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Carbon Capture and Storage Opportunities and Cluster Deployment in the Beibu Gulf Basin Region:

Navigating the Net-Zero Transition in the Energy and Industrial Sectors



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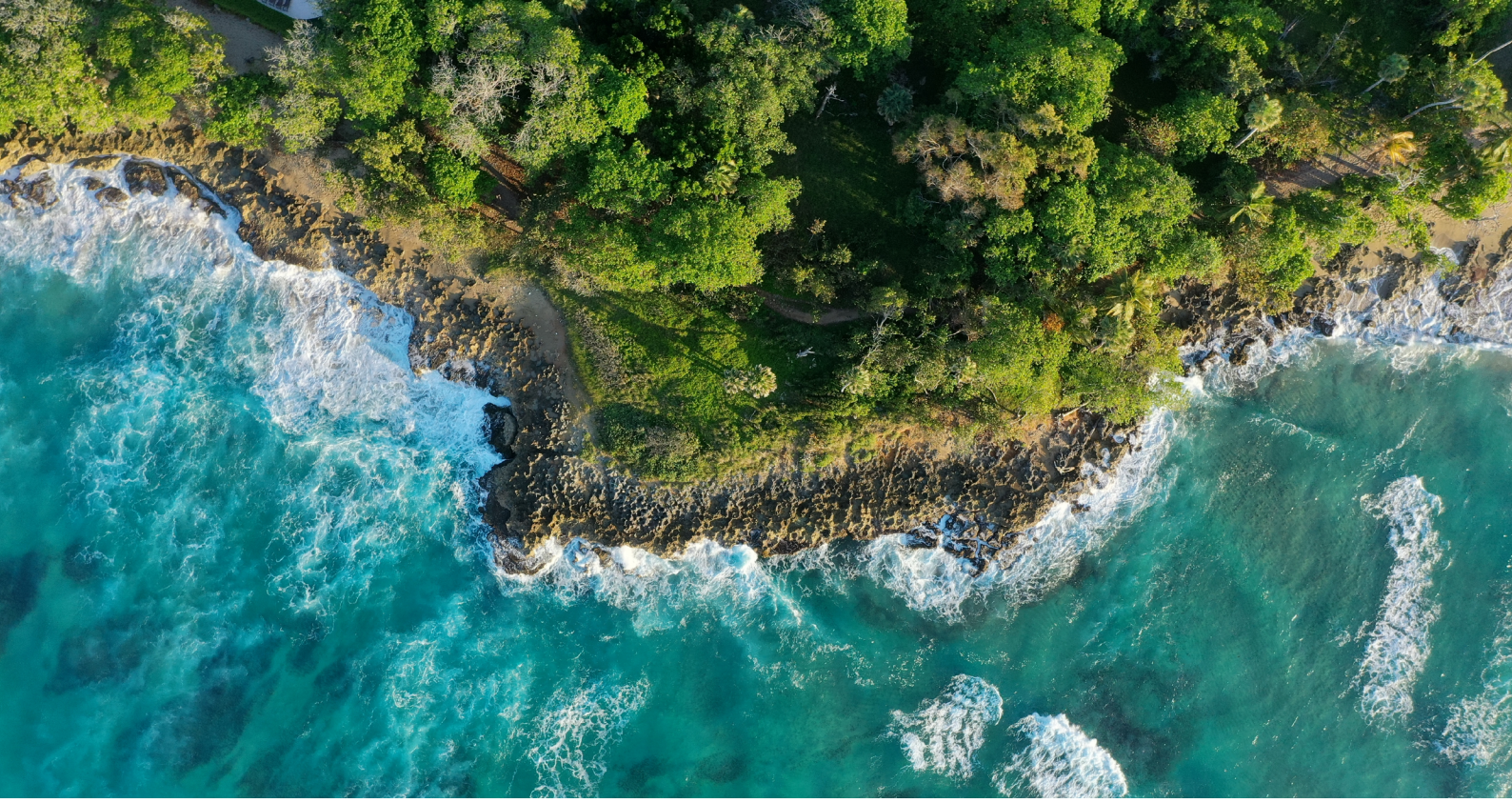
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Executive Summary

The Beibu Gulf Basin region presents a premier opportunity for the deployment of Carbon Capture, Usage, and Storage (CCUS) clusters in South China. This potential is underpinned by favourable geological conditions, existing infrastructure, and growing commitments from both government and industry. Situated at the southern extremity of the Chinese mainland, the Beibu Gulf serves as a maritime gateway connecting the southern and southwestern regions of China to the world. With a prosperous coastal industry driven by the petrochemical, metallurgical, and energy sectors, the Beibu Gulf Basin region faces an imperative to reduce carbon emissions. This study aims to contribute to the net-zero transition of the energy and industrial sectors in the region by examining the prospects for CCUS deployment.

This study has identified 72 major CO_2 emission sources encircling the Beibu Gulf Basin, which are distributed across the west of Guangdong Province, the south of Guangxi Zhuang Autonomous Region, and the north of Hainan Province. These 72 sources emit over 200 million tonnes of CO_2 annually. The power generation industry is responsible for nearly half of the total emissions, while steel mills contribute a third. Other key contributors encompass the cement, refinery, and papermaking sectors. Despite relatively low emissions from biomass power plants and waste incineration facilities, they hold the potential to generate carbon removal credits.

The Beibu Gulf Basin possesses considerable potential for CO_2 storage, particularly in its deep saline aquifers and depleted oil and gas reservoirs. Various research institutions have estimated the basin's storage capacity, with estimates ranging from 23.6 billion to 485.6 billion tonnes. Additionally, the volcanic basalts in the region offer extra storage potential, further enhancing the region's capacity for carbon sequestration.

