Carbon Capture, Usage & Storage (CCUS) Supply Chain Cooperation:

Unlocking the full potential of CCUS for the UK and China

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Foreword

I am delighted to be writing the foreword to this excellent report into the opportunities in China for UK businesses in Carbon Capture, Usage & Storage (CCUS).

Both the UK and China have ambitious targets for reducing carbon emissions - net zero emissions by 2050 for the UK and carbon neutrality by 2060 for China. CCUS is an important part of achieving this and offers a pathway to reduce greenhouse gas emissions and secure a sustainable future. The UK's independent Climate Change Committee (CCC) has described CCUS as a 'necessity, not an option.'

This comprehensive report examines the critical aspects of CCUS technology, its current state, and the immense potential it holds for both the UK and China. It outlines the opportunities for collaboration across the CCUS supply chain highlighting areas where the UK and China should work together to accelerate the advancement and expedite the deployment of CCUS solutions and how to maximise their impact.

China's impressive portfolio of nearly one hundred CCUS projects across various sectors, along with its ambitious goals for carbon capture capacity expansion, presents a significant opportunity for collaboration. UK industry holds the potential to contribute its commercial expertise in engineering consultancy, project development, financing, and the supply of key components. Through strengthened cooperation, we can enhance our capabilities and drive forward innovation in CCUS technology.

In particular, this report identifies several sectors within the CCUS domain where UK companies can make significant commercial contributions, including high-efficiency amine solutions, biomass carbon capture solutions, offshore carbon storage solutions, and key CCUS equipment, among others.

This report also highlights challenges that UK companies may encounter when entering the Chinese market, while explaining that China actively encourages foreign investment and participation in the CCUS industry, as evidenced by the policies and initiatives.

I hope that this report serves as a catalyst for increased participation by UK companies in CCUS projects in China. There is much potential for commercial success, as well as addressing the global challenge of climate change that transcends borders. By working together, we can unlock the full potential of CCUS and contribute to a sustainable future for all.

I would like to express my gratitude to the UK companies that have contributed to this report through their valuable insights and expertise. I also extend my sincere thanks to the dedicated teams and experts who have compiled this report. I look forward to seeing the positive impact that this work has on UK-China collaboration in CCUS and on the global fight against climate change.

His Majesty's Trade Commissioner

Key messages from the report

01

The UK and China both recognise the essential role of CCUS in their decarbonisation strategies and are at the forefront of the global efforts to deploy this transformative technology.

The UK's commitment to earmark £20 billion in the development of four CCUS clusters by 2030, coupled with China's extensive portfolio of approximately one hundred CCUS projects spanning diverse industries, highlights how they both have leading roles in the global CCUS sector.

02

The UK's CCUS industry are well-positioned to tap into substantial opportunities within the fast-growing Chinese CCUS market.

The UK excels in multiple CCUS sectors, including critical carbon capture component manufacturing, offshore CO_2 transport and storage technologies, and a dedication to CCUS innovation. Several UK companies have already ventured into China's CCUS market, signalling promising opportunities for collaboration and growth.

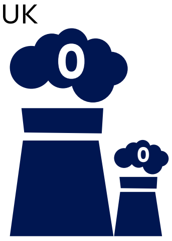
03

Collaboration between China and the UK in the CCUS sector will yield benefits that extend beyond national borders, contributing to the global efforts of combating climate change.

China encourages foreign investment in its CCUS sector, and the contribution of UK companies would aid in decarbonising the world's largest CO_2 emitter, thereby creating positive impacts on a global scale.

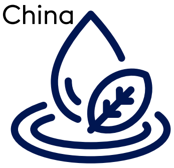
Executive Summary

UK

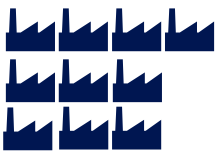


2050
Net Zero Emissions

China



2060
Carbon Neutrality



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CCUS Projects

The United Kingdom (UK) and the People's Republic of China (herewith referred to as China) are both committed to developing strong carbon capture, usage and storage (CCUS) industries to achieve their respective targets of net zero by 2050 and carbon neutrality by 2060. Given their shared commitment towards CCUS, this report aims to identify opportunities for alignment between the UK and China in the CCUS supply chain and to provide recommendations for how the two countries can work together to accelerate the scaling up of CCUS demonstrations and unlock the full potential of the technologies.

China currently has approximately one hundred CCUS projects spanning various phases, offering a prime window for CCUS technology deployment between 2025 and 2035. To achieve carbon neutrality by 2060, China must significantly increase its carbon capture capacity from 6 Mt/yr to 2100-2500 Mt/yr, according to the assessment by China's Ministry of Science and Technology.

The UK Government has committed £20 billion for early CCUS deployment. Key UK capabilities, such as engineering consultancy, project development, financing expertise, and component supply, can add value in the Chinese market.

In specific CCUS sectors, UK companies can excel. High-efficiency amine solutions are in demand in the amine-based carbon capture sector. Additionally, the UK can be competitive in supplying heat exchangers, column internals, and filters. Other sectors like biomass flue gas carbon capture, CO_2 separation membranes and direct air capture, all offer collaboration opportunities due to limited Chinese experience.

China's CO_2 transport sector currently relies on tanker transport but has potential for pipeline design, planning, and construction. UK expertise in pipeline design, corrosion resistance, and detection can contribute.

In the CO_2 storage field, UK companies can find opportunities in carbon storage and monitoring processes, including injection, risk analysis, leakage management, and advanced monitoring techniques. Offshore CO_2 storage offers potential for UK capabilities in reservoir design, marine and subsea operations.

Two primary barriers exist for UK companies in China: restrictions on foreign ownership of water transport companies and state-owned oil company dominance in CO_2 storage.

China actively encourages foreign investment in the CCUS industry, as evidenced by its policies and the Catalogue of Industries for Encouraging Foreign Investment. The need to decarbonize China's economy and address climate change presents significant commercial opportunities for the UK's CCUS-related industries. Collaborative efforts between China and the UK on climate change issues will yield benefits that extend beyond national borders, fostering advantages for the global community.

Chapter 1.

Introduction

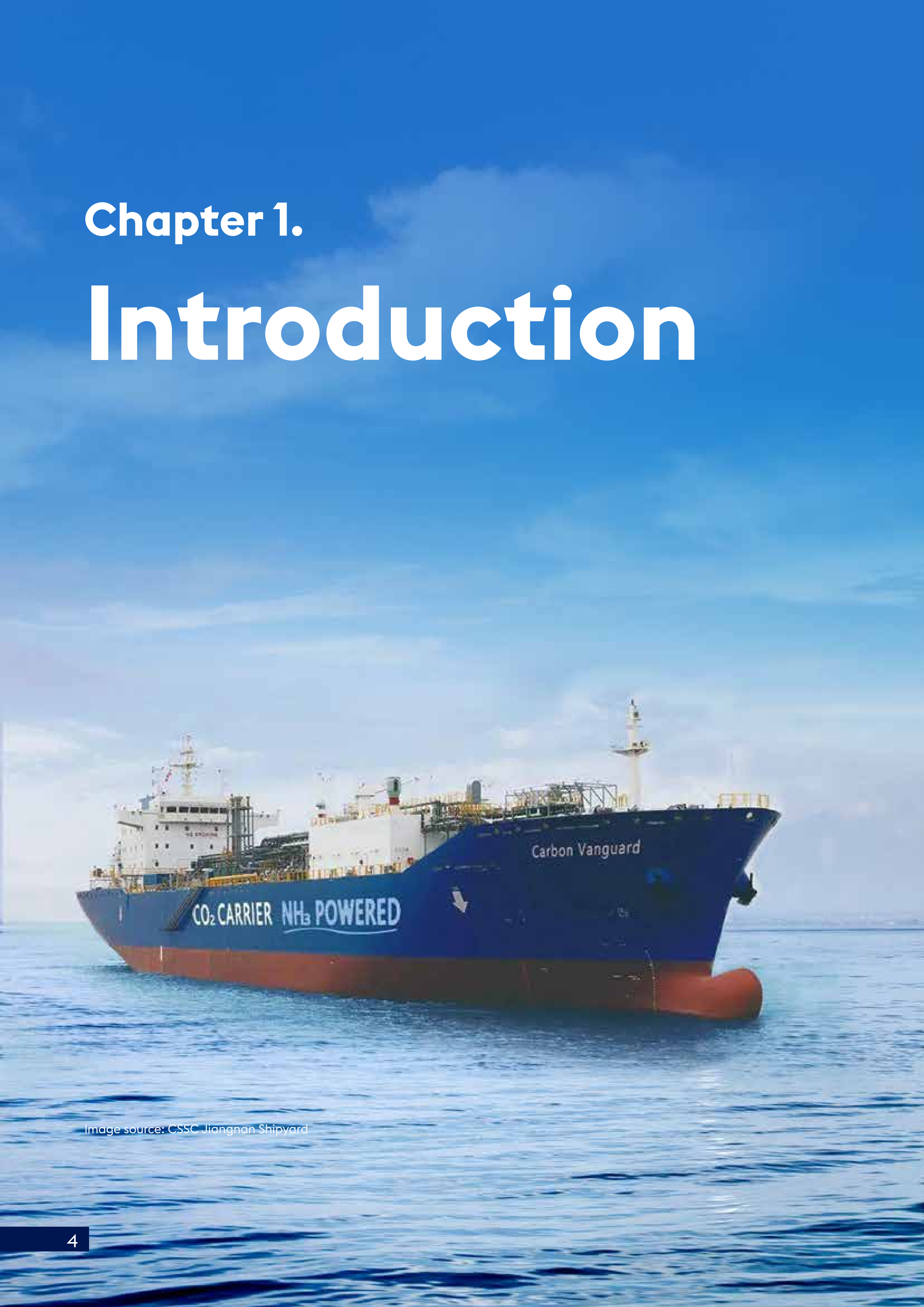


Image source: CSSC Jiangnan Shipyard

Carbon Capture Usage and Storage (CCUS) captures CO_2 emissions from industry or power generation, offering options for CO_2 usage or permanent underground storage. CCUS is vital in combatting climate change by preventing CO_2 release into the atmosphere, reducing emissions from key industries.

Both the UK and China recognise CCUS's importance and support its development.

In the UK, CCUS is crucial for achieving net-zero emissions by 2050 and fostering a greener economy. The government has launched initiatives like the £1 billion CCUS Infrastructure Fund and the £315 million Industrial Decarbonisation Challenge, while also committing £20 billion for early CCUS cluster deployment.

China, too, considers CCUS pivotal in its national development plans, with approximately one hundred CCUS projects across various sectors already underway.

The UK has a history of international collaboration in CCUS, notably with China. The UK CCS Research Centre (UKCCSRC) and Scottish Carbon Capture and Storage (SCCS) partnered with the Guangdong Electric Power Design Institute (GEDI) to establish the UK-China (Guangdong) CCUS Centre in 2013, promoting CCUS research and projects in China.

Given the shared commitment to CCUS, there are significant opportunities for UK-China collaboration in the CCUS supply chain. This report identifies these opportunities and provides recommendations for unlocking CCUS's full potential.

£20 billion

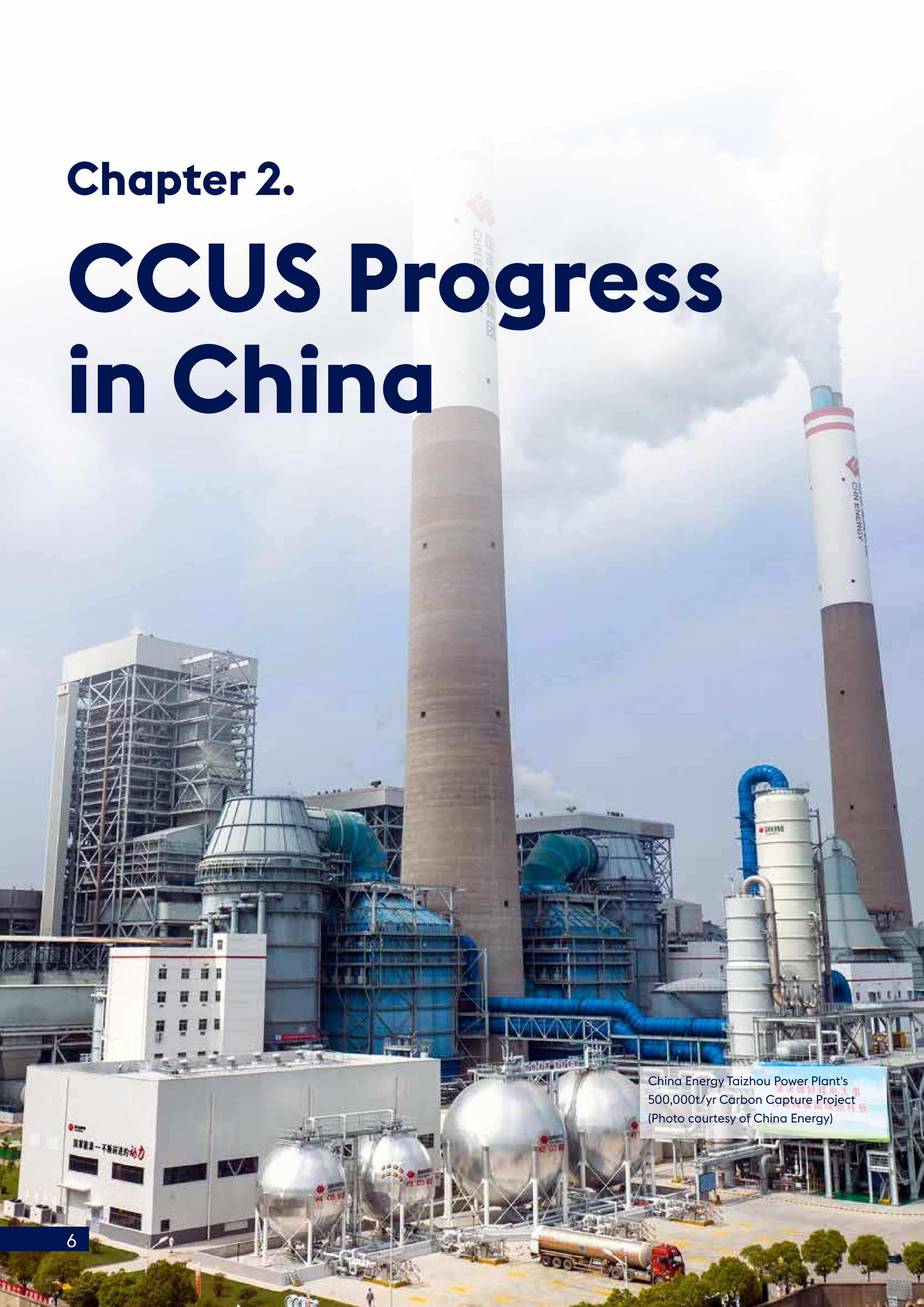
The government has committing £20 billion for early CCUS cluster deployment.

