Asian and European markets, Chinese traders were unable redirect their cargoes to Europe in 2023, which explains the flow back to China inventories, the economy not being strong enough to absorb the excess supplies.

If that import trend continues for the rest of 2023, China could regain its status as the world's largest LNG importer, overtaking Japan.

China's LNG annual import capacity could therefore reach 200-240 MT by 2040, these capacities being clustered around three kay areas: Bohai Rim, Greater Bay Area and Yangtze River Delta.

Chinese companies (CNPC, Sinopec, Zhejiang Energy, ENN, Beijing Gas) have secured around 15 Mt of LNG supplies through various long-term contracts (Sinopec and CNPC have secured contracts as long as 27 years).

China is contracting huge LNG volumes for the long-term (over 10 years), unlike other countries which are focused more on the short- and medium term (2-10 years). This contrast probably partially reflects different concepts and timelines for their climate engagements.

Moreover, some of these LNG purchase contracts came with complementary equity stakes in corresponding liquefaction projects, such as CNPC and Sinopec deals with Qatar Energy in the North Gas Field, another demonstration of China's strategic foresight and long-term interest in LNG as a buffer to its energy market requirements.

1.4 China New Gas Central & Provincial Policies Issued Since January 2023

New policies and/or regulations have been published in 2023 with regards to natural gas and LNG:

- LNG Terminals - NEA released the 'Highlights of Energy Regulation Work', requiring its agencies and departments to provide guidance on the high quality and fair opening of LNG receiving terminals and other related facilities in order to better serve and maintain the supply of natural gas and stabilise its price.
- Action Plan on Accelerating the Integration of Oil & Gas Exploration and Development with New (Renewable) Energy (2023-25). The action plan calls for the creation of an integrated development of offshore wind power and natural gas power generation to provide stable and reliable green power for offshore platforms.
- Notice for the Construction of a National LNG-based backbone Cold Chain Logistics Base in 2023; in this notice, use of LNG in cooling energy is to be actively promoted, relying on the layout of existing LNG facilities.
- A Three-Year Action Plan for building a Green, Low-Carbon and High-Quality Development Pilot Zone has been issued by Shandong Province (2023-25).

According to the plan, several ‘Mt’-scale LNG receiving terminals will be built in Qingdao and Yantai ports leading to the overall creation of a 10 Mt coastal LNG receiving and discharging base.

- Guidance on Energy Work. Under the guidance, the intensive layout of gas storage facilities will be promoted with underground gas storage as the primary, and coastal LNG storage tanks as auxiliary.
- A Discussion Draft of Natural Gas Utilisation Policy has been released to the public for comments. According to this draft, the following users are classified as the precedence class:
  1. Ocean transportation, engineering, public vessels and marine engineering equipment (including dual fuel and LNG as a single fuel) for the development, utilisation and protection of the ocean.
  2. Transportation, engineering, public vessels and equipment using LNG as a single fuel in inland rivers, lakes and coastal areas, cargo trucks, inter-city passenger vehicles and other transport vehicles fueled by LNG.
- Shenzhen Carbon Peak Implementation Plan:

The Dapeng LNG Corridor is intended to support the role of natural gas. It includes construction of Shenzhen Natural Gas Reserve and Peaking Storage Phase II, Guangdong Dapeng LNG Receiving Terminal expansion project gas storage facilities, and Shenzhen LNG Emergency peaking Station Phase II of PipeChina.

Promotion of the Shenzhen Natural Gas Trading Center will continue, with completion of the LNG bunkering center in East Asia to be accelerated, refueling 500 000 cubic meters of bonded LNG (liquid) on international sailing ships by 2025. The project includes plans to attract domestic and high-quality foreign gas enterprises to set up trading companies in Shenzhen, all aiming to build a natural gas trading hub city.

1.5 China LNG Trade CNY Cross-Border Settlement

A highly significant geopolitical development in 2023 was the establishment of the Chinese yuan as a reference currency in LNG trading and cross-border settlement, as is shown in the sequence of events outlined below:

a) China’s first yuan-settled purchase of LNG was completed in March 2023 by CNOOC and TotalEnergies in March via the Shanghai Petroleum and Natural Gas Exchange (SHPGX), which launched international LNG trading in August 2020.

b) In April 2023, a unit of China’s state-owned PetroChina and a subsidiary of UAE’s Abu Dhabi National Oil Co (Adnoc) also completed a cross-border LNG trade settlement in yuan.

c) In August 2023, China National Offshore Oil Corporation (CNOOC) and Singapore’s Pavilion Energy completed an international LNG trade settled in yuan, this being the first CNY-settlement transaction for LNG overseas sales, according to a statement by the SHPGX.

d) China International United Petroleum & Chemicals Co. Ltd, a wholly owned subsidiary of Sinopec, completed its first CNY settlement transaction for LNG purchase with ADNOC.

1.6 LNG Shipping and Bunkering

In 2023, China has made further progress on building of LNG carriers and LNG bunkering services.

Firstly, under the new round of development planning for 2026-28, large Chinese shipyards have obtained continuous orders, allowing Chinese companies' global share of the LNG carrier market to soar from 7% to 35%. Chinese shipbuilders won 55 orders for large LNG carriers in 2022.

Secondly, three companies have conducted LNG bunkering business for ocean vessels in China. The first is Shanghai SIPG Energy Service Ltd, owned by Shanghai International Port Group (SIPG). It owns a 20 000 cubic meter LNG bunkering vessel, the largest in the world. Since February 2023, it has provided bunkering services for CMA-CGM, ZIM and other shipping companies 50 times, for a total bunkering amount of 71 million MMBtu. It also signed an LNG bunkering standard terms agreement with Mediterranean Shipping Company Limited (MSC) on 21 September 2023. The second company is Shenzhen International LNG bunkering - PetroChina, Ltd. Its bunkering ship capacity is 8 500 cubic meters. and it has provided bunkering services for CMA CGM container vessels and bulk carriers. The third company is International Marine Clean Energy Ltd., CNOOC (Shenzhen), which has refueled CMA CGM container vessels and oil tankers. CNOOC has also signed an international LNG bunkering cooperation agreement with Pavilion Energy and Gasum to provide global integrated LNG bunkering services in China, Singapore and Europe.

1.7 New LNG Purchase and Sale Agreements

Since the start of 2023, Chinese companies have signed ten LNG contracts.

One is a sales contract signed between PetroChina and the Electricity Generating Authority of Thailand (EGAT) in August 2023.

The other nine are purchase contracts, representing a total annual contract quantity (ACQ) of about 10.9 MMtpa (see table below).

Date Signed	Seller	Buyer	Contract Type	ACQ mmtpa	Start Date	Contract Duration (Years)
Sep-23	PetroChina	EGAT	LNG SPA	1.2	2025-01-01	3
Sep-23	ADNOC LNG	PetroChina	LNG SPA	0.2	2028-01-01	5
Jul-23	Mexico Pacific Limited	Zhejiang Energy Group	LNG SPA	1	2028-12-01	20
Jun-23	Cheniere Marketing	ENN Natural Gas	LNG SPA	1.8	2030-01-01	20

Date Signed	Seller	Buyer	Contract Type	ACQ mmtpa	Start Date	Contract Duration (Years)
Jun-23	Cheniere Marketing	ENN Natural Gas	LNG SPA	0.9	2026-07-01	4
Jun-23	Qatar Energy	CNPC	LNG SPA	4	2026-01-01	27
Apr-23	PETRONAS	PetroChina	LNG SPA	0.6	2025-01-01	5
Apr-23	PETRONAS	PetroChina	LNG SPA	0.4	2023-05-01	9
Feb-23	Venture Global LNG	China Gas Holdings	LNG SPA	1	2027-07-01	20
Feb-23	Venture Global LNG	China Gas Holdings	LNG SPA	1	2026-07-01	20

***Box 1**: **China LNG related chronological events list in 2023**.*

Chinese LNG capacities are continuing to grow at a steady pace. Some LNG regasification terminals have reached significant milestones, while new projects have been approved. A record of these events is shown below for reference.

a) On 7 February 2023, the main construction of the first 27 ,000 cubic meters of LNG storage in the Guangdong-Hong Kong-Macao Greater Bay Area (GBA) was completed. It is part of the second phase of CNOOC's Jinwan Green Energy Port project. The storage tank will greatly enhance the security of natural gas supply in the GBA.

b) On 14 May 2023, Hong Kong FLNG launched a trial operation as the world's largest offshore LNG terminal with a capacity of 263 000 cubic meters. On 21 September 2023 the terminal was formally put into operation.

c) On 18 June 2023, the first phase of the Caofeidian Xintian Company's Tangshan LNG project was put into operation and entered production trial stage. This project has a designed annual unloading capacity of 12 Mt, planning and construction of twenty LNG storage tanks, each with a capacity of 200 000 cubic meters, and two docking and unloading berths, with a total investment of CNY 25.39 billion (EUR 2.98 billion). On13 July 2023, the Caofeidian Company signed a strategic cooperation agreement with Shanghai Oil and Gas Trading Centre (SOGTC) to jointly expand the service of LNG receiving terminals and to promote the coordinated and orderly development of the whole natural gas industry chain.

d) On 21 June 2023, the Jiangsu Rudong LNG receiving terminal project, owned by China Resources Gas, began construction ahead of schedule at Yangkou Port, Rudongyang Sunshine Island. Four LNG berths are under construction in Yangkou port. When fully completed, Sunshine Island annual handling scale will reach 22 Mt, equivalent to about 30.8 bcm of natural gas.

e) On 25 June 2023, the largest LNG storage tank in China, and the first 270 000 cubic meter LNG storage tank, was completed in Qingdao, Shandong Province. When in operation, the Qingdao LNG terminal will have an annual transfer capacity of 7 Mt.

f) According to a Shell China statement, a medium- and long-term LNG terminal use agreement was signed with PipeChina on 20 June 2023.

g) On 28 July 2023, it was reported that sea use by the Hanas Putian LNG project was approved by the State Council, with an allocated sea area of 2 107 acres. The project includes one new LNG berth and two LNG storage tanks, each with a capacity of 200 000 cubic meters.

h) On 10 September 2023, Jiangsu Guoxin Rudong LNG Phase II project was approved to enter construction preparation stage. After the completion of the two phases of this project, total tank capacity will be 800 000 cubic meters, the maximum gas storage capacity will be 480 million cubic meters, and maximum daily gas supply can reach 60 million cubic meters, guaranteeing the gas needs for the province's industries for three days. The LNG special receiving and unloading terminal supporting the project has an annual loading capacity of 800 000 tons and an annual turnover capacity of 6 Mt.

i) Tianjin Dagang port forms the LNG receiving and unloading pattern of 'one port two enterprises (Sinopec LNG and Beijing Gas LNG) three berths). Sinopec Tianjin LNG terminal Phase II is completed and will be put into operation by the end of 2023, with gas storage of 1.08 bcm, while Beijing Gas LNG has entered its commissioning phase with gas storage of 1.2 bcm.

j) Zhejiang Energy has started construction of its Zhoushan Liuheng LNG Receiving Terminal Phase I. A special terminal is planned for 150 000-ton LNG vessels, four storage tanks, each with a capacity of 220 000 cubic meters, and corresponding process facilities. After completion, it could supply 8.4 bcm of natural gas per year.

k) In Yantai, three LNG receiving terminals are under construction which are planned to come into operation by the end of 2023. Longkou Nanshan regasification terminal belongs to PipeChina with a receiving capacity of 20 Mt of LNG per year and gas supply capacity of 28 bcm per year. Sinopec Longkou is another terminal with the receiving capacity of 6.5 Mt/yr. Xigang LNG receiving terminal has a maximum capacity of 5.9 Mt/yr.

l) Guangxi Province has announced its intention to accelerate construction of large-scale gas storage facilities at coastal LNG receiving terminals in Beihai and Fangchenggang.

1.8 Cooperation with European Companies

In its European Business Position Paper 2023-24 released in the summer of 2022, the EU Chamber of Commerce in China highlighted key recommendations relating to natural gas in China.

Among them several deserve to be quoted and highlighted in this report, as they are relevant to the current overall climate for foreign investments and the overall energy business environment in China. The recommendations follow:

- Emphasise the role of gas in achieving carbon neutrality in China's energy policies.
- Accelerate reform of the gas infrastructure regulatory regime:
    1. Open investment to all entities, including private companies and foreign-invested enterprises.
    2. Ensure open access to all upstream producers and downstream end-users.
    3. Clarify the conditions of third-party access for natural gas infrastructures.
    4. Optimise the terms of terminal use agreements (short, mid and long-term) in tariffs, conditions of capacity attributions and prioritisation, penalties.
    5. Adopt non-discriminatory rules for the sale of infrastructure capacity.

- Encourage provincial pipeline companies to open to both PipeChina Co. as well as foreign enterprises.
- Encourage PipeChina Co. to open to foreign equity.
- Improve downstream competition by giving smaller companies fair and open access to supply and allowing city gas companies and industrial companies to source directly from gas producers.
- Encourage the building of gas storage systems, particularly underground storage, that are open to all domestic and international investors.
- Develop underground gas storage in a market system with an independent performance index.
- Clarify market regulation to foster foreign direct investments in natural gas infrastructures to improve security of supply and reduce imports needs.
- Encourage LNG bunkering by setting up national standards in line with international ones.
- Incentivise the deployment of methane abatement measures and technologies along the gas value chain.

1.9 Business Opportunity Considerations

Recommendations for market reform have previously been published in earlier editions of the European Chamber Position Paper and in various China-EU exchange forums. However, the need for fundamental gas market reforms remains strong.

Energy is a sensitive and national security matter. This is true for China, as it is for any sovereign state. Multinational energy companies have demonstrated their value in providing end-users their products and services at the best cost as well as bringing innovation and creating value if allowed to operate at full market scale. However, the conditions in which foreign energy entities can operate and develop their activities in China have remained challenging over several decades.

Moreover, as evidenced by the paucity of breakthrough announcements in the field of energy cooperation in recent years, it seems that barriers inherent to the specific mix of centralised and decentralised structure of the Chinese administrative structure are preventing foreign energy companies from playing an effective role in the economic development of the country.

It is therefore essential that far-reaching reforms, such as those recommended in the previous chapter, can be carried out as fast as possible in the gas sector, allowing foreign companies – large and small – to develop safely and, in return, allowing Chinese companies an international move upmarket enabling them to effectively achieve the ambitious carbon neutrality targets set by the country' s authorities.

Foreign entities already operating in China, which have successfully navigated its complex environment and already demonstrated their capabilities to invest in national and regional gas infrastructures, should be accorded priority status and allowed to participate in the development of the Chinese gas sector more widely in all its dimensions, from the upstream to the downstream of the value chain.

Worsening global economic conditions, recurrent crises, high interest rates, the pressure of both geopolitical competition and energy transition challenges, are all signaling the need for a higher level of cooperation between China and the EU in the energy sector in general, and the natural gas/LNG field in particular.

2. Hydrogen

2.1 Introduction

Today, hydrogen represents only a tiny fraction of the global energy mix. It comes also with a twist: hydrogen is currently essentially produced from fossil fuels (natural gas and coal). To consider it as a fuel of first choice in an expanded version of what it is today would therefore require cost-effective, decarbonised processes to be developed concomitantly to address related emissions within the existing supply chain.

Compared to natural gas, the uses for hydrogen appear more limited due to its relatively low energy efficiency. This points in the direction of specific but limited uses like transport and industry. Additionally, hydrogen may also be able to play a role in ensuring the stability of electricity grids.

What is at stake here is the rapid development of new technologies, equipment and infrastructure, and market instruments, requiring the successful, coordinated implementation of dedicated supporting policies.

Various international institutions have debated the role hydrogen could play in China and globally.

In 2021, the IEA stated in a special report that 'Hydrogen could contribute to China's energy system decarbonisation strategy, such as through the use as a fuel and feedstock in industrial processes; in fuel cell electric transport, and for the production of synthetic hydrocarbon fuels for shipping and aviation.'

Thanks to its large share of the global chemical industry and its huge oil refining capacity, which are the primary sources of hydrogen demand today, China leads the world in hydrogen production, but its coal-reliant production is emissions-intensive. In 2020, hydrogen production in China was around 33 Mt, or 30% of the world total, mostly produced from coal (two-thirds) with correlated emissions of around 360 Mt of CO_2.

Long-term hydrogen development therefore depends on strategic supply and demand choices and must include carbon storage if methane-based (see below section on CCUS).

To be emissions-neutral, hydrogen must be produced from renewable energy or nuclear electrolysis. Under such conditions, hydrogen that is produced from coal or natural gas with embedded CCS can only play a role during the transition period.

The future is therefore green hydrogen i.e., hydrogen produced from renewable or nuclear electrolysis.

Both China (2022, Medium and Long-Term Development Plan for the development of the Hydrogen Industry 2021-35) and the EU (A Hydrogen Strategy for a Climate-Neutral Europe) have released hydrogen dedicated strategies. While the EU and several of its Member States have set detailed quantitative targets, China has been reluctant to do the same until very recently, reflecting its initially limited confidence in developing a self-reliant and cost-effective value chain for green hydrogen. However, as shown in this report, events in 2022 and 2023 and trends in the green side of the industry appear to show an inflexion in this strategy driven by ambitious initiatives, notably in some regions and provinces.

Because of these signs of a sector building momentum, options for cooperation between China and the EU may be developing in the areas of hydrogen value chain governance, supportive policy making, decarbonisation, and industrial applications.

These could represent sizeable business opportunities for European companies which may be able to engage with Chinese firms as suppliers (for instance manufacturers of electrolysers or hydrogen producers) as well as R&D and joint venture partners.

Clearly, the benefits for the European side should be weighed as usual against the risks associated with accelerating the development of Chinese manufacturing and the sharing of technology.

With this in mind, we will review first the status of the hydrogen industry in China, focusing on the 2022 and 2023, then elaborate on business climate and opportunities after a brief overview of the outlook for hydrogen development in the EU.

2.2 China's National Hydrogen Policy: Analysis

2.2.1 National Policy 2022 Release: Establishing 2025 Goals to Support Renewable Energy Hydrogen Production

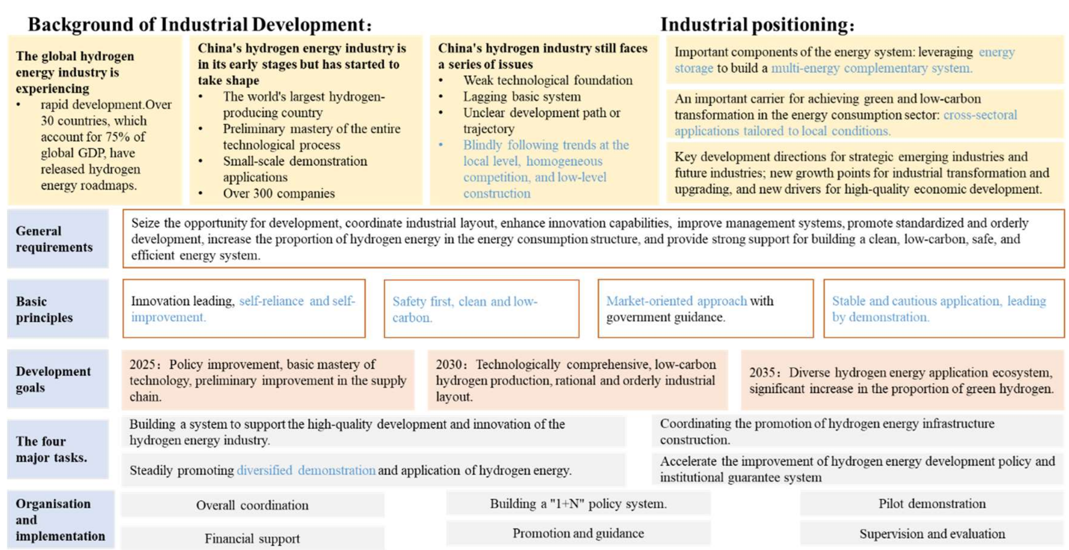
On 23 March 2022, the National Development and Reform Commission (NDRC) and the National Energy Administration (NEA) jointly released the 'Medium and Long Term Plan for the Development of the Hydrogen Energy Industry (2021-35)'. This document for the first time provides a clear positioning for the development of hydrogen energy, especially in the broader context of national energy strategy. In this plan, hydrogen is stated to be an important component of China's national energy system, an vital carrier of the green transformation, and a key field of development for emerging industries.