Based on the distribution of industries, the study suggests the establishment of CCUS clusters or CO_2 transport and storage systems in six strategic regions around the Beibu Gulf Basin. These regions include Zhanjiang and Maoming-Yangjiang in Guangdong Province, Qinzhou-Fangchenggang and Beihai in Guangxi Zhuang Autonomous Region, as well as Haikou-Chengmai and Yangpu in Hainan Province.

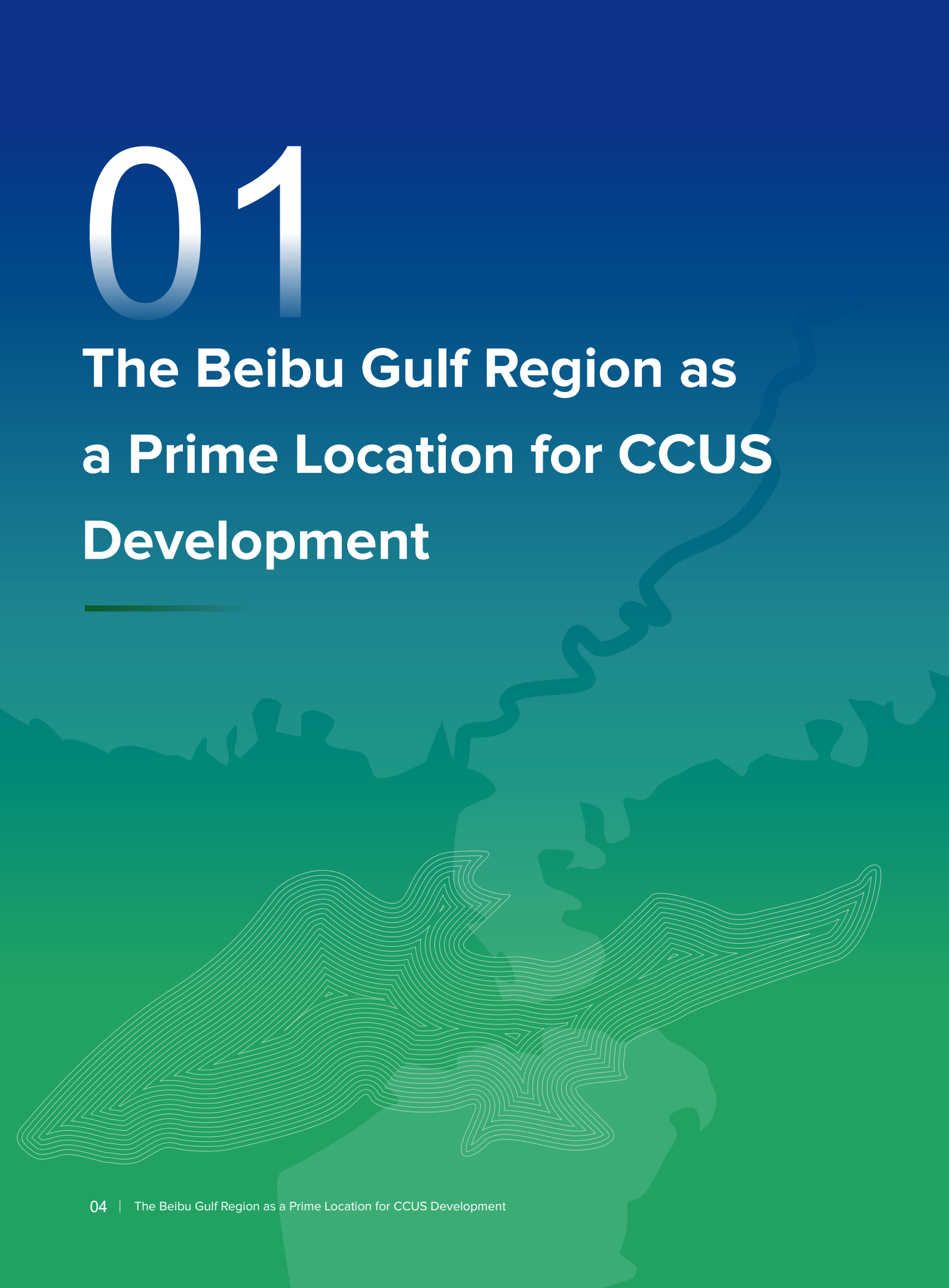
The development of CCUS clusters around the Beibu Gulf Basin presents a multitude of challenges and necessitates a range of support measures. During the initial stage (cluster incubation phase), government policies play a pivotal role. For example, tax credit incentives have been enacted to bolsters CCUS projects in the United States and Canada. Meanwhile, in the United Kingdom, Norway, Denmark, and the Netherlands, governments adopt subsidy policies to partially offset the investment and operational costs of CCUS projects, thereby supporting the initiation and growth of CCUS initiatives and clusters. Drawing on global experiences in CCUS development and considering the current progress of CCUS projects in the Beibu Gulf Basin, this study recommends that local governments focus on several key policy areas. These include: conducting CCUS planning studies to guide future development; setting regional CCUS targets to align with broader climate goals; exploring tailored business models and incentive mechanisms to enhance project viability; establishing a robust regulatory framework to ensure safe and effective implementation; and promoting regional and international cooperation to leverage shared knowledge and resources.

The CCUS industry in the Beibu Gulf is at an early stage, offering significant commercial opportunities across planning, engineering, construction, equipment supply, and monitoring services. As CCUS matures, the region has the potential to become a leading hub for low-carbon industrial development in South China.



01

The Beibu Gulf Region as a Prime Location for CCUS Development



The Beibu Gulf, China's largest semi-enclosed bay, spans a dynamic region encompassing parts of Guangdong Province, the Guangxi Zhuang Autonomous Region, and Hainan Province (Fig. 1). Bordered by the South China Sea, this ecologically rich area is distinguished by pristine beaches, biodiverse mangrove forests, and strategic economic significance as a nexus of the Maritime Silk Road under the Belt and Road Initiative. Its unique position bridges southern and southwestern China to global trade networks, fostering a thriving coastal industrial base driven by petrochemicals, metallurgy, and energy sectors.