100 CCUS Projects

China, too, considers CCUS pivotal in its national development plans, with approximately 100 CCUS projects across various sectors already underway.

Chapter 2.

CCUS Progress in China



China Energy Taizhou Power Plant's 500,000t/yr Carbon Capture Project (Photo courtesy of China Energy)

China's emissions from the energy combustion and industrial process amounted to 12.1 Gt CO_2 in 2022, accounting for 32.8 percent of the global total, making it the world's largest emitter of carbon[1]. According to the latest nationwide survey conducted by the China Ministry of Science and Technology, as of the end of 2022, there are a total of 96 CCUS projects in China either in operation, under construction, or in the planning stages, with operational CO_2 capture capacity of 6 Mt/yr[2]. Table 2-1 illustrates representative CCUS projects in China, covering various sectors such as the power, cement, steel, chemical and oil sectors. Collectively, these projects have a total CO_2 capture capacity of approximately 9 million tons per year, with the majority of the captured CO_2 being utilised and less than 1 million tons being stored geologically.

Table 2-1 List of representative CCUS projects in China (arranged by the earliest first)

No.	Project Name (Scale)	Sector	Entity	Start Year (Status*)	Location
1	Daqing Oilfield CO_2-EOR Demo (200 kt/yr)	Oil	China National Petroleum Corporation (CNPC)	2003 (O)	Daqing, Heilongjiang
2	Jilin Oilfield CO_2-EOR Project (600 kt/yr)	Oil	CNPC	2008 (O)	Songyuan, Jilin
3	Shidongkou Power Plant Carbon Capture Demo (120 kt/yr)	Power	China Huaneng Group	2009 (O)	Shanghai
4	Shuanghuai Power Plant Carbon Capture Demo (10 kt/yr)	Power	State Power Investment Corporation	2010 (O)	Chongqing
5	Ordos Basin Saline Aquifer Storage Project (100 kt/yr)	Chemical	China Energy Investment Corporation	2011 (M)	Erdos, Inner Mongolia
6	Datang Beijing Gaojing Plant Gas Turbine CO_2 Capture Project (2 kt/yr)	Power	China Datang Corporation	2012 (O)	Beijing
7	35MW Oxy-fuel Combustion Demo (100 kt/yr)	Power	Huazhong University of Science and Technology	2014 (O)	Yingcheng, Hubei
8	Xinjiang Oilfield CO_2-EOR Project (100 kt/yr)	Oil	CNPC	2015 (O)	Karamay, Xinjiang
9	IGCC Power Plant Carbon Capture Project (100 kt/yr)	Power	China Huaneng Group	2016 (O)	Tianjin
10	CO_2 Reforming to Syngas Plant (20 kt/yr)	Chemical	Shanghai Advanced Research Institute, Chinese Academy of Sciences	2017 (O)	Changzhi, Shanxi

1. International Energy Agency (IEA), CO2 Emissions in 2022[R], 2023
2. The Administrative Center for China's Agenda 21, Global CCS Institute, CCUS Progress in China – A Status Report[R], 2023

11	Changqing Oilfield CO_2-EOR Project (50 kt/yr)	Oil	CNPC	2017 (O)	Yulin, Shaanxi
12	Baimashan Cement Plant Carbon Capture Demo (50 kt/yr)	Cement	Anhui Conch Cement	2018 (O)	Wuhu, Anhui
13	Guangdong Carbon Capture Test Platform (20 kt/yr)	Power	China Resources Power	2019 (O)	Shanwei, Guangdong
14	Huadian Jurong Power Plant Carbon Capture Demo (10 kt/yr)	Power	China Huadian Corporation	2019 (O)	Zhenjiang, Jiangsu
15	CO_2-based Biodegradable Plastics Project (300 kt/yr)	Chemical	Changchun Institute of Applied Chemistry, Chinese Academy of Sciences	2021 (O)	Jilin
16	CO_2 Capture Project of Exhaust Gas from Coal Hydrogen Production (200 kt/yr)	Chemical	Sinopec	2021 (O)	Nanjing, Jiangsu
17	Baotou Steel CCUS Project (2000 kt/yr)	Steel	Baotou Steel	2021 (C)	Baotou, Inner Mongolia
18	Jinjie Power Plant CCUS Project (150 kt/yr)	Power	China Energy Investment Corporation	2021 (O)	Yulin, Shaanxi
19	Enping 15-1 Oilfield CO_2 Reinjection Demo (300 kt/yr)	Oil	China National Offshore Oil Corporation (CNOOC)	2022 (O)	Offshore, Guangdong
20	Qflu Petrochemical - Shengli Oilfield Project (1000 kt/yr)	Oil	Sinopec	2022 (O)	Shandong
21	Yanchang Petroleum CO_2-EOR Demo (300 kt/yr)	Chemical and Oil	Yanchang Petroleum Group	2022 (O)	Yulin, Shaanxi
22	Chemical looping combustion megawatt-class demon project	Power	Dongfang Boiler Group, Total	2022 (O)	Deyang, Sichuan
23	Guanghui Energy CCUS Project (100 kt/yr)	Oil	Guanghui Energy	2022 (C)	Hami, Xinjiang
24	Lanxi Power Plant CCUS Project (15 kt/yr)	Power	Zhejiang Provincial Energy Group	2022 (C)	Lanxi, Zhejiang
25	Caofeidian CCUS Demo (150 kt/yr)	Power	China Resources Power	2022 (C)	Tangshan, Hebei
26	Longdong CCUS Project (1500 kt/yr)	Power	China Huaneng Group	2023 (C)	Qingyang, Gansu
27	Taizhou Power Plant CCUS Project (500 kt/yr)	Power	China Energy Investment Corporation	2023 (O)	Taizhou, Jiangsu
28	Changxing Island Power Plant CCUS Demo (100 kt/yr)	Power	State Power Investment Corporation	2023 (O)	Shanghai
29	Ningdong Base CCUS Demonstration Project (1000 kt/yr)	Chemical and Oil	China Energy Investment Corporation, CNPC	2023 (C)	Ningxia

*O means in operation, C means under construction, M means under CO_2 storage monitoring.

2.1 Carbon Capture

China employs various carbon capture technologies, including oxy-fuel combustion, pre-combustion, and post-combustion (Table 2-2). Most carbon capture demonstration projects in China focus on the power sector, primarily using post-combustion capture with amine solution. Other methods are also being explored, such as membrane CO_2 separation at the China Resources Haifeng CCUS demonstration project and pre-combustion carbon capture combined with integrated gas combined cycle (IGCC) at the Huaneng plant in Tianjin. Oxy-fuel combustion for CO_2 capture is operational at Huazhong University of Science and Technology, while chemical looping combustion for CO_2 capture is applied in Deyang, Sichuan Province.

In the cement sector, Conch Cement pioneered China's first carbon capture plant in 2018, capable of producing 30,000 tons of food-grade CO_2 and 20,000 tons of industrial-grade CO_2 annually. United Cement Qingzhou started a carbon capture demo project in June 2023, using the oxy-fuel combustion process (200 kt/yr). China Resources Cement's oxy-fuel combustion and carbon capture project (100 kt/yr) in Zhaoqing, Guangdong, awaits commencement after successful environmental assessment.

In the steel sector, Baosteel is constructing China's first carbon capture project in Baotou, Inner Mongolia, with an amine-based CO_2 capture system aiming to capture 2 million tons of CO_2 annually, including a 500,000t/yr carbon capture project in its first phase. The captured CO_2 will be utilised through reactions with steel slag and for EOR purposes.

In the coal chemical sector, Rectisol CO_2 separation technology, using methanol as a solvent, is commonly applied in the process of capturing high-concentration CO_2 (>80%vol.) in the water-to-gas shift process. Representative cases of this technology include the Yanchang Petroleum CCUS Project and the Ningdong CCUS Demonstration Project.

Fig. 2-1 Natural Gas Power Plant Carbon Capture Demostration Project (2 kt/yr) at Huaneng Yangpu Plant, Hainan Province (Photo courtesy of Huaneng)

Table 2-2 Representative carbon capture projects in China (arranged by sector and chronological order)

Project Name (Scale)	Operating Entity	Technology	Sector	Start Year (Status*)	Location
Huaneng Shidongkou Power Plant Carbon Capture Demo (120 kt/yr)	Huaneng Group	Post-combustion	Power	2009 (O)	Shanghai
Datang Beijing Gaojing Plant Gas Turbine CO_2 Capture Project (2 kt/yr)	China Datang Corporation	Post-combustion	Power	2014 (O)	Beijing
HUST 35 MW Oxy Combustion (100 kt/yr)	Huazhong University of Science and Technology	Oxy-fuel combustion	Power	2015 (O)	Yingcheng, Hubei
Tianjin IGCC power plant carbon capture (100 kt/yr)	Huaneng Group	Pre-combustion	Power	2016 (O)	Tianjin
Guangdong Carbon Capture Platform (20 ky/yr)	China Resources Power	Post-combustion	Power	2019 (O)	Shanwei, Guangdong
China Energy Jinjie CCS Full Chain Demonstration (150 kt/yr)	China Energy Investment Group	Post-combustion	Power	2021 (O)	Yulin, Shaanxi
Chemical looping combustion megawatt-class demon project	Dongfang Boiler Group, Total	Chemical looping combustion	Power	2022 (O)	Deyang, Sichuan
Taizhou Plant CO_2 Capture and Utilization Project (500 kt/yr)	China Energy Investment Group	Post-combustion	Power	2023 (O)	Taizhou, Jiangsu
Longdong CCUS Project (1500 kt/yr)	Huaneng Group	Post-combustion	Power	2023 (C)	Qingyang, Gansu
Huaneng Yangpu Natural Gas Plant Carbon Capture Demo (2 kt/yr)	Huaneng Group	Post-combustion	Power	2023 (O)	Danzhou, Hainan
Baimashan Cement Plant Carbon Capture Demo (50 kt/yr)	Anhui Conch Cement	Post-combustion	Cement	2018 (O)	Wuhu, Anhui
United Cement Qingzhou Carbon Capture Demo (200 kt/yr)	China National Building Material	Oxy-fuel combustion	Cement	2023 (C)	Weifang, Shandong
Baotou Steel CCUS integration demonstration project (2000 kt/yr)	Baotou Steel	Post-combustion	Steel	2022 (C)	Baotou, Inner Mongolia
Yanchang Petroleum CCUS Project (300 kt/yr)	Shaanxi Yanchang Petroleum Group	Pre-combustion (Rectisol)	Chemical	2012 (O)	Yulin, Shaanxi
Sinopec Qilu Petrochemical-Shengli Oilfield CCUS Project (1000 kt/yr)	Sinopec	Pre-combustion (Rectisol)	Chemical	2022 (O)	Zibo, Shandong
Ningdong CCUS Demon Project (2500kt/yr)	China Energy Investment Group, CNPC	Pre-combustion (Rectisol)	Chemical	2022 (C)	Ningdong, Ningxia

*O means in operation, C means under construction.

Fig. 2-2 Carbon Capture Facility at Yanchang Petroleum Yulin Coal Chemical Plant, Shaanxi Province (Photo courtesy of Yanchang Petroleum)

2.2 Carbon Transport

CCUS projects in China are mostly in the demonstration stage and are generally small-scale. Tanker transport is currently the prevailing method. China possesses the capacity to construct CO_2 transport vessels. China International Marine Containers (Group) has collaborated with China Resources Power to develop a CO_2 transport ship design and operation scheme for a megaton-scale CCUS project at Haifeng Power Plant in Guangdong in 2020.

Pipeline transport for megaton-scale CO_2 in China is in early stages. CNPC's Jilin oilfield CCUS project features a 20 km CO_2 pipeline transport project (Table 2-3). Concurrently, the Qilu Petrochemical Shengli Oilfield CCUS project is constructing a 108 km onshore pipeline. Subsea CO_2 pipeline transport is currently in the feasibility study phase in China.