The document proposes a quantitative goal: 'By 2025, the number of fuel cell vehicles (FCV) will be about 50 000, and a batch of hydrogen refueling stations will be deployed and constructed accordingly. The renewable energy hydrogen production capacity will reach 100 000-200 000 tons per year.' It is noteworthy that the goal of '50 000 fuel cell vehicles' is in line with the overall fuel cell vehicle demonstration city cluster subsidy policy proposed by the Ministry of Industry and Information Technology in 2021. This means that the central subsidy of the country is a key element in supporting promotion of EVs to achieve its goals. However, the goal of producing 100 000-200 000 tons of hydrogen per year from renewable energy sources appears relatively conservative considering that in recent years, several of the projects currently under construction already exceed 10 000 tons. For instance, some local governments, such as Inner Mongolia, are planning to produce 500 000 tons per year by 2025.

In terms of encouraging development direction, in addition to the previous reference to support for the transportation sector, the document focuses on ‘energy storage, electricity, and industrial sectors’. Renewable energy hydrogen production will play an important role in supporting the development of hydrogen energy, and energy storage and electricity will become important application directions.

This means that the new policy is clearly prioritising hydrogen sourced from renewables rather than from fossil fuels, which are currently the source of most of the hydrogen produced in China.

Figure 2.1: Medium and Long Term Development Plan for China's Hydrogen Energy Industry

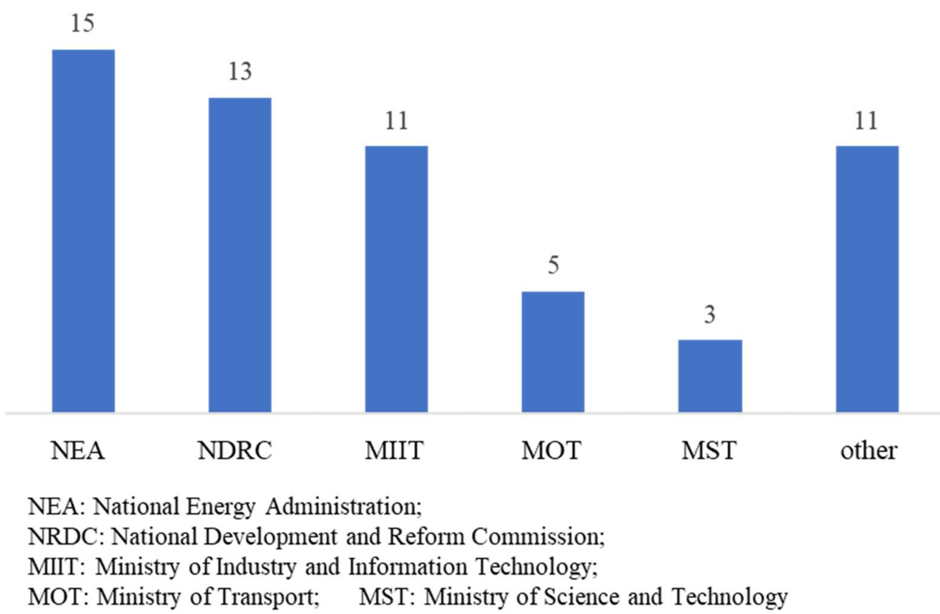


Source: Government websites, organised by China Automotive Technology&Research Center.

2.2.2 National Ministerial-Level Policies: Hydrogen Energy is More Comprehensively and More Widely Integrated into Other National Policies

According to EnerScen Research analysis, from 2022 to the end of June 2023, various national ministries and commissions issued a total of 58 policies related to hydrogen that guide, encourage, and support the development of the hydrogen energy industry. The policy release situation is illustrated in Figure 2.2 (including policies jointly issued by multiple departments and bureaus). Among these publications, the establishment of hydrogen energy related standards has received special attention, with 15 national ministerial policies mentioning ‘standards’, mostly along with ‘new energy storage’, covering multiple links in the hydrogen energy industry chain. In addition, policy support has expanded from fuel cells to the entire industry chain, with emphasis on hydrogen production, hydrogen storage, hydrogenation, and fuel cells.

Figure 2.2: Number of hydrogen-related policies released by various national ministries and commissions from 2022 to the end of June 2023



Source: Official websites of various ministries and commissions, organised by EnerScen Research

Among these, the National Development and Reform Commission (NDRC) and the Energy Administration (NEA) are the main institutions responsible for issuing policies in the energy sector, and the hydrogen energy industry is mentioned in various contexts:

- The first is to promote cost reduction and efficiency enhancement of renewable energy, such as proposing joint research focusing on technologies related to efficient and low-cost hydrogen production.
- The second is to promote the diversified and orderly utilisation of hydrogen energy, including mentioning hydrogen energy in the 14th Five-Year Plan', proposing 'to promote the industrialisation of renewable energy power generation and hydrogen production, create large-scale green hydrogen production', and also mentioning the hydrogen energy field in energy-saving and carbon reduction transformation, as well as green development of the shipping industry.
- Thirdly, the policies encourage international cooperation and development. This involves improving the internationalisation of the new energy industry, strengthening international technological cooperation and research and development, and issuing policies such as the 'Opinions on Promoting Green Development of the Belt and Road Initiative'.
- Fourthly, the policies encourage acceleration of the establishment of hydrogen energy safety regulations, such as establishing relevant requirements for accident prevention, e.g., the fire hazard level of hydrogen refuelling stations is ranked as a severe hazard level.

- In addition, other ministries such as the Ministry of Industry and Information Technology (MIIT), the Ministry of Transport, the Maritime Safety Administration, and the Ministry of Science and Technology (MST) have issued over 20 policies relating to the development of the hydrogen energy industry.

These policies mainly focus on hydrogen energy applications and technological development. In terms of hydrogen energy applications, policies relating to hydrogen energy issued by the MIIT encourage the use of hydrogen energy as a green alternative in traditional high-energy-consuming industries. The Maritime Safety Administration (MSA), the Ministry of Transport (MOT), and others have issued policy documents supporting technological breakthroughs in the application of hydrogen fuel on inland and domestic navigation vessels, as well as exploring the use of methanol and ammonia fuel on vessels. In terms of R&D relating to core hydrogen energy technologies, the MST focuses on supporting the exploration and development of new hydrogen production and storage technologies, as well as various cutting-edge technologies for electrolytic water hydrogen production.

Table 2.1: Representative Policies Relating to Hydrogen Energy Released by the National Development and Reform Commission

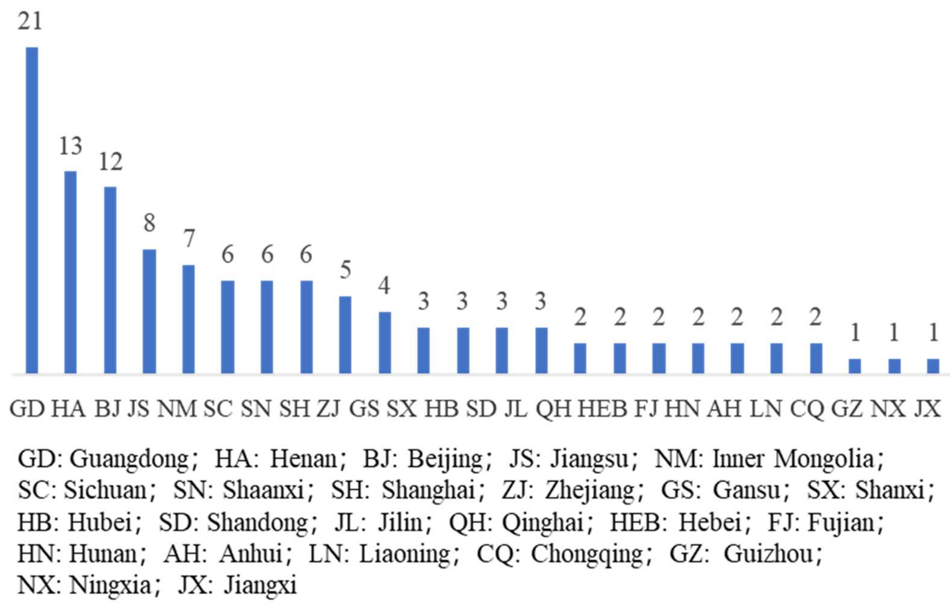
Release time	Institutions	Policy Name	Content
2022.3.23	NRDC	Medium and Long Term Plan for the Development of Hydrogen Energy Industry (2021-2035)	By 2025.a relatively complete supply chain and industrial system will be preliminary established. By 2030, a relatively complete technological innovation system for the hydrogen energy industry. as well as a clean energy hydrogen production and supply system, will be formed. By 2035, a hydrogen energy industry system will be formed.
2022.6.1	NRDC	The 14th Five Year Plan for the Development of Renewable Energy	Promote the large-scale demonstration of renewable energy hydrogen production, and promote the industrialization of renewable production in areas with low renewable energy generation costs and good conditions for the development of hydrogen energy storage and transmission industries, creating a large-scale green hydrogen production base.
2022.9.26	NRDC	Guiding Opinions on Accelerating the Green and Intelligent Development of Inland Ships	Strengthen the research and development of technical equipment such as marine hydrogen fuel cell power systems, hydrogen storage systems, and refueling systems, explore the application of hydrogen fuel cell power technology in passenger ships, and encourage the use of green hydrogen electrolyzed by renewable energy such as solar energy.

NRDC: National Development and Reform Commission

2.2.3 Local Government Policies: Different Regions' Policy Priorities are Beginning to Change

Between the start of 2022 to the end of June 2023, local governments in China issued 186 policies relating to hydrogen energy and 120 special policies relating to hydrogen energy. The provinces that issued the most hydrogen energy special policies were Guangdong, followed by Beijing and Henan (see Figure 2).

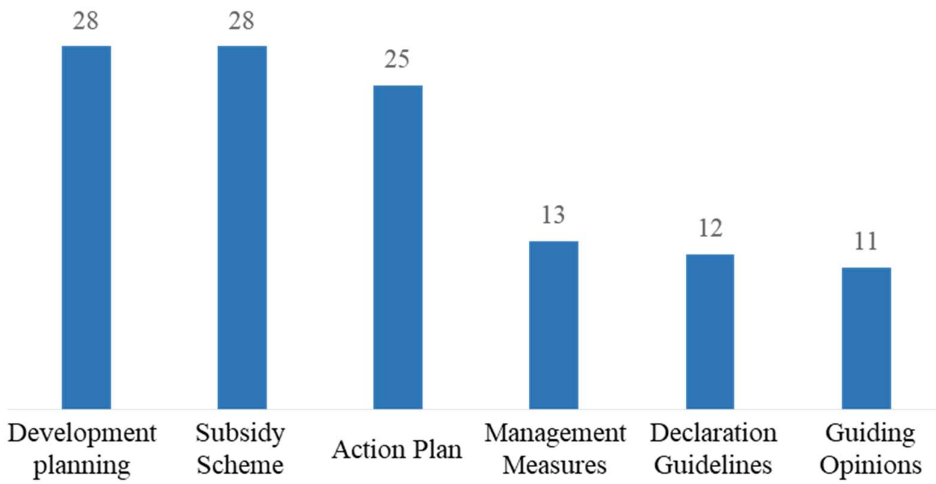
Figure 2.3: Release of hydrogen energy special policies in various provinces of China from 2022 to June 2023



Source: Local government websites, compiled by EnerScen Research.

In terms of the types of the special policies issued on hydrogen energy, most relate to development plans, followed by subsidy plans and action plans (see Figure 2.4).

Figure 2.4: Local government specialised hydrogen energy policy issued from 2022 to June 2023



Source: EnerScen Research.

As far as local policies are concerned, they can be mainly divided into two categories. One category relates to developed provinces mainly in the eastern region, such as Beijing, Shanghai, Guangdong, and a few other places nearby. They are included in the 2021 urban agglomeration planning and have a good foundation in scientific research and manufacturing, and aim to cultivate the creation of technologically advanced and highly competitive enterprises. The other category relates to provinces mainly located in the northwest region, which has vast renewable energy resources, which want to use hydrogen energy as an important carrier for utilising renewable energy, the ultimate goal being to foster new economic growth and new jobs.

- **Guangdong**: The development plan for the hydrogen energy industry got under way some time ago and has been implemented by the county government. Financial subsidies focus on supporting the construction and operation of hydrogen refuelling stations and the promotion and application of fuel cell vehicles.
- **Beijing**: This is where the highest number of hydrogen energy special policies have been released, with a total of 24 gas energy policies released so far(including 10 district level government policies). Relying on strong financial strength, the subsidy policy involves the entire hydrogen energy industry chain, and the subsidy intensity is high. For example, Beijing’s Daxing District has proposed to provide up to CNY 20 million of subsidies per year for each hydrogen energy enterprise's R&D and equipment investment in Daxing.
- **Shanghai**: Based on the development advantages of the automotive industry in this area, the province aims to accelerate the development of the fuel cell vehicle industry.
- **Inner Mongolia**: Relying on its wealth of natural resources such as wind and solar, the province is focusing on supporting the construction of wind and solar hydrogen storage projects to provide safe and sustainable hydrogen supply for the fuel cell vehicle demonstration city cluster.

- **Xinjiang**: Based on the region's rich resources and strong local industrial foundations, its local government is prioritising hydrogen energy technology innovation and industrial application demonstration, promoting west-to-east hydrogen transmission, and creating a national large-scale green hydrogen supply and export base.

2.2.4 Status of Standards and Certifications Policies: Top-Level Policy Has Begun to Promote Comprehensive Construction

China's hydrogen energy industry standard system has begun to take shape. According to EnerScen Research, as of July 2023, a total of 292 standards at all levels have been released in the domestic hydrogen energy field, including 106 national standards, 30 industry standards, 137 group standards, and 19 local standards, covering various stages of production, storage, transportation, and refuelling.

On 8 August 2023, the National Standardisation Administration, the National Development and Reform Commission, the Ministry of Industry and Information Technology, the Ministry of Ecology and Environment, the Ministry of Emergency Management, and the National Energy Administration jointly issued the 'Guidelines for the Construction of the Hydrogen Energy Industry Standard System (2023 Edition)'. This hydrogen energy guide is the leading document guiding development of the hydrogen energy standard system, playing a role in top-level design and overall planning. Its core task is to promote the adaptation of the hydrogen energy field to new industrial development trends and carry out the development of full industry chain technical standards.

This comprehensive hydrogen energy 'guideline' includes several features that are worth highlighting. Firstly, it promotes breakthroughs in core technology standards at every link of the entire industry chain, with a focus on key equipment standards relating to production, storage, and utilisation. This includes requirements for PEM electrolysis cells, hydrogen compressor product specifications, and others. Secondly, it sets out a proactive plan for new technological paths and associated standards. Technologies still in the early stages of R&D and demonstration, such as photolysis hydrogen production, organic liquid hydrogen storage, and hydrogen internal combustion engines, are also included in this standardisation plan. Thirdly, it emphasises communication and cooperation between standard-setting organisations. This includes the joint promotion of enterprise, group, and industry standards alongside national standards to accelerate standard generation; as well as a focus on the transfer of internationally-advanced hydrogen energy standards and a strengthened role for China in international standard-setting.

The hydrogen energy standard system will accelerate the progress of major projects and restructure the industrial landscape. The impact of improving standards on the hydrogen energy industry will be felt in four ways:

- The standard is the minimum requirement for industry products to enter the market, and a certain threshold will be set to prevent generation of low-end overcapacity.
- Standards will accelerate supply chain construction and eliminate outdated enterprises and products.

- Standards are a key element in ensuring project and product safety and play a significant role in promoting the implementation of large projects and infrastructure construction.
- The integration of domestic and international standards will also assist domestic enterprises in their internationalisation.

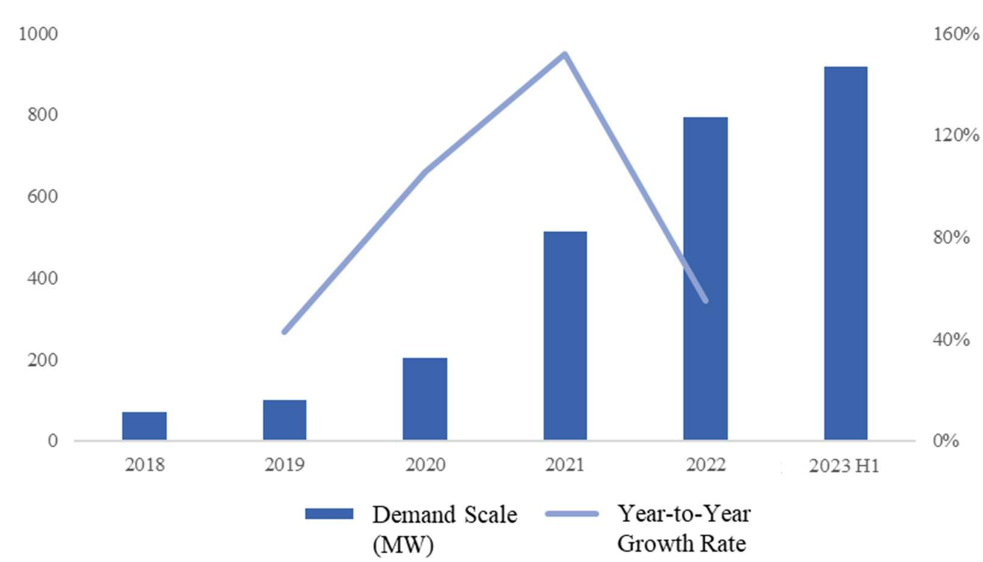
2.3 Current Business Scale and Objectives

2.3.1 Hydrogen Production Scale: The Increase in Planned 10 000-ton Hydrogen Production Projects Has Driven a Rapid Increase in Demand for Electrolytic Cells

From the start of 2022 to June 2023, a total of 28 green hydrogen projects have been put into operation, and new green hydrogen capacity has reached about 30 000 tons/year. As of June 2023, the total number of green hydrogen projects under construction and planning is approximately 342, of which 189 projects have a disclosed production capacity of over 5 Mt per year.

Demand is continuing to grow for electrolytic cells in China. The demand has increased from 70 MW in 2018 to 795 MW in 2022, representing a compound annual growth rate of 63%. The growth rate had slowed in 2022 due to factors such as the pandemic lockdown. But the demand for electrolytic cells in the first half of the 2023 has been catching up, already surpassing the full year of 2022, at 920 MW, and is expected to continue to grow rapidly during the rest of 2023.

