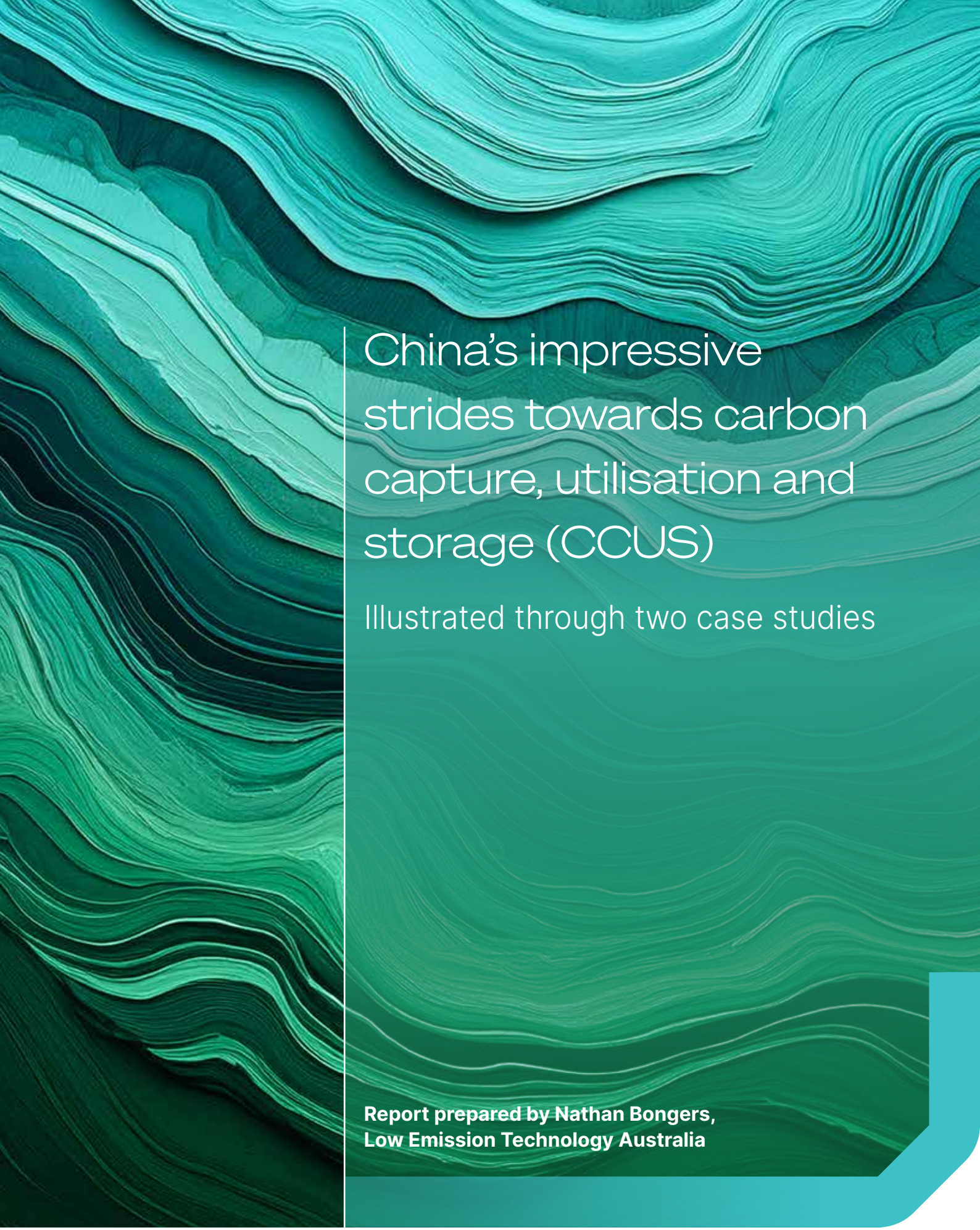

China's impressive strides towards carbon capture, utilisation and storage (CCUS)

Illustrated through two case studies

Report prepared by Nathan Bongers, Low Emission Technology Australia

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Low Emission Technology Australia

China's impressive strides towards carbon capture, utilisation and storage (CCUS): Illustrated through two case studies

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Report edited by Damian Dwyer and Clare Dahlstrom, With special thanks to Siyuan Liu, Hanming Liu, Steve Malss, Peter Morris and Geoff Bongers

Preface

This report has been produced by Low Emission Technology Australia (LETA) for the International Energy Agency's (IEA) Coal Industry Advisory Board (CIAB). It is based on analysis of information provided by China Energy Investment Corporation (China Energy) and China Huaneng Group (China Huaneng), discussions with organisations and individual experts that have been integral to the development of the next generation of CCUS projects in China, and other relevant published literature. The assistance of those providing information and commentary is gratefully acknowledged. The views expressed in this report are those of the author's and not necessarily shared by those who supplied information, or our member organisations.

Introduction to LETA

LETA is a not-for-profit investment fund that accelerates the development and large-scale deployment of technology solutions to reduce and remove greenhouse gas emissions from critical industries like steel, cement and power generation.