Table 2-3 CCUS projects transporting CO_2 with pipeline in China

Project Name (Scale)	Status	Distance (km)
CNPC Daqing Oilfield CO_2-EOR Demo (200 kt/yr)	Operation	-
CNPC Jilin Oilfield CO_2-EOR Project (600 kt/yr)	Operation	20
Sinopec Qilu Petrochemical- Shengli Oilfield CCUS Project (1000 kt/yr)	Under construction	108

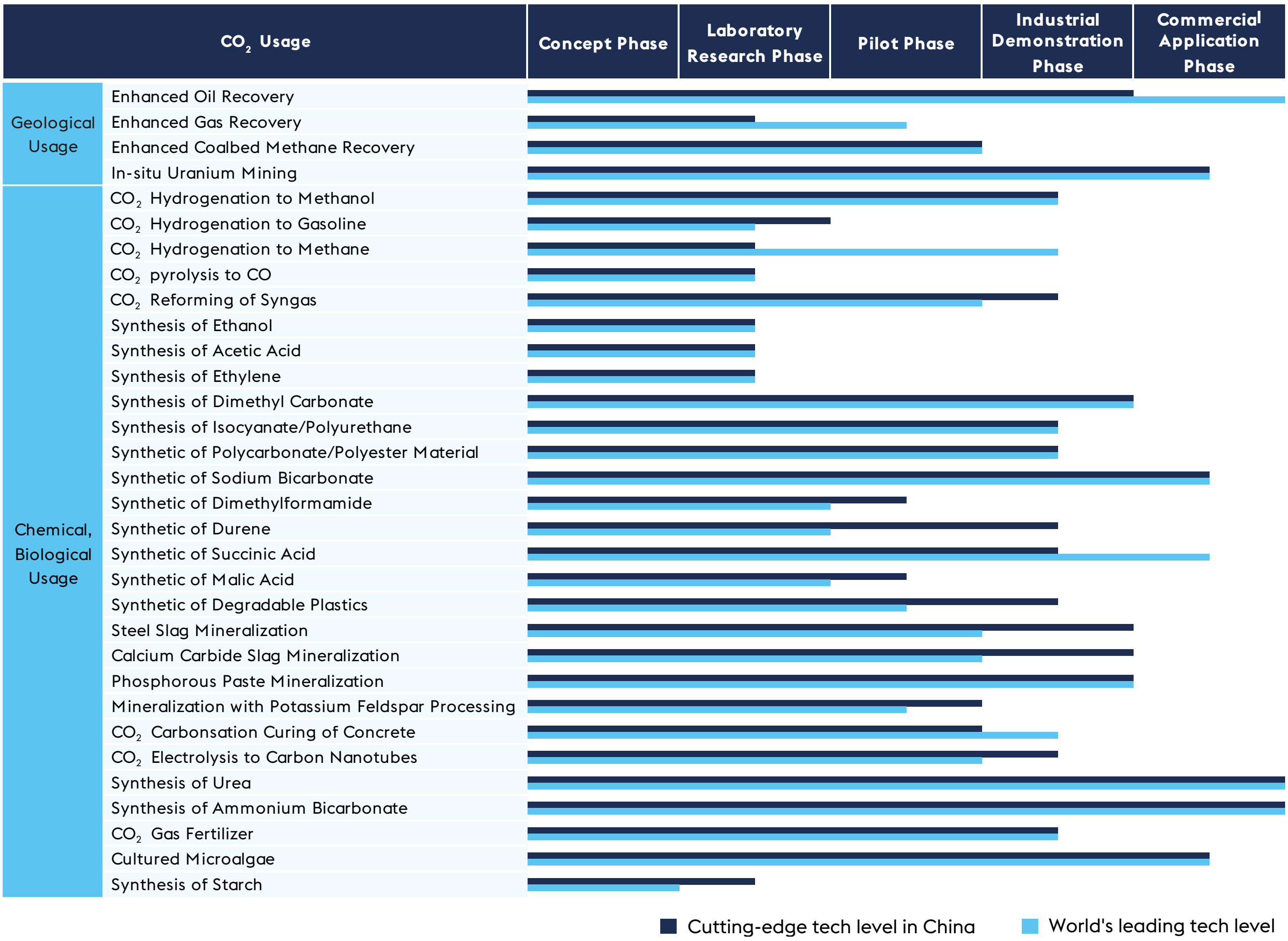


Fig. 2-3 Advancements in CO_2 usage technologies in China vs. cutting-edge global standards. China showcases pioneering CO_2-to-fuel tech with methanol and syngas synthesis demos. China also have demonstrated the usage of CO_2 to make a range of chemicals, including dimethyl carbonate, polyurethane and more. It is also notable that, in China, a range of industrial waste, including steel slag, calcium carbide slag and phosphorous paste, have been used to sequester CO_2 for the creation of building materials, such as marble[3].

3. UK-China (Guangdong) CCUS Centre, Research Report on the Development Path of Carbon Dioxide Industry in Ningxia[R] (in Chinese), 2023

2.3 Carbon Usage

In recent years, the field of CO_2 usage technology has made significant progress worldwide, and China has also made notable strides in this area. New CO_2 usage technologies and projects are continually emerging, with industrial demonstrations making steady progress.

China's CO_2 usage projects employ various methods, including geological, chemical, and biological approaches. These encompass techniques like CO_2 enhanced oil recovery (CO_2-EOR) and the conversion of CO_2 into an array of materials, including methanol, syngas, biodegradable plastics, calcium carbonate, nanomaterials, and carbon-negative building materials. Overall, China's level of carbon dioxide usage technology is comparable to that of the international cutting-edge level and in some cases, even showcases a technological advantage (Fig. 2-1).

For example, in the area of CO_2 geological usage, China has widely used CO_2 to enhance oil recovery in its major onshore oil fields. The country has also established pilot projects for the production of green methanol, synthetic gasoline, and syngas from CO_2, with its technical capabilities leading globally in the area of CO_2 synthetic fuels. Additionally, China has conducted pilot projects in the fields of CO_2 synthetic dimethyl carbonate, isocyanate, dimethylformamide, durene, succinic acid, biodegradable plastics, carbon nanotubes, and others, with some of its application technologies at the leading level globally. In the area of CO_2 agricultural applications, CO_2 synthetic urea and ammonium bicarbonate are mature industries, CO_2 gas fertilizers have been demonstrated and promoted in some provinces, and commercial applications of CO_2-cultivated microalgae have reached a state of maturity. The list of the Chinese research institutions or companies that possess these CO_2 usage technologies can be found in Section 4.3.

Fig. 2-4 CO_2 injection site at CNPC's Jilin Field (Photo courtesy of CNPC)

2.4 Carbon Storage

China has vast CO_2 storage potential both onshore and offshore, encompassing sedimentary basins and basaltic rock formations.

The potential for geological CO_2 storage in China's deep saline aquifers accounts for over 90 percent of the total potential within the sedimentary basins, with an estimated storage capacity of approximately 7.69 trillion tonnes, according to the Center for Hydrogeology and Environmental Geology Survey, China Geological Survey[4]. Furthermore, the study estimates offshore saline aquifer storage potential at approximately 2.34 trillion ton. A 2022 reassessment by the Qingdao Institute of Marine Geology confirmed a similar figure of 2.58 trillion tonnes, reinforcing China's significant saline aquifer storage potential[5].

China has conducted CO_2 storage demonstrations in onshore and offshore saline aquifers. China's first deep saline aquifer CO_2 storage demonstration project initiated by Shenhua Group in Ordos in 2011, with a capacity to inject 100,000 tons of CO_2 per year. The injection process spanned three years and resulted in the storage of 300,000 tons of CO_2. To date, the project remains in the monitoring phase, with the stored CO_2 maintaining a safe status. In 2021, CNOOC initiated China's first offshore CO_2 storage project at the Enping 15-1 oilfield, which aims to capture and store 300,000 tons of CO_2 annually. This project operates at a water depth of approximately 80 meters, injecting CO_2 into deep saline aquifers at 800 meters via a directional injection well connected to the oil platform.

Additionally, the concept of CO_2 storage in basalt has gained significant attention in recent years due to its advantages, such as rapid mineralisation and low cost features[6]. Researchers from China University of Petroleum have assessed the total CO_2 storage potential in the basalts of China, revealing theoretical mineral storage capacities of 607.79-1121.44 Gt for supercritical CO_2 injection and 201.13-303.85 Gt for carbonated water injection, respectively[7]. Preliminary assessments by Carbfix and Tencent of the carbon storage potential in basaltic rock formations across China have indicated that the theoretical CO_2 storage capacity of Chinese basalt ranges from trillions to tens of trillions of tons[8]. However, given that CO_2 storage in basalt is still in its early stages in China, further verification is necessary, and it offers a crucial complement to CO_2 storage in sedimentary basins.

4. Guo J, Wen D, Zhang S, et al. Potential evaluation and demonstration project of CO2 geological storage in China[J]. Geol Surv China, 2015, 2(4): 36-46.
5. China Ministry of Natural Resources, The predicted potential for geological CO2 storage in China's maritime areas reaches 2.58 trillion tons, 2023, https://www.mnr.gov.cn/dt/ywbb/202301/t20230116_2773942.html
6. Snæbjörnsdóttir S Ó, Sigfússon B, Marieni C, et al. Carbon dioxide storage through mineral carbonation[J]. Nature Reviews Earth & Environment, 2020, 1(2): 90-102.
7. Zhang L, Wen R, Li F, et al. Assessment of CO2mineral storage potential in the terrestrial basalts of China[J]. Fuel, 2023, 348: 128602.
8. Carbfix, Tencent, Pre-feasibility screening study for CO2 mineral storage potential in China[R], 2021

Fig. 2-5 CO_2 processing and reinjection module on the Enping 15-1 Field Platform (Photo courtesy of CNOOC).

2.5 Deployment of CCUS Clusters in China

The Chinese Government, along with certain provinces and state-owned oil companies, are exploring the implementation of CCUS clusters.

The China Ministry of Science and Technology (MOST) has identified several regions with favourable conditions for the deployment of CCUS clusters. These regions include the Erdos Basin in Inner Mongolia, Ningxia, and Shanxi Province; the Junggar Basin, Turpan-Hami Basin, and Tarim Basin in the Xinjiang Autonomous Region; the Songliao Basin in Heilongjiang and Jilin Province; the Sichuan Basin in Sichuan Province; and the Pearl River Mouth Basin offshore Guangdong.

At the provincial level, Guangdong has proposed the design for provincial CCUS clusters. Four are suggested: Eastern Guangdong CCUS Cluster, Pearl River Delta CCUS Cluster, West Pearl River Delta CCUS Cluster, and Western Guangdong CCUC Cluster (Fig. 2-6). The Pearl River Delta CCUS Cluster, the largest emitter at over 120 $MtCO_2$/yr, includes Guangzhou and Shenzhen. Western Guangdong emits around 70 $MtCO_2$/yr, while the Eastern Guangdong and Pearl River Delta West Bank clusters each emit 50 $MtCO_2$/yr and 40 $MtCO_2$/yr, respectively.

CNPC plans to capture 3.0 million tonnes of CO_2 each year from one of its own facilities by 2025, and to construct the relevant pipelines and system for geological storage and usage through EOR (Table 2-4). In the second phase, which is expected to capture 10 million tonnes of CO_2 per year by 2030, the project will capture CO_2 from nearby coal-fired power plants, steel mills, cement plants and other high-emission industries, while expanding the transport system.

Table 2-4 CNPC's planned CCUS hubs

Planned hubs	Storage	Location	Scale (Mt CO_2 per year)	Operation starts	Potential industries
China NW	Junggar Basin	North West	3.0	2025	Chemicals, power, steel, cement
Daqing	Songliao Basin	North East	3.0	By 2030	Chemicals, power, steel, refining, cement, biomass
Changqing	Ordos Basin	North Central	3.0	By 2030	Chemicals, power
Dagang	Bohai Bay Basin	North East	1.0	By 2030	Chemicals, power, steel, refining, cement, biomass

Sinopec is leading the regional CCUS deployment, around the areas around Shanghai, Zhejiang, Jiangsu and Anhui. Sinopec signed a Memorandum of Understanding on cooperation with Shell, China Baowu and BASF in November 2022, aiming to develop the first CCUS project in China with a capacity of 10 Mt CO_2 and provide effective integrated CO_2 reduction solutions for various industrial enterprises.

CNOOC is studying the feasibility of CCUS clustering in Southern China. In January 2023, CNOOC, the Guangdong Development and Reform Commission, Shell and ExxonMobil signed a joint study agreement for the Daya Bay area CCUS project. The purpose of this agreement is to collaborate in seeking opportunities to build an 10 Mt offshore carbon capture and storage cluster in China.

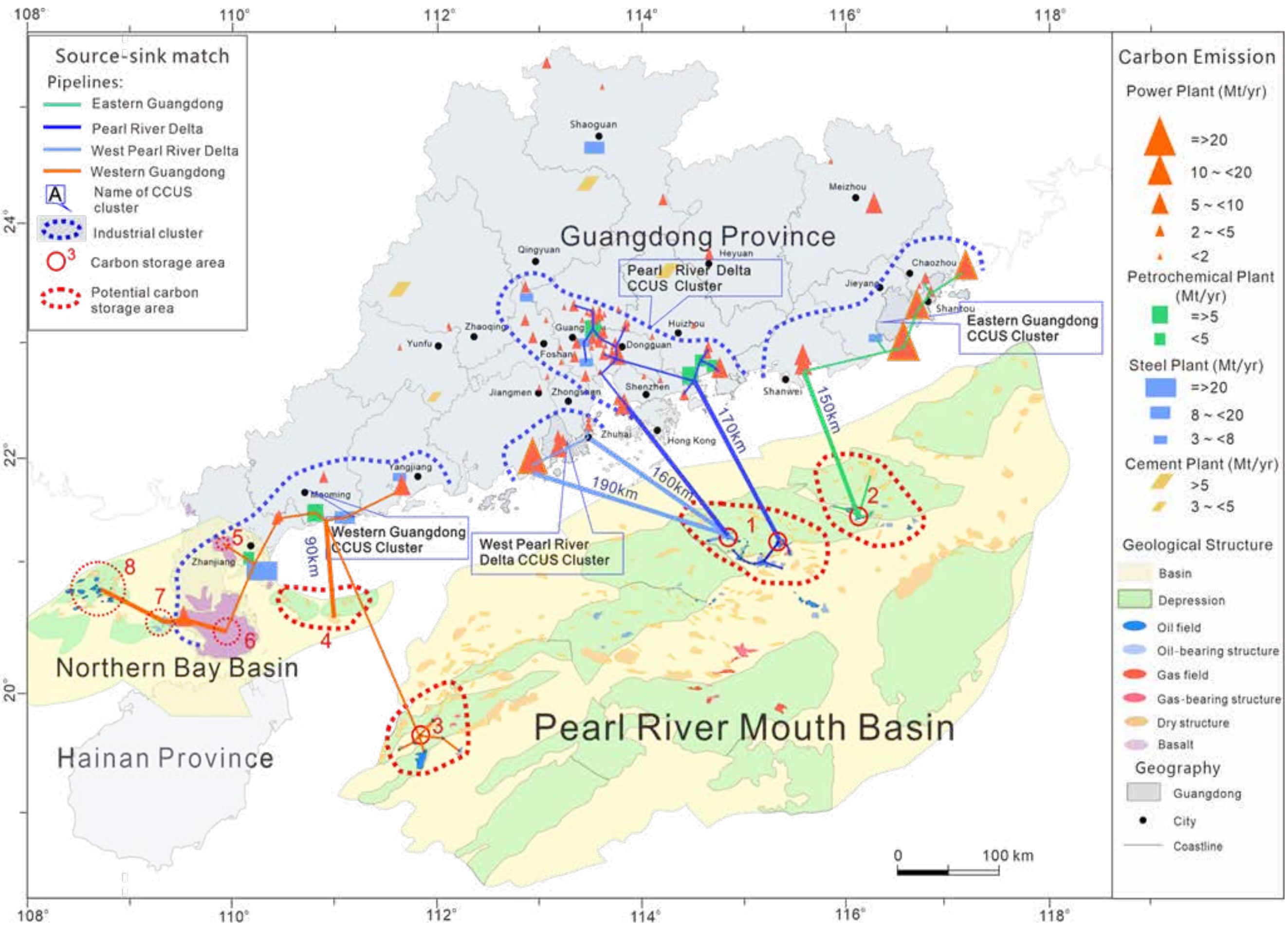


Fig. 2-6 The deployment design of CCUS Clusters in Guangdong.