Figure 2.5: Scale of demand for electrolytic cells in China from 2018 to June 2023



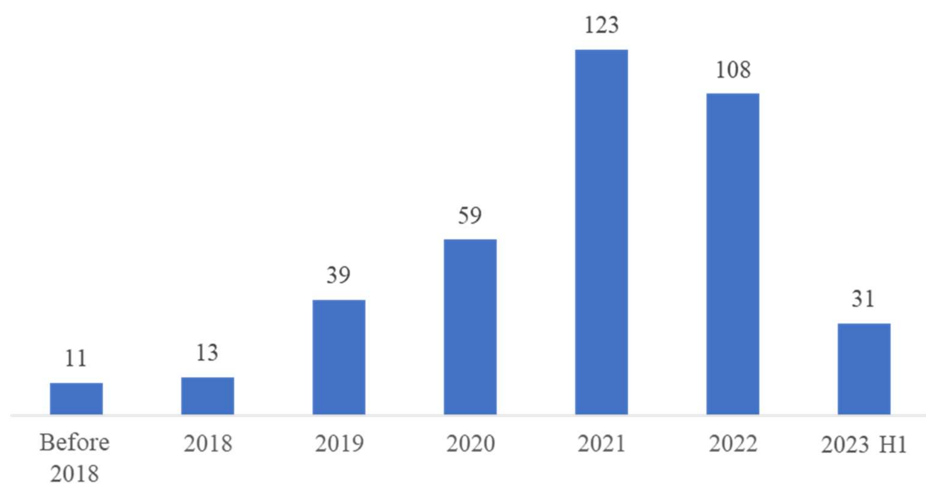
Source: Public data compiled by National Institute of Energy, Economics & Technology.

2.3.2 Scale of Hydrogen Refuelling Stations: Construction Has Started to be Rationalised

According to EnerScen data, 2021 marked a peak period for the construction of hydrogen refuelling stations in China, with 123 new stations built and a cumulative total of 245 stations completed. However, by 2022, the number of hydrogen refuelling stations in China had started to decline, with only 108 completed. The pace continued to decline in 2023: as of June 2023, only about 31 new hydrogen refuelling stations were built in China, a year-on-year decrease of over 30%.

The decline in the construction pace of hydrogen refuelling stations may be related to oversupply. In the main cities promoting fuel cell vehicles, the number of hydrogen refuelling stations built has exceeded the demand for fuel cell vehicle refuelling, leading to a decrease in the operating rate of completed hydrogen refuelling stations. These cities are therefore beginning to pay more attention to economic factors, instead of continuing the construction spree.

Figure 2.6: Number of domestic hydrogen refuelling stations completed as of June 2023

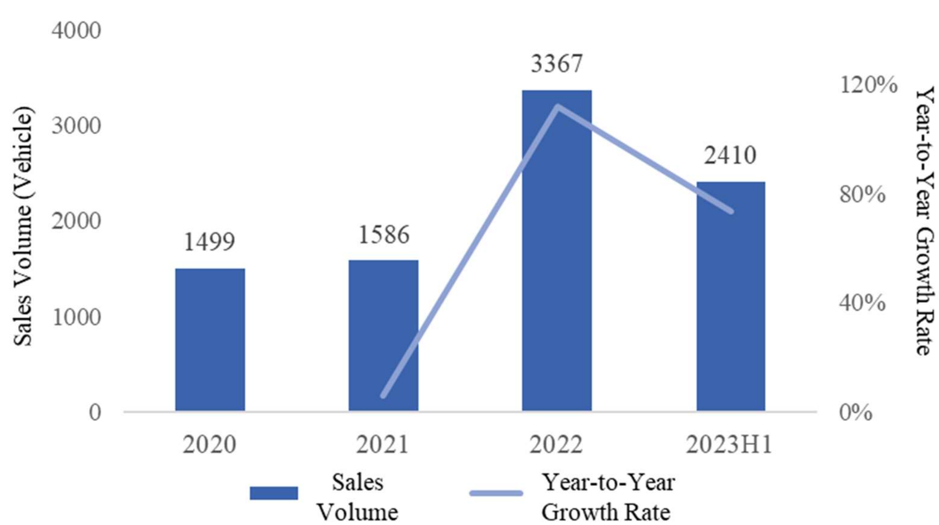


Source Public data, EnerScen Research.

2.3.3 Scale of Fuel Cell Vehicles: At a Low Rate

Annual sales of fuel cell vehicles (as distinct from electric vehicles) in China remain in the range of a few thousand vehicles in 2023. According to data from the China Association of Automobile Manufacturers, in the first half of 2023 sales of fuel cell vehicles in China reached 2 410 units, a year-on-year increase of 73.5%, bringing the total number of fuel cell vehicles on the road in China to approximately 15 000.

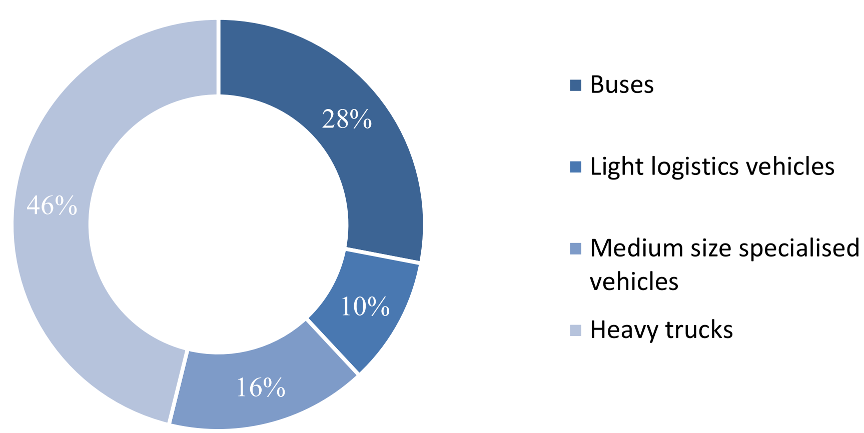
Figure 2.7: H1 sales of fuel cell vehicles in China 2020-23



Source: China Association of Automobile Manufacturers.

In terms of vehicle sales structure, heavy trucks represent the majority (see Figure 2.8). According to data from the China Association of Automobile Manufacturers, in 2022 sales of fuel cell vehicles in China accounted for 26.4%, 5.0%, 17.2%, and 51.4% of passenger cars, light logistics vehicles, medium specialised vehicles and heavy trucks, respectively. In the first half of 2023, the categories did not change significantly, with passenger cars, light logistics vehicles, medium specialized vehicles, and heavy trucks accounting for 28.0%, 10.1%, 15.8%, and 46.1%, respectively.

Figure 2.8: H1 sales of fuel cell vehicles in China in 2023



Source: China Association of Automobile Manufacturers, compiled by EnerScen Research.

2.4 Hydrogen Industrial Chain

2.4.1 Hydrogen Production Industry Chain: Alkaline Electrolyser Products are Homogenised, Number of PEM Electrolyser Enterprises Has Increased

In China, the hydrogen production equipment that has entered the industrialisation stage mainly consists of two types: alkaline electrolysers and PEM (Proton Exchange Membrane) electrolysers.

Alkaline electrolysers are cost-effective and can reach a power capacity of up to 5 MW per unit, making them suitable for bulk application in large-scale renewable energy hydrogen production projects, ranging from tens of MW to several hundred MW. However, there are drawbacks, including relatively lower energy utilisation efficiency and a poorer adaptability to fluctuating power output from wind and solar sources.

PEM electrolysers, on the other hand, exhibit rapid response and good adaptability to the variability of wind and solar power, with generally higher energy utilisation efficiency compared to alkaline electrolysers. The drawback of PEM electrolysers resides in their market price which is relatively high, approximately five times the price of alkaline electrolysers.

In recent years, the electrolyser manufacturing industry in China has experienced rapid development and demonstrates a number of new trends in product technology and applications.

Firstly, there has been a rapid increase in the number of alkaline electrolytic cell manufacturers in China, resulting in a certain degree of product homogenisation. Due to the relatively well-established supply chain for alkaline electrolyser components in China, the production and manufacturing barriers for alkaline electrolysers have been lowered, resulting in a rapid increase in the number of companies entering the alkaline electrolyser manufacturing sector. Currently, there are more than 40 manufacturers in China offering alkaline electrolysers, many of which offer electrolysers with a scale of 1000 Nm^3/h or higher. However, there is also a noticeably high level of homogenisation in the structure, components, and performance of China’s alkaline electrolyser products. Many manufacturers are focusing on expanding the specifications of individual alkaline electrolyser units in order to achieve a competitive edge, and there is insufficient investment in the independent development and optimisation of components.

Secondly, PEM electrolytic cells have entered the initial stage of large-scale production.

In 2023, China saw its largest procurement contract for PEM electrolysers. A 50 MW PEM electrolyser procurement contract was signed for a ’green hydrogen to green ammonia’ project in Da'an City, Jilin Province. These electrolysers will be used for hydrogen production powered by wind and solar electricity and subsequent synthesis into green ammonia.

In terms of supply, China has seen a steady growth in the number of PEM electrolyser production facilities. For instance, in April 2023, Cummins Enze Corporation launched its PEM electrolyser production facility in Guangdong. The initial production capacity of this facility can reach 500 MW, with the potential for expansion to 1 GW in its second phase.

With the gradual localisation of upstream components and the continuous improvement of the component supply chain, PEM electrolysers may well achieve significant reductions in both production costs and market prices. For example, the core component of PEM electrolysers in China, the proton exchange membrane, used to be highly reliant on imports from foreign companies such as US-based DuPont and Dow Inc. However, in recent years, companies such as Dongyue Group Ltd have begun to offer domestically produced alternatives.

Electrolytic cell production companies are continuously expanding their output capacity.

The scale of electrolytic cell production capacity construction is growing and moving towards the GW level. According to public data, there are seven electrolytic cell manufacturers in China with GW level production capacity in 2022, and most of their production capacity is centred around alkaline electrolytic cells. This situation is illustrated in Table 2.2.

Table 2.2: Construction of GW Level Electrolytic Cell Production Capacity in China			
Enterprise	**Electrolyser Type**	**Manufacturing Capacity in 2022**	**Ownership**
PERIC Hydrogen Technologies	ALK、PEM	1.5 GW	state-owned
LONGi Hydrogen Energy Technology	ALK	1.5 GW	private
Cockerill JingLi Hydrogen	ALK	1 GW	private
Auyan New Energy Technology	ALK	1 GW	private
CPU Hydrogen Power	ALK	1 GW	private
Tianjin Mainland Hydrogen Equipment	ALK	1 GW	private
SUNGROW	ALK	1 GW	private

Source: Public data, compiled by EnerScen Research.

Moreover, the pace of electrolytic cell production equipment capacity construction is increasing rapidly. In August 2022, Shengqing Hydrogen Production launched its first set of 100 standard cubic meters of alkaline electrolytic water hydrogen production equipment. Only 120 days later, Shengqing Hydrogen Production's 1000 standard square meters of alkaline electrolytic water hydrogen production equipment was successfully launched in Foshan. At present, Shengqing Hydrogen Production has the capacity to produce 50 sets of high-power electrolytic cells per year.

Finally, the concentration of businesses in the electrolytic cell market has intensified. In 2022, the top three manufacturers in China's electrolytic cell sector were Cockerill Jingli, Peric Hydrogen, and Longji Hydrogen, between them accounting for a total domestic market share of about 72%. The top three manufacturers in China's electrolytic cell sector in the first half of 2023 are Peric Hydrogen, Sunshine Power, and Longji Hydrogen, with a total market share of about 60%.

2.4.2 Storage, Transportation and Refuelling: Multiple Modes of Storage and Transportation are Entering the Market

Long-distance hydrogen pipelines are now being implemented in China. In 2022, multiple medium and short distance hydrogen transmission pipelines were constructed, and relevant technical verifications were conducted. In the first half of 2023, work got under way on long-distance hydrogen transmission pipeline construction projects, while hydrogen blending technology using natural gas pipelines has also seen steady progression. The first such project was the 258 km Baotou-Linhe gas pipeline from Inner Mongolia, constructed by Western Natural Gas Company. This is China's first long-distance high-pressure pipeline with hydrogen blending capacity. The second project is Sinopec’s 400 km Ulanqab - Yanshan pure hydrogen pipeline project, launched in April 2023, for which the total investment is CNY 40 billion. Site selection surveys and project planning have already begun. Finally, in a natural gas hydrogen blending pipeline research project, PetroChina has achieved a hydrogen blending ratio of 24%.

Hydrogen transmission pipelines have a large hydrogen transmission capacity and low transmission costs. According to available calculations, the cost of transporting hydrogen by pipeline is much lower than by hydrogen tube trailers. When natural gas is mixed with 25% hydrogen, the hydrogen transportation cost is just half that of the tube trailer; when pure hydrogen is transported by pipeline, the cost is one fifth lower than that of the tube trailer. Construction of hydrogen transmission pipelines is currently at a demonstration or pilot stage, but is expected to peak within three to five years.

Furthermore, the liquid hydrogen industry is set to enter the demonstration and promotion stage, and enterprises will then increase their R&D effort for production and capacity construction. China's liquid hydrogen technology has decades of R&D history which has been successfully applied in the aerospace field. However, its application in civil sectors got under way relatively recently. For a long time, China did not engage in research and manufacturing of civil equipment relating to liquid hydrogen, such as large hydrogen turbo-expanders, ortho-para hydrogen converters and catalysts, liquid hydrogen tanks, liquid hydrogen pumps, and liquid hydrogen refuelling technologies. In recent years, domestic liquid hydrogen technology has gradually entered a period of exceptional achievement through key scientific research and breakthroughs by research institutions and enterprises such as Beijing Aerospace Experimental Technology Research Institute, Zhongke Fuhai, and National Energy Group. In the future, the costs associated with liquid hydrogen will likely improve, and hydrogen transportation between node cities and international ocean transportation hubs is also expected to adopt liquid hydrogen storage and transportation mode. The corresponding demonstration projects for liquid hydrogen are currently at the planning stage.

In addition, domestic cooperation relating to liquid hydrogen technology is being implemented gradually. For example, in June 2022, Beijing Aerospace Experimental Technology Research Institute signed a cooperation agreement with Sinopec Sales Co., Ltd. and Sinopec Safety Engineering Research Institute Co., Ltd. The three parties intend to cooperate in the research and development of key technologies and equipment for liquid hydrogen refuelling, promotion and demonstration of liquid hydrogen refuelling stations, and safe utilisation of liquid hydrogen.

2.4.3 Fuel Cells: Capacity is Growing Faster Than Market Growth; Costs are Falling Rapidly

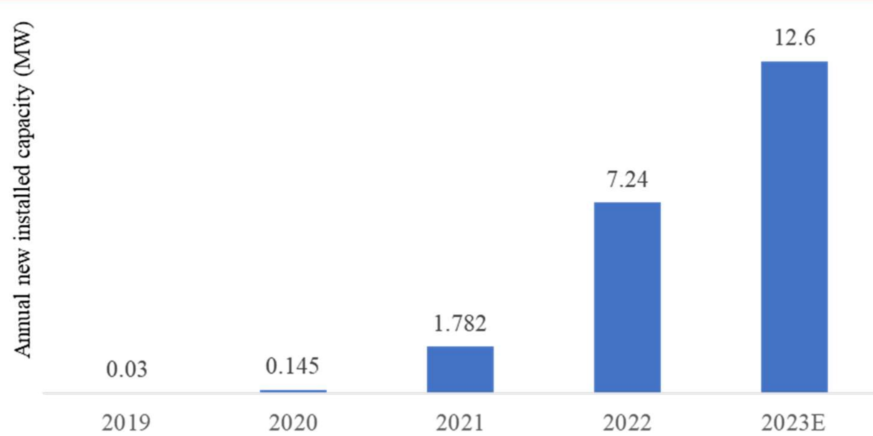
Companies that produce fuel cells and their components are actively expanding their production capacity. As of July 2023, the disclosed fuel cell stack construction capacity in China has reached 200 000 units per year. Eight companies, including Guohong Hydrogen Energy and Weichai, have a stack production capacity of over 10 000 units per year. Driven by the expansion of fuel cell production, the production capacity for fuel cell components and related equipment has also accelerated. For example, Zhejiang Feite has built a metal bipolar plate production line of 3 million pieces per year, which is expected to supply 10 000 units per year for 100 kW fuel cell production capacity. The 1 million m^2/yr proton exchange membrane (PEM) production line currently under construction by Kerun New Materials can produce 100 000 sets/year of 100 kW fuel cells.

As a result, fuel cell systems and components costs are falling. Driven by factors such as technological progress, market demand and expansion of production scale, and decline in marginal costs of production, the overall cost of many key components of fuel cell systems has decreased significantly between 2019 to 2022, especially costs of air compressors, membrane electrodes, bipolar plates, and so on. During this period, the market price of air compressors has declined by about 30% annually, the market price of membrane electrode has dropped by about 27% annually, and the market price of graphite bipolar plate has fallen by about 10% annually.

2.4.4 Other Fuel Cell Application Fields: Stationary Power Generation and Miniaturised Power Systems are Emerging

The application of fixed fuel cell power generation has entered a period of rapid development. According to data from the China Hydrogen Energy Alliance, the newly-built scale of fixed fuel cell power generation in China reached 3.8 MW in 2021 (see Figure 2.9). In 2022, the scale of newly-built projects continued to increase to 7.2 MW, a year-on-year increase of 96%. Of these, PEM fuel cells are the main technological path. In 2022, the fixed power generation scale of PEM fuel cells was 6 693 kW, accounting for 93.0%.

Figure 2.9: Installed capacity of fixed fuel cell power generation in China 2019-23



Source: EnerScen Research, July 2023.

China is also actively promoting the commercialisation and expansion of the light duty fuel cell power market. Here, fuel cell-powered shared bicycles are the leading product, with over 3 500 fuel cell-powered shared bicycles brought into use in China between 2021 to 2023.

Additionally, practical tests and trials have got under way in fields such as food delivery and sightseeing vehicles. In 2022, Meituan (a leading domestic food delivery service) launched China’s first commercial demonstration project for hydrogen-powered electric delivery vehicles in Shenzhen.

Meantime household lightweight power is still in the product launch stage. In 2022, Youon Technology launched China's first commercially-produced hydrogen-powered bicycle. As of

July 2023, online platform sales amounted only to around 50 bicycles (for the month), but the product has not yet reached its full sales potential.

Applications in Industrial Sectors: Green hydrogen as a synthesis of ammonia and methanol has begun to attract attention.

2.5 On Market Expectations and Prospects

2.5.1 China's Green Hydrogen Projects are Entering the 10 000-ton Production Stage

China's green hydrogen projects have entered the 10 000-ton production stage. Since the end of 2023, there has been a rapid increase in the planning of China's 10 000-ton scale projects. As of the end of June 2023, there were over 80 planned 10 000-ton green hydrogen projects, and construction has got under way on more than ten of these projects. In June 2023, China Three Gorges Corporation's Naritsong Green Hydrogen Project and Sinopec's Kuche Green Hydrogen Project, two 10 000-ton green hydrogen projects, were completed. The Sinopec Kuche project was the first to hit the drawing board, and has been under construction for about a year and a half. It has now become the first implemented 10 000-ton green hydrogen project.