LETA's investment in technology unlocks a faster, cheaper pathway to net zero for hard-to-abate industries that are critical to our economy, provide thousands of Australian jobs and support our households every day.

Since 2006, LETA members have contributed more than A$400 million to low emission projects and unlocked a total investment of A$1.1 billion. LETA members recognise the crucial role of low emission technology in enabling a net zero future for their industries, their customers, their workforces and Australian communities.

LETA works with our members, industry, governments, international trading partners and research organisations to unlock new technologies that will help meet Australia's climate targets and contribute to global emissions reduction.

LETA has invested in leading edge projects that explore opportunities for global decarbonisation across the energy and manufacturing lifecycle, with an investment portfolio focus on:

- Reducing emissions from resource extraction and mining operations.
- New advanced near-zero emission on-demand power generation and clean fuel technologies like hydrogen, using coal, natural gas or biomass.
- Decreasing the costs and improving the efficiency of carbon capture in many industries like steel, cement and fertiliser production.
- Facilitating partnerships between Australian industries and trading partners on large-scale carbon capture hubs.
- Developing large scale and cost-effective transport solutions for captured CO_2.
- Commercial utilisation of captured CO_2, including in food and beverage manufacturing and construction.
- Decreasing the costs, improving the efficiency and developing new areas for permanent and safe CO_2 storage.

Introduction to CIAB

The CIAB consists of a group of high-level executives from coal-related enterprises. It was established by the IEA in July 1979 to provide advice to the IEA on a wide range of issues relating to coal. CIAB Members are drawn from 12 countries accounting for approximately 70–80 per cent of world coal production and coal consumption. Members are drawn from major coal producers, electricity producers, other coal-consuming industries and coal-related organisations. The CIAB provides a wide range of advice to the IEA, through its workshop proceedings, meetings, work programme and associated publications and papers.

Executive summary

Reaching net zero without CCUS will be 'all but impossible' ...

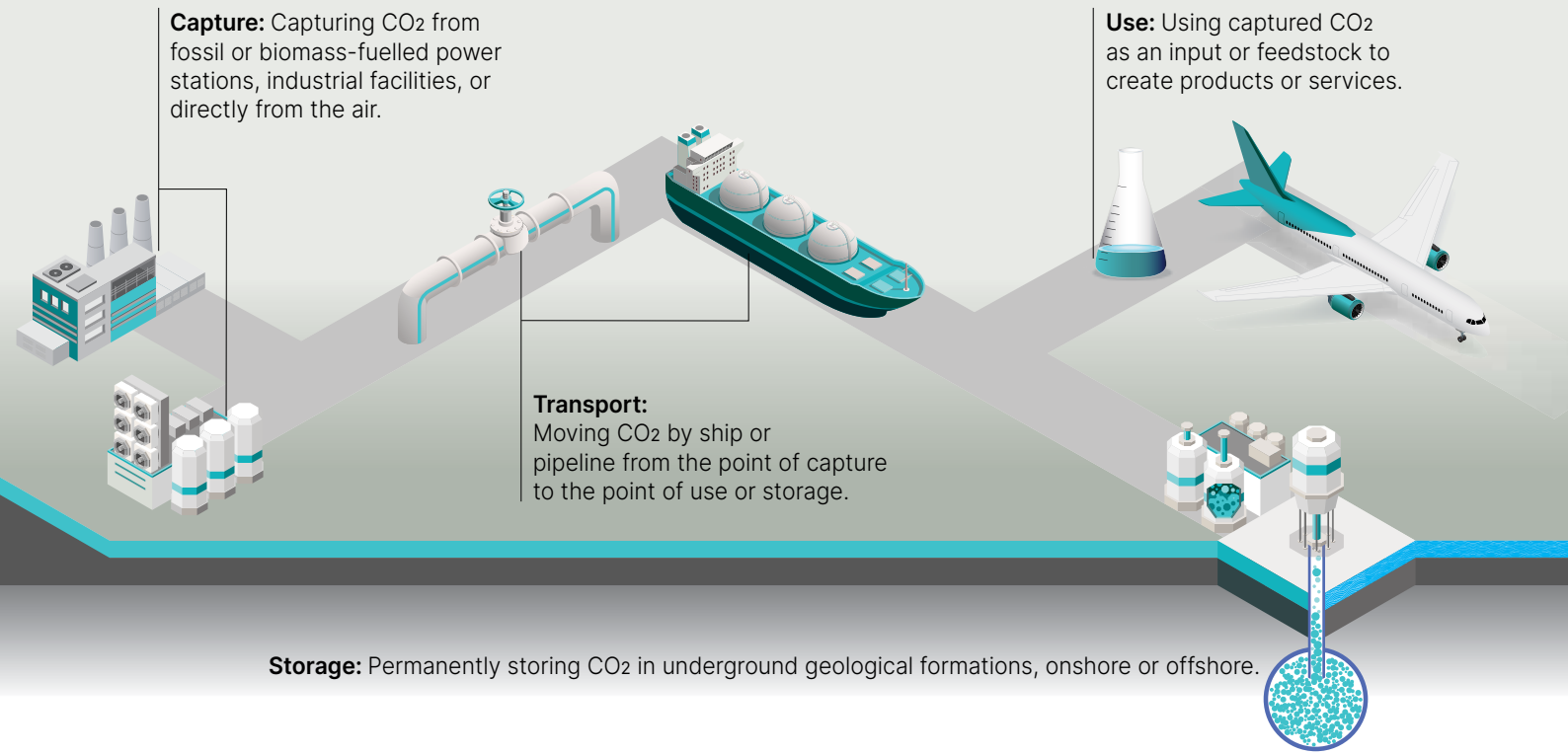
Following the ratification of the Paris Agreement in 2016, most Parties to the Agreement have committed to achieving net zero greenhouse gas emissions by 2050 (or earlier). Other major economies to commit to net zero include China and Indonesia by 2060 and India by 2070.