Geographically, the Beibu Gulf Basin extends eastward across the Leizhou Peninsula in Guangdong, flanked by Guangxi to the north and Hainan to the south. This basin presents exceptional geological

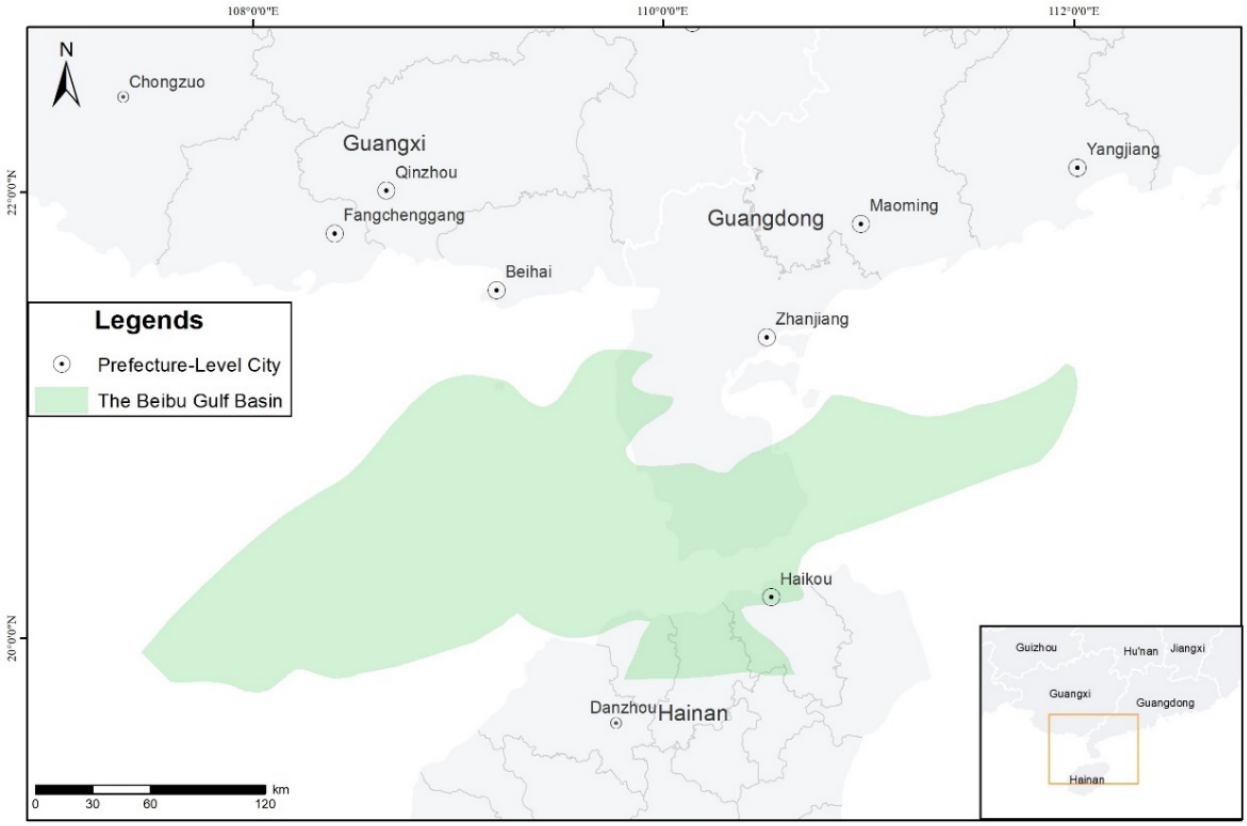


Fig. 1 Spatial extent of the Beibu Gulf Basin, stretching eastwards across the Leizhou Peninsula in Guangdong Province, bordered by Guangxi Zhuang Autonomous Region to the north and Hainan Province to the south.

conditions for carbon dioxide geological sequestration, characterized by thick sedimentary layers and well-sealed formations. Decades of oil and gas exploration have established infrastructure that could be repurposed for CO_2 injection and storage, significantly lowering the costs and timelines for deploying CCUS projects. Proximity to major industrial emission sources further enhances the basin's viability as a strategic CCUS hub.

Economically, the region faces growing urgency to align industrial growth with sustainable practices. Rapid development in energy-intensive sectors has amplified carbon emissions, necessitating innovative decarbonization strategies. The Beibu Gulf's integration of industrial clusters and geological advantages positions it as a critical testing ground for large-scale CCUS deployment.

This report aims to conduct a comprehensive analysis of the potential and opportunities for CCUS development in the Beibu Gulf region. Through a detailed examination of carbon emissions and geological formations, the study seeks to propose holistic frameworks for establishing CCUS clusters and identifying early-stage implementation opportunities. The objective is to contribute to the net-zero transition of the region's energy and industrial sectors by leveraging the Beibu Gulf's unique geographical, geological, and industrial advantages.

02

CCUS Development Progress in the Beibu Gulf Region

2.1 Guangdong Province

Guangdong Province has prioritised CCUS development as a strategic initiative. In 2021, it initiated China's first provincial-level CCUS development plan, study proposing the establishment of four large-scale CCUS clusters across the province. Among these, the Western Guangdong Cluster—encompassing Zhanjiang, Maoming, and Yangjiang cities—has emerged as a strategic focus. This momentum continued in April 2024 with the release of the Guangdong Province Action Plan for Cultivating and Developing Future Green and Low-Carbon Industrial Clusters[1]. The plan strategically outlines eight key green industries, with CCUS identified as a core focus area for building future low-carbon industrial ecosystems. The Action Plan emphasises leveraging coastal high-capacity thermal power plants and CO_2-intensive industrial parks, including the Donghai Island Petrochemical Industrial Park in Zhanjiang, to expedite CCUS cluster development. Specific targets include developing integrated CO_2 transportation networks, establishing manufacturing bases for CCUS equipment and materials, and cultivating industrial clusters along the coastal economic belt.