2.6 CCUS Government Policies in China

In line with its carbon neutrality goals, China aims to develop the CCUS industry by progressively enhancing incentives, laws, and regulations to provide more significant financial support as the sector matures. From 2006 to 2023, the Chinese government has issued over 30 policies, development plans, action plans, and roadmaps concerning CCUS. These policies offer guidance for CCUS technology development, demonstration, application, and broader implementation.

The Chinese government has been incorporating CCUS technology into their national plans and policies since the 11th Five-Year Plan (2006-2010). The 12th and 13th Five-Year Plans (2011-2015 and 2016-2020) saw the development of a strategic deployment plan for CCUS and promotion of systematic demonstration projects. In the 14th Five-Year Plan period (2021-2025), the government is focusing on scaling up the industry and providing more financial support[9]. However, despite the introduction of various policies, there is still a lack of substantive incentive policies, binding laws and regulations, and inter-sectoral cooperation and synergy.

Considering China's large emissions reduction target and the limited time to achieve it, updating CCUS policies during the 14th Five-Year Plan period is crucial. The next crucial steps involve the government's establishment of substantive incentive policies, binding legal regulations, and fostering inter-sectoral cooperation and synergy. Furthermore, the creation of a regulatory framework with uniform approval procedures and the implementation of a unified method for accounting for CCUS emission reductions are essential to enhance the economic viability of CCUS projects.

CO_2 Hydrogenation to Methanol "Liquid Sunshine" Project in Lanzhou, Gansu Province

9. State Council of the People's Republic of China, Peaking Carbon Emissions Action Plan Before 2030 (in Chinese), 2021

2.7 CCUS Standards in China

CCUS standards are important for providing a consistent framework for designing, operating, and reporting CCUS activities. These standards help to establish common criteria for project development and ensure CCUS projects are implemented in a consistent and transparent manner, and enable stakeholders to evaluate CCUS projects effectiveness and contribution towards mitigating climate change.

In April 2023, the China National Standards Commission issued the "Guidelines for the Construction of Carbon Peak and Carbon Neutrality Standard System." The objective of this document is to facilitate the advancement of fundamental standards pertaining to green technologies, encompassing terminology and industrial flows. Presently, China has over ten CCUS-related standards, with compliance remaining voluntary (Table 2-5). The goal is to establish a comprehensive CCUS standard system comprising national, industry, and group standards to harmonize various sectors.

2.8 China CCUS Market Outlook

China's power generation sector, responsible for over 50percent of the nation's carbon emissions, emits more than 4 billion tonnes of CO_2 annually from 2,000 plus sources. The realisation of carbon neutrality heavily depends on the adoption of CCUS technology within the power sector, with a targeted annual reduction of approximately 990 million tons of CO_2 emissions for thermal power plants by 2060[2] . Forecasts suggest a swift deployment of CCUS in the power sector between 2030 and 2050 (Fig. 2-7).

In the steel industry, CCUS is anticipated to curtail emissions by 3 $MtCO_2$/yr in 2030, rising to 98 $MtCO_2$/yr by 2060. As for the cement sector, predictions suggest that CCUS should lead to an 8 $MtCO_2$/yr reduction in cement industry emissions by 2030 and a further 248 MtCO2/yr by 2060.

The petrochemical and chemical sector in China offers opportunities for early and cost-effective CCUS demonstrations, due to high-concentration CO_2 emissions from coal, ammonia, and methanol plants. Achieving carbon neutrality will require the widespread application of CCUS in these industries, with a targeted reduction of 190 $MtCO_2$/yr.

Shenhua carbon storage in saline aquifer project (Photo courtesy of Shenhua)

Table 2-5 Representative published CCUS-related standards in China (sorted with sector and chronological order)

No.	Sector	Standard Name (Standard Publication Number)	Leading editorial organisation	Time
1	Carbon capture, usage and storage	Technical Guideline on Environmental Risk Assessment for Carbon Dioxide Capture, Utilization and Storage (on Trial)	Chinese Academy of Environmental Planning	2016
2	Carbon capture	Standard of design of carbon dioxide capture and purification engineering for fuel gas (GB/T 51316 - 2018)	Sinopec Petroleum Engineering Design Co., Ltd.	2018
3	Carbon capture	Technical Specifications for Energy Consumption Measurement of Flue Gas Carbon Dioxide Capture Systems in Thermal Power Plants.	China Energy Investment Group New Energy Technology Research Institute	2022
4	Carbon capture	Key Performance Indicators and Testing Methods for Post-Combustion CO_2 Capture Absorption Solutions (ISO 27927)	Clean Energy Technology Research Institute of China Huaneng Group	2022
5	Carbon transport	Specifications for engineering and carbon dioxide pipeline transportation (SH/T 3202-2018)	Sinopec Petroleum Engineering Design Co., Ltd.	2018
6	Carbon transport	Carbon dioxide capture, transportation and geological storage—Pipeline transportation systems (GB 20211022-T-469)	CNPC Engineering Materials Research Institute	2021
7	Carbon transport	Specification for construction and acceptance of process pipeline in long distance carbon dioxide pipeline station	CNPC Natural Gas Pipeline Engineering Co., Ltd.	2023
8	Carbon usage	Technical guideline for methanol preparation from carbon dioxide (GB/T 34236-2017)	Southwest Chemical Research and Design Institute	2017
9	Carbon usage	Technical code for safety of methanol preparation from carbon dioxide (GB/T 34250-2017)	Southwest Chemical Research and Design Institute	2017
10	Carbon usage	Safety code for oil and gas field development carbon dioxide injection (SY/T 6565-2018)	CNPC Jilin Oilfield	2018
11	Carbon usage	Design code for the injection and production systems of CO_2 flooding oilfield (SY/T 7440-2019)	CNPC Jilin Oilfield	2019
12	Carbon usage	Techical specification for carbon emission reduction accounting of carbon dioxide flooding and storage project (DB37/T 4548-2022)	Sinopec Shengli Oilfield	2022
13	Carbon storage	Leakage risk assessment specification for geological CO_2 utilization and storage projects	Institute of Rock and Soil Mechanics,Chinese Academy of Sciences	2022
14	Offshore CCUS	Inspection Guidelines for Carbon Capture, Utilization, and Storage Systems in Offshore Oil and Gas Fields	China Classification Society	2023

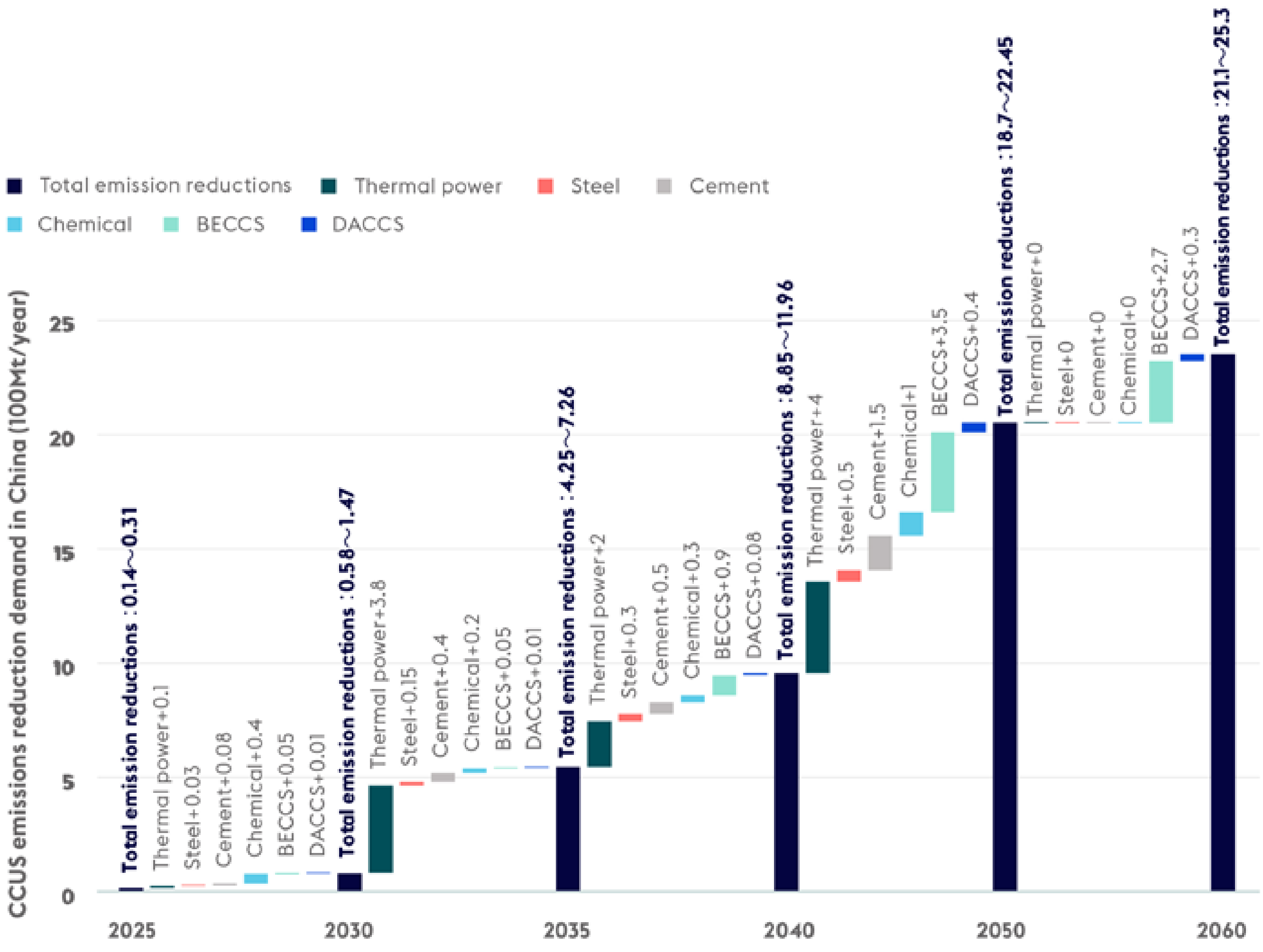


Fig. 2-7 CCUS emission reduction demand in various industries of China from 2025 to 2060[2]

2.9 Cost of CCUS in China

Cost is important for CCUS projects because it affects their economic viability, attractiveness to investors, industries competitiveness, compliance with emissions targets, and the ability to scale up deployment.

The carbon capture process typically constitutes a significant portion of CCUS project expenses, and its costs are influenced by factors such as CO_2 concentration and flue gas impurities. In China, the lowest cost for separating CO_2 from flue gas is in the natural gas processing sector (Fig. 2-8). The coal chemical and petrochemical industries also benefit from relatively low carbon capture costs, due to high CO_2 concentrations present in their flue gas emissions. For coal-fired power plants, CCUS costs typically range from 200-600 yuan/tCO_2, based on actual project expenses. On the other hand, gas power plants tend to have higher carbon capture costs compared to coal-fired power plants due to the lower CO_2 concentrations in their flue gas emissions. Cement plants face high capture costs, ranging from 305-730 yuan/tCO_2.

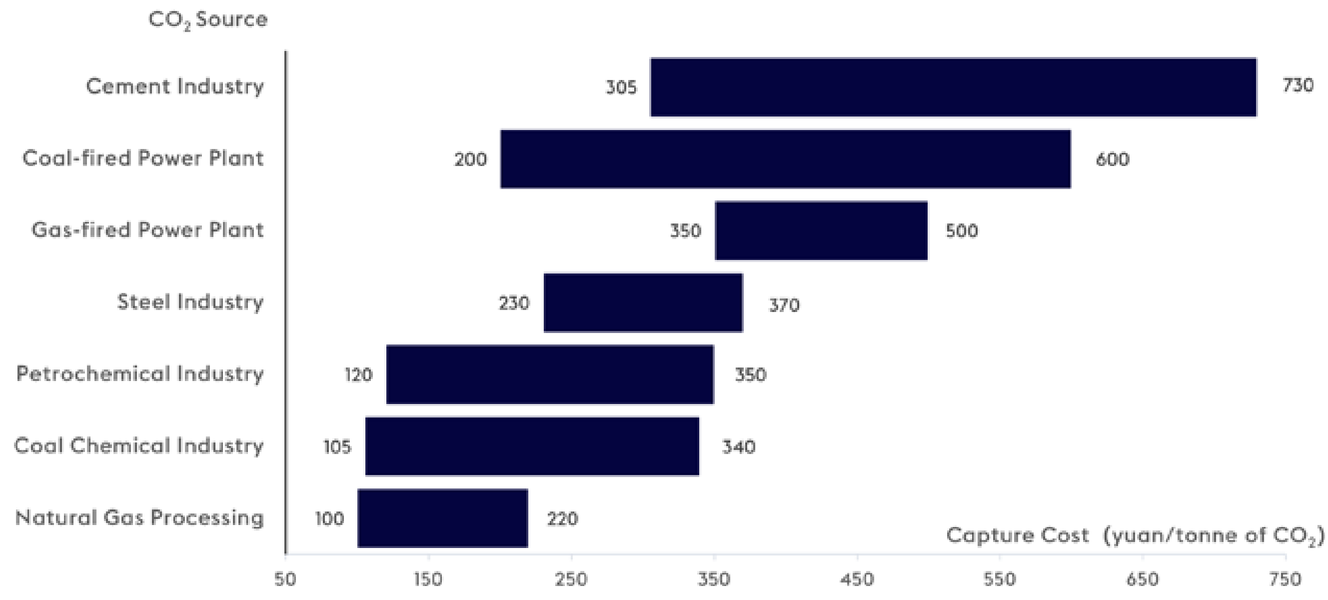


Fig. 2-8 Carbon capture costs by sectors in China. The cost data is drawn from actual CCUS project experiences in China2, supplemented by pre-feed study results for carbon capture from gas power plants. The approximate exchange rate is about nine Chinese Yuan (CNY) for one British Pound (GBP).

In the CO_2 transport sector, tank truck transportation costs 0.9-1.4 yuan/(tCO_2·km), while pipelines become more cost-effective for projects exceeding one million tons per year, with costs ranging from 0.3-0.8 yuan/(t CO_2·km)[10].