Parties to the Paris Agreement outline and communicate their proposed climate actions every five years through their Nationally Determined Contributions (NDCs). To date, 27 Parties include or reference carbon capture, utilisation and storage (CCUS) amongst these measures in their NDCs.

CCUS includes a suite of technologies that are used to capture and transport carbon dioxide (CO_2) to be injected into geological formations where it is trapped and permanently stored or to be utilised in a range of industrial applications and products.

The International Energy Agency has found that reaching net zero without CCUS will be 'all but impossible'. Similarly, the Intergovernmental Panel on Climate Change has pointed to the role for CCUS technologies in limiting the impacts of climate change.

Overview of CCUS technology



CCUS is deployed in a wide range of industrial projects, including coal-fired power generation ...

Carbon capture technology is deployed or is capable of being deployed across the globe in industries including but not limited to cement, steel, fertiliser, power generation and natural gas processing. For over 80 years, CO_2 has been captured, transported, and used by business and industry.

Coal-based CCUS technologies have been in operation since 2007 when the first capture of CO_2 from a coal-fired power station was undertaken at China Huaneng's Gaobeidian plant in Beijing. Subsequent demonstrations have seen the technology maturing to support wider technological deployment and improve capital and operating costs.

Over the past decade or so two significant, large-scale projects, both located in North America, have led the way for coal-based CCUS. The SaskPower, Boundary Dam 3 capture unit came online in 2014, with a design capture capacity of 1 Mtpa. The WA Parish power plant's Petra Nova CCUS project began in 2017 with a capture capacity of 1.4 Mtpa.

In Asia, where industrialisation and urbanisation continue, unabated coal remains the dominant source of energy. With the average age of the coal-fired power generation fleet in Asia being relatively low, the retrofit of CCUS to existing power plants is not only technically feasible, but key to enabling the region to reach net zero and still maintain energy security and accessibility.

The pipeline of CCUS projects continues to grow, but accelerating the pace of project development remains vital ...

As of July 2024, there were 50 CCUS projects operating around the world, with capture capacity of around 51 Mtpa. An additional 44 projects, with capture capacity of 51 Mtpa, are under construction. The total pipeline of CCUS projects totals 628 projects, with capture capacity of 416 Mtpa.

A key goal for many nations as they seek to reduce emissions is to do so at the lowest possible cost. Many of these nations, particularly developing nations, have rapidly growing economies that rely on coal and natural gas and have established power generation fleets, and steel, alumina and cement plants.

This means there is an important role for low emission technologies, including CCUS, in reducing emissions in these 'hard-to-abate' sectors. The rapid scaling up of CCUS that is essential to meeting global emissions reductions targets can drive down costs through economies of scale and scope, and process and technology improvements.

China has a significant focus on CCUS due to its substantial domestic resources of coal and its emissions reduction ambitions ...

As a Party to the Paris Agreement, China has outlined 'Dual Carbon Goals', to see emissions peak by 2030 and achieve carbon neutrality by 2060. China is a nation where CCUS will play a vital role in reducing emissions while ensuring energy security and economic growth are maintained.

China is the world's largest consumer, producer and importer of coal and operates the world's largest and one of the youngest fleets of coal-fired power stations. China also utilises coal in the world's largest chemicals industry and extensively in steel production along with a broad range of industrial applications.