Based on the project initiation status and the progress plans disclosed by each planned project, it is likely that China will have no less than ten 10 000-ton green hydrogen projects completed by the end of 2025, accelerating the large-scale development of China's green hydrogen industry.

2.5.2 State-Owned Enterprises (SOEs) Become the Pathfinders and Promoters of the Current Hydrogen Energy Construction in China

Since 2022, nearly one-third of domestic central enterprises have participated in hydrogen energy infrastructure planning, including equipment manufacturing, green hydrogen production and capital investment. According to EnerScen’s compilation of data from renewable energy hydrogen production projects, nearly 300 SOE planning projects have been announced, with planned investments exceeding CNY 400 billion, for a total scale of more than 50 GW. In the construction and planning of green hydrogen projects, the participation of SOEs has reached more than 80%. National Energy Group, China Energy Construction Group and Sinopec have announced the largest total planned investments. Based on their traditional business areas, SOEs in different industries are exploring new energy business models such as hydrogen energy production, hydrogen energy transportation, green hydrogen in the chemical sector, and hydrogen metallurgy. It is not unlikely that as hydrogen energy technology develops, the original business models of these companies will change and overlap, thus promoting the generation of new supply and demand relations and new energy patterns.

2.5.3 The Overall Cost of the Hydrogen Energy Industry Chain Will Steadily Decline

From 2022 to June 2023, the cost and price of hydrogen energy equipment and core components such as electrolysers and fuel cell systems have been going down steadily. On the one hand, Chinese enterprises continue to carry out key technological research and achieve domestic substitution in the higher-cost links of the hydrogen energy industry chain. On the other hand, hydrogen energy-related equipment and parts have begun to enter large-scale production. As the number of related enterprises has swelled, competition between enterprises has intensified, resulting in significant price reductions for hydrogen energy-related equipment and parts.

2.5.4 Chinese Enterprises Start to Actively Seek International Cooperation

A few SOEs cooperate with foreign companies to expand overseas markets and promote capital cooperation at home and abroad. Their activities centre mainly around the electrolytic cell, fuel cell stack and research and development on other products. Some examples follow:

Sinopec and Germany's ThyssenKrupp AG are exploring large-scale, high-efficiency green hydrogen application and supply systems through demonstration projects.

SPIC Hydrogen Energy and the Saudi International Power and Water Company are cooperating in the fields of green electricity hydrogen production and hydrogen energy technology promotion and application.

China Power Overseas Investment Co., Ltd. and Strohm BV, from the Netherlands, are jointly promoting the development of offshore wind power hydrogen pipeline technology.

China's PERIC Hydrogen Technologies has sold its electrolysers to more than 20 countries worldwide and has successfully implemented over 120 projects globally with different hydrogen production capacities. Additionally, PERIC is a primary supplier of H2 production systems for leading natural gas producers worldwide, such as Air Liquide, Air Products, Linde, and Praxair.

These are promising indicators for the potential development of cooperation initiatives and demonstrate the potential yield from synergies between China and the rest of the world.

2.6 A Brief Overview of Hydrogen Development in the EU

Beyond its Hydrogen Strategy for a Climate-Neutral EU, and the Green Deal Industrial Plan, the European Commission is working on a 'Hydrogen Valleys' Roadmap that will provide a strategic framework to enable the EU to achieve the REPowerEU objective, to double the number of Hydrogen Valleys by 2025.

2.6.1 What is the EU Hydrogen Hub Concept 'Hydrogen Valleys'?

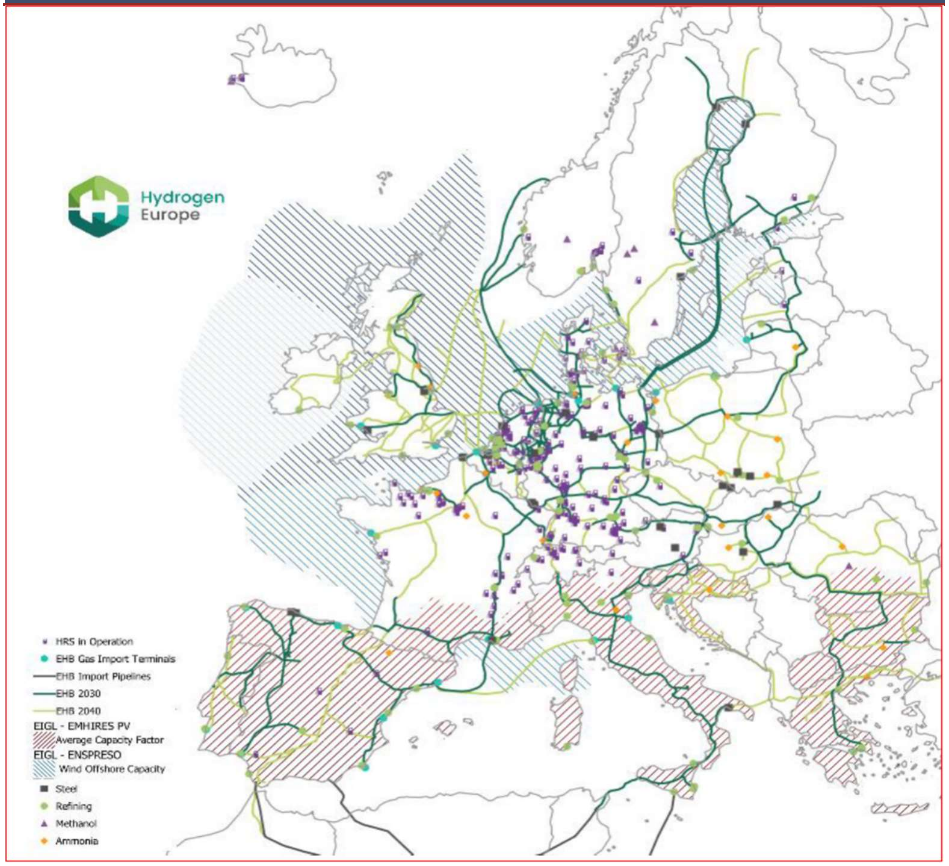
'Hydrogen Valleys' is a concept defined by the European Clean Hydrogen Partnership. 'Hydrogen Valleys' are geographically and industrially integrated areas where existing and future hydrogen applications are combined into an integrated ecosystem that consumes significant amounts of hydrogen. Projects that fall within this definition cover the entire hydrogen value chain: from production, storage, to distribution and end-usage. Some 'Hydrogen Valleys' that have already been implemented present different characteristics based on the amount of clean hydrogen under consideration, number of end-users, or the clustering mode itself (cities, regions, islands, ports, industrial parks, etc.). However, these projects share a defining characteristic: they showcase economically viable and publicly acceptable business cases for various types of hydrogen usage.

2.6.2 'Hydrogen Valleys' Strategic Deployment

With the number of 'Hydrogen Valleys' booming in the EU, a more strategic approach to their deployment is needed. Ideally, 'Hydrogen Valleys' should be deployed in areas where there is easy access to resources for producing hydrogen (i.e., renewable energy, waste, water, land) and close to large or multiple consumers to ensure stable hydrogen demand. They should be on or close to existing, repurposed, or planned hydrogen infrastructure. 'Hydrogen Valleys' can also play an important role in the deployment of import infrastructure, which is needed to meet the REPowerEU import target of 10 Mt of green hydrogen by 2030.

Finally, in the context of the climate objectives set out in the 'Fit for 55' package, REPowerEU and Green Deal Industrial Plan, 'Hydrogen Valleys' will trigger actions that can leverage investments or subsidies from public authorities. This will contribute not only to a more sustainable energy system (hydrogen can be used for long-term storage of energy and feedstock) but also to the EU's resilience. If placed in strategically valuable locations, 'Hydrogen Valleys' can foster and connect local ecosystems and enable the development of hydrogen technologies that would otherwise not be possible due to lack of demand or supply, or infrastructure. This will ultimately contribute to the interconnection between regions and the establishment of the so-called European Hydrogen Backbone (EHB) (see Figure 2.10).

Figure 2.10: European Hydrogen Backbone (EHB)



Source: Hydrogen Europe Partnership.

2.6.3 Value Chain Considerations

To be successful, the hydrogen economy needs to address the inclusive development of the manufacturing components (equipment and materials) within the value-chain.

Therefore, specific attention must be accorded to critical raw materials in the value-chain, particularly in the context of the Net Zero Industry Act and the Critical Raw Materials Act, which both emphasise the requirement of sustainable sourcing and supply, together with ambitious recycling ratios.

A comprehensive illustration of the above factors has been developed by Hydrogen Europe to support policymakers and project promoters (see Figure 8). The map includes renewable energy potential, the current and planned European Hydrogen Backbone (EHB) and the network of hydrogen refuelling stations, as well as the location of likely hydrogen users (such as refineries).

2.6.4 Supportive Regulatory Framework

'Hydrogen Valleys' are bound by the regulatory framework in the EU and in Member States. The Renewable Energy Directive, the Alternative Fuels Infrastructure Regulation, the Hydrogen and Decarbonised Gas Market package, and the revised EU Emissions

Trading Scheme all impact the design, capital intensity and feasibility of hydrogen projects. Meanwhile, the Net Zero Industrial Act will provide the necessary support for the manufacturing of electrolysers and fuel cells. A clear and predictable regulatory framework will ensure the cost-effective and timely deployment of a hydrogen economy and 'Hydrogen Valleys' across the EU.

However, the transposition of EU Directives and complementary Delegated Acts in Member States brings a risk of complexity. At the local level, where public authorities will have to deal with complex rules applicable to new technologies, supporting the application and interpretation of EU legislation will be of utmost importance to avoid or remove barriers to project development. The European Clean Hydrogen Alliance has highlighted the challenges facing project developers, such as long permitting procedures, lack of appropriate legal framework, insufficient experience and/or technical knowledge for hydrogen projects in public administration, as well as lack of established procedures. Exchange of experience and of best practice (for instance from the chemical or the oil and gas industries) is the most effective solution to develop the necessary capacity for hydrogen projects administration, whilst guaranteeing safety and sustainability.

2.6.5 Certification

Another challenge facing project developers relates to certification processes. The lack of a consistent approach to certification with regard to the different production pathways of hydrogen needs to be addressed: transparent and consistent certification of hydrogen and its derivatives will be fundamental to investment decisions.

2.7 Recommendations

In its most recent Position Paper (2023/24), the European Chamber of Commerce in China issued a series of recommendations for actions that would enhance the green hydrogen supply chain and help develop the hydrogen market in China.

Of these, this report has identified some that would provide a basis for potential cooperation between China and European enterprises in the domain of green hydrogen:

- Adoption of a certification scheme aligned with international standards, such as CertifHy in Europe, to define low carbon and/or renewable hydrogen.
- Strengthening of mechanisms to incentivise the large-scale production of low-carbon or renewable-based hydrogen by electrolysis of water using curtailed electricity.
- Definition and simplification of specific safety regulations that need to be harmonised at the national level for hydrogen production, distribution, storage (such as liquid hydrogen) and usage (for example, hydrogen refueling stations), and applied at an early stage in dedicated parks to minimise potential negative impacts.
- Promotion of medium and long-distance hydrogen transportation using different methods, including pipelines, rail and/or shipping.
- Availability of tangible updates for on-board liquid storage mechanisms following the regulations to produce and transport hydrogen in a liquid form.

- Promotion of hydrogen usage for power generation, heating and decarbonising highly polluting industries, including by supporting carbon capture and utilisation projects.

2.8 Conclusion: On Generating Hydrogen Business Opportunities

Hydrogen is set to play a pivotal role in improving the environmental impact of the energy sector globally and is a primary focus for industrialised countries. While it is hard to predict how fast it will be adopted more widely, the hydrogen industry has taken off both in the EU and in China, as illustrated in this report. Interest in hydrogen has surged despite uncertainties around the stability of government policies at central and provincial level, industrial safety issues and the need to work out long distance offtake and transportation modes.

Clearly, the EU and China are facing a multitude of risks and challenges with regards to the development of their respective hydrogen industries. Despite a faster start and economic conceptualisation in the EU, China's strong policies and subsidy programme are enabling it to catch up rapidly, helped by its large scale manufacturing base and its ability to upscale.

As this report highlights, China is also rapidly developing its regulation and legislation system to support and stabilise the nascent hydrogen industry. The development of the hydrogen industry in China and Europe face many of the same challenges. These challenges have the potential to generate synergies which in turn could serve as cooperation seeds to develop harmonised market conditions in both regions and facilitate future inter-regional exchanges. Existing joint initiatives could then be intensified, and new ones established. Cooperation between the two regions' administrations and institutions could help overcome barriers to trade. At the same time, leading enterprises can also work together to develop mutually profitable ventures based on their respective advantages.

There is a need to develop hydrogen demand harmoniously in both regions to avoid falling into the joint traps of supply overcapacity and excessive subsidies: these are destabilising for the industry and can turn out to be highly damaging to the market.

Two 'external' factors are likely to accelerate (or slow) the adoption of hydrogen and the pace of growth: first, renewable power availability and cost, and second, long term high fossil fuel prices. Both the EU and China will need to navigate these variable factors without consuming excessive capital and human resources.

The handful of joint projects highlighted in this report illustrate that the collaboration on hydrogen between the EU and China is in its infancy. There is room for growth provided goodwill exists on both sides to provide a level playing field in the market and valid business cases that will allow the industry to flourish. Innovative industrial partnerships should be designed and launched now, with the hydrogen industry in its initial stage, and can then be further developed when certification and market conditions have been homogenised at an acceptable level.

3. Carbon Capture, Utilisation and Sequestration (CCUS)

3.1 Introduction

The past two to three years have been pivotal for the development of Carbon Capture, Utilisation and Storage (CCUS) worldwide, a suite of technologies that is finally being recognised as among the most important solutions for decarbonisation of the world's energy systems and meeting its final climate objectives. According to the IEA's 'Net Zero Emissions by 2050' scenario, one way or another around 5.9 Gt of captured CO_2 must be stored annually by 2050.

In 2023, the message on CCUS is much more optimistic than it was a few years ago: the technology has now been widely shown to be safe, effective, and scalable. Substantial challenges remain however, technically and economically, which need to be addressed. This is where international cooperation can play its role and business opportunities can arise.

Historically, some piloting and demonstration activity for CO_2 storage had been carried out since the early 1990s, building upon 50 years of lessons learned from CO_2 enhanced oil recovery (EOR) together with over 150 years of subsurface activity by the oil and gas industry. Indeed, CO_2 is present in variable amounts in many natural gas fields where it must be removed from the raw gas and separated from methane. Since the 1970s, CO_2 has been routinely injected into oil reservoirs to improve oil recovery.

Thanks to this period of trial-and-error, access to safe and secure geological CO_2 storage was identified as the critical factor to CO_2 management. In fact, the industry would be hesitant to invest in CO_2 capture without the assurance that sufficient CO_2 storage capacity were available.

Yet, global CO_2 storage development still lags behind the development of CO_2 capture, while research on the uses for CO_2 is still ongoing and has probably not delivered its full potential.

Targeted government intervention and expansion of policy support to include CO_2 storage development is therefore required to enable the overall process to progress further and faster in a consistent manner.

In Europe, a new wave of projects is under way with over 80 projects (including demonstration projects) in 16 countries. Of these, 13 involve the production of low-carbon hydrogen.If successful, simulations show that these projects could in theory store over 50 million tons of CO_2 per year (Mt CO_2/yr) by 2030.

Northern Lights, Norway's CO_2 transport and storage company, is the most advanced industry-size CCUS project in Europe. Approved in 2020, it has led to a revival of the technology in Europe, representing a game changer. The investment decision of the project promoters (Equinor, Shell, and TotalEnergies) in May 2020, followed by that of the Norwegian government in December the same year, prompted several countries, including the UK, Netherlands and Germany, to accelerate development of their own CCUS projects and shared CO_2 transport and storage infrastructure.

The authorities in most Member States have realised that climate neutrality cannot be achieved without CCUS, and have therefore included it in their climate and energy policies. Europe's 'Fit for 55' policy has led the way, setting a target to reduce greenhouse gas (GHG) emissions by at least 55% by 2030, and this has certainly been a key factor in accelerating the deployment of CCUS. CCUS is now an integratal component of the European Green Deal.

It is worth noting that hydrogen and CCUS policies may be seen as complementary, with potential synergies between them. Accordingly, CCUS can easily be integrated into in the following key applications:

- First, the decarbonisation of the industrial sector, in particular energy-intensive industries (such as steel, cement, chemicals and petrochemicals) which are difficult to decarbonise using current technologies.
- Second, the production of low-carbon hydrogen to produce hydrogen at a scale large enough to enable the establishment of the infrastructure network required for its economic deployment.

In China, the country's leadership is prioritising self-sufficiency, alongside a strong push into green hydrogen and CCUS. The hydrogen and CCUS sectors are benefiting from strong state support for market creation and new technologies. Some state-owned enterprises (SOEs) and public-funded R&D centres are leading development of technologies required by these sectors all along their value chains in the expectation of a massive ramp-up in the medium to long term.

It is worth conducting a detailed review of CCUS in China, and seeking to identify where cooperation is possible and desirable between China and European enterprises beyond the necessary role of government policy.

3.2 Development of CCUS Policies in China

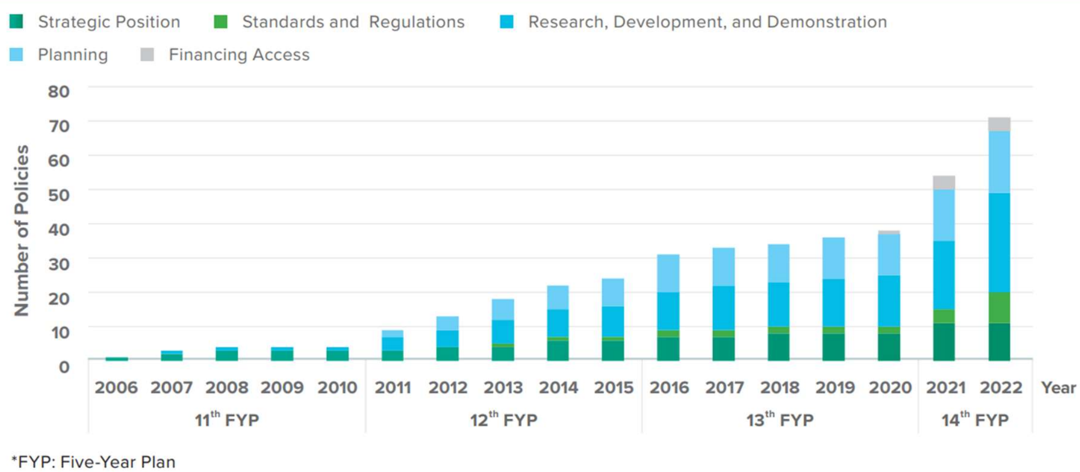
Carbon Capture, Utilisation and Storage (CCUS) technology was introduced into China more than two decades ago. With the carbon neutrality vision becoming clear and mitigation actions being accelerated, the role of CCUS has become more prominent in China.

Today, China's CCUS technologies extend to most important industry sectors (power, coal to chemicals, oil and gas, fertilisers and methanol) but they are currently small scale or at a pilot or demonstration stage.