Zhanjiang City Government has formulated a phased CCUS development strategy in collaboration with Zhanjiang Bay Laboratory[2]. The initial phase focuses on near-source carbon storage at the Datang Leizhou Power Plant and the offshore Wushi Oilfield, while the second phase targets large-scale saline aquifer storage in the Donghai Island-Leidong Sag area, supplemented by basalt mineralisation research[2].

Currently, West Guangdong hosts five operational and under-construction CCUS projects (Table 1). In addition, major industrial players, including Baowu Steel Group, Datang Leizhou Power Plant, and CNOOC Zhanjiang are also planning CCUS projects in the region, demonstrating the region's emergence as a pioneering demonstration hub for CCUS technologies.

1 Guangdong Provincial Development and Reform Commission (2024). Notice on Issuing the "Guangdong Province Action Plan for Cultivating and Developing Future Green and Low-Carbon Industrial Clusters" (in Chinese). Available at: https://sqzc.gd.gov.cn/rdzt/wlcy/zcsd/content/post_4382073.html (Accessed: 9 February 2025).

2 Lin, Y., Yang, J. and Fang, X. (2023) Zhanjiang accelerates the promotion of CCUS technology research and development and industrial development. Zhanjiang Cloud Media, 19 July. Available at: [https://www.gdzjdaily.com.cn/p/2857469.html] (Accessed: 9 February 2025).

Table 1 Operational/Under-Construction CCUS Projects in West Guangdong (2024)

No.	Project Name	Entity	Location
1	Biomass Power Plant CO_2 Capture and Microalgae cultivation project	Guangdong Energy Group	Zhanjiang
2	Biomass-based Green Methanol Demonstration Project	CIMC Group	Zhanjiang
3	CO_2 Synthesis of Carbonate Compounds (Lithium Battery Electrolyte Solvent) Project	Zhanjiang Zhongjie Jingchuang Advanced Materials Co., Ltd.	Zhanjiang
4	200,000 t/yr Petrochemical Off-gas CO_2 Recovery and Utilization Project	Xinhua Yue (Zhanjiang) Co., Ltd.	Zhanjiang
5	400,000 t/yr Petrochemical Off-gas CO_2 Recovery and Utilization Project	Maoming Huayue Huayuan Gas Co., Ltd.	Maoming

2.2 Guangxi Zhuang Autonomous Region

Guangxi remains in the early exploration phase of CCUS development. However, policy support has been progressively strengthened. The 14th Five-Year Plan for Energy Development in Guangxi Zhuang Autonomous Region explicitly proposes to advance research, development, and application of CCUS technologies through tax incentives and other policy tools[3]. Additionally, the plan emphasises establishing a green finance mechanism to channel funding toward CCUS demonstration projects.

While Guangxi remains in the early exploration phase, four operational CCUS projects have been deployed in southern Guangxi as of 2024 (Table 2). One project employs calcium oxide (CaO) sorbents for CO_2 capture and conversion to calcium carbonate ($CaCO_3$). Three projects focus on CO_2 separation from industrial off-gas streams, with liquid CO_2 production as the primary output.

3 Government of Guangxi Zhuang Autonomous Region (2021) Notice of the People's Government of Guangxi Zhuang Autonomous Region on printing and distributing the outline of the 14th Five-Year Plan for National Economic and Social Development of Guangxi Zhuang Autonomous Region and the long-range objectives through the year 2035. Available at: http://www.gxzf.gov.cn/zwgk/zfwj/t8687263.shtml (Accessed: 9 February 2025)

Table 2 Operational/Under-Construction CCUS Projects in South Guangxi (2024)

No.	Project Name	Entity	Location
1	38,000 t/yr Industrial Waste Gas CO_2 Capture via CaO Absorption ($CaCO_2$ Production)	Beihai Meite Environmental Technology Co., Ltd.	Beihai
2	15,000 t/yr Alcohol Fermentation Off-Gas CO_2 Recovery	Guangxi COFCO Biomass Energy	Beihai
3	220,000 t/yr Petrochemical & Chemical Industry Off-Gas CO_2 Recovery	Guangxi Wanxing Chemical Technology	Qinzhou
4	60,000 t/yr Alcohol Fermentation Off-Gas CO_2 Recovery	Guangxi Xintiande Energy	Qinzhou



220,000 t/yr Petrochemical & Chemical Industry Off-Gas CO_2 Recovery by Guangxi Wanxing Chemical Technology Co., Ltd., Qinzhou, Guangxi (Photo source: Guangxi Wanxing)

2.3 Hainan Province

Hainan has established concrete CCUS development targets through provincial policy frameworks. The Implementation Plan for Carbon Peaking in Hainan Province (2022) proposed to promote pilot work on technologies such as CCUS in the cement, petrochemical, and chemical industries, and mandated the objectives to achieve 500,000 t/yr carbon storage capacity by 2030[4].

In 2018, PetroChina Fushan Oilfield successfully launched Phase I CO_2-enhanced oil recovery pilot project. By 2022, the oilfield had established a CO_2 liquefaction and storage infrastructure capable of sequestering 100,000 tons annually. Under the 14th Five-Year Plan, Fushan Oilfield aims to scale up its CCUS processing capacity to 300,000 tons per year by 2025 while initiating construction of a one-million-ton carbon storage demonstration base[5]. This strategic expansion gained international collaboration momentum in March 2023 when PetroChina Southern Exploration Company and bp (China) Investment Co., Ltd. signed a low-carbon cooperation agreement in Hainan. Their partnership focuses on developing clean and green oilfield standards and establishing a Hainan CCUS regional centre as a hub for technology transfer and deployment. A significant milestone followed in July 2024 with the launch of the Fushan Sag Saline Aquifer CO_2 Storage Demonstration Project at the Jinfeng 7x well site[6].