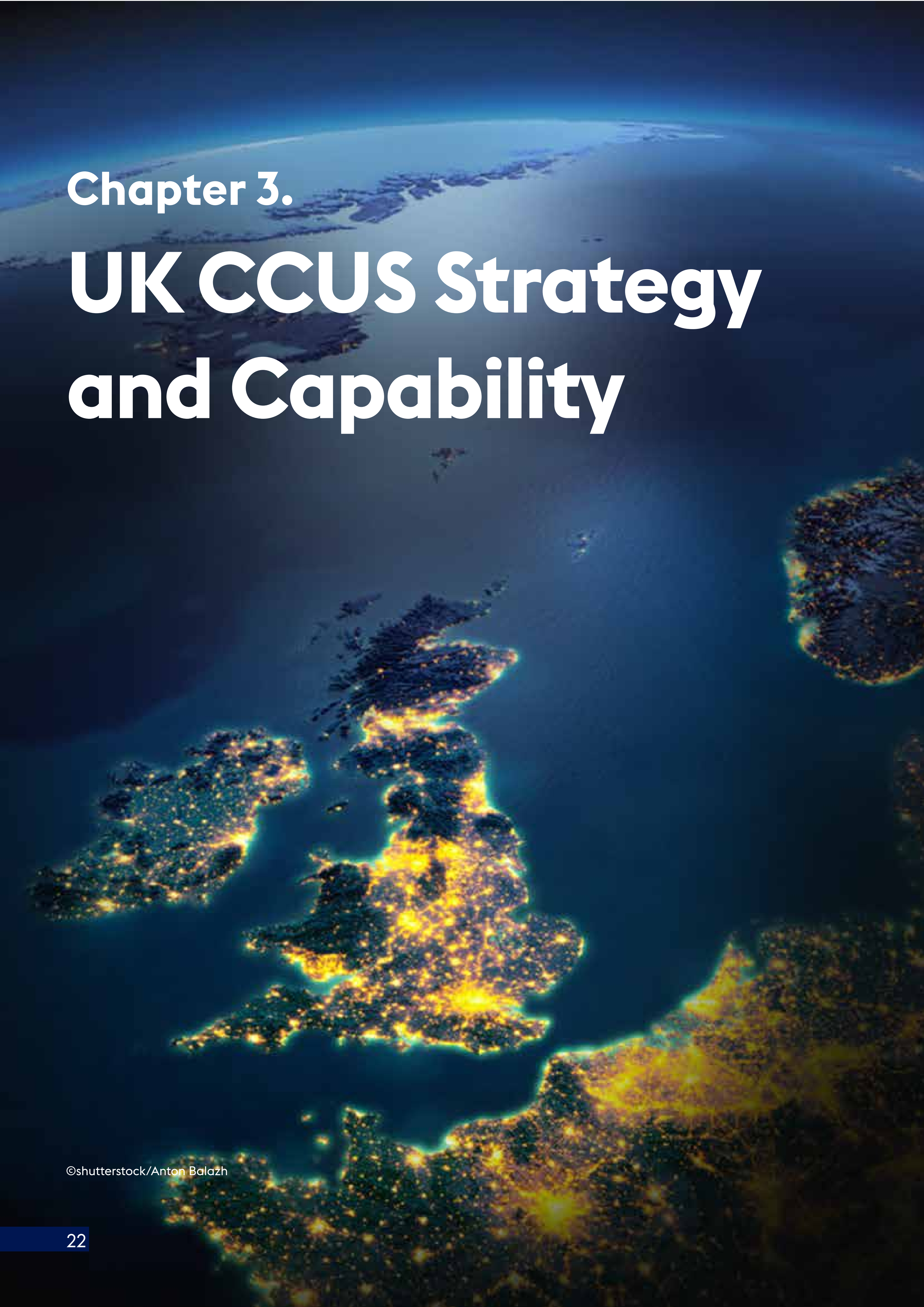
For onshore sedimentary basin CO_2 storage, the cost can be managed within the range of 50-60 yuan/tCO_2. However, offshore CO_2 storage in China lacks extensive engineering experience, and initial cost estimates exceed 300 yuan/tCO_2.

In China, CCUS costs can be 10-30 percent lower than in developed countries due to reduced labour costs, efficient equipment manufacturing, transportation, and access to cost-effective materials. However, CCUS projects in China face challenges due to lower carbon prices in the market, ranging from 50-75 yuan/tCO2, as of August 2023. These prices are insufficient to cover project costs, highlighting the need for additional financial support to ensure the sustainability of CCUS projects.

10. China Environmental Planning Institute, Ministry of Ecology and Environment. China Carbon Dioxide Capture Utilization and Storage (CCUS) Annual Report (2021) - China CCUS Pathway Study[R] (in Chinese), 2021

Chapter 3.

UK CCUS Strategy and Capability



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3.1 Current CCUS Deployment Plans in the UK

The UK's current CCUS plans are centred on clusters across various areas, all with access to offshore geological storage, either through pipelines or ships (e.g., South Wales and Southampton clusters). There is also a strategic effort to leverage clusters in the Northern North Sea for CO_2 storage from Europe.

In line with the November 2020 'The Ten Point Plan for a Green Industrial Revolution'[11] and the April 2022 'The British Energy Security Strategy'[12], the UK aims to implement CCUS in two industrial clusters by the mid-2020s, expanding to four sites by 2030, capturing up to 10 Mt of CO_2 annually. Funding comes from the Industrial Decarbonisation Challenge (£170 million) [13], the £1 billion CCS Infrastructure Fund[14], and market-based business models for CO_2 transport and storage, power, and industrial carbon capture[15].

After a proposal call, five prospective CCUS clusters were funded to develop plans, with the HyNet and East Coast Clusters chosen as Track 1 clusters for potential operation in the mid-2020s. The UK Spring Budget in March 2023 confirmed £20 billion for CCUS[16], unlocking private investment and job creation, especially in the East Coast and North West of England and North Wales. Acorn and Viking CO_2 transport and storage systems are the preferred Track 2 candidates as of July 31, 2023[17] , with final decisions pending due diligence and affordability assessments.

3.2 UK's Capability in the CCUS Sector

Key UK CCUS capabilities that hold value in the Chinese market encompass services, engineering consultancy, and knowledge-based skills across diverse domains. This includes expertise in project development, financing, and the supply of essential components, either directly or through licensing agreements, originating from the UK. Table 3-1 highlights significant UK CCUS capabilities developed through CCUS cluster and project deployments. While some capabilities are well-established, ongoing CCUS cluster and project deployments will further enhance others. In 2023, the Department for Energy Security and Net Zero organised a systematic assessment of UK capabilities in the CCUS supply chain, identifying strengths in CCUS engineering and design, fabrication of critical equipment (e.g., column vessels, process control systems, heat exchangers), and more[18].

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11. HM Government, The Ten Point Plan for a Green Industrial Revolution[R], 2020.
12. HM Government, British Energy Security Strategy: Secure, clean and affordable British energy for the long term[R], 2022.
13. UK Research and Innovation (2021), Industrial decarbonization challenge[R], 2021
14. Department for Business, Energy & Industrial Strategy (2021a), "The Carbon Capture and Storage Infrastructure Fund", May 2021.
15. Department for Business, Energy & Industrial Strategy (2021e), "Research and analysis: Carbon capture, usage and storage (CCUS),: business models", Updated 5 October, 2021.
16. HM Treasury, "Spring Budget 2023: Copy of the Budget Report – March 2023 as Laid before the House of Commons by the Chancellor of the Exchequer when opening the Budget.", 2023
17. HM Government , Cluster sequencing for carbon capture, usage and storage (CCUS): Track-2, 31 July 2023
18. Department for Business, Energy & Industrial Strategy, Department for Energy Security and Net Zero, Industrial decarbonisation strategy, 2021, https://www.gov.uk/government/publications/industrial-decarbonisation-strategy/industrial-decarbonisation-strategy-accessible-webpage

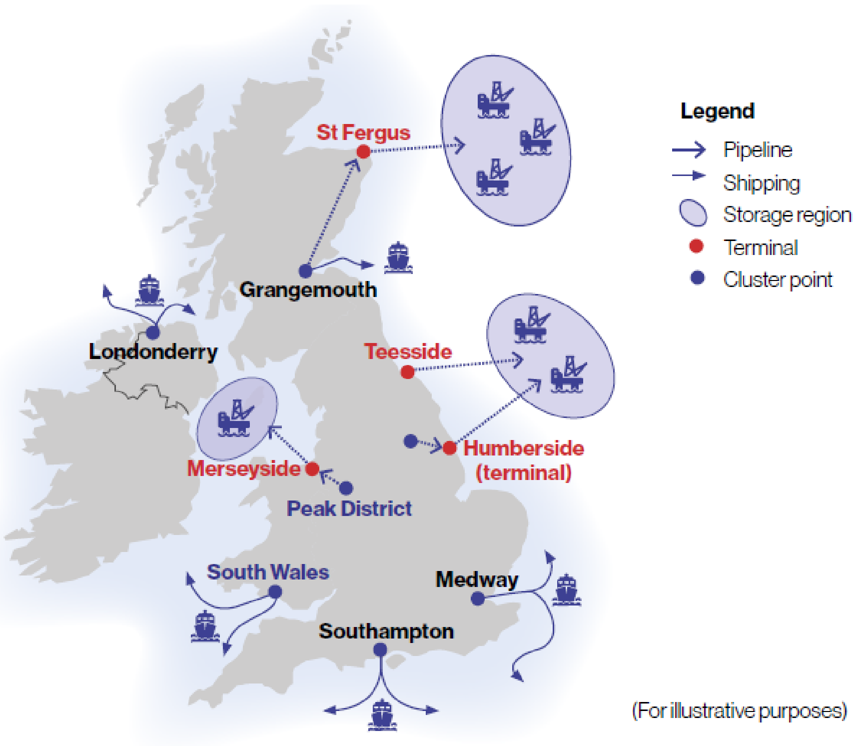


Fig.3-1 Potential carbon transport and storage strategy in the UK[19]

Table 3-1 UK CCUS capabilities developed through CCUS cluster and project deployments

CO_2 capture project design and delivery	Example
Power	East Coast Cluster (Keadby, West Burton, Staythorpe, Alfanar and Whitetail Plants)
Biomass	East Coast Cluster (Drax Plant, MGT Teeside, Lynemouth Power)
Energy-from waste	East Coast Cluster (Altalto Immingham waste to jet fuel project, STV project)
Cement	Breedon Cement, Hanson Padeswood Cement Works, ZerCaL250 Project
Steel	Liberty Steel Brinsworth Plant
Refining	Stanlow Refinery, Prax Lindsey Oil Refinery
Glass	East Coast Cluster (Saint-Gobain Glass Plant), Glass Futures and Pilkington Plants
Direct air capture	Sizewell C DAC Project, ENCORE Project, DACMIN Project, CO_2CirculAir Project

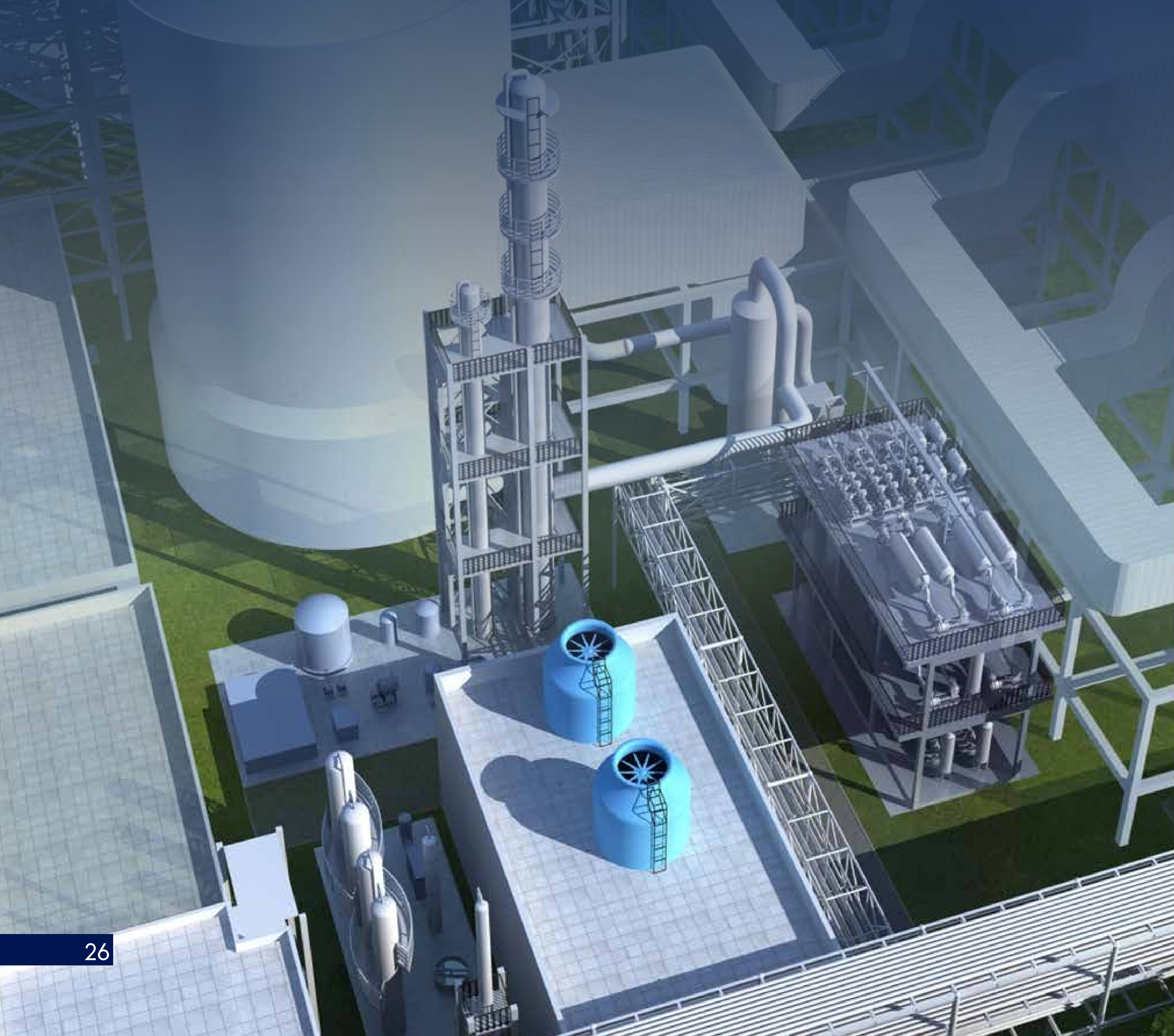
19. Department for Energy Security and Net Zero.'A Remarkable New Infrastructure System' Opportunities for economic growth in the UK's Carbon Capture & Storage Industry[R], 2023

Hydrogen production with CCUS	
Advanced natural gas reforming	Hynet and East Coast Clusters
CO_2 transport	
Re-use of existing pipelines for CO_2	Hynet Cluster, Acorn and Viking T&S system
Onshore CO_2 pipelines	Both Track 1 and 2 clusters[a]
Offshore CO_2 pipelines	Both Track 1 and 2 clusters
Beach crossings, including environmentally sensitive areas	Both Track 1 and 2 clusters
Shipping	Acorn and Viking T&S system
Ship-loading terminals	Acorn and Viking T&S system
Ship-to-pipeline transfer terminals	Acorn and Viking T&S system plan to receive shipped CO_2 from other UK and EU areas.
Road CO_2 tankers and operation	To be confirmed (TBC) as progress unfolds.
Ship-to-pipeline transfer terminals	TBC
CO_2 usage	
TBC	TBC
Geological storage	
Depleted oil and gas reservoirs	Both Track 1 and 2 clusters
Saline aquifers	East Coast Cluster, Acorn T&S system
Offshore storage assessment techniques	Both Track 1 and 2 clusters
Offshore MMV techniques	Both Track 1 and 2 clusters
Co-use of offshore locations and spatial planning	Both Track 1 and 2 clusters
Permitting, regulation and finance	
HSE permitting assessments and documentation	Capacity and expertise will evolve as Track 1 and Track 2 clusters advance.
Business models and contracts for all CCUS sectors	as above
Project-to-project contract arrangements	as above
CCUS project risk management and financing	as above

Note: [a] The UK Government has committed to deploying CCUS in two industrial clusters by the mid-2020s and two more by 2030. The Track-1 clusters are HyNet and East Coast Clusters, with Acorn and Viking T&S systems as Track-2 selections.