To achieve the goal of carbon neutrality, China needs to establish a zero-carbon energy system based on non-fossil energy, decoupling its economic development from carbon emissions. CCUS, as an important part of the carbon-neutral technologies, is the technology of choice for low-carbon utilisation of fossil energy and represents the main technical means to maintain the flexibility of the power system. Moreover, CCUS is a feasible technical solution for difficult emission reduction industries such as steel and cement. In addition, the negating emission technology coupled with CCUS and new energy is also the base technology guarantee to offset the failure to formally reduce carbon emissions and achieve carbon neutrality.

With the establishment of China's '1+N' policy system for emission peaking and carbon neutrality, more CCUS-related policies have been released. As of October 2022, China has issued about 70 CCUS-related policies at the national level (see Figure 3.1), including plans, standards, roadmaps, and technology catalogues[2]. CCUS has been included for the first time in China's 14th National Five-Year Plan (2021-25). 'The Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy, The Action Plan for Carbon Dioxide Peaking before 2030', and other policy documents issued by the Chinese government at all levels, have set out proactive plans for future CCUS research and development, investment, and technology cooperation.

Figure 3.1: Number of CCUS-related national policies issued in China



Source: CCUS PROGRESS IN CHINA - A STATUS REPORT (2023), by ACCA 21, Global CCS Institute and Tsinghua University.

Since the start of the 14th Five-Year Plan period (2021-25), CCUS-related policies in China have made progress, positioning CCUS in a more prominent role within the national strategy addressing climate change.

- First, policy instruments mentioning CCUS now extend to new areas. Most of the policies focus on the R&D and demonstration of CCUS, while the number of policies and provisions relating to technical standards, investment and financing is also rising, such as the Climate Investment and Financing Pilot Work Plan, the Green Bond Endorsed Projects Catalogue (2021 Edition), China's National Standardisation Development Outline, and the Implementation Plan for Science and Technology Support for Carbon Dioxide Peaking and Carbon Neutrality (2022-30).

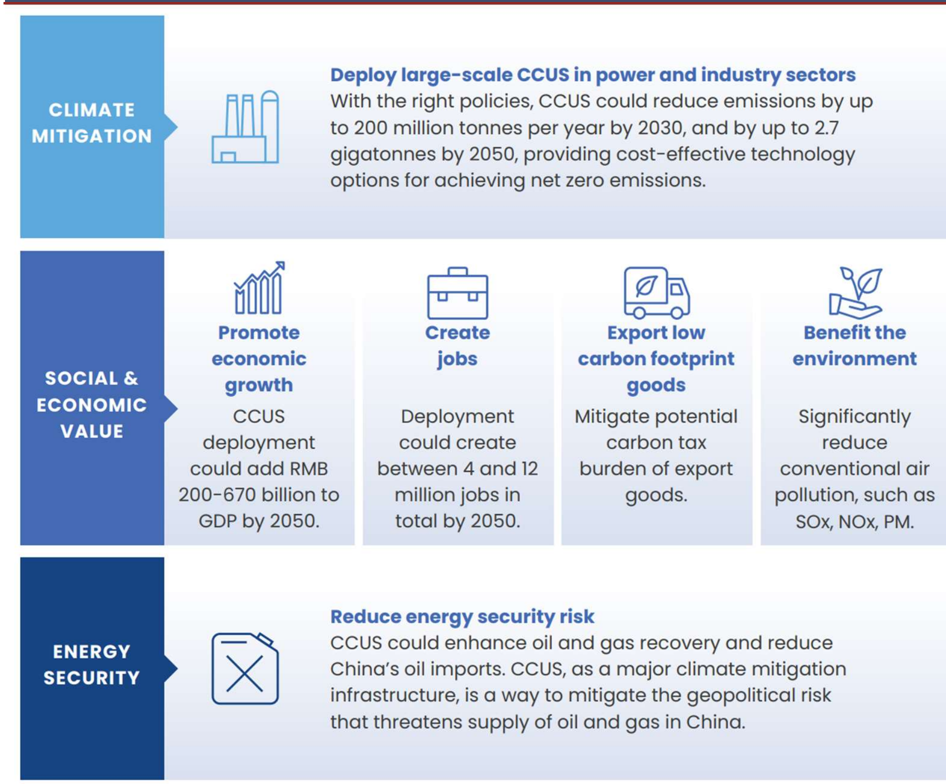
[2] See Annex I Part of CCUS Related Policies in China

- Second, references to CCUS are included in more industrial sectoral policies. Previously, CCUS was only mentioned in the power and oil and gas industries; now CCUS has been added to more hard-to-abate sectoral policy guidelines, including 'Guidelines on the Transformation and Upgrading of Energy Intensive Industries and Key Areas for Energy Conservation and Carbon Reduction' (2022 Edition) as well as the 'Carbon Peaking Implementation Plan for the Industrial Sector'.
- Third, local governments have increased their support for CCUS development. As of October 2022, ten subnational governments have deployed CCUS R&D and promotion programs in line with local conditions.

3.3 The Value of CCUS for China

CCUS is likely to be a crucial technology for China as it races to reduce absolute emissions from its use of fossil fuels so that they peak before 2030. Such a scale-up would also directly enhance the future competitiveness of Chinese industry – supporting the low-carbon transformation of both the energy sector and high-emission industries. Development of CCUS would preserve and create jobs, stabilise and boost foreign trade, secure energy supplies and bring economic value far greater than the cost of deployment (see Figure 3.2).

Figure 3.2: Key values unlocked for China by CCUS



Source: Bo Peng and Xi Liang et al, The Value of CCUS in China, 2021.

3.3.1 Climate Mitigation

If CCUS is supported by focused policy measures and developed at scale in the coal-derived chemical sector, thermal power, steel and other high-emitting industries, studies suggest it could capture and store between 1.5 Gt and 2.7 Gt per year by 2050. That would represent roughly a quarter (between 16% and 28%) of China's annual energy-related carbon emissions (based on 2018 emissions data).

3.3.2 Economic Value

Analyses based on IEA and Asian Development Bank (ADB) investment scenarios show the potential economic impact that CCUS industrial investment could have on key emitting sectors in China. These estimates suggest that by 2030, CCUS could create additional value, equivalent to between 0.2% and 0.6% of China's 2019 GDP. At this stage, CCUS would be in the early phase of development and would therefore require significant public investment in the large-scale CCUS demonstration projects using low-concentration sources such as steel and chemicals.

From 2030, as CCUS moves into a more operational mode, the GDP impact of CCUS projects would increase and could reach between RMB 200 billion and RMB 670 billion. In addition to the direct impact on GDP, export markets are expected to provide significant opportunities for China's CCUS industrial chain, specifically in engineering services, equipment manufacturing, and materials.

An opportunity will be lost if China does not simultaneously accelerate the deployment of CCUS demonstration projects designed to lead to mature technology. While Chinese industries would be able to provide materials (such as steel and cement) and equipment with lower profit margins, they may miss the higher value-added links of the emerging international CCUS market – areas such as preliminary engineering consulting and design, general contracting, process package licensing, operations and management consulting.

3.3.3 Jobs

CCUS industrial investment creates jobs both directly (during construction and operation) and indirectly through the chain reaction of preserving or upgrading existing industries. As an extension of traditional energy industries, CCUS has less impact on production process adjustments than other deep decarbonisation technologies and can avoid the social impact of job losses due to industry re-localisation. According to analysis based on key heavy industries, the deployment of CCUS is expected to lead directly to between 90 000 and 200 000 jobs by 2030. The development of the CCUS industry will bring with it an indirect employment leverage effect of two to four times the amount of direct employment referred to above. It is estimated that between 4 million and 11.6 million jobs could be created by 2050. That is equivalent to between 1% and 3% of China's urban employed population in 2019.

The main industries primarily involved in CCUS are mining, metal manufacturing, service industries, machinery industry, and transportation, among other sectors. However, the wide application of CCUS will also promote infrastructure, technology development, financial services and other industries, creating a wide range of job opportunities while bringing high value-added innovation.

3.3.4 Risk of Unilateral Carbon Taxation: CCUS to Promote Low-Carbon Exports

As countries try to decarbonise their heavy industries while ensuring they remain globally competitive, there will be a greater focus on using unilateral carbon border taxes or other instruments to reduce carbon leakage – the shift of emitting company operations to less regulated jurisdictions. The EU, for example, has announced plans to impose a Carbon Border Adjustment Mechanism (CBAM) on key emitting industries by 2023, potentially putting a price on EU imports such as steel, cement, fertilisers and aluminium depending on their carbon footprint intensity.

The use of CCUS technology to reduce the embedded emissions in China's export products could alleviate the negative impact of these instruments on exports. Indeed, since Chinese exporters to the EU might face the hard choice of paying carbon taxes or introducing CCUS into their industries, it could encourage export-oriented industries to take the lead in launching CCUS projects to improve product competitiveness.

3.3.5 Air Pollution

CCUS can have a synergistic effect on other environmental pollutants, such as sulphides, nitrogen oxides and airborne particulate matters depending on where and how it is deployed.

The combination of pre-combustion capture and advanced natural gas power generation technology, for example, can greatly reduce traditional air pollutant emissions. Similarly, oxy-combustion technology not only achieves CO_2 capture, but also helps to reduce other emissions. If CCUS is used in coal power plants, this capability needs to be embedded into the project planning. For example, a pretreatment unit can be installed before the main capture facility as a way of cutting sulphur content and particulate matters in the flue gas. If CCUS is introduced without a pretreatment unit, the negative impact on pollution will rise since operation of the capture equipment will require additional energy.

3.3.6 Energy Security

As the world's largest importer of oil and natural gas, the security of China's oil and gas supplies can easily be negatively affected by geopolitical tensions, which in turn affect the stability and development of domestic industrial production. CCUS has the potential to support China's energy security in two key aspects. First, it can help to boost domestic oil production by re-injecting CO_2 into oil fields using enhanced oil recovery (EOR). If China commits to CCUS deployment, significant emissions reductions will result, and an indirect benefit from that could be a boost to international cooperation and stabilisation of foreign trade.[3]

[3] CCUS in China -The Value and Opportunities for Deployment, Oil and Gas Climate Initiative (OGCI), 2021

3.4 Current Status of CCUS Development in China

3.4.1 Positioning

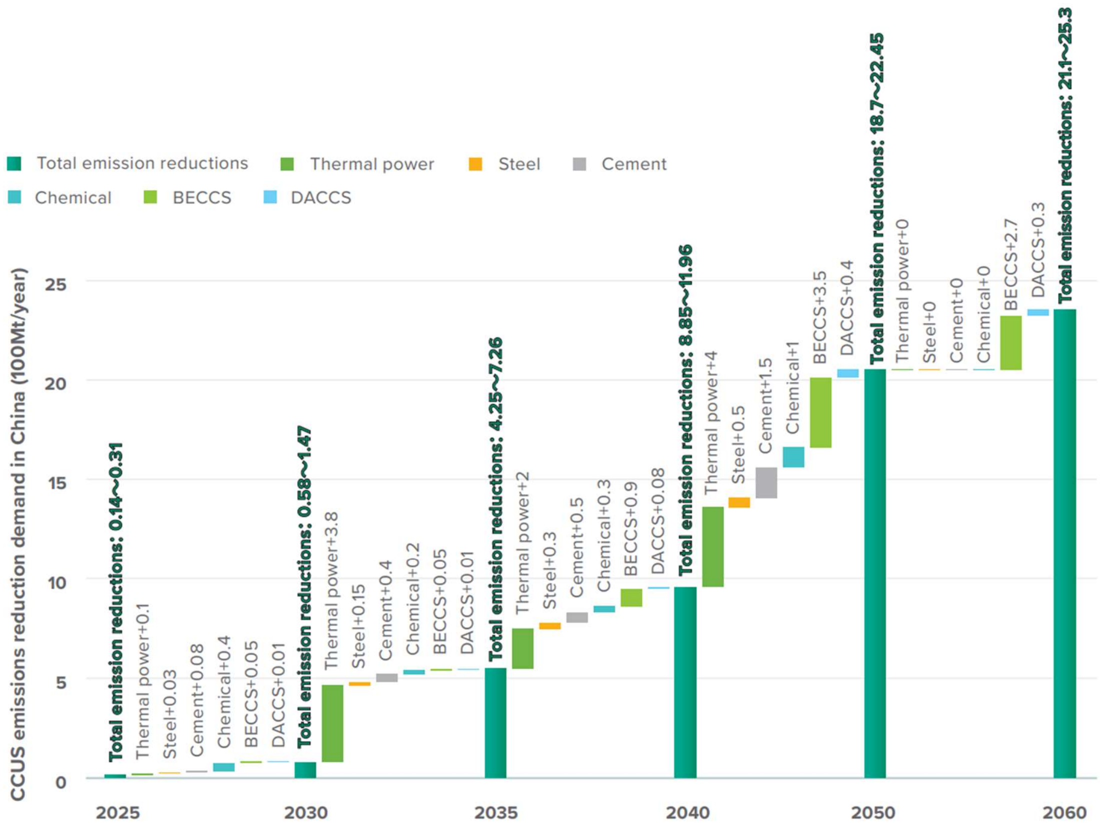
As a developing nation, China has taken on a considerable challenge with its aim to achieve carbon peaking in less than a decade and to reach carbon neutrality within four decades. The targets require consistent emissions reductions while maintaining a stable economy. Energy market reform, industrial restructuring, and clean energy promotion measures have all been promulgated in pursuit of these goals. China's energy mix is composed primarily of fossil fuels and, as a major global manufacturing base, fossil fuels will remain the major energy source for some time to come. This makes China the largest potential market in the world for the development and deployment of CCUS.

Drawing on the Ministry of Ecology and Environment's 2021 China CCUS Roadmap, CCUS in China has been recognised as:

- the only technology offering low carbon utilisation of fossil energy.
- the primary technology to keep the power system flexible under the scenario of carbon neutrality.
- a widely applicable decarbonisation technology for heavy industries, such as steel and cement, with hard-to-abate emissions.
- the underpinning technology for China's 2060 carbon neutrality target by coupling with biomass and direct air capture of CO2.

A comprehensive analysis of future demand for CCUS shows that under the 30/60 goals, CCUS could deliver annual CO_2 reductions of 24 Mt (14–31 Mt) by 2025, rising to nearly 100 Mt (58–147 Mt) by 2030, about 1 000 Mt (885-1 196 Mt) by 2040, over 2 000 Mt (1 870-2 245 Mt) by 2050, and about 2 350 Mt (2 110-2 530 Mt) by 2060 (see Figure 3.3). In view of China's current installed coal power generation capacity and the hard constraint of energy security, the thermal power industry is set to be a major focus of CCUS applications. 1 Gt CO_2 abatement per year through CCUS can be expected by 2060 in this industry alone. It is expected that the annual contribution of CCUS to decarbonisation in steel, cement, and chemical industries by 2060 will reach 500 Mt. Before carbon neutrality is achieved, Bioenergy with Carbon Capture and Storage (BECCS) and Direct Air Capture (DAC) technologies are expected to remove 500–800 Mt CO_2 per year.

Figure 3.3: CCUS emissions reduction demand in China

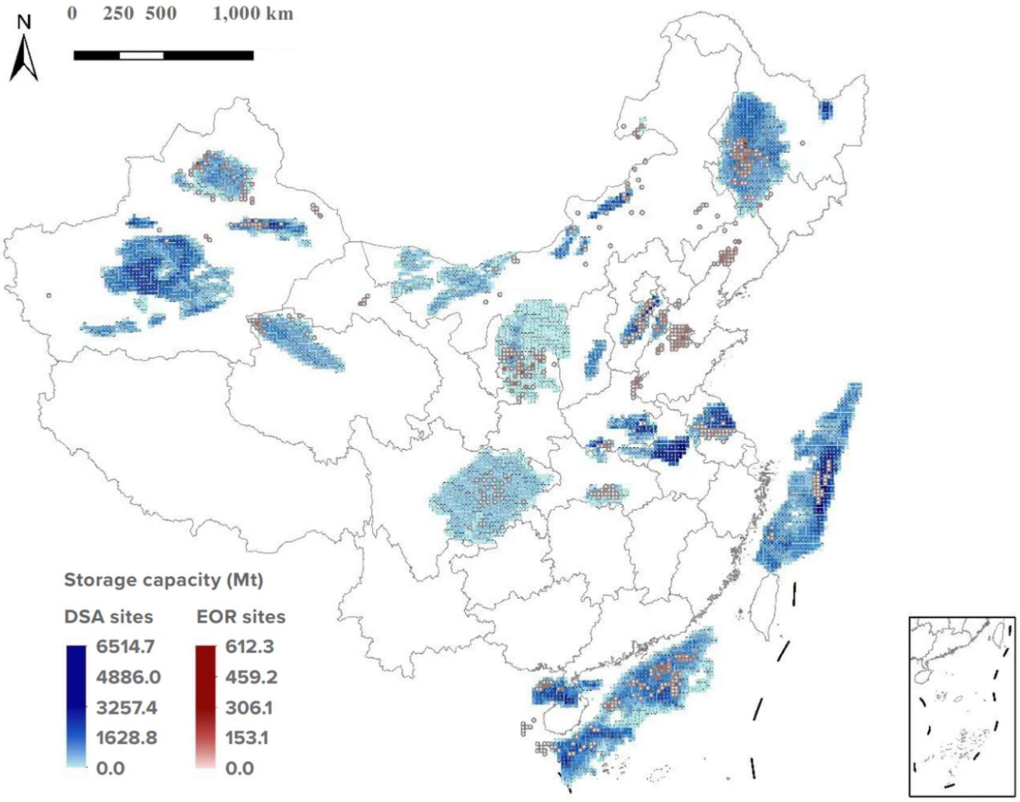


Source: CCUS PROGRESS IN CHINA - A STATUS REPORT (2023), by ACCA 21, Global CCS Institute and Tsinghua University.

3.4.2 Storage Capacity

The theoretical geological storage capacity in China is estimated at between 1.21 trillion tonnes and 4.13 trillion tonnes (Tt), mainly consisting of saline aquifers, oil and gas fields and other underground geological formations. Oil fields under consideration are mainly located in Songliao Basin, Bohai Bay Basin, Ordos Basin and Junggar Basin. The storage capacity of onshore oil fields suitable for CO_2 storage is over 20 000 Mt, and CO_2-EOR can store about 5 000 Mt CO_2. Gas reservoirs are mainly located in the Ordos Basin, Sichuan Basin, Bohai Bay Basin and Tarim Basin, and the proven CO_2 storage capacity of these gas reservoirs is about 15 000 Mt. The storage capacity of deep saline aquifers is beween 0.16 Tt and 2.42 Tt. Large and medium-sized sedimentary basins such as Tarim Basin, Ordos Basin, Songliao Basin, Bohai Basin and Pearl River Basin are more suitable for CO_2 storage (see Figure 3.4).