Parallel advancements have emerged in other sectors. In 2023, Huaneng Hainan Yangpu Power Plant commissioned a post-combustion carbon capture system at its natural gas power facility, achieving an annual CO_2 capture capacity of 2,000 tons. Meanwhile, China Resources Cement (Changjiang) Co., Ltd. initiated construction of a carbon neutrality R&D platform, which includes a sub-project designed to capture and utilize 60,000 tons of CO_2 annually from cement production processes. These projects underscore Hainan's cross-sectoral efforts to integrate CCUS into energy, industry, and resource extraction activities while aligning with provincial decarbonization objectives.

4 Hainan Provincial People's Government (2022) Implementation Plan for Carbon Peaking in Hainan Province (No. Qiong Fu [2022] 27). Hainan Provincial People's Government Website. Available at: https://www.hainan.gov.cn/hainan/ldhy/202208/22af5e1c2f3a4d7ebf9d8e7d9c9d7a9a.shtml (Accessed: 9 February 2025).

5 China Petroleum News Centre (2022). South Exploration Company: A Chronicle of Building a Green Enterprise. Available at: [https://www.cnpc.com.cn/cnpc/jtxw/202205/69bc24bc69974c0a8d2b0e91eb34d7c0.shtml] (Accessed: 9 February 2025).

6 China Petroleum News Centre (2024) China National Petroleum Corporation launches first saline aquifer CCS pilot injection project, 15 July. Available at: [http://news.cnpc.com.cn/system/2024/07/15/030137084.shtml] (Accessed: 9 February 2025).

Table 3 Operational/Under-Construction CCUS Projects in North Hainan (2024)

No.	Project Name	Entity	Location
1	100,000t/yr Fushan Oilfield CCUS Project	PetroChina Hainan Fushan Oilfield Exploration & Development Co., Ltd.	Chengmai
2	2,000 t/yr Natural Gas Power Plant Carbon Capture Demonstration Project	Huaneng Yangpu Power Plant	Danzhou
3	60,000 t/yr Cement Industry Carbon Capture & Usage Project	China Resources Cement (Changjiang) Co., Ltd.	Changjiang



CO_2 compressor at the Fushan Oilfield in Hainan. Natural gas is dehydrated through molecular sieves and adsorption towers. The CO_2 in the gas is then pressurized and condensed into liquid form for underground storage and enhanced oil recovery. (Photo courtesy of China State Shipbuilding Corporation)



bp and PetroChina Sign MOU for Hainan Low-Carbon Cooperation



CO_2 Injection pump at PetroChina Fushan Oilfield, Chengmai, Hainan Province“(Photo source: PetroChina)



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

03

Carbon Emissions from the Energy and Industrial Sectors

This chapter analyses the carbon emissions generated by energy and industrial activities in the Beibu Gulf region. The analysis encompasses eight sectors: two power generation sectors (gas-fired and coal-fired plants), four industrial sectors (steel, cement, petrochemicals, and papermaking), and two environmental energy sectors (biomass power generation and waste incineration). To ensure cost-effectiveness, commercial carbon capture projects must achieve significant scale, thereby driving down the cost per tonne of CO_2 captured. Thus, power plants and industrial facilities with annual CO_2 emissions exceeding 100,000 tonnes were prioritised for inclusion in the CCUS cluster network. Biomass power plants and waste incineration facilities, which generate carbon removal credits of higher market value, were also chosen for carbon capture, with a lower threshold of 50,000 tonnes compared to fossil fuel power plants and industrial factories, reflecting their particular value in the carbon market.

A comprehensive survey identified 72 major CO_2 emission sources around the Beibu Gulf Basin (Table 4), categorised as follows:

- Fossil fuel power generation dominates with 29 facilities (12 gas-fired and 17 coal-fired plants), responsible for 107.7 million tonnes (Mt) of CO_2 annually.
- Industrial activities contribute 25 sources, including 7 steel mills (65.5 Mt/yr), 10 cement plants (10.7 Mt/yr), and 8 refineries (11.3 Mt/yr).
- Environmental energy sectors, though smaller in scale, include 7 biomass plants (0.8 Mt/yr) and 4 waste incineration facilities (0.4 Mt/yr), offering unique opportunities for carbon-negative technologies.

Table 4 Estimated Carbon Emissions from Facilities Across the Eight Sectors in Beibu Gulf region

Emission source	Facilities	CO_2 emission (Mt/yr)
Gas-fired Power Plants	12	6.2
Coal-fired Power Plants	17	101.5
Steel Mills	7	65.5
Cement Plants	10	10.7
Petrochemical Plants	8	11.3
Paper Mills	7	10.6
Biomass Power Plants	12	0.8
Waste Incineration Plants	15	0.4

Coal-fired power generation contributes to nearly half of all CO_2 emissions (Fig. 2), while steel mills are responsible for a significant one-third. The cement, refinery, and papermaking industries also play a notable role, each emitting approximately 10 million tonnes of CO_2 annually (Fig. 2). While gas-fired plants are more numerous, their emissions (~6 Mt/yr) remain modest compared to coal. In contrast, emissions from biomass and waste incineration facilities are relatively minimal, amounting to less than 1 million ton CO_2 in the region.

Emissions are spatially concentrated, with Guangdong's western region emerging as the largest contributor (27 sources, 105 $MtCO_2$/yr), driven by dense industrial and energy infrastructure. Southern Guangxi follows closely with 30 emission sources and an annual emission of 84 $MtCO_2$. In contrast, Hainan's emissions (14 sources, 16.8 Mt/yr CO_2) are comparatively limited, aligning with its smaller industrial base.