Chapter 4.

China CCUS Supply Chain Assessment



To become carbon neutral, China need to increase its carbon capture capacity from the current level of 6 Mt/yr to 2100-2500 Mt/yr by 2060[2], marking a more than 100-fold market scale increase. It's vital to assess China's CCUS supply chain readiness and robustness to meet current and future demand.

This section assesses China's CCUS supply chain capabilities using Technology Readiness Level (TRL) and Manufacturing Readiness Level (MRL) indexes. TRL measures technology maturity from research to deployment (1-9 scale; Table 4-1), while MRL assesses manufacturing process maturity from principles to full-scale production (1-10 scale; Table 4-2). Evaluating both TRL and MRL is crucial to ensure technology and manufacturing readiness for quality, quantity, and cost-effective deployment or production.

Table 4-1 TRL Summaries[20]

Level	Description
1	Basic principles observed and reported.
2	Technology concept and/or application formulated.
3	Analytical and experimental critical function and/or characteristic proof of concept.
4	Component and/or breadboard validation in laboratory environment.
5	Component and/or breadboard validation in relevant environment.
6	System/subsystem model or prototype demonstration in a relevant environment.
7	System prototype demonstration in an operational environment.
8	Actual system completed and qualified through test and demonstration.
9	Actual system has proven through successful mission operations.

Table 4-2 MRL Summaries[21]

Level	Description
1	Basic manufacturing implications identified.
2	Manufacturing concepts identified.
3	Manufacturing proof of concept developed.
4	Capability to produce the technology prototype in a laboratory environment.
5	Capability to produce prototype components in a production-relevant environment.
6	Capability to produce a prototype system or subsystem in a production-relevant environment.
7	Capability to produce systems, subsystems, or components in a production-representative environment.
8	Pilot line capability demonstrated; ready to begin low rate initial production (LRIP).
9	LRIP demonstrated; capability in-place to begin full rate production (FRP).
10	FRP demonstrated and lean production practices in-place.

20. US National Aeronautics and Space Administration (NASA), Technology Readiness Assessment Best Practices Guide [R], 2020, https://ntrs.nasa.gov/api/citations/20205003605/downloads/%20SP-20205003605%20TRA%20BP%20Guide%20FINAL.pdf
21. US Department of Defense, Manufacturing Readiness Level (MRL) Deskbook[R], 2022, http://www.dodmrl.com/MRL_Deskbook_2022__20221001_Final.pdf

4.1 Carbon Capture Supply Chain

Carbon capture encompasses a diverse array of methods, including pre-combustion separation, oxy-fuel combustion, post-combustion, and chemical looping combustion capture. In China, the development of these technologies varies, with some in commercial use and others in research phases.

Pre-combustion capture technologies focus on capturing CO_2 before the combustion of fossil fuels. Pre-combustion natural gas processing is a well-established technology with a high TRL of 9 and MRL of 10 (Table 4-3). On the other hand, pre-combustion integrated gasification is less mature, with a TRL of 7 and MRL of 9. A significant milestone was achieved with the Huaneng 250MW GreenGen IGCC plant in Tianjin, which has a capture capacity of 50,000 t/yr.

Oxy-fuel combustion involves burning fossil fuels in a mixture of pure oxygen and recirculated flue gas, enabling easier CO_2 capture. In China, oxy-fuel combustion coal power plants are currently at a less mature stage, with a TRL of 7 and MRL of 8-9. The pilot project (400kW) and demonstration project (35MW) set up by Huazhong University of Science and Technology, are progressing to explore its feasibility and efficiency.

Post-combustion capture involves capturing CO_2 from flue gas after the combustion process, including absorption and adsorption technologies. Absorption using amine solvents has become a mature and widely used technology in China, boasting a TRL of 9 and MRL of 10. It has been adopted in several large carbon capture projects including, for example, the 150 ktCO_2/yr carbon capture project at Jinjie Power Plant, Shaanxi Province, and the 500 ktCO_2/yr carbon capture project at Taizhou Power Plant, Jiangsu Province. However, other post-combustion technologies like phase change solvents and next-gen absorbents (ionic liquids, water-lean solvents, amino acids) are less mature, with TRLs ranging from 3 to 6. Membrane separation technologies utilise selective membranes to capture CO_2. Membrane separation technology, which uses selective membranes to capture CO_2, is well-established for natural gas processing (TRL 9, MRL 10) but mainly applied in the natural gas industry. Polymeric membrane-solvent hybrids are less developed, with a TRL of 7 and MRL of 8.

Chemical looping combustion capture is a less mature technology in China, with a TRL of 7 and MRL of 7-8 (Table 4-3). Notable pilot projects have been established, including one 4 MW pilot project by China Dongfang Boiler Corporation and Total in Deyang, Sichuan Province.

Chemical absorption with amine solution is a commonly used post-combustion carbon capture method in China, with potential for wide adoption. Table A 1 lists Chinese providers of amine-based carbon capture equipment. The chemical industry in China has a full supply chain for this technology, featuring multiple local manufacturers for all necessary equipment. Foreign companies can tap into this market by offering products, which are more durable or energy-efficient products than their domestic alternatives.

4.2 CO_2 Transport Supply Chain

In CO_2 transport, China's infrastructure manufacturing capabilities are well-established, although some engineering design experience is still lacking (Table 4-4):

- CO_2 truck transport is firmly established and meets market demand.
- Small-scale transport ships exist (up to 10,000 m^3 capacity), sufficient for the food and beverage industry. Larger capacities needed for CCS have not been demonstrated[22].
- Pipelines are mature but pose challenges for large-scale CCS, especially offshore, demanding special materials and corrosion-resistant coatings, while regulatory frameworks remain incomplete.
- CO_2 compression equipment, a crucial element in CO_2 transport, is widely used in various industrial and commercial applications.
- CO_2 gasifiers, another key component in CO_2 transport, are commonly employed in the gas industry with readily available supply chains.

Table 4-3 Assessment of carbon capture supply chain readiness in China

Technology		TRL	MRL	Maturity Level	Note
Pre-combustion					
Pre-combustion natural gas processing		9	10	Mature	Widely used in the natural gas industry.
Pre-combustion integrated gasification		7	9	Less mature	China Huaneng Group constructed the GreenGen 250MW IGCC demonstration plant in Tianjin, with a capture capacity of 50,000 t/yr.
Pre-combustion sorbent-enhanced water gas shift		5	—	—	—
Oxy-fuel combustion					
Oxy-fuel combustion coal power plant		7	8-9	Less mature	Pilot and demonstration projects at HUST
Oxy-fuel combustion gas turbine		4	—	—	—
Post-combustion					
Absorption	Amine solvent	9	10	Mature	Widely used in large-scale carbon capture projects. Several pilot-scale demonstration projects are in operation.
Absorption	Phase change solvents	6	—	—	—
Absorption	Next-generation absorbents, e.g. ionic liquids, water-lean solvents, amino acids	3	—	—	—
Adsorption	Commercially available adsorbents	7	7-8	Less mature	Pilot-scale demonstration.
Adsorption	Next-generation adsorbents e.g. MOFs	3	—	—	—
Membranes separation	Membrane for natural gas processing	9	10	Mature	Widely used in the natural gas industry.
Membranes separation	Polymeric membranes/ solvent hybrid	7	8	Less mature	Tianjin University has a pilot-scale demonstration project with a capacity of 50,000 m^3/d.
Membranes separation	Dense inorganic membrane	3	—	—	—
Chemical looping					
Chemical looping		7	7-8	Less mature	A 4 MW pilot project is operating in Deyang, Sichuan Province.

22. Bui M, Danaci D. Supply chain readiness for widespread deployment of carbon capture and storage[J]. 2022.

Table 4-4 Assessment of carbon transport supply chain readiness in China

Key components	TRL	MRL
CO_2 Tankers	9	10
CO_2 Ships	7	10
CO_2 Onshore Pipeline	9	10
CO_2 Offshore Pipeline	7	10
CO_2 Compressor	9	10
CO_2 Gasifier	9	10

A list of manufacturers related to CO_2 transport equipment in China are provided in Table A 2,

4.3 CO_2 Usage Supply Chain

China's CO_2 usage technologies involve complex supply chains. This chapter provides a brief overview of the technology readiness levels (TRL) and key providers for advanced carbon usage technologies in China (Table 4-5).

In CO_2 geological usage, CO_2-enhanced oil recovery (EOR) is at TRL 9, implemented in various onshore oilfields by CNPC and Sinopec. CO_2-enhanced coalbed methane recovery reached TRL 6 during a pilot project in Shanxi Province from 2002-2007, while CO_2-enhanced gas recovery is at TRL 3, currently in laboratory research.

CO_2-to-fuels synthesis is progressing rapidly. CO_2 hydrogenation to methanol is at TRL 9, with successful pilot projects in Ordos in Inner Mongolia, Dongfang in Hainan Province, Anyang in Henan Province and Lanzhou in Gansu Province[23]. CO_2 hydrogenation to gasoline is at TRL 8, with a pilot-scale unit in Jining, Shandong Province. CO_2 hydrogenation to produce methane or CO is at TRL 3, confined to laboratory research. A CO_2 reforming-to-syngas facility in Changzhi, Shanxi Province, and the technology is at TRL 8.

In CO_2 synthesis to chemical products, technologies like ethanol, acetic acid, and ethylene are experimental (TRL 3-4). However, CO_2 conversion to dimethyl carbonate (TRL 9) and other products is making progress (TRL 7-8) with some commercial applications (Table 4-5).

CO_2 can also regenerate valuable products from industrial waste materials, such as steel slag and calcium carbide slag, at TRL 8-9. There are ongoing projects of this kind in Shanxi, Shandong Province, and Inner Mongolia.

In CO_2 biological usage, microalgae cultivation using CO_2 is practiced in several Chinese provinces, and CO_2 gas is used as fertilizer in Ordos and Baotou, Inner Mongolia.

Table 4-5 TRL and key provider of CO_2 usage technology

CO_2 Usage		TRL	Provider
Geological Usage	Enhanced Oil Recovery	9	• CNPC, Sinopec, Yanchang Petroleum Group
	Enhanced Coalbed Methane Recovery	6	• China United Coalbed Methane Co., Ltd.
	Enhanced Gas Recovery	3	• CNPC

23. Ye Z, Rao N, Xia C, et al. Advances in catalysts and project progress for CO_2 hydrogenation to methanol (in Chinese with English abstract) [J], Clean Coal Technology, 2023

CO_2 Usage		TRL	Provider
Chemical Usage	CO_2 Hydrogenation to Methanol	9	• Dalian Institute of Chemical Physics, Chinese Academy of Sciences
	CO_2 Hydrogenation to Gasoline	8	• Dalian Institute of Chemical Physics, Chinese Academy of Sciences; Zhuhai Futian Energy Technology Co., Ltd.
	CO_2 Hydrogenation to Methane	3	—
	CO_2 Pyrolysis to CO	3	• Tianjin Feynman Dynamics Technology Co., Ltd.; Dalian Institute of Chemical Physics, Chinese Academy of Sciences; Shanghai Advanced Research Institute, Chinese Academy of Sciences
	CO_2 Reforming to Syngas	8	• Shanghai Advanced Research Institute, Chinese Academy of Sciences
	Synthesis of Ethanol	3	• Jiangnan University; Dalian Institute of Chemical Physics, Chinese Academy of Sciences
	Synthesis of Acetic Acid	3	• Wuhan University of Technology
	Synthesis of Ethylene	3	—
	Synthesis of Dimethyl Carbonate	9	• Zhejiang Petrochemical Co., Ltd.; Shandong Shida Shenghua Chemical Group; Institute of Coal Chemistry, Chinese Academy of Sciences
	Synthesis of Isocyanate/ Polyurethane	7	• Institute of Process Engineering, Chinese Academy of Sciences
	Synthetic of Polycarbonate/Polyester material	8	• Chengdu Organic Chemistry Co. Ltd., Chinese Academy of Sciences; Hainan Huasheng Group
	Synthetic of Sodium Bicarbonate	9	—
	Synthetic of Dimethylformamide	8	• Shanghai institute of Organic Chemistry,Chinese Academy of Sciences; Weijiao Holding Group
	Synthetic of Durene	8	• Tsinghua University
	Synthetic of Succinic Acid	8	• Tianjin Institute of Industrial Biotechnology, Chinese Academy of Sciences; Shandong Landian Biological Technology Co., Ltd.
	Synthetic of Malic Acid	7	• Tianjin Institute of Industrial Biotechnology, Chinese Academy of Sciences; Anhui BBCA Fermentation Technology Engineering Research Co., Ltd.
	Synthetic of Degradable Plastics	8	• Changchun Institute of Applied Chemistry, Chinese Academy of Sciences
	Steel Slag/ Calcium Carbide Mineralization	9	• Shandong Jingyun Taibo Negative Carbon Technology Co., Ltd.; Yuanchu Technology (Beijing) Co., Ltd.; Institute of Process Engineering, Chinese Academy of Sciences
	Phosphorous Paste Mineralization	8	• Sichuan University; Institute of Process Engineering, Chinese Academy of Sciences
	Mineralization with Potassium Feldspar Processing	7	• Sichuan University
	CO_2 Carbonation Curing of Concrete	8	• CleanCO_2 Co.,Ltd.; Zhejiang University; Hunan University
	CO_2 Electrolysis to Carbon Nanotubes	7	• Jiangyin Luojia Green Carbon Technology Co., Ltd.; Jiangsu Green Carbon Nanotechnology Co., Ltd.
	Synthesis of Urea	9	—
	Synthesis of Ammonium Bicarbonate	9	—
Biological Usage	CO_2 Gas Fertiliser	9	—
	Cultured Microalgae	9	• Zhejiang University; Fuqing King Dnarmsa Spirulina Co., Ltd
	Synthesis of Starch	3	• Tianjin Institute of Industrial Biotechnology, Chinese Academy of Sciences

4.4 CO_2 Storage Supply Chain

Several CO_2 storage technologies are in development in China (Table 4-6):

- CO_2 in-situ uranium mining storage is commercially used.
- CO_2-EOR is in industrial demonstration near oil fields.
- Saline aquifer storage has successful demonstration.
- Deep unmineable coal seams (ECBM) is in the pilot stage.
- CO_2 mineralization is in industrial experiments.