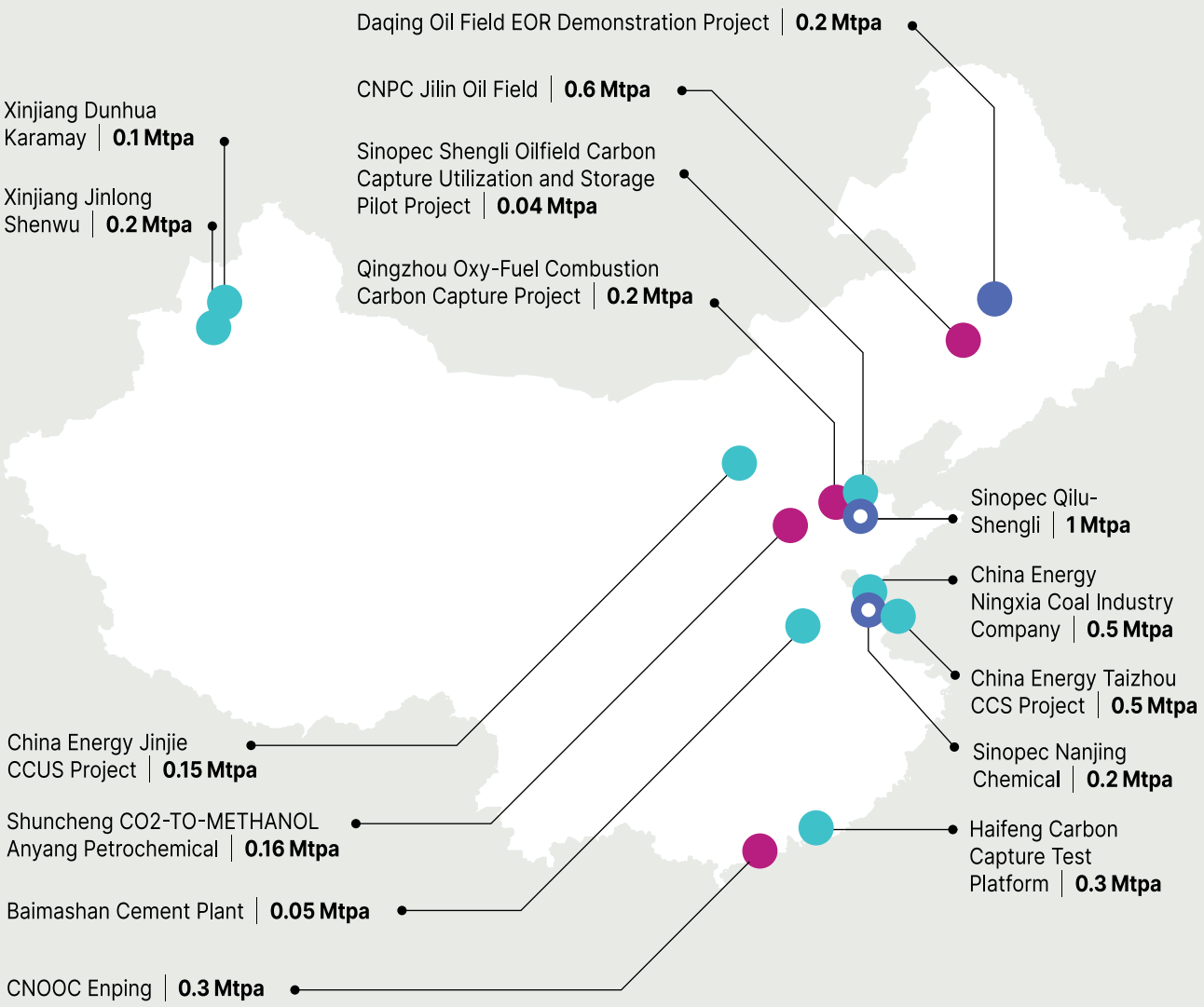
China has been developing its domestic carbon capture technology expertise for over 20 years, with multiple industrial-scale pilot plants built to progress the development of capture technology. China has also been developing both stand-alone carbon capture technologies and various CCUS opportunities through to fully integrated capture-to-storage projects.

Post-combustion capture (PCC) is widely deployed across the globe and has been used commercially for more than 80 years. PCC equipment can be retrofitted to existing facilities, which has the potential to reduce both the cost and speed to operation. Given these advantages, China is focussing on PCC technology to decarbonise its fleet—the world's largest—of coal-fired power plants.

The importance of those low emission coal technologies is recognised within policy documents across multiple levels of the Chinese government. For example, the Global CCS Institute has identified more than 55 individual Chinese policies that exist in support of CCUS.

China's advancement of CCUS projects was initially supported by the demand for industrial use CO_2, including for food and industrial purposes, but now is heavily influenced by environmental drivers, particularly the 2030/2060 targets.

Some of the operational CCUS projects in China



The multiple inclusions of CCUS in the 14th Five Year Plan, supporting the growing CCUS industry, highlights China's goal to 'Foster low-carbon development and the circular economy'. To scale-up low-carbon development, more investments in strategic clean and low-carbon technologies will be required.

In addition, China has a long history of international collaboration on CCUS and other low emission coal technologies. For example, the US–China 2023 Sunnylands Statement on Enhancing Cooperation to Address the Climate Crisis includes that '... the two countries aim to advance at least five large-scale cooperative CCUS projects each by 2030, including from industrial and energy sources.'

China's advancement of CCUS projects was initially supported by the demand for industrial use CO_2, including for food and industrial purposes, but now is heavily influenced by environmental drivers, particularly the 2030/2060 targets.

China has more than 100 CCUS demonstration projects either in operation, completed or in the development pipeline. The aim is to transition these through learning-by-doing from small- and medium-scale to large-scale operations. Among these projects, coal-based CCUS projects have a high priority.