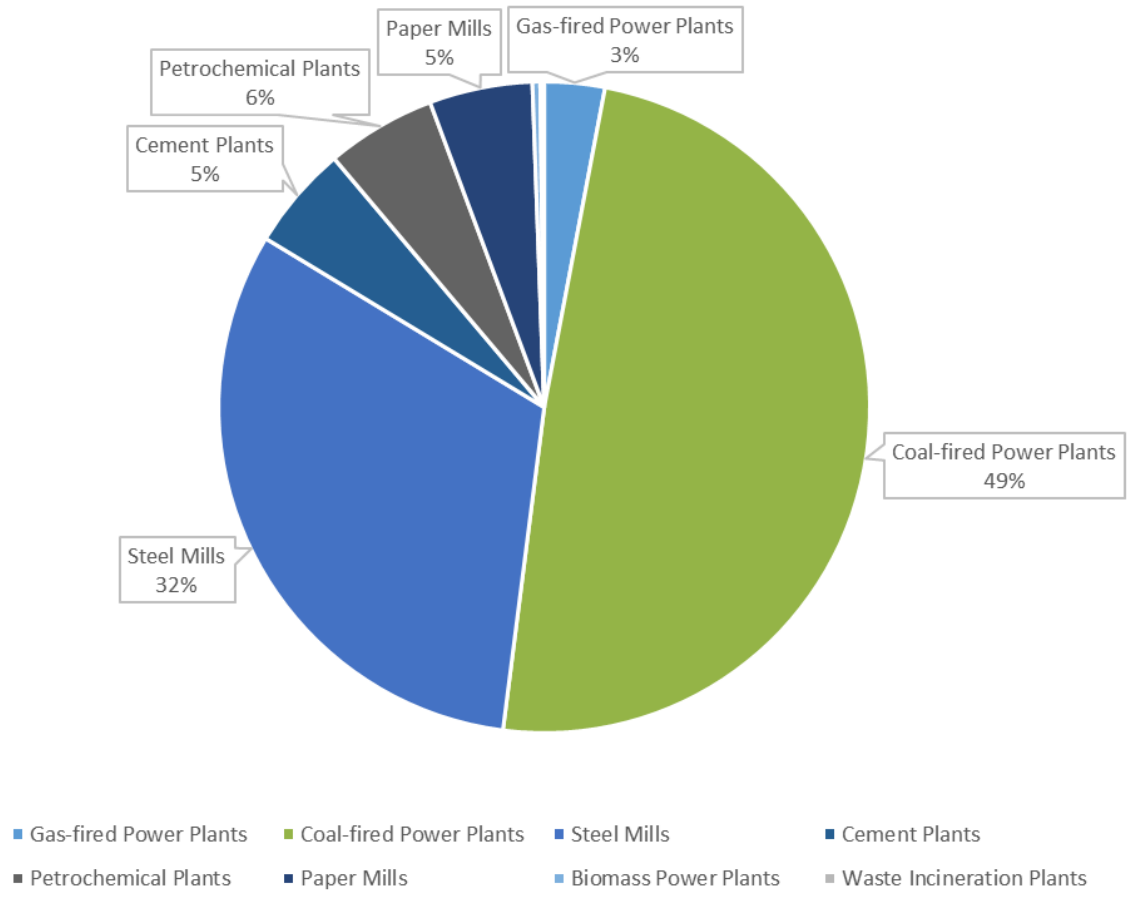
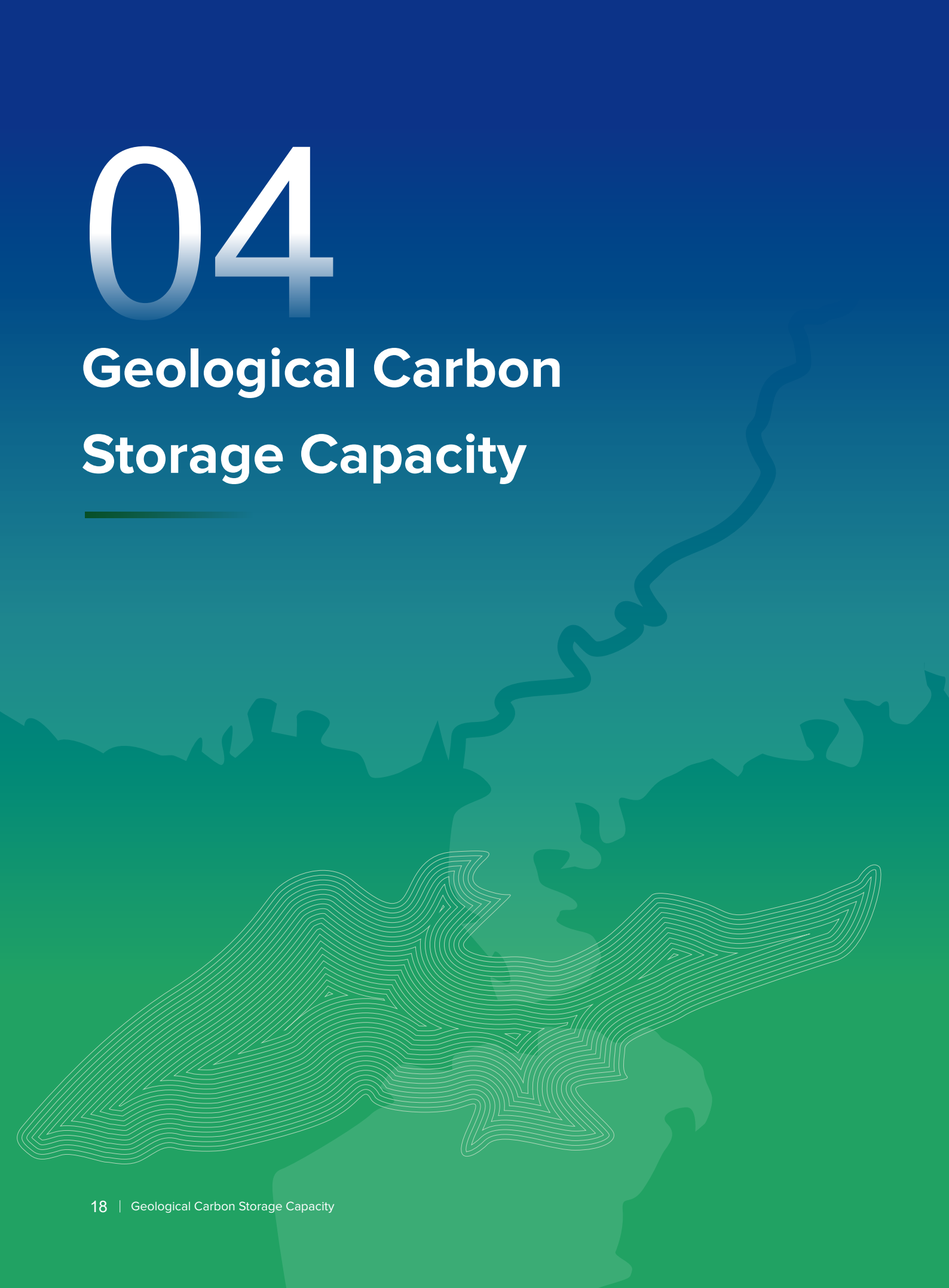