The following key technologies for CO_2 injection, storage, and monitoring are less developed in China than in western countries[24]:

a) Long-term safety and environment risk analysis and evaluation.
b) Site characterization and evaluation technique integration.
c) Large-scale site monitoring.
d) Multi-layer injection and monitoring.
e) Near-surface, shallow soil gas, and water quality monitoring.
f) Deep flow sampling and monitoring.
g) CO_2 leakage risk management (integrated monitoring technique).
h) Compression/pumping with subcritical liquefaction/large-scale injection pump.
i) Consulting services for technology integration and management.
j) Well completion cement resistant to CO_2 corrosion

Equipment needed for carbon geological storage is similar to the petroleum industry. Special equipment includes CO_2 booster devices, storage, and monitoring equipment. A list of Chinese suppliers of the equipment is in Table A 3.

Table 4-6 Supply chain readiness for deployment of CO_2 storage in China

CO_2 Geological Storage	Readiness Evaluation Methods	
	TRL	MRL
Saline Aquifers	9	9
Depleted Oil & Gas Reservoirs	9	9
ECBM	6	7
Mineralisation Storage	6	9

4.5 Commercial Opportunities for UK CCUS Companies

1. Carbon Capture Market

The UK excels in carbon capture plant design and can target opportunities in heat exchangers, column internals, flue gas blowers, and filters. UK companies can also explore carbon capture amine solutions, adsorption materials, and membrane technologies. Direct air capture technologies represent another promising area for UK companies to innovate and collaborate in.

2. Carbon Transport Market

The UK is strong in pipeline design and corrosion resistance solutions, particularly for offshore environments. Consultancy services for pipeline design, operation, and maintenance can be offered by UK companies.

24. Wei N, Liu S, Li X, et al. Key technologies inventory of CO2 geological utilization and storage [J]. Clean Coal Technology, 2022, 28(6): 14-25.

3. Carbon Usage Market

The Chinese market seeks innovative carbon usage methods, particularly in jet fuels, methane, syngas, and degradable plastics production. UK technologies with efficient solutions can find opportunities in this sector.

4. Carbon Storage Market

For onshore sedimentary basins, UK companies can supply high-quality CO_2 injection pumps and the technologies listed in Section 4.4. In the emerging offshore CO_2 storage sector, collaboration opportunities exist in subsurface and reservoir design, engineering, and marine and subsea operations.

5. Capacity Building in the CCUS Industry

With the growing CCUS industry, there is a demand for skilled labour and software support. Offering CCUS training and education and software services in project design, CO_2 injection simulation, storage monitoring, and emission reductions MRV can lead to commercial opportunities.

4.6 Foreign Company Entry

The Foreign Investment Law (FIL) of China, effective from January 1, 2020, promote a more favourable environment for foreign businesses. It emphasises equal treatment for domestic and foreign investors and provides enhanced legal safeguards, including provisions on technology transfer, intellectual property rights, and foreign-invested enterprise establishment.

Two issues pose potential market entry barriers for foreign companies looking to enter the Chinese market. Firstly, as specified in China's Foreign Investment Negative List (FINL), domestic water transport companies must have a majority ownership by Chinese entities. This implies that foreign companies cannot hold a controlling stake in CO_2 ship transport firms.

The second barrier relates to access to the carbon storage industry. This is primarily due to state-owned oil companies, including CNPC, Sinopec and CNOOC, holding exploration rights and extensive geological data. Geological data collection is a costly and regulated process, providing state-owned oil companies with a clear first-mover advantage in the carbon storage industry. Opportunities for foreign companies may be to establish joint ventures with local oil companies to gain market access. For example, Shell and BASF have partnered with Sinopec in a CCUS cluster in eastern China (see Section 5.1 for further information); Shell and ExxonMobil have collaborated with CNOOC in a CCUS cluster in Guangdong Province; and bp has collaborated with CNPC in a CCUS cluster in Hainan Province.

However, in addition to the FINL, China has also published Catalogue of Industries for Encouraging Foreign Investment (2022)[25], which offers a green light to foreign investors in a number of areas, including the following fields related to CCUS:

(1) The development and application of new technologies for geological exploration and development, including geophysical prospecting, drilling, logging etc. (Article 26 in the catalogue).
(2) Construction and operation of carbon capture, usage, and storage projects (Article 73).
(3) Converting carbon dioxide and light hydrocarbons into carbon monoxide (Article 83).
(4) Manufacturing of geophysical exploration equipment, logging equipment, and more (Article 173).
(5) Manufacturing of environmental monitoring instruments (Article 382).
(6) Research and services related to carbon capture, usage, and storage technology (Article 474).

This catalogue offers a wide range of opportunities across the entire CCUS value chain, inviting foreign companies, including those from the UK, to explore and invest in this rapidly evolving and vital sector.

25. China National Development and Reform Commission, Ministry of Commerce, Catalogue of Industries for Encouraging Foreign Investment (2022 Version), 2022. https://www.gov.cn/zhengce/zhengceku/2022-10/28/5722417/files/cc050615b11b40fc8f2d55fd1daf3c57.pdf

Chapter 5.

UK CCUS Companies in China and Strengthening UK-China Collaboration

5.1 UK CCUS Companies' Presence in China

UK companies play a significant role in China's industrial sector, providing advanced products and services across various industries. Arup, Baker Hughes, bp, Howden, Shell, and Wood have shared insights into their involvement in China's CCUS industry for this report, highlighting UK-China commercial cooperation.

Shell is a major player in China's CCUS industry, collaborating in different regions. In eastern China, Shell partnered with Sinopec, Baowu Steel, and BASF to explore an open-source CCUS cluster in Shanghai and Jiangsu. In southern China, Shell joined forces with CNOOC and ExxonMobil for a 10-Mt-scale CCUS hub in Huizhou, Guangdong. Shell also contributed its Cansolv carbon capture amine solution for a technology test platform at China Resources Haifeng Power Plant. In northwestern China, Shell signed a research agreement with the Yulin Government in Shaanxi Province to assess CCUS feasibility in the Yushen Industrial Park.

bp collaborates with CNPC on CCUS initiatives, including the "Hainan Low-Carbon Cooperation Memorandum." CNPC has completed a full-scale CCUS system project in Hainan Province and has a strategic plan for storage capacity. bp will share its expertise from UK projects and contribute to CCUS technology development in China.

Howden supplies essential equipment for CCUS projects in China, including fans, heat exchangers, compressors, and rotary heaters. They have supported projects like Huaneng Group's 1.5 million-ton CCUS project in Qingyang and Baotou Steel's 500,000-ton CCUS project in Inner Mongolia.

Wood, with over 30 years of experience, provides comprehensive CCUS solutions. In Shaanxi Province, Wood has aided Yulin's energy and chemical industries with carbon reduction pathways and effective strategies.

Arup and Baker Hughes have extensive global CCUS experience. Arup's projects include Kingsnorth Carbon Capture Demonstration Project, Ferrybridge Carbon Capture Project, and more. Baker Hughes has participated in projects worldwide and expresses interest in exploring CCUS opportunities in China.

Apart from these, other UK companies are closely linked to China's CCUS sector. Johnson Matthey, with factories in Shanghai, offers carbon capture solutions. Oliver Valvetek and BEL Valves supply valves to China's offshore oil and gas industry, holding market potential in the field of offshore CO_2 storage.

10-Mt-scale CCUS

Shell joined forces with CNOOC and ExxonMobil for a 10-Mt-scale CCUS hub in Huizhou, Guangdong

Collaboration

bp collaborates with CNPC on CCUS initiatives

5.2 Suggestions for Enhancing UK-China Collaboration on CCUS

During the UK entity survey, companies expressed ongoing evaluation of China's CCUS market, offering valuable insights to enhance UK-China CCUS collaboration. Based on this advice and the 10-year experience of the UK-China (Guangdong) CCUS Centre, the following recommendations are made:

1. For the Government

(1) Promote Bilateral Exchanges: The UK Government should facilitate knowledge sharing of CCUS best practices and technologies to China. Utilize the UK-China (Guangdong) CCUS Centre as a platform for industry exchanges. Organize business delegations, trade missions, and CCUS-focused networking events to foster collaboration between UK and Chinese CCUS sectors. Engage with key Chinese departments overseeing CCUS, including the China National Development and Reform Commission, Ministry of Ecology and Environment, Ministry of Science and Technology, Ministry of Industry and Information Technology, and Ministry of Commerce.

(2) Support Market Intelligence and Research: Invest in market research to provide UK companies with insights into the Chinese CCUS market. Analyse market trends, competitors, regulations, and technology needs to assist UK companies in making informed decisions and strategies.

(3) Promote UK Education and Training: Promote UK's CCUS expertise through marketing campaigns, industry participation, and successful case studies. Collaborate with Chinese educational institutions to offer training programs for Chinese engineers.

(4) Joint Full-scale CCUS Project: Collaborate with the Chinese Government to establish a joint full-scale CCUS project in China, potentially using a UK company's plant. This project would demonstrate UK CCUS technologies' effectiveness and viability in the Chinese context, with possible UK Government support.

2. For UK CCUS companies

(1) Engage with British Diplomatic Missions: Maintain contact with the British Embassy in Beijing and British Consulates in China for policy updates, market opportunities, and collaborations. Regular communication can align strategies with government priorities.

(2) Strategically Focus on Specific Regions: Prioritise regions in China poised to develop CCUS clusters and become significant markets. Consider areas like the Energy and Chemical Industry Golden Triangle (Ningdong-Ordos-Yulin), Bohai Bay, Shanghai-Jiangsu, Pearl River Delta Region and more. Explore opportunities in Hong Kong for carbon capture and offshore storage.

(3) Collaborate with Foreign-invested Plants: Seek collaborations with foreign companies operating plants in China requiring decarbonisation through CCUS. This includes refineries and cement plants of companies like Shell, ExxonMobil, BASF, Aramco, SABIC, and Heidelberg.

(4) Domestic Production of Equipment: Consider establishing domestic production facilities in China for selected CCUS equipment to reduce costs and enhance competitiveness.

(5) Participate in Standard Development: Engage in the development of key CCUS standards, particularly in amine-based carbon capture, CO_2 pipeline transport, and CO_2 geological storage, collaborating with Chinese state-owned corporations or independently publishing standards via the Standards Administration of China.

(6) Patience and Optimism: Recognise that China's CCUS market is evolving, primarily led by state-owned energy giants. While immediate profitability may not be guaranteed, market opportunities will grow as China progresses towards carbon neutrality goals. Private and foreign companies will find increasing opportunities as the carbon market matures, emphasising technology performance and efficiency over time.

Fig. 5-1 Companies engaged in various sectors of CCUS industry. Listed companies are not exhaustive.

5.3 Market Risks and Mitigation Strategies

Entering China's CCUS industry offers UK companies exciting opportunities to participate in a significant global climate change effort. However, international investments always carry risks. One key risk involves market competition in China, driven by growing interest in CCUS from both domestic and international players. UK companies can mitigate this by leveraging their expertise and forming strategic local partnerships.

Another risk is related to technology transfer and intellectual property protection. As China advances CCUS technologies, there may be concerns about safeguarding proprietary information. UK firms can address this through careful planning, strong partnerships, and robust contractual agreements to protect their intellectual property.

A third risk involves regulatory uncertainties due to evolving environmental regulations in China. Navigating permitting and compliance for CCUS projects may pose challenges, but the Chinese Government's commitment to emissions reduction and sustainable practices provides a stable policy environment. UK companies can engage with relevant authorities to address regulatory concerns.

In summary, while risks exist in China's CCUS industry, they can be managed with due diligence, collaboration, and engagement with local partners and authorities. The vast market potential, government support, and China's commitment to sustainability make it an attractive landscape for UK companies to contribute to global climate efforts and lead the green revolution.