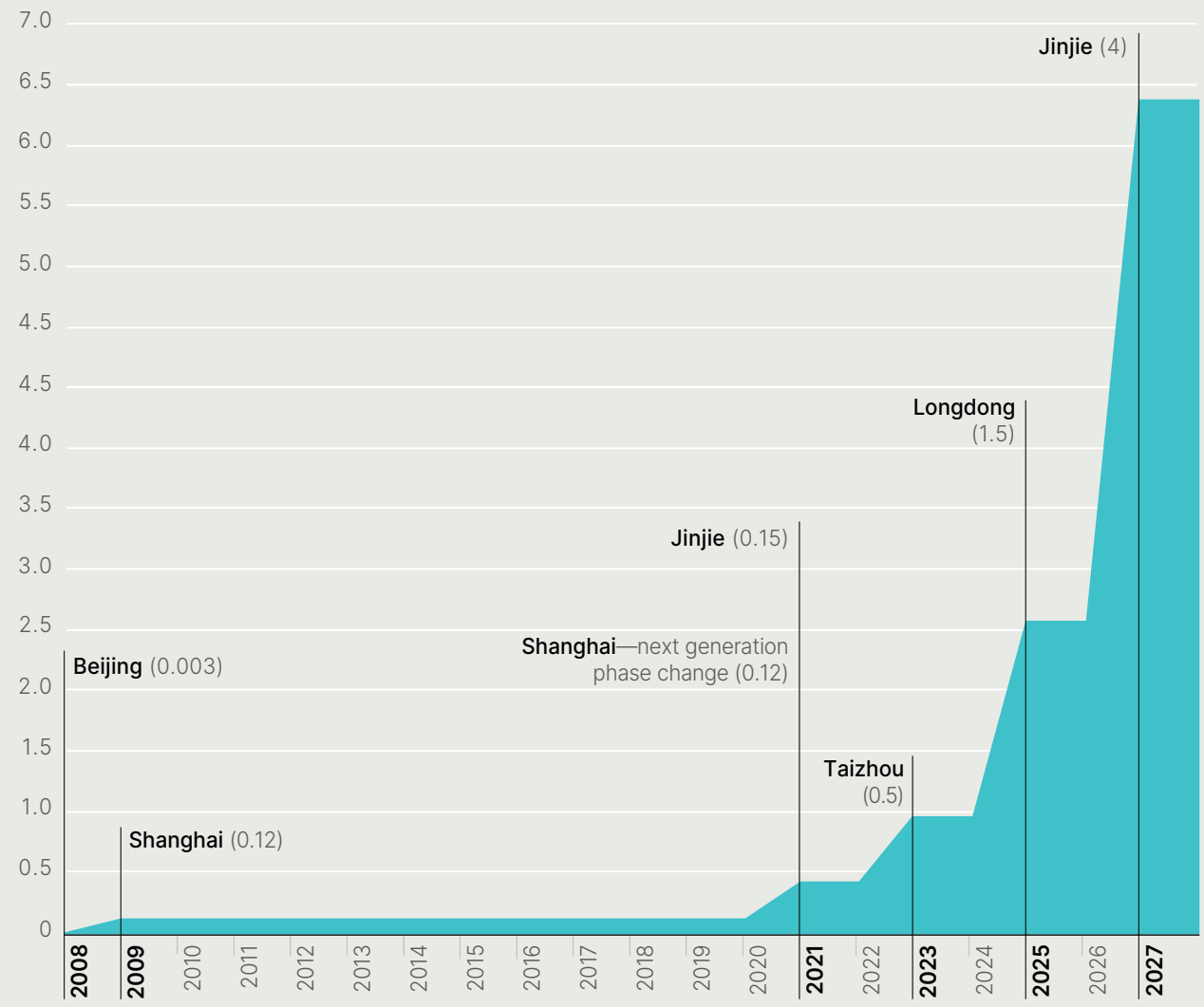
China's 14th Five-Year Plan documentation

Date	Name	Contents
3 December 2021	14th Five-Year Plan on Industrial Green Development	CCUS is included in exploration of industrial carbon abatement pathway, focusing on technology, demonstration, and financing policy support.
6 December 2021	14th Five-Year Plan for High-Quality Development Standardization Mechanism Establishment	CCUS standards were included.
22 March 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.
2 April 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 mega tonne all-chain demonstration projects and relevant technology research are planned.
1 May 2022	14th Five-Year Plan for Renewable Energy	Encourage demonstration on BECCS.

CCUS in action: CCUS coal-fired power generation projects ...

This report illustrates CCUS in action by outlining the development of new full-scale, globally significant carbon capture projects deployed by China Energy and China Huaneng. These projects focus on reducing greenhouse gas emissions from coal-fired power generation in China.

China coal-based CCUS growth (Mtpa)



CCUS in action: China Energy ...

China Energy Investment Corporation (China Energy) is a key central state-owned energy enterprise that integrates 'coal, power, railway, port, and shipping', 'production, transportation, sales, storage and utilisation' and 'coal, power, oil, gas, and chemicals'.