Figure 3.4: Theoretical geological storage capacity in China



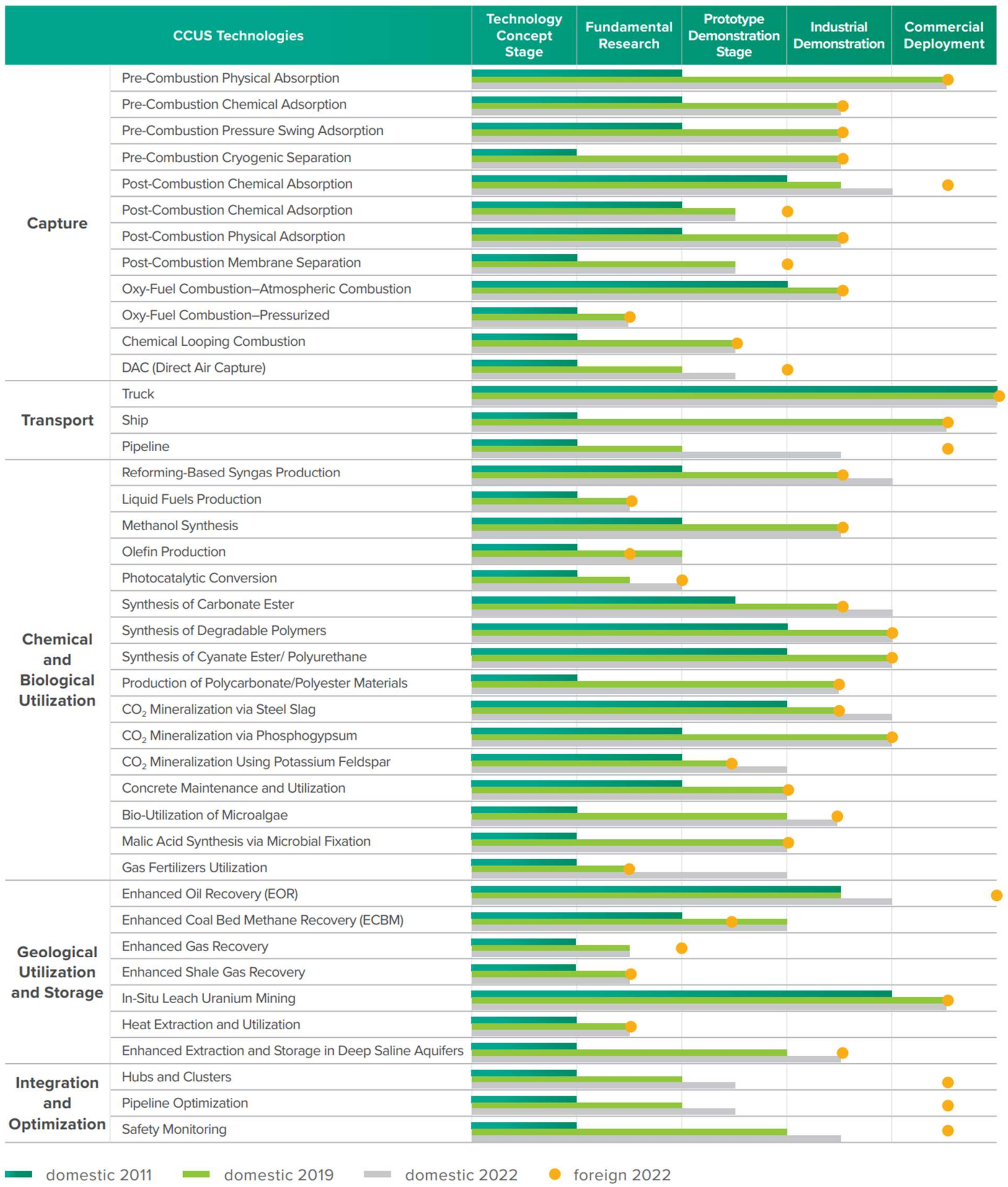
Source: CCUS PROGRESS IN CHINA - A STATUS REPORT (2023), by ACCA 21, Global CCS and Tsinghua University.

3.4.3 CCUS technologies

China has made significant progress in CCUS technology development in recent years and now has the capability to design and demonstrate the large-scale capture, pipeline (transportation), utilisation and storage of CO_2 (see Figure 3.5).

Overall, the development status of CO_2 capture technologies is relatively more advanced, but the development of different paths within CO_2 capture technologies is uneven. Among the first-generation capture technologies, the precombustion physical absorption technology is relatively mature and is already in the commercial application stage, while the post-combustion chemical absorption method is in the industrial demonstration stage. The second and third generation of capture technologies have fallen behind, and the pressurised oxy-fuel combustion (POFC) and chemical looping combustion (CLC) are only at the laboratory stage. In addition, China has started to explore Carbon Dioxide Removal technologies (CDR) such as BECCS and DAC. Zhejiang University and Shanghai Jiaotong University have made progress in the research and development of key technologies such as high-performance adsorbent and absorption material preparation in the field of DAC.

Figure 3.5: Development of CCUS technologies at home and abroad



Source: CCUS PROGRESS IN CHINA - A STATUS REPORT (2023), by ACCA 21, Global CCS Institute and Tsinghua University.

As far as CO_2 transportation is concerned, both road transportation and inland river transportation have been deployed commercially, targeting less than 100 Kt CO_2 per year. Most of the existing CCUS pilot projects in China are relatively small in scale and the majority use trucks for transportation. CO_2 ship transportation is mainly for liquefied gases. China already has the capability to build such ships, but pipelines are the cheapest way of transporting CO_2 in large quantities. The total length of China's existing CO_2 pipelines is about 150 km. In August 2022, construction got under way on the 100-km CO_2 pipeline project at Qilu Petrochemical-Shengli Oilfield, with completion expected in 2023. It will be the first long-distance CO_2 pipeline in China. Offshore pipelines for CO_2 transportation are still at basic research stage in China.

Biological and chemical utilisation technologies for CO_2 are on the whole at the industrial pilot stage, and CO_2-to-synthetic-chemical-material technologies has already reached the industrial demonstration phase. CO_2 mineralisation using steel slag and phospho-gypsum is close to commercial application. In July 2022, construction work began on the Phase-I pilot project of Baogang Steel Group's 100 000-ton steel slag comprehensive utilisation, which was expected to be officially put into operation in early 2023.

In terms of geological underground storage, China's CO_2 Enhanced Oil Recovery (EOR) projects are relatively mature and are at the stage of industrial demonstration and commercial application. In terms of offshore geological storage, following the Ordos CCS demonstration project of National Energy Investment Group, CNOOC announced in June 2022 that the construction of equipment for China's first offshore CO_2 storage project was fully completed, with CO_2 storage expected to reach 300 kt/yr after it is put into operation.

Meanwhile, CCUS integration has entered the commercial stage in many countries. However, large-scale full chain demonstration experience is lacking in China, especially in pipeline and hub integration development, which has only reached the pilot stage.

3.4.4 Demonstration Projects

CCUS demonstrations in China are under rapid development. Compared with 2021, there has been a significant increase in both the number and scale of projects.

Simultaneously, the number of industries which have started deploying CCUS technologies has also risen significantly.

By number, scale and location:

As of November 2022, there are around 100 CCUS demonstration projects of various sizes in operation or at the planning stage in China[4] (see Figure 3.6). Of these, nearly half of the projects have been put into operation, representing CO_2 capture capacity of more than 4 Mt per year and CO_2 injection capacity of more than 2 Mt per year, an increase of about 33% and 65%, respectively, compared with 2021.

Over 40 projects have a capacity of 100kt CO_2. Of these, 10+ projects have a capture capacity of 500kt CO_2. In August 2022, China's first Mtpa-scale CCUS project, Qilu Petrochemical-Shengli Oilfield, was officially put into operation. The construction of Huaneng 1.5 Mt coal power CCUS project is expected to be completed in 2023 in Zhengning, Gansu province. CNPC is building several large-scale CCUS demonstration projects, including a 1.4 Mtpa project at Daqing Oilfield and a 1 Mtpa scale project at Jilin

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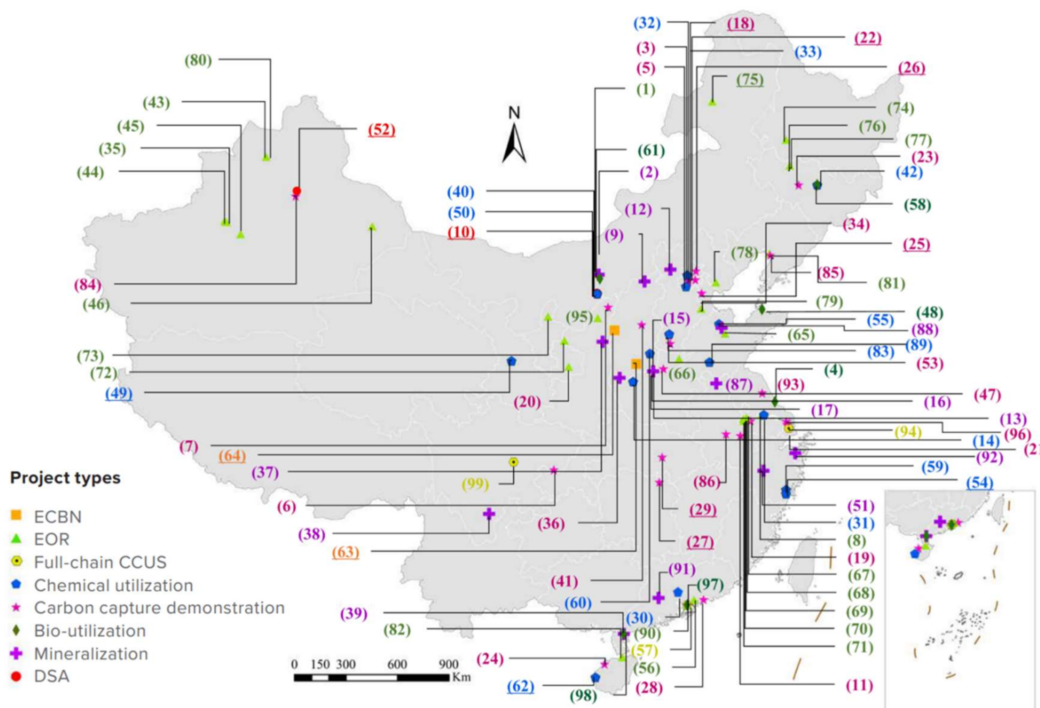
[4] See complete list of CCUS demonstration projects in Annex II.

Oilfield, while its CCUS cluster in Xinjiang is expected to reach an annual capacity of 10 Mt CO_2 by 2030. Shaanxi Yanchang Petroleum plans to build a 5 Mt CCUS project and will complete a 1 Mt CCUS industrial demonstration by the end of the 14th Five-Year Plan in 2025.

Regarding foreign participation in CCUS in China, Guangdong Development and Reform Commission, CNOOC, Shell and ExxonMobil signed an MoU to jointly study a 10 Mt-scale CCUS cluster in the Daya Bay area in June 2022. In November 2022, Sinopec, Shell, Baowu Steel and BASF announced that they are to conduct a collaborative study to launch an open-source 10 Mt scale CCUS project in East China.

Figure 3.6: CCUS demonstration projects in China



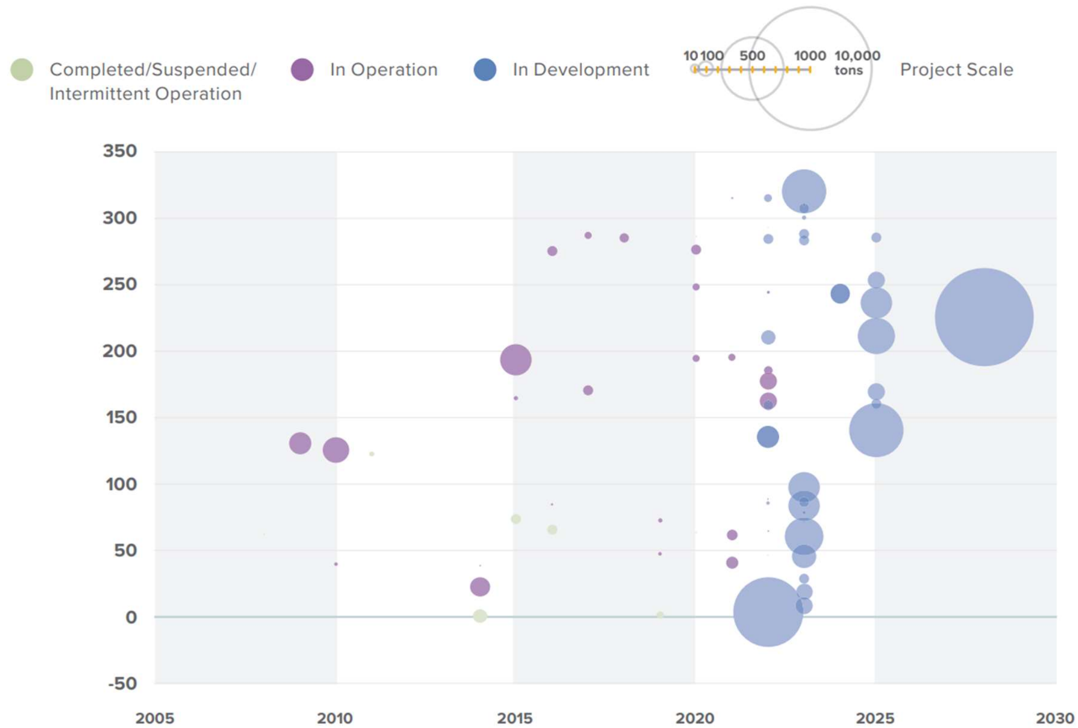
Source: CCUS PROGRESS IN CHINA - A STATUS REPORT (2023), by ACCA 21, Global CCS Institute and Tsinghua University.

By industrial sector:

China has demonstrated or plans to demonstrate CO_2 capture in the power sector (over 20 projects), oil & gas, chemical, cement, steel, etc. (see Figures 3.7 and 3.8). The 150 Ktpa scale post-combustion CO_2 capture demonstration project at the National Energy Group's Jinjie Coal power plant, which was commissioned in June 2021, has achieved a comprehensive capture energy consumption of 2.35 GJ/ton; both the cost and energy consumption are expected to decline in its upcoming 500 Ktpa coal power project at the Taizhou Power Plant. The number of CCUS demonstration projects in hard-to-abate industries such as cement and steel have significantly increased in 2022-23. In June 2022, the first phase of the 2 Mtpa scale CCUS (500 000 tons in Phase I) demonstration project of Baogang Steel Group started construction. In October 2022, China National Building Material Group (CNBM) completed the world's first CO_2 capture in the glass making process, with an annual capacity of 50 000 tons. In addition, there are more than 40 CCUS demonstration projects planned or in operation in the oil and gas, coal-derived chemical, petrochemical, ethanol, and fertilizer production industries.

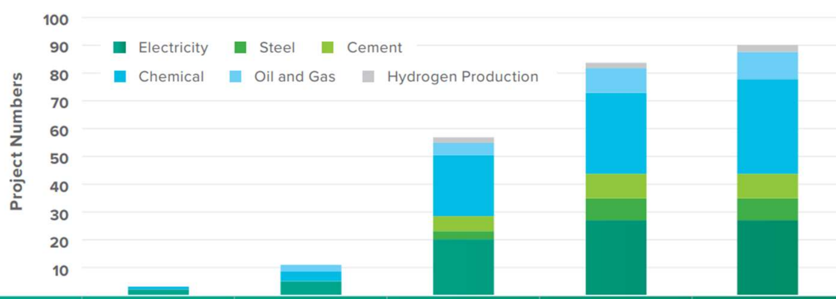
CO_2 geological utilisation (EOR) has been the focus of China's CO_2 utilisation trials so far; however, chemical and biological utilisation projects have been increasing year by year (see Figure 3.9). There are more than 30 CO_2-EOR projects, a small number of enhanced coal-bed methane projects, and a few saline storage projects in China. In 2022, Chinese multinational Tencent announced that it intends to achieve carbon neutrality by 2030, and it has been working with Carbfix from Iceland to build a CO_2 storage project in a basalt formation in China, which is expected to be completed and commissioned in 2023. Among the CO_2 chemical utilisation projects, a few are adopting the CO_2 mineralisation approach to prepare construction materials such as concrete blocks, while the rest are using CO_2 to prepare high-value chemicals. In November 2022, a CCUS demonstration facility was commissioned by National Energy Group's Datong Power Plant; the project is based on ammonium chloride solution and calcium carbide slag utilisation and has successfully produced finished calcium carbonate slurry. The number of CO_2 bio-utilization projects in China is increasing year by year: the projects are focused mainly on microalgal cultivation and CO_2 sequestration and preparation of high value-added products. In January 2022, Zhejiang University and China Resources Group cooperated to build China's first demonstration project, with a column-type microalgae photosynthesis reactor for CO_2 reduction and utilisation by using flue gas from coal-fired power plants at CR Power (Haifeng) Co. In December 2022, Zhejiang University and Guangdong Energy Group cooperated to build the first demonstration project using flue gas for microalgal cultivation and CO_2 sequestration at Guangdong Yudean Zhanjiang Biomass Power Generation Co.

Figure 3.7: CCUS demonstration projects by industry in China (partial)



Source: CCUS PROGRESS IN CHINA - A STATUS REPORT (2023), by ACCA 21, Global CCS Institute and Tsinghua University.

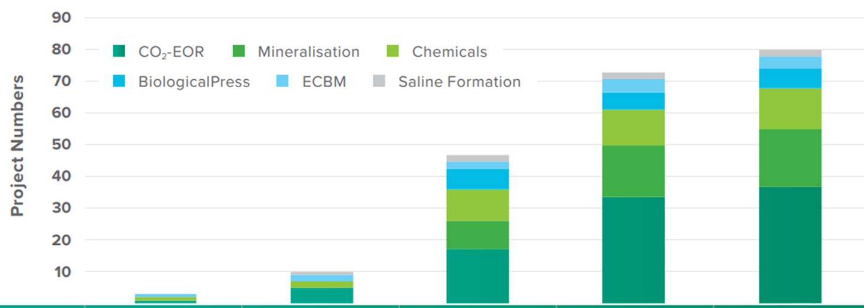
Figure 3.8: CCUS demonstration projects in China by industry subsector



	2010	2015	2022	2025	2030
Electricity	2	5	20	27	27
Steel	0	0	3	8	8
Cement	0	0	6	9	9
Chemical	1	4	21	30	34
Oil and Gas	0	2	5	9	10
Hydrogen Production	0	0	2	2	2

Source: CCUS PROGRESS IN CHINA - A STATUS REPORT (2023), by ACCA 21, Global CCS Institute and Tsinghua University.