Fig. 2 Sectoral Contribution to CO_2 Emissions in the Beibu Gulf Region

04

Geological Carbon Storage Capacity



The Beibu Gulf Basin originated during the early Paleogene (~65 million years ago) as a continental basin. Over millennia, regional subsidence and marine transgression transformed it into a shallow marine environment, where alternating deposition of sandstone reservoirs and shale seals occurred in lacustrine, coastal, and marine settings. This geological history endowed the basin with layered sedimentary structures critical for secure CO_2 storage, particularly within four key sandstone formations: the Jiaowei (Miocene), Xiayang (Miocene), Weizhou (Oligocene), and Liushagang (Eocene). Table 5 summarises the characteristics of these formations, which combine substantial reservoir thickness (120–212 m) with impermeable shale seals, ensuring long-term containment integrity.

Table 5 Characteristics of the Main CO_2 Storage Reservoir Formations in the Beibu Gulf Basin[7,8]

Age		Strata			Lithology	CO_2 Storage	
		Formation		Thick-ness(m)		Reservoir	seal
Quaternary				170-603	Muddy sandstone		
Pliocene		Wang-lougang			Upper sandstone, lower mudstone		
Miocene	Late	Deng-loujiao		135-491	Sandstone		
	Middle	Jiaowei		172-900	Mudstone sandstone interlayer		
	Early	Xiayang		61-724	Sandstone		
Oilgocene	Late	Weizhou	1st	0-3400	Mudstone sandstone interlayer		
	Early		2nd				
			3rd				
Eocene	Late	Liusha-gang	1st	0-4400	Mudstone sandstone interlayer		
	Middle		2nd		Mudstone		
			3rd		Mudstone sandstone interlayer		
	Early	Changliu		0->800	Mudstone sandstone interlayer		
Paleocene	Late				Mudstone		

7 Xiong Pengfei,Fang Xiaoyu,Le Wenxi,et al. Reservoir-cap combination optimization and potential evaluation of CO_2 geological storage in saline aquifer, in Wenxinan sag of Beibu Gulf Basin[J]. Journal of China Coal Society,2024,49(5):2405−2413.

8 SCSIO (South China Sea Institute of Oceanology). Feasibility Study of CCS-Readiness in Guangdong Province, China (GDCCSR) Final Report: Part 2: Assessment of CO_2 Storage Potential for Guangdong Province, China[R]. Guangzhou: South China Sea Institute of Oceanology, Chinese Academy of Sciences, 2013.

Multiple institutions have evaluated the basin's CO_2 sequestration capacity, yielding estimates that reflect methodological and spatial variability. The South China Sea Institute of Oceanology (SCSIO) conducted a preliminary assessment in 2013, estimating an effective storage capacity of 48.56 billion tonnes in deep saline aquifers across the basin's depressions[8]. From 2010 to 2012, the Hydrogeology and Environmental Geology Survey Center (HEGSC) of China Geological Survey calculated a more conservative estimate of 23.6 billion tonnes through the National CO_2 Geological Storage Potential Assessment and Demonstration Project[9]. The Qingdao Institute of Marine Geology further quantified this potential, reporting 22.8 billion tonnes at a 90% confidence level and 45.6 billion tonnes at a 50% confidence level, reflecting uncertainties linked to subsurface heterogeneity[10]. In addition to broad saline aquifer assessments, targeted studies have refined localized estimates. The Zhanjiang Bay Laboratory focused on the Weizhou Graben's Jiaowei and Weizhou formations, identifying 1.123 billion tonnes of high-suitability storage in optimized sandstone units[7].

Based on the proven reserves of oil and gas fields in the Beibu Gulf Basin, their effective CO_2 sequestration potentials are 42.3 million tonnes of CO_2 (with an effective sequestration coefficient of 0.25) and 62.3×10^6 tons (with an effective sequestration coefficient of 0.63), respectively[12]. Oil and gas discoveries have been made in multiple depressions within the Beibu Gulf Basin, including the Weixi'nan Depression, Wushi Depression, Maichen Depression, Haizhong Depression, Fushan Depression, and Leidong Depression[11](Fig.3). Among them, the Weixi'nan Depression has been developed into an important crude oil production area in the western South China Sea, and both the Wushi Depression and Fushan Depression currently have oil fields in production. Li et al. evaluated the effective CO2 sequestration potential of seven oil fields in the Weixi'nan Depression, which is approximately 4.42×10^6 tons[11].

9 Guo J, Wen D, Zhang S, et al. National CO_2 Geological Storage Potential Assessment and Demonstration Project[R]. Beijing: Hydrogeology and Environmental Geology Survey Center, 2014.