China Energy started in the CCUS industry in 2015, and by 2021 had deployed the first 150,000 tpa PCC unit on coal-fired power generation in China, which remains a key testing facility for China Energy's capture technologies. To support China Energy's continued research and development, the coal-based National CCUS Technology and Research Development Centre was established in April 2023.

Launched in 2015, China Energy's Jinjie 150,000 tpa CCUS Demonstration Project, known as the Jinjie CCUS Project, located at the Jinjie Power Plant, has been recognised as a major 'sci-tech innovation project' of China Energy since 2016 and is listed in China's key research and development (R&D) projects.

As the first large scale deployment of CCUS on a coal-fired power generation project in China, China Energy collaborated with more than ten entities, bringing together industry and universities to move from research to large-scale applications.

As the project moved into construction, multiple challenges were addressed. These included new chemical project management standards and procedures, gaps in equipment safety technology, and the developing nature of core materials such as absorbents. The project continued to collaborate through multiple CCUS project implementation promotion and technical exchange meetings with universities, research institutes, and the design units to tackle these challenges.

Significant work was undertaken to develop a new blended amine absorbent, with high performance and low energy consumption, contributing to reducing the plant's regeneration energy consumption. In addition, China Energy developed process intensification equipment to reduce cost and explored efficient energy-saving processes across the plant.

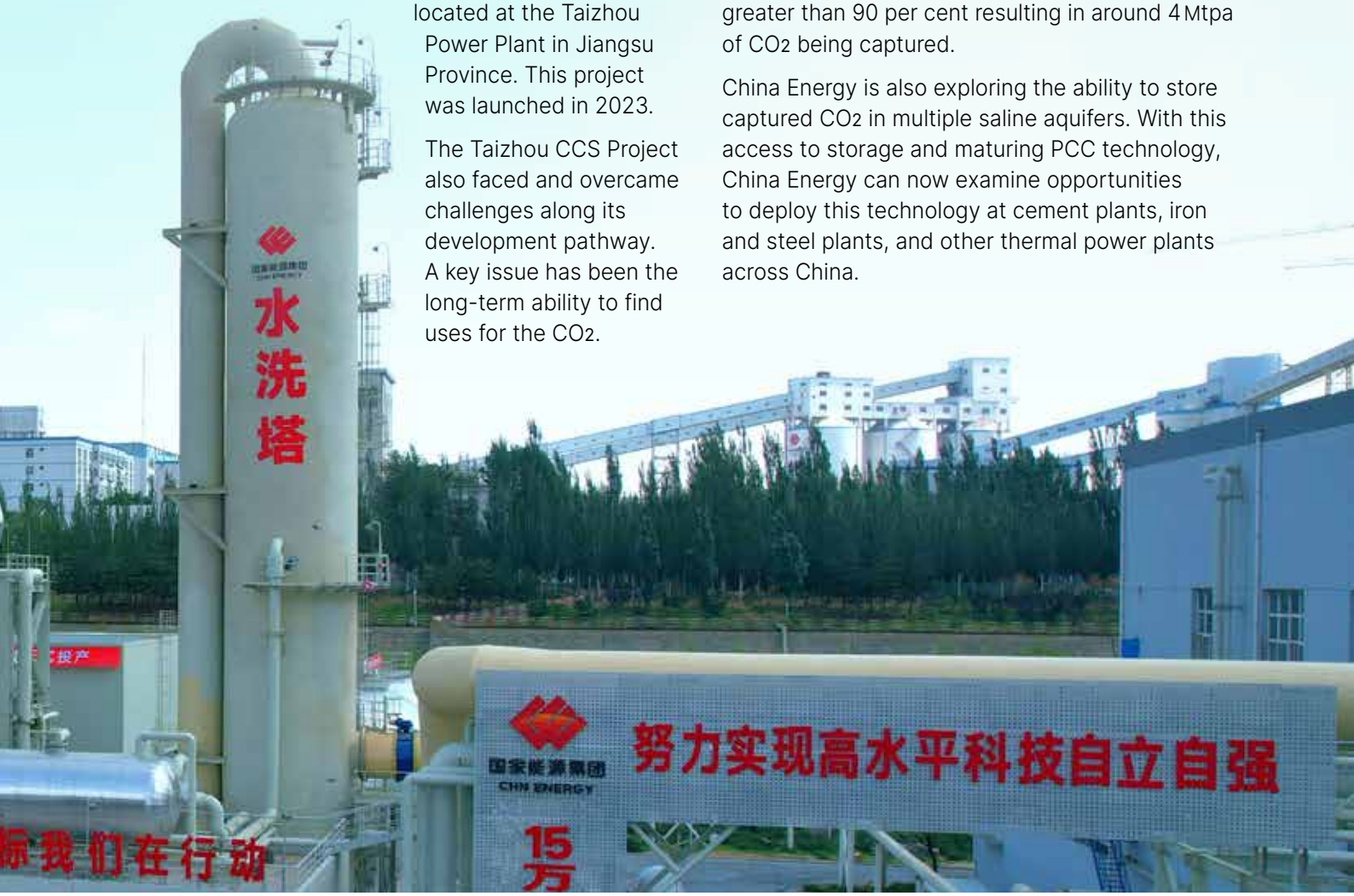
Alongside the Jinjie project, China Energy developed the Taizhou 500,000 tpa Carbon Capture Demonstration Project, known as the Taizhou CCS Project, located at the Taizhou Power Plant in Jiangsu Province. This project was launched in 2023.