Figure 3.9: CCUS demonstration projects in China by utilisation



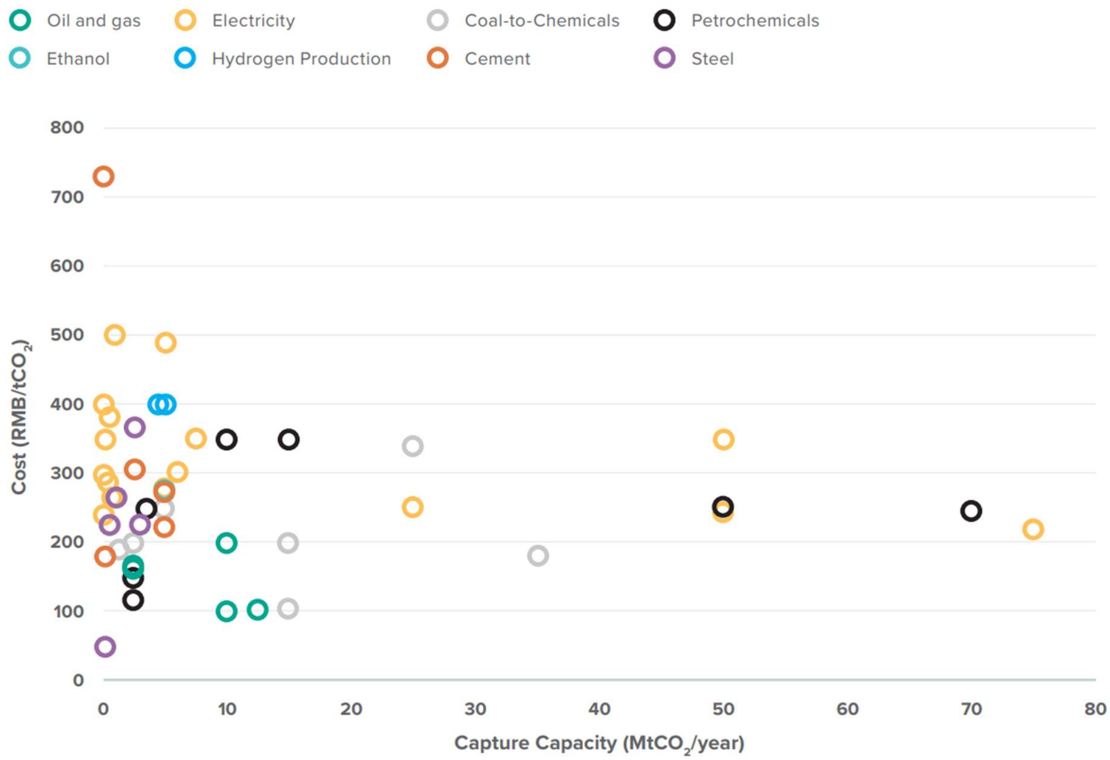
OPERATION YEAR	2010	2015	2022	2025	2030
CO_2-EOR	1	4	17	34	37
Mineralisation	0	0	9	18	18
Chemicals	1	2	10	11	13
Biological Process	0	0	6	6	6
ECBM	1	2	2	4	4
Saline Formation	0	1	2	2	2

Source: CCUS PROGRESS IN CHINA - A STATUS REPORT (2023), by ACCA 21, Global CCS Institute and Tsinghua University.

The average cost of China's CCUS demonstration projects is at a medium to low level compared with the rest of the world.

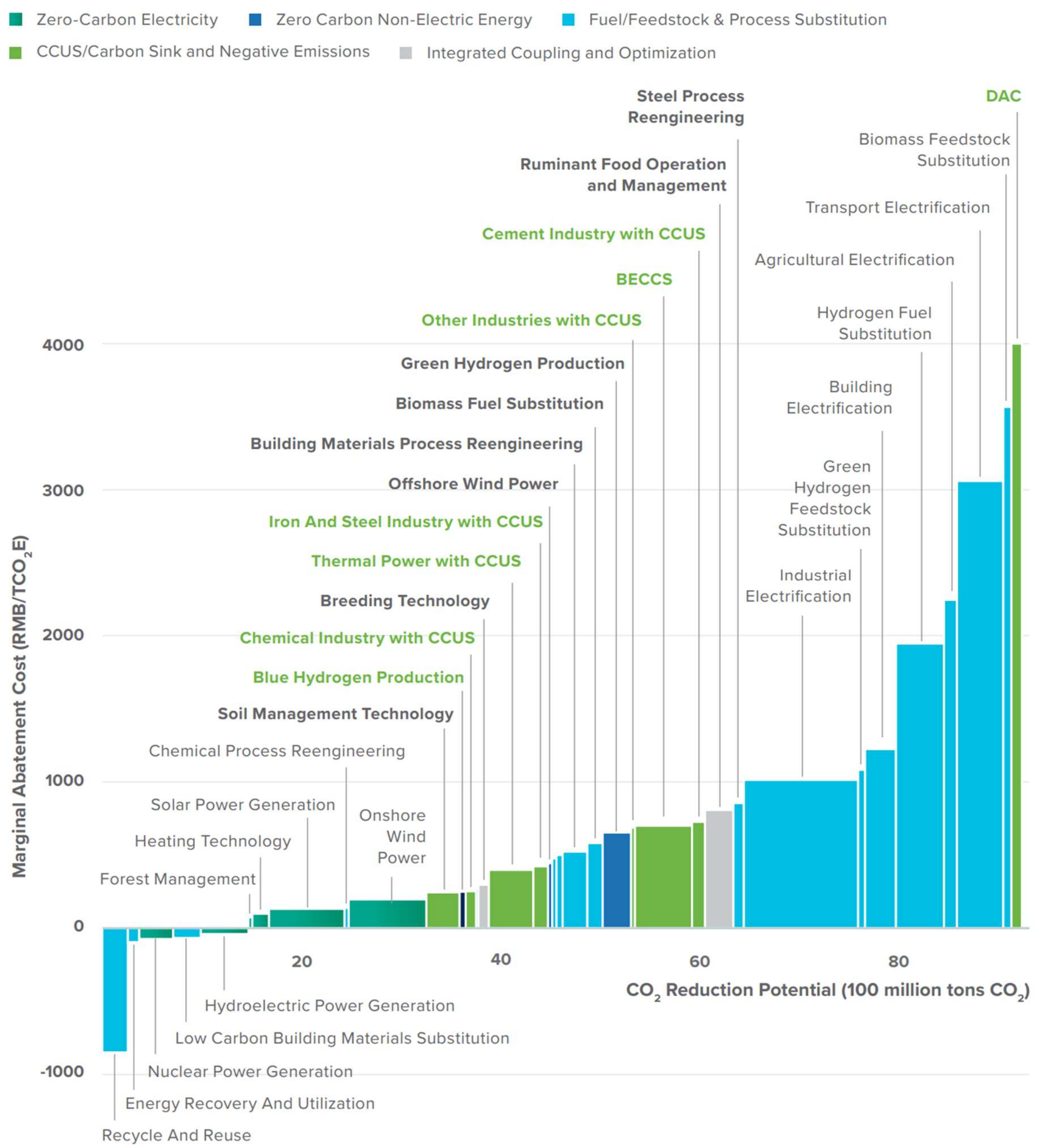
The cost of CCUS demonstration projects remains high, but compared with other countries, China has certain cost advantages (see Figures 3.10 and 3.11). The cost of China's demonstration projects has been decreasing year on year as scientists draw lessons from each scheme. The integrated CCUS projects in China's coal and petrochemical sectors have relatively low costs at CNY 105-250/tCO_2. The CO_2 capture cost of the power and cement industries is relatively high, ranging from CNY 200 to 600/tCO_2 and CNY 305 to 730/t CO_2, respectively. Currently, CCUS does not have an obvious cost advantage over other abatement technologies.

Figure 3.10: The cost of CCUS demonstration projects in operation in China



Source: CCUS PROGRESS IN CHINA - A STATUS REPORT (2023), by ACCA 21, Global CCS Institute and Tsinghua University.

Figure 3.11: Marginal abatement cost of CCUS and other low-carbon technologies



Source: CCUS PROGRESS IN CHINA - A STATUS REPORT (2023), by ACCA 21, Global CCS Institute and Tsinghua University.

3.5 Conclusion and Recommendations: Challenges Ahead

China has made significant progress in applying CCUS technology, and recognises the key role of CCUS in achieving the country's ambitious 30/60 climate targets. Yet it faces challenges when it comes to achieving commercial-scale integrated CCUS projects, including high CO_2 abatement costs, lack of effective business models, insufficient incentives and regulatory measures, and difficulties in CO_2 sources-sinks matching. Considering the key role CCUS will need to play in achieving China's 30/60 goals, it will have to be further integrated into the country's carbon neutrality innovation and energy system.

The following recommendations were made by the Asian Development Bank in August 2022, which if implemented could reinforce and enhance the progress China has already made with regard to CCUS development[5]:

- **Urgently develop large-scale integrated CCS demonstration projects in the following key sectors: power, steel, cement, and petrochemical.** Each project should exceed 1 Mt of CO_2 in capacity with capture, transportation, utilisation, or storage components. Although CCS is prioritised in China in the light of its energy structure and the percentage of coal use in primary energy, the country lags behind its international partners in building large-scale CCS demonstration projects. The first group of large-scale integrated CCS demonstration projects should start construction at the end of the 14th FYP, i.e., 2024 to 2025.
- **Integrate CCUS into PRC's carbon market.** Carbon pricing is an important driver for CCUS in Norway and Canada. .In Canada, 1 ton of CO_2 avoidance allows a the Canadian CCS project to generate 2 tons of credit, and a similar system could be a useful mechanism to accelerate CCS deployment in China. China's emission trading system (ETS) could draw on Canada's experience, and allow CCS projects to generate multiple emission reduction credits linked with the China Certified Emission Reductions (CCER) scheme. The usage of auctioning revenue for financing CCS, such as the European Union (EU) NER300 and NER400 scheme, are also excellent examples.
- **Adopt CCUS readiness design for all large stationary emission sources in China and for state-owned enterprises (SOEs) development abroad.** CCS readiness design could help avoid a carbon lock-in effect. A guidance document for promoting CCS readiness in the PRC and on overseas investments could reduce the climate transition risk (i.e., a high carbon price introduces the risk of stranded assets in the future).
- **Increase R&D policy support for CCS technologies.** The level of R&D policy support in the 14th Five-Year Plan and in later years needs to be increased, in light of the fact that other major global economies are significantly increasing the level of support for CCS.
- **Mitigate CO_2 storage liability risk for early CCS demonstration projects.** Early-stage CCS demonstration projects take significant technology risks, e.g., failure of capture plant or CO_2 storage site injectivity. Therefore, the government should create a risk mitigation mechanism to absorb most of the CO_2 storage long-term liability exposure, e.g., through a special and favourable insurance scheme. A

[5] Road Map Update for CCUS Demonstration and Deployment in the People's Republic of China, Asian Development Bank, August 2022

government regulatory framework is needed to address long-term liability issues. Liability transfer to governments is a mechanism typically used in countries with commercial CCS projects.

- **Provide other carbon pricing signals on the sectors with high-concentration emission sources not yet included in ETS.** Deployment of CCS at high concentration emission sources (e.g., >70% CO_2 by volume) is significantly cheaper than capturing from other sources (e.g., power, cement, steel). It would be beneficial for China to define and identify high concentration emission sources and develop a tailored policy incentive to trigger CCS from these early opportunities, such as carbon tax and mandatory internal carbon pricing for SOEs. One example is the Form 45Q tax credit in the US, which enables the highest concentration CO_2 sources in the US to deploy CCUS technologies.
- **Establish a trial regulatory framework for CCS.** The complexity of the approval process for CCS projects and the number of administrative departments involved increase the risks and costs of the project. Led by the Climate Department of the Ministry of Ecology and Environment of China, the state should take the lead in designing a unified approval process to clarify the implementing organs, conditions, procedures, and deadlines of various approvals. At the same time, it would be helpful to provide clear guidance on the responsibilities and role of each regulatory department in China, so that project developers can navigate the regulatory hurdles more effectively.
- **Establish an internationally recognised method to measure CO_2 emissions and assess the abatement cost of CCS technologies.** Internationally, inconsistent emission accounting and cost measurement methods are applied to CCS. Developers or technology vendors usually adopt a method that serve their own interests. The key debate centres on life cycle emissions and cost for CO_2 utilisation such as CO_2-EOR and converting CO_2 to chemicals. It will help policy makers to understand the social benefits, costs, and potential opportunities of different technologies if a fair and uniform costing and carbon accounting method is in place. China has a key role to play in ensuring such a method is established and adhered to.

The Role of International Cooperation

Many large-scale foreign enterprises have ongoing operations in China either wholly owned or owned in partnership with Chinese companies. To meet their own climate ambitions in China and internationally, they share the common interest of developing their cooperation in China and could contribute significantly to closing the capacity gap and accelerating technology learning and development, through knowledge sharing, facilitating coordination, and public awareness enhancement. Some of them have already initiated such kinds of cooperations (See section 3.4 in this report).

From the perspective of governments, CCUS as a low carbon technology is also one of the most promising areas for international cooperation. Both official intergovernmental and unofficial trade mechanisms could provide platforms to connect policymakers, enterprises, and researchers to explore various forms of collaboration. For industries and other non-governmental organisations, connecting with stakeholders in China, especially industry players, can bring about significant change. Knowledge sharing should act as a key tool to inform policy makers on effective CCUS deployment policies, as well as enhancing public understanding of the technology. Further collaboration in projects, such as joint studies and joint engineering works, will further stimulate China's CCUS industry. Moreover, by collaborating, these different companies and organisations can shoulder risks and costs together. International cooperation with ad-hoc mechanisms appropriate to the situation at hand may result in better coordination, efficient sharing of cost and risk, and transparent communication, potentially improving outcomes for all parties involved.

Chinese SOEs are at the forefront of this effort (see Annex II). By the nature and breadth of their activity and the fact that many of them have joint ventures with foreign companies in China or internationally, they are naturally the partners of choice for European companies which want to move faster to achieve their net-zero emissions standards in their Chinese and/or international operations.

Considering geological storage potential, several European companies have a vast experience which would be very useful for application in China where there is less experience of CO_2 injection in natural underground reservoirs (for example, Norway's Northern Lights project). It is important to stress that geological conditions for long-term CO_2 storage vary considerably from one area to another and figuring out these differences takes time and money. Therefore, access to this European know-how would greatly benefit CCUS implementation in China. A promising area fo cooperation in the field of CCUS could be natural gas production and processing, as CO_2 has to be removed from natural gas before further processing or liquefaction.

3.6 Annex I: Part of CCUS Related Policies in China

Part of CCUS Related Policies in China

NO.	ISSUE ENTITY	DATE	NAME	CONTENTS
1	State Council	2/7/2006	National Mid- and Long-Term Development Plan on Science and Technology	Explore efficient, clean and near-zero emission fossil fuels technology
2	MOST, NDRC, Ministry of Foreign Affairs(MFA), Ministry of Environment(MOE, (now MEE), and other 10 ministries	6/13/2007	National Actions on Addressing Climate Science and Technologies	CCUS is listed as one of the key technologies that will be supported and demonstrated with focus
3	State Council	6/30/2007	National Program on Climate Change(Canceled in 2015)	CCUS is inlcuded as one of clean and efficient use of coal
4	MOST	7/4/2011	National 12th Five-Year Plan on Science and Technology	CCUS is listed
5	Ministry of Land and Resources(MLR, (now Ministry of Natural Resources, MNR)	9/13/2011	National 12th Five-Year Plan on Land and Resources Science and Technology	CCUS related geological research and technology development is listed
6	State Council	12/1/2011	National Work Plan for Controlling Greenhouse Gas Emissions during the 12th Five-Year Plan Period	Conduct CCUS demonstration projects and encourage relevant research on new technologies with independent intellectual property rights
7	NDRC	3/18/2012	National 12th Five-Year Plan for Coal Industry	Support CCUS research and demonstration projects
8	MOST, MFA, NDRC, MOE, MIIT and other 11 ministries	5/4/2012	National 12th Five-Year Plan on Science and Technology for Addressing Climate Change	Conduct CCUS research and demonstration, with clarification on focus of research and industry
9	MIIT, NDRC, MOST, MOF	12/31/2012	National Action Plan for Addressing Climate Change in Industry Sector(2012-2020)	Conduct CCUS research, demonstration projects and capacity building in industry sector
10	State Council	1/1/2013	National 12th Five-Year Plan for Energy	Conduct IGCC projects(400-500 MW) and CCUS demonstration projects
11	MOST	2/16/2013	National Science and Technology Plan on CCUS during the 12th Five-Year Plan Period	Promote CCUS all-chain demonstration projects and and technology breaktrough.
12	NDRC	2/22/2013	Guiding Cataloague of Strategic and Emergent Industry Key Products and Services(Amended on 21 September 2016)	Clarified CCUS as one of the advanced environmental protection technologies
13	State Council	2/23/2013	National Mid- and Long-Term Plan on Key Science and Technology Infrastructure Construction	Research on CCUS infrastructure to support addressing climate change
14	NDRC	4/27/2013	Notice on Promoting CCUS demonstration	Promote CCUS demonstration projects through policies, incentives, strategies, standards and international cooperation
15	State Council	8/1/2013	State Council Guidance on Accelerating Energy Saving and Environmental Protection Industry	Deploy CCUS facilities in advance
16	MOE	11/5/2013	Notice on Promoting Environmental Protection for CCUS Demonstration Projects	Enhance environmental protection and evaluation for CCUS projects

NO.	ISSUE ENTITY	DATE	NAME	CONTENTS
17	NDRC	8/25/2014	Key National Low Carbon Technologies Promotion Catalogue	CCUS is listed into one of the low carbon technologies that the country will promote greatly
18	NDRC, MOE, NEA	9/14/2014	Action Plan for Thermal Power Energy Saving and Emissions Reduction Upgrade and Retroffiting(2014-2020)	Conduct in-depth research and demonstration of CCS
19	NDRC	9/19/2014	National Plan on Climate Change (2014-2020).	Conduct CCUS all-chain integrated demonstration projects and explore ways of CO_2 utilization
20	NEA, MOE and MIIT	12/26/2014	NEA, MOE and MIIT's Guidance on Promoting Green Exploitation and Clean/Efficient Use of Coal	Conduct CCUS research and demonstration projects
21	NEA	4/27/2015	Ation Plan for Clean and Efficient Use of Coal(2015-2020)	Encourage CCUS deployment and across-sector collaboration in coal and gas related industries
22	NDRC	11/18/2015	Enhanced Actions on Climate Change: China's Intended National Determined Contributions	CCUS is listed to promote technology development and commercial demonstration
23	NDRC	12/6/2015	Key National Low Carbon Technologies Promotion Catalogue(2nd)	CCUS is included
24	MOE	12/24/2015	Pollution Prevension and Control Policies in Sythestic Ammonia Industry	CCUS is listed in one of the new technologies to develop
25	MOE	6/20/2016	CCUS Environmental Risk Assessment Guidance(Trial)	Clarified risk assessment for CCUS projects
26	State Council	7/28/2016	National 13th Five-Year Plan on Science, Technology and Innovation	Focus on CCUS research and development, conduct 1-million-ton per annum post-combustion demonstration projects
27	State Council	10/27/2016	National Work Plan for Controlling Greenhouse Gas Emissions during the 13th Five-Year Plan Period	CCUS is included
28	MOST, MOE, China Meterological Administration(CMA)	4/27/2017	National 12th Five-Year Plan on Science and Technology for Addressing Climate Change	CCUS is listed as one of the mitigation technologies, with a focus on low cost and large scale
29	NDRC	4/1/2017	Key National Energy Saving and Low Carbon Technologies Promotion Catalogue(low carbon part in 2017 version)	CCUS is listed
30	MOHURD	9/11/2018	Engineering Standards for Flue Gas Carbon Dioxide Capture and Purification	Clarified engineering standards for flue gas CCS projects
31	People's Bank of ChinaPBC, NDRC and China Securities Regulatory Commission CBRC(now CBIRC)	7/8/2020	Project Catalogue for Green Bonds(2020)	CCUS is included
32	MEE(previous MOE)	10/21/2021	Guidance on Promoting Climate Financing	CCUS is included
33	State Council	2/22/2021	Circular on urging efforts to build an economic system featuring green, low-carbon and circular development, and to promote an overall green transformation of the economy and society	CCUS is included in the part regarding accelerating infrastructural construction for green upgrade

NO.	ISSUE ENTITY	DATE	NAME	CONTENTS
34	National People's Congress(NPC)	3/13/2021	the 14th Five-Year Plan (2021-2025) for National Economic and Social Development and the Long-Range Objectives Through the Year 2035	CCUS is included for the first time in the National Five-Year Plan
35	Special Envoy for Climate Change Affairs	4/18/2021	U.S.-China Joint Statement Addressing the Climate Crisis	CCUS is included in the "concrete actions in the 2020s to reduce emissions aimed at keeping the Paris Agreement"
36	MEE, MOFCOM, NDRC, MOHURD, PBC, Customs, NEA, National Forestry and Grassland Administration	5/28/2021	Guidance on Promoting High-Quality Development and Enhancing Ecological and Environmental Protection in Free Trade Zones	Exlore and conduct scaled all-chain CCUS demonstration projects.
37	National Development and Reform CommissionNDRC	6/23/2021	Notice on Submitting Materials for CCUS Projects	Submit CCUS project materials to repare for implementing following key projects in an orderly manner.
38	the General Offices of the Communist Party of China Central Committee and the State Council	10/10/2021	Outline to promote standardized development at the national level	Conduct research and establish CCUS standards
39	High-Level Environment and Climate Dialogue (HECD) between China and the EU	10/11/2021	Joint Press Communiqué following the Second EU-China High Level Environment and Climate Dialogue	Both participants agreed to continue and expand the cooperation in the fields of biodiversity conservation, chemicals management, climate legislation, energy conservation and energy efficiency improvement, circular economy, renewable energy, green transportation, green buildings, green finance, CCUS and hydrogen energy etc.
40	The Communist Party of China Central Committee and the State Council	10/24/2021	Working Guidance For Carbon Dioxide Peaking And Carbon Neutrality In Full And Faithful Implementation Of The New Development Philosophy	CCUS focal areas: technology research, industrial application, and investment policies.
41	State Council	10/26/2021	Action Plan for Carbon Dioxide Peaking Before 2030	CCUS application in industry through research, integrated demonstration and international collaboration to realize low cost large-scale commercial deployment is included.
42	China Government	10/28/2021	China's Achievements, New Goals and New Measures for Nationally Determined Contributions	CCUS is included as one of "basic and cutting-edge technologies" with focus on technology research, demonstration, industrial application and international collaboration.
43	People's Bank of ChinaPBC	11/10/2021	New tool set to increase lending to emission reduction projects	According to the PBOC, after financial institutions issue carbon emission reduction loans to eligible companies, the lenders can apply for loans from the central bank equal to 60 percent of the principal, at an interest rate of 1.75 percent for one year. The new tool aims to leverage more social capital to promote the low-carbon transition of key industries and support the development of clean energy, energy saving, environmental protection and carbon emission reduction technologies, said the PBOC announcement.