Table A 1 Equipment and Technology Providers in the Amine-based Carbon Capture Supply Chain in China (not exhaustive)

	Device	Function	Provider in China
Pre-treatment	Direct contact cooler (fuel gas cooler/ pre-scrubber)	Cool down the inlet flue gas to the required temperature for the absorber, typically around 40-50 °C	• Shuangdun Environment Technology Co.,Ltd.
	Fuel gas fan (blower)	A centrifugal flue gas fan shall be included in the system to ensure that the required volume of flue gas is extracted and that sufficient head is provided to overcome the pressure drop along the flue gas pipe, the capture process equipment and the pipe returning the cleaned flue gas to the main stack	• Shenyang Blower Group Co., Ltd. • Xi'an Shaangu Power Co., Ltd. • Shenyang Turbine Machinery Co., Ltd. • Shanghai Blower Factory Co., Ltd. (Note that these companies also produce compressor and condenser)
CO_2 capture	Amine solvent	Capture carbon dioxide (CO_2) from flue gas emissions	• China Huaneng Group Clean Energy Technology Research Institute Co., Ltd. • China Energy Investment Group New Energy Technology Research Institute Co., Ltd. • Sinopec Nanjing Research Institute of Chemical Industry Co., Ltd. • Dalian University of Technology • Guangdong Runtan Technology Co., Ltd. • Beijing Mojie Innovation Technology Co., Ltd.
	Absorber/ Stripper column	The shell of the absorber, typically a cylindrical or rectangular pressure vessel made of steel	• Zhangjiagang Liberty Steel Products Co., Ltd. • Nantong CIMC Energy Equipment Co., Ltd. • Yongsheng Machinery Industry (Kunshan) Co., Ltd.
	Heat exchanger	1.Heat exchanger remove heat from the process and control the temperature at the desired set point 2.Heat rich solvent to a temperature close to the regenerated temperature	• Alfa Laval (Shanghai) Technology Co., Ltd. • Siping Juyuan Hanyang Plate Heat Exchanger Co., Ltd. • SPX (China) Investment Co., Ltd. • Kelvion Heat Exchanger (China) Co., Ltd. • Siping Vickers Exchanger Thermal Equipment Co., Ltd. • Heat Transfer Plate Heat Exchanger (Beijing) Co., Ltd. • Jiangsu Zhongsheng Pressure Vessel Manufacturing Co., Ltd. • Saunders Heat Exchanger (Taicang) Co., Ltd. • April Heat Exchanger (Suzhou) Co., Ltd.
	Reboiler (kettle-type heat exchanger)	Heat and partially vaporize the loaded absorbent that exits the stripper column	Refer to heat exchanger
	Tower internals	Including packing, gas/liquid distributor, tray, demister, etc.	• Shanghai Sulzer Engineering Machinery Manufacturing Co., Ltd. • Pingxiang Jinfeng Chemical Packing Co., Ltd. • Beijing Zehua Chemical Engineering Co., Ltd. • Tianjin Tianda Tianjiu Technology Co., Ltd. • Beiyang National Distillation Technology Engineering Development Co., Ltd.

Compression	Condenser	Cool down the CO_2 gas and condense residual moisture and amine	Refer to compressor
	Separator	Separate the condensate and CO_2	• Sulzer Chemtech • Alfa Laval • Worley • Frames Group
	Dehydration	Further remove water in CO_2 gas (triethylene glycol (TEG) or molecular sieves)	• Hangzhou Linuo Machinery Equipment Co., Ltd. • Hangzhou Fucheng Gas Equipment Co., Ltd. • Hangzhou Kuaikai High Efficiency and Energy Saving New Technology Co., Ltd.
	Compressor	Compress CO_2 to supercritical status	• Sinopec Oilfield Equipment Corporation • Chongqing Gas Compressor Factory Co., Ltd. • Chengdu Zhanwang Energy Machinery Co., Ltd. • CNPC Jichai Power Company Limited Chengdu Compressor Branch • Shenyang Yuanda Compressor Co., Ltd. • Moon Environment Technology Co.,Ltd.; Bingshan Refrigeration&Heat Transfer Technologies Co., Ltd. • Hangyang Group Co., Ltd.
	Refrigeration	Reduce the temperature of the compressed CO_2	Refer to compressor
	CO_2 storage tank	Store CO_2	• Zhuhai Gongtong Low Carbon Technology Co., Ltd. • Hangzhou Kuaikai Hi-Tech Co., Ltd.
General equipment	Vessel	Holding amines solvents or water	• Nantong CIMC-Special Transportation Equipment Manufacture Co. Ltd. • Zhuhai Gongtong Low Carbon Technology Co., Ltd.
	Pump	—	• Dalian Songlone Pump Mading Co.,Ltd., Shandong Chuangjia New Energy Technology Co., Ltd. • Ebara Great Pumps Co., Ltd. • Hunan Neptune Pump Co.,Ltd. • HERMETIC-Pumps Dalian Co., Ltd. • Hangzhou Alkali Pump Co.,Ltd.
	Valve	—	• Jiangsu Suyan Valve Machinery Co.,Ltd. • CNNC SUFA Technology Industry Co.,Ltd. • Yancheng Seiko Valve Co., Ltd. • Shanghai Kaigong Valve Stock Co., Ltd.
	Filter	Remove solid impurities, such as dust and ash, from the flue gas before it enters the absorber	• Wuxi Inoco Filtration Equipment Co.,Ltd. • Wenzhou Dong'ou Micro-filtration Co., Ltd
	Instrumenta-tion	—	• Jiangsu Wanxing Petroleum Equipment Co., Ltd. • Shandong Huareda Precision Instrument Co., Ltd. • Wuxi Smart Auto-control Engineering Co., Ltd.
	Lab analytical device	—	• Mettler • Dionex • Metrohm
Others	Solvent purification	Removes solid contaminants in lean solvent before it is returned to the absorber	• Wuhan Yida Water Treatment Engineering Co., Ltd. • Zhejiang Hainiu Environment Technology Co., Ltd.
	Engineering construction	—	• China Energy Engineering Group Guangdong Electric Power Design Institute Co., Ltd. • China Petroleum Engineering Construction Corporation • Sinopec Yangzi Petrochemical Co.,Ltd. • China Huaneng Group • Sinopec Group Nanjing Chemical Industry Co., Ltd. • Spic Yuanda Environmental-Protection Co., Ltd.

Table A 2 Carbon Transport Supply Chain in China (not exhaustive)

	Device	Provider
Pipeline	Seamless steel tubes	• Jiangyin Changjiang Steel PIPE Co., Ltd.; • Yantai Baofeng Metal Material Co., Ltd; • Jiangyin Chuangzheng Metal Materials Co., Ltd; • Shanghai Haitai Steel Tube (Group) Co., Ltd.
	Pipe anticorrosion and thermal insulation	• Baoji Petroleum Steel Pipe Co., Ltd; • CNPC Bohai Equipment Manufacturing Co., Ltd.
	Expander	• Hangzhou Hangyang Expander Co., Ltd.
	Engineering design and construction	• China Ocean Engineering Equipment Technology Development Co., Ltd; • SINOPEC Oilfiled Service Corporation; • CNPC Offshore Engineering Co., Ltd.
Shipping	Ship	• Dalian Shipbuilding Industry Co., Ltd; • Jiangnan Shipyard(Group)Co.,Ltd.
Highway and railway tanker	Tanker	• Dongying Ruide Electromechanical Equipment Co., Ltd; • Yangzhou Yangming Automobile Service Co., Ltd; • Hebei Changhua Special Vehicle Co., Ltd; • Hebei Hongtai Special Truck Co., Ltd.
General equipment	Valve	• CNPC Bohai Equipment Manufacturing Co., Ltd; • Hangzhou Hangyang KOSO Pump & Valve Co., Ltd; • Sichuan AIR Separation PLANT (GROUP) Co., Ltd.
	Compressor/Pump	• Hangzhou Oxygen PLANT Group Co., Ltd; • Moon Environment Technology Co., Ltd; • Shanghai Luoji Pump Co., Ltd.; • Sichuan AIR Separation PLANT (GROUP) Co., Ltd; • Kobelco Wuxi Compressors Co., Ltd.
	Heat exchanger	• Sichuan AIR Separation PLANT (GROUP) Co., Ltd; • Hangzhou Oxygen PLANT Group Co., Ltd.
	Gasifier	• Hangzhou Chuankong GENERAL Equipment Co., Ltd; • Hangzhou Hangyang Cryogenic Vessel Co., Ltd.
	CO_2 storage tank	• Hangzhou Chuankong GENERAL Equipment Co., Ltd; • Hangzhou Hangyang Cryogenic Vessel Co., Ltd; • Zhuhai Gongtong Low Carbon Technology Co., Ltd.

Table A 3 Carbon Storage Supply Chain in China (not exhaustive)

Process	Equipment	Provider	Price Ranges
Drilling & Completion	Drill bits and tools	• Baoji Oil Field Machinery Co., Ltd. • CNPC Bohai Petroleum Equipment Manufacturing Co., Ltd. • Honghua Group Ltd. • Hejian Deris Petroleum Drilling Equipment Co., Ltd. • Cangzhou Lockhed Petroleum Machinery Co., Ltd.	• 311mm teeth drill bits are priced from 18,000 yuan; • API 12 1/4 Tricone Bit: US $999-2199; • 8 1/2 PDC Drill Bit US $1,800
	Downhole tubing and casing	• CNPC Baoji Petroleum Steel Pipe Co., Ltd. • Baoji Petroleum Machinery Co., Ltd. • CNPC Bohai Petroleum Equipment Manufacturing Co., Ltd. • Honghua Group Ltd. • Hebei Bohai Oil Pipeline Group Co., Ltd. • Cangzhou Beigang Oil Pipeline Co., Ltd.	• The price of 139mm*7.72mm oil casing starts from 3800 yuan / ton
	Packers	• CNPC Baoji Petroleum Steel Pipe Co., Ltd. • CNPC Bohai Petroleum Machinery Co., Ltd.	• The price of oilfield packers starts from 1200 yuan per unit
	Wellhead blow-out preventer	• Baoji Xinrui Petroleum Machinery Co., Ltd. • Yantai Jereh Petroleum Equipment Technology Co., Ltd.	• The price of manual single gate blowout preventer starts from 18000 yuan per unit
Injection	Oil and gas pipelines	• Hebei Bohai Pipeline Machinery Group Co., Ltd. • CNPC Bohai Petroleum Machinery Co., Ltd. • Yantai Jereh Petroleum Equipment Technology Co., Ltd.	• 325*12mm 3PE anti-corrosion steel pipe is priced at 100-200 yuan per meter
	CO_2 injection pump	• Baoji Petroleum Machinery Co., Ltd. • CNPC Bohai Petroleum Machinery Co., Ltd. • Yantai Jereh Petroleum Equipment Technology Co., Ltd.	• CO_2 injection pumps are priced from 35,000 yuan. • The price varies depending on the specification
	CO_2 compressor and supporting equipment	• CNPC Jichai Power Co., Ltd. • Yantai Jereh Petroleum Equipment Technology Co., Ltd.	• The price of the complete set of carbon dioxide booster pump equipment starts from 1,000,000 yuan
	CO_2 storage tank	• Lanzhou Lanshi Heavy Equipment Co., Ltd. • Beijing Yunteng Gas Equipment Co., Ltd. • Hebei Runfeng Cryogenic Equipment Co., Ltd. • Jiangsu Hongyang Gas Equipment Co., Ltd.	• 20 cubic 1.6mpa suitable for liquid oxygen, liquid nitrogen, liquid argon storage tank, priced at 215,000 yuan per unit
Monitoring	Tracer monitoring	• Luoyang Telai Chemical Technology Co., Ltd. • Hunan Yuanchuang Gas Co., Ltd. • Luoyang Philier Specialty Gases Co., Ltd. • Fujian Del Technologies Inc.	• The price of the 8L of SF6 gas starts at 1180 yuan/L
	Microseismic well	• Beijing Shuangjie Technology Co., Ltd. • Hunan Aocheng Technology CO., Ltd. • Xuzhou MTOS Technology Ltd. • Changsha Dimai Intelligent Manufacturing Research Center	• The ESG micro seismic monitoring systems are priced from 100,000 yuan

Drilling & Completion	Drill bits and tools	• Baoji Oil Field Machinery Co. Ltd.; • CNPC Bohai Petroleum Equipment Manufacturing Co. Ltd.; • Honghua Group Ltd.; • Hejian Deris Petroleum Drilling Equipment Co. Ltd.; • Cangzhou Lockhed Petroleum Machinery Co. Ltd.	• 311mm teeth drill bits are priced from 18,000 yuan; • API 12 1/4 Tricone Bit: US $999-2199; • 8 1/2 PDC Drill Bit US $1,800
	Downhole tubing and casing	• CNPC Baoji Petroleum Steel Pipe Co. Ltd.; • Baoji Petroleum Machinery Co. Ltd.; • CNPC Bohai Petroleum Equipment Manufacturing Co. Ltd.; • Honghua Group Ltd.; • Hebei Bohai Oil Pipeline Group Co. Ltd.; • Cangzhou Beigang Oil Pipeline Co. Ltd.	• The price of 139mm*7.72mm oil casing starts from 3800 yuan / ton
	Packers	• CNPC Baoji Petroleum Steel Pipe Co. Ltd.; • CNPC Bohai Petroleum Machinery Co. Ltd.	• The price of oilfield packers starts from 1200 yuan per unit
	Wellhead blow-out preventer	• Baoji Xinrui Petroleum Machinery Co. Ltd.; • Yantai Jereh Petroleum Equipment Technology Co. Ltd.;	• The price of manual single gate blowout preventer starts from 18000 yuan per unit
Injection	Oil and gas pipelines	• Hebei Bohai Pipeline Machinery Group Co. Ltd.; • CNPC Bohai Petroleum Machinery Co. Ltd.; • Yantai Jereh Petroleum Equipment Technology Co. Ltd.;	• 325*12mm 3PE anti-corrosion steel pipe is priced at 100-200 yuan per meter
	CO_2 injection pump	• Baoji Petroleum Machinery Co. Ltd.; • CNPC Bohai Petroleum Machinery Co. Ltd.; • Yantai Jereh Petroleum Equipment Technology Co. Ltd.;	• CO_2 injection pumps are priced from 35,000 yuan • The price varies depending on the specification
	CO_2 compressor and supporting equipment	• CNPC Jichai Power Co. Ltd.; • Yantai Jereh Petroleum Equipment Technology Co. Ltd.;	• The price of the complete set of carbon dioxide booster pump equipment starts from 1,000,000 yuan
	CO_2 storage tank	• Lanzhou Lanshi Heavy Equipment CO. Ltd.; • Beijing Yunteng Gas Equipment Co. Ltd.; • Hebei Runfeng Cryogenic Equipment Co. Ltd.; • Jiangsu Hongyang Gas Equipment Co. Ltd.	• 20 cubic 1.6mpa suitable for liquid oxygen, liquid nitrogen, liquid argon storage tank, priced at 215,000 yuan per unit
Monitoring	Tracer monitoring	• Luoyang Telai Chemical Technology Co. Ltd.; • Hunan Yuanchuang Gas Co. Ltd.; • Luoyang Philier Specialty Gases Co. Ltd.; • Fujian Del Technologies Inc.	• The price of the 8L of SF6 gas starts at 1180 yuan/L
	Microseismic well	• Beijing Shuangjie Technology Co. Ltd.; • Hunan Aocheng Technology CO. Ltd.; • Xuzhou MTOS Technology Ltd.; • Changsha Dimai Intelligent Manufacturing Research Center	• The ESG micro seismic monitoring systems are priced from 100,000 yuan

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