The Taizhou CCS Project also faced and overcame challenges along its development pathway. A key issue has been the long-term ability to find uses for the CO_2.

To mitigate this risk and provide for the continuous operation of the project, China Energy is exploring opportunities to expand the CO_2 utilisation market, and invest into technical research into carbon storage, EOR and other chemical utilisation such as methanol or sustainable aviation fuel.

China Energy is now undertaking a feasibility study to deploy a full unit scale capture plant at the Jinjie Power Plant. This capture plant will be fed by the entire flue stream from one unit of the 600 MW coal-fired units, with an estimated capture rate greater than 90 per cent resulting in around 4 Mtpa of CO_2 being captured.

China Energy is also exploring the ability to store captured CO_2 in multiple saline aquifers. With this access to storage and maturing PCC technology, China Energy can now examine opportunities to deploy this technology at cement plants, iron and steel plants, and other thermal power plants across China.



CCUS in action: China Huaneng ...

China Huaneng Group (China Huaneng) is a state-owned company with total assets of over 1.2 trillion RMB, an installed electricity capacity of over 290 GW and over 130,000 employees. China Huaneng also produces approximately 86 Mtpa of coal.

China Huaneng undertook the first capture of CO_2 from a coal power station in 2007. In 2006, it established the Clean Energy Research Institute (CERI) as an innovation research and development centre. CERI is dedicated to developing and commercialising advanced carbon capture technology and other clean energy technologies such as renewable energy, integrated gasification combined cycle and coal technology for China and the world. This includes construction of multiple demonstration projects, such as the 3,000 tpa CO_2 capture system in Beijing in 2008 (the first in China) and the 1,000 tpa two phases CO_2 capture industrial plant in Changchun in 2014, both at coal-fired power generators.

China Huaneng is constructing the largest coal-fired power generation capture plant in the world, a 1.5 Mtpa CCUS plant, capturing 27 per cent of the CO_2 from Unit 1 at the Longdong Energy Base in Gansu Province. The Longdong Project will demonstrate that coal with CCUS can be a flexible solution, co-existing alongside the increasing penetration of variable renewable energy in power generation.

China Huaneng continues to promote the integration of CCUS technology with traditional industries and emerging industries to support the development of low-carbon industry. This will also be demonstrated as part of the Longdong project with the integration of the capture and compression component (upstream) and CO_2 utilisation and storage (downstream).

A key challenge in integrating a PCC unit in a coal-fired steam power plant is that it traditionally leads to a reduction in net power generated. To reduce this efficiency loss, the Longdong Projects deploys an innovative new generation capture technology—a two-phase absorption solution. This has effectively reduced the heat consumption required for the capture plant.

In addition to this important innovation, a range of challenges have been addressed during the development and construction of the Longdong Project.

These have included:

- The need for careful systems integration to ensure that the CCUS system can work flexibly along with the power plant unit.
- A policy regime that appropriately recognises the role of low emission technologies.
- The need for collaboration and research, development and demonstration (RD&D) to overcome storage cost hurdles, as the need for large scale dedicated geological storage grows.
- Effective ongoing communication to ensure all stakeholders remain fully informed on the important emission reduction opportunity demonstrated by projects such as Longdong, and that they can be undertaken in a safe and reliable manner.

Governments and industry have drawn valuable lessons from the operation of the projects ...

Valuable lessons can be drawn from the development and construction of China Energy's Jinjie CCUS Project and Taizhou CCS Project and China Huaneng's Longdong Project.

These lessons include improved operating methods, novel optimisations, significant cost reductions for the next generation of coal-power with CCUS, reduced energy consumption per tonne of CO_2 captured, and strategies for optimising CO_2 capture. Six key lessons have emerged:

1 **China's success is driven by significant government support.** This includes the significant investment in research and development by both China Energy and China Huaneng. China's support for CCUS has also been explicitly led by government, which recognises the technology as a key enabler to reaching its carbon emission reduction pledges. China incorporates CCUS in policy and actively advocates for it in global decarbonisation.

2 **China's technical success will provide for a global scale-up of CCUS on coal power.** The technology developed can be deployed in coal-fired power stations across the globe, increasing the opportunities for other countries to follow in China's footsteps. The projects have demonstrated significant technical advancements for PCC units, with costs savings and efficiency improvements through 'learning-by-doing' as new units are developed. China Energy and China Huaneng have been able to reduce the cost of capture for these projects to under US$35/$tCO_2$, compared with current capture costs of greater than US$60/$tCO_2$. This results in a cost reduction of more than 40 per cent.