10 Wang J, Yuan Y, Chen J, et al. Geological conditions and suitability evaluation for CO_2 geological storage in deep saline aquifers of the Beibu Gulf Basin (South China)[J]. Energies, 2023, 16(5): 2360.

11 Li P, Zhou D, Zhang C, et al. Assessment of the effective CO_2 storage capacity in the Beibuwan Basin, offshore of southwestern PR China[J]. International Journal of Greenhouse Gas Control, 2015, 37: 325-339.

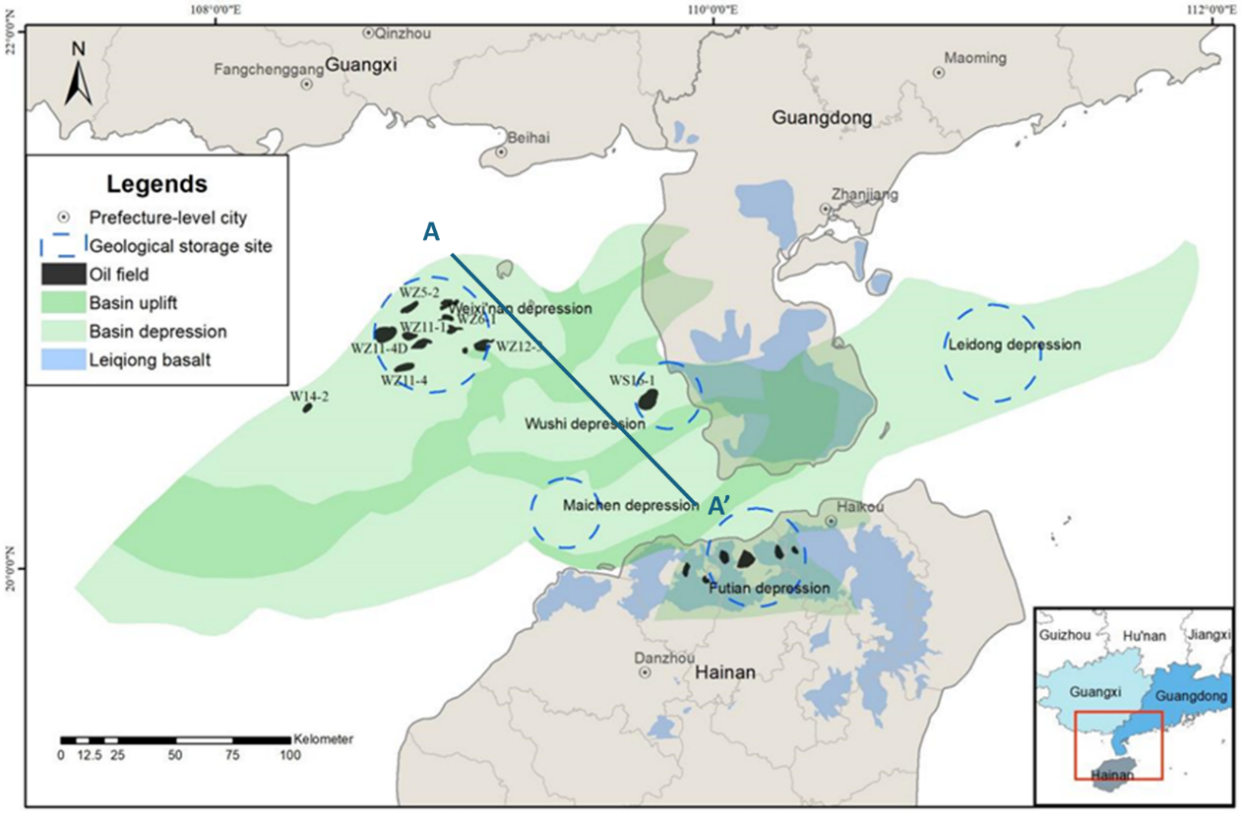


Fig. 3 The distribution of potential carbon storage regions, oil and gas fields, and basalts in the Beibu Gulf Basin.

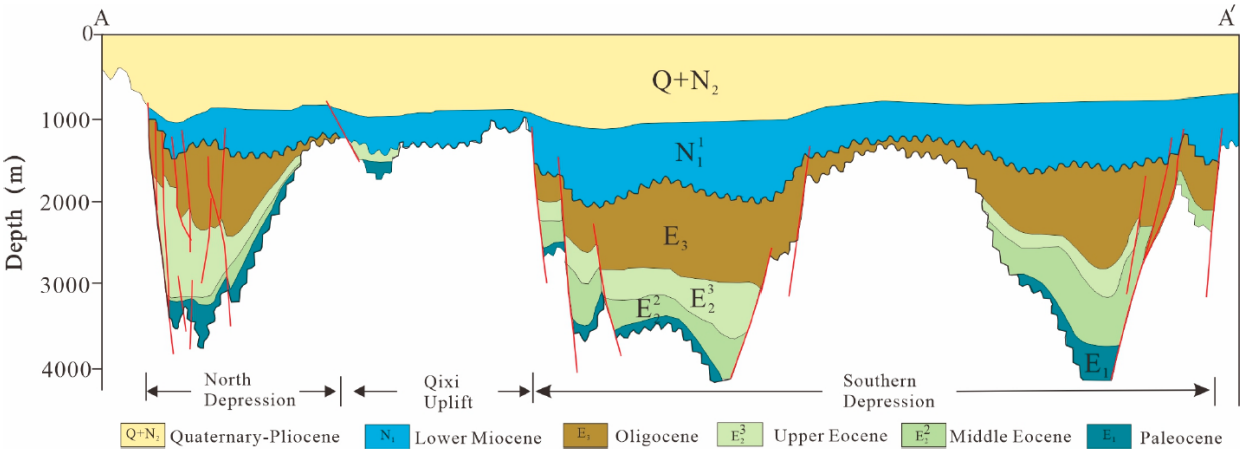


Fig. 4 Geological cross-section across the Beibu Gulf