NO.	ISSUE ENTITY	DATE	NAME	CONTENTS
44	China and US Government	11/10/2021	U.S.-China Joint Glasgow Declaration on Enhancing Climate Action in the 2020s	The two sides intend to cooperate on: ...... deployment and application of technology such as CCUS and direct air capture. ...... The two sides intend to establish a "Working Group on Enhancing Climate Action in the 2020s,"
45	MIIT	12/3/2021	14th Five-Year Plan on Industrial Green Development	CCUS is included in exploration of insdustrial carbon abatement pathway, focusing on technology, demonstration and financing policy support.
46	Standardization Administration of PRCSAC"	2021/12/6	14th Five-Year Plan for High-Quality Development Standardization Mechanism Establishment	CCUS standards were included
47	SASAC	12/30/2021	Guidance on Promoting High-Quality Development and Realizing Carbon Peak and Carbon Neutrality of State-Owned Enterprises	Technology breakthrough in CCUS and low cost, all-chain, integrated and scaled demonstration projects will be enhanced.
48	NDRC, NEA	2/10/2022	Guidance on Institutions, Mechanisms and Policies to Improve Green and Low Carbon Transition of Energy	CCUS technological development and demonstration in coal-fired power plants and oil&gas sector is highlighted with policy support.
49	NDRC, MIIT, MEE, NEA	2/11/2022	Implementing Guidance on Energy Saving and Carbon Emissions Reduction Retroffiting in Key Sectors in Energy-Intensive Industries	CCUS demonstration is highlighted in the coal-to-chemistry, cement, plate glass, steel and ferroalloy sectors.
50	NDRC, NEA	3/22/2022	14th Five-Year Plan on Modern Energy System	The document mentioned CCUS in terms of major national demonstration projects in provinces like Shanxi, Shaanxi, Inner Mongolia and Xinjiang, exploring commercial pathway, providing financial support and enhancing international collaboration.
51	NEA	3/29/2022	The Guidance on Energy Work 2022	Establish innovation platforms focusing on CCUS and other 5 major directions.
52	NEA	4/2/2022	14th Five-Year Plan for Science and Technology Innovation in Energy Sector	The document highlights CCUS technology application and development in depleted oilfield and green use of coal where megatonne all-chain demonstration projects and relevant technology research are planned.
53	MOE	4/24/2022	Working Plan on Establishing on Higher Education Talents System for Carbon Peak and Carbon Neutrality	To develop and attract CCUS talents.
54	NDRC, NEA, MOF, MNR, MEE, MOHURD, MOA, CMA, Forestry	6/1/2022	14th Five-Year Plan for Renewable Energy	Encourage demonstration on BECCS
55	MEE, NDRC and other 5 ministries	6/17/2022	Implementation Plan for Synergizing the Reduction of Pollution and Carbon Emission	Encourage CCUS application in industry sectors.

Source: Repositioning CCUS for China's Net-Zero Future, Global CCS Institute, September 2022.

3.7 Annex II: CCUS Demonstration Projects in China

CCUS Demonstration Projects in China		
No.	**Name of Project**	**Company**
1	Baotou 2-million-ton (Phase I 500,000 ton) CCUS demonstration project	Baogang Group
2	Baotou Carbonization Method Steel Slag Comprehensive Utilization Project	Baorong Environment and New Material
3	Demonstration of CO_2 Capture Technology in Complex Air Environments	Beijing Building Materials Research Institute
4	Yancheng Microalgae Carbon Fixation Project	C.B.N.
5	Beijing Gaojing Thermal Power Plant CO_2 Capture Project	Datang
6	Chongqing Shuanghuai Power Plant CO_2 Capture Demonstration Project	SPIC
7	CO_2 Capture and Sequestration 150,000 ton/year Post-combustion Demonstration Project at Jinjie Power Plant	China Energy
8	Taizhou Power Plant 500,000 tons/year CCUS Project	China Energy
9	CO_2 Chemical Mineralization Capture and Utilization at Guodian Datong Power Plant	China Energy
10	Ordos CO_2 Saline Aquifer Storage Project	China Energy
11	Wuhu Baimashan Cement Plant CO_2 Capture and Purification Demonstration Project	Anhui Conch Group
12	Zhangjiakou Hydrogen Energy Development and Utilization Engineering Demonstration Project	HBIS Group
13	Calcium Carbide Slag Mineralization and Utilization Project	Henan Energy Kaixiang Chemical Industry
14	50,000 tons/year Chemical Synthesis Gas Separation CO_2 to Produce Dry Ice Project	Henan Energy Kaixiang Chemical Industry
15	CO_2 Solid Waste Utilization Project	Henan Qiangnai New Materials
16	Beijing Fangshan Cement Plant CO_2 Capture Project	Hongyu Huanneng
17	Jurong 10,000 tons/year CO_2 Capture Project	Huadian Group
18	Zhengning Power Plant 1.5 million tons/year CO_2 Capture and Storage Project	Huaneng Group

CCUS Demonstration Projects in China		
No.	**Name of Project**	**Company**
19	Shanghai 120,000 tons/year Phase-change CO_2 Capture Industrial Device	Huaneng Group
20	Beijing Thermal Power Plant 3,000 tons/year CO_2 Capture Demonstration Project	Huaneng Group
21	Changchun Thermal Power Plant 1000 tons/year Phase-Change CO_2 Capture Industrial Device	Huaneng Group
22	Yangpu Thermal Power Gas Unit 2000 tons/year CO_2 Capture Project	Huaneng Group
23	Tianjin IGCC Power Plant 100,000 tons/year CO_2 Pre-combustion Capture Project	Huaneng Group
24	Beijing Miyun Gas 1,000 tons/year CO_2 Capture Demonstration Project	Huaneng Group
25	Hunan Yueyang Low Temperature Method CO_2 and Pollutant Collaborative Removal Project	Huaneng Group
26	Haifeng Carbon Capture Testing Platform	China Resources Power
27	Yingcheng 35MW Oxy-fuel Combustion Industrial Demonstration	Huazhong University of Science and Technology
28	Foshan 10000 tons/year Flue Gas CO_2 Capture and Sequestration Demonstration Project	Jialida Environmental Protection Technology
29	Taizhou CO_2 Solidification and Utilization Project producing Polypropylene Carbonate	Zhongke Jinlong
30	Liulihe Cement Plant CO_2 Capture and Utilization Project	Jinyu Group
31	Beijing Cement Plant CCUS Project	Jinyu Group
32	Daqing Oilfield Sanzhao CCUS Project	CNPC
33	Kuche Million-ton CCUS Integrated Demonstration Project	Tong Petrotech
34	Yuncheng Medium Temperature Pressure Adsorption H2/CO_2 Separation Pilot Demonstration Device	Tsinghua University
35	Steel Slag and Dust Removal Ash Indirect Mineralization Utilization Project	Jinheng Lvliang
36	Xichang CO_2 Mineralized Slag Desulfurization Key Technology Demonstration and 10,000-ton Industry Application Project	Sichuan University

CCUS Demonstration Projects in China		
No.	**Name of Project**	**Company**
37	Zhanjiang Basalt CO_2 Mineralization and Storage Demonstration Project	Tencent
38	Ordos CO_2 Electrolysis to Syngas Project	Tianjin University
39	Taiyuan Ruiguang Power Plant CO_2 Capture Project	Southwest Chemical Research and Design Institute
40	Jilin Baicheng Fermentation Gas CO_2 Capture Project	Southwest Chemical Research and Design Institute
41	Chengdu Coal Chemical Chain Combustion Full Process Demonstration System	Tsinghua University
42	Tahe Refining and Chemical Hydrogen Production Release Gas CCUS Full Process Project	Sinopec
43	Tarim CCUS Project	CNPC
44	Hami CCUS Demonstration Project	CNPC
45	CCUS Full Process Project	Xin Lian Xin Chemicals Group
46	Yantai Penglai Power Plant Microalgae Carbon Fixation Project	Hairong
47	Lanzhou Liquid Sunshine Synthesis Demonstration Project	Lanzhou New Area Petrochemical Group
48	Ordos Liquid Sunshine Demonstration Project	China Coal
49	Lanxi CO_2 Capture and Mineralization Utilization Integrated Demonstration Project	Zhejiang Energy
50	Fukang CCUS Full Process Project	Water Environment Center of Geological Survey Bureau
51	Tianjin Iron Plant CO_2 Capture Project	China Coal Geology Administration
52	Lishui LS36-1 Gas Field CO_2 Capture and Purification Project	CNOOC
53	Bozhong 19-6 Condensate Gas Field Phase I Development Project	CNOOC
54	Southern Oilfield Chengmai CCUS Project	CNPC

CCUS Demonstration Projects in China		
No.	**Name of Project**	**Company**
55	Southern Oilfield Chengmai CCUS Project	CNOOC
56	Jilin CO_2 based Biodegradable Plastics Project	Changchun Institute of Applied Chemistry, Chinese Academy of Sciences
57	Ruian CO_2 to Polyol Project	Changchun Institute of Applied Chemistry, Chinese Academy of Sciences
58	Changzhi CO_2 Industrial Waste Gas Large Scale Reforming and Transformation Project	Shanghai Institute of Advanced Research, Chinese Academy of Sciences
59	Ordos CO_2 Microalgae Biological Fertilizer Project	Shanghai Advanced Research Institute, Chinese Academy of Sciences
60	Industrial Trial of Dongfang 1,000-Ton CO_2 Hydrogenation to Methanol	Shanghai Advanced Research Institute, Chinese Academy of Sciences
61	Qinshui CO_2 Enhanced Coalbed Methane Recovery Project	China United Coalbed Methane
62	Liulin Coalbed Methane Injection Production Project	China Australia Cooperation
63	Shengli Oilfield CO_2 Capture, Utilization and Storage Full Process Project	Qilu Petrochemical
64	Zhongyuan Oilfield Puyang CO_2-EOR Demonstration Project	Sinopec
65	East China Oil and Gas Field CCUS Project - Nanhua Synthetic Ammonia Tail Gas Recovery Auxiliary Device (Phase I)	Sinopec
66	East China Oil and Gas Field CCUS Project - Nanhua Synthetic Ammonia Tail Gas Recovery Auxiliary Device (Phase II)	Sinopec
67	East China Oil and Gas Nanhua CO_2 Capture Project (Phase III)	Sinopec
68	East China Oil and Gas Nanhua CO_2 Capture Project (Phase IV)	Sinopec
69	Jinling Petrochemical Jiangsu Oilfield CO_2 Capture Project	Sinopec
70	Changqing Oilfield Jiyuan CCUS Pilot Test Project	CNPC

CCUS Demonstration Projects in China		
No.	**Name of Project**	**Company**
71	Changqing Oilfield Ningxia CCUS Project	CNPC
72	Daqing Oilfield-Daqing Petrochemical Cooperation CCUS Project	CNPC
73	Hulunbuir CCUS Project of Daqing Oilfield	CNPC
74	Jilin Oilfield-Jilin Petrochemical Cooperation CCUS Project	CNPC
75	Jilin Daqingzijing Oilfield CCUS Project	CNPC
76	Jidong Oilfield CCUS Project	CNPC
77	North China Oilfield Cangzhou CCUS Project	CNPC
78	Xinjiang Oilfield CCUS Industrialization Project	CNPC
79	Liaohe Oilfield Panjin CCUS Project	CNPC
80	Southern Oilfield Lingao CCUS Project	CNPC
81	Xingtai Coke Oven Smoke CO_2 Capture Demonstration Project	Xuyang Group
82	Urumqi Ouyeel Furnace Metallurgical Gas CO_2 Capture Project	Baowu Group
83	Yingkou Green Hydrogen Fluidized Bed Direct Reduction Technology Demonstration Project	Ansteel Group
84	New Energy Photovoltaic Cell Packaging Materials Phase II and CO_2 Capture and Purification Project	China Building Materials (Hefei)
85	Xuzhou 10,000-ton CO_2 Purification - Steel Slag Mineralization Comprehensive Utilization Testing Project	Xuzhou Steel Group
86	Zoucheng 10,000-ton Flue Gas Direct Mineralization Demonstration Line	Jingbo Group
87	1000 t/a CO_2 Hydrogenation Gasoline Production Project	Dalian Institute of Chemical Physics, Chinese Academy of Sciences
88	Unit 31 million-ton/year Flue Gas CO_2 Capture Project	China Resources Power (Shenzhen)

CCUS Demonstration Projects in China		
No.	**Name of Project**	**Company**
89	100,000-tons/year Flue Gas CO_2 Capture and Mineralization Project	China Resources Group (Zhaoqing)
90	20,000 tons/year Lime Kiln Tail Gas CO_2 Capture and Mineralization Project	Ningbo Steel
91	Yancheng Thousand-ton Phase Change Capture Technology Demonstration Project	Tsinghua University
92	Xinjiang Oilfield CCUS Pilot Project	CNPC
93	Yulin Coal Chemical Company 300,000-tons/year CO_2 Capture Project	Yanchang Petroleum
94	Changxing Island Power Plant 100,000-ton CCUS project	SPIC
95	Microalgae Carbon Fixation Project	China Resources Power (Shenzhen)
96	Zhanjiang Biomass Power Plant Smoke Microalgae Carbon Fixation Project Demonstration	Guangdong Energy
97	Ansai Huaziping 100,000 tons/year CO_2 EOR and Storage Demonstration Project	Yanchang Petroleum
98	Jingbian Wuqi 50,000 tons/year CO_2 EOR and Storage Pilot Project	Yanchang Petroleum

. Source: China CCUS Annual Report 2023 (translated from Chinese)

4. Joint Conclusions

Any transformation process brings risks and challenges, but let us not forget the opportunities.

The world has engaged in the 'energy transition', a profound transformational process, the most important since the industrial revolution by its magnitude and spread. it is already impacting many aspects of the energy ecosystem we are living in. The present report is a clear illustration of these transformations in three selected sectors, with a specific attention given to the business opportunities each sector is offering, or could offer, to European companies in China:

- Hydrogen, a nascent and promising new energy vector which is likely to feature large in the future energy supply to private and industrial consumers.
- Carbon Capture and Utilisation/Storage/ (CCUS), a resurrected technology now returning to favour in several industry sectors.
- LNG, a mature energy source derived from natural gas which is developing in a well-established and globalised market.

Neither hydrogen nor CCUS are new technologies per se. Both got off to a poor start several decades ago and followed a well-known pattern of excessive initial expectations followed by disillusion.

This report argues that both are now experiencing a rapid and solid entry into the energy landscape of Europe and China.

While Europe was the first to draw up a strategy for hydrogen and CCUS, this report shows that China is catching up rapidly and may already have taken the lead in some segments of the value chains, particularly when it comes to manufacturing and up-scaling (e.g., hydrogen production), where China has traditional strengths and advantages.

However, as these two technologies (or group of integrated technologies) are at the very start of their industrialisation process, and that correlatively the market size is still limited, their economic ecosystems are still unstable and fragile. In order to grow, they will require intense government support both in terms of policy making and financing. A priority must be to enable these industries to flourish and play the role which is expected from them to offset emissions-intensive industrial activities and transportation modes and as such help the EU and China to meet their respective climate goals.

A key requirement is a level playing field for all market players, international and Chinese. To deliver this, China needs to further strengthen IP protection and eliminate market barriers, national and sub-national. For its part, the EU needs to ensure its own IP protection is fair both to EU and non-EU countries, and that it does not throw up barriers to energy-efficient foreign innovators with more effective technologies.

These are necessary conditions for cooperation to be implemented at large scale between China and the EU.

There are clear areas of cooperation which could help accelerate the establishment of hydrogen and CCUS as meaningful players in the global energy system. Policy making, regulations and standards elaboration are among those, together with a homogenised certification processes.

Less straightforward is the issue of market harmonisation which requires some level of alignment in regulations and market conditions. In the long-term, one such area for collaboration is the value given to carbon: both hydrogen and CCUS applications will be driven directly or indirectly by the value of carbon and its related taxation mechanisms.

As far as hydrogen is concerned, while a sizeable number of companies have already started to tap into the business opportunity this new energy could represent, most are questioning the potential size of the demand and how fast it can really grow. Therefore, government-sponsored stimulation of demand is another area which could affect the quality and sustainability of business plans for these companies as well as the capacity to attract investments. However, such state intervention needs to be conducted without generating undesired overcapacities and introducing excessive subsidies.

The LNG business is thriving, with significant connections already established between Chinese and foreign companies. By opening up China’s gas market to new players, such connections can be developed further. The result will be that the gas industry in China will benefit from the experience and expertise of gas market players with relevant and useful knowledge.

5. List of Figures

6. List of Tables

86-10 6587 6175

info@ececp.eu

Unit 3123 & 3125, Level 31, Yintai Office Tower C,
2 Jianguomenwai Avenue, Chaoyang District,
Beijing 100022, People's Republic of China

www.ececp.eu

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