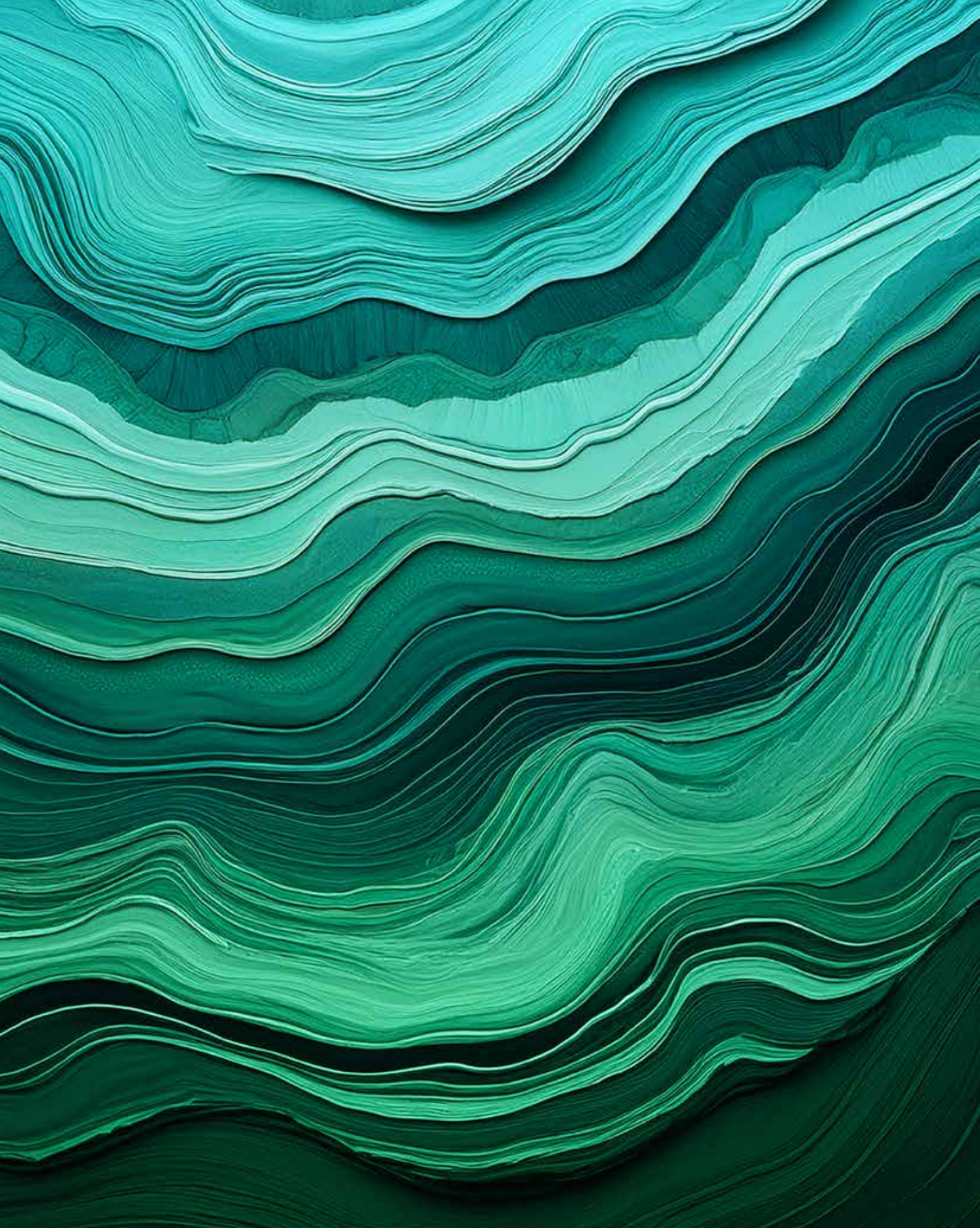
3 **Scale-up success**. Both China Energy and China Huaneng have been successful in significantly scaling-up their technology, with both the scale of the projects and technical readiness level improving with each new project. The projects are now significant assets to China's CCUS industry, providing opportunities for continual testing development and proving up CCUS technology.

4 **The CCUS business case continues to evolve.** CCUS technology is commercially available and has so far been successfully deployed in over 50 large-scale facilities and demonstration projects around the world. For the business case to improve, there are various factors to be considered, including but not limited to: capital expenditure cost, the cost of CO_2 storage or a market for CO_2 utilisation/sale.

5 **Speed at which projects move from concept to operation**. China has been investing in RD&D in key areas of the CCUS value chain. These activities involve increasing levels of scale, system integration and operational learning-by-doing. This has been achieved in a relatively short timeframe partly informed by collaborative research and applying the public domain learning from other CCUS projects around the world.

6 **Application of the next generation's technological advancements to the harder-to-abate sector.** Capture technologies like PCC can also be applied to enable the harder-to-abate sector to decarbonise. This includes steel and cement facilities, responsible for around 14 per cent of global greenhouse gas emissions.

These projects send a clear signal to governments and policymakers that CCUS technology is available now and ready for deployment to help countries meet their Paris Agreement targets.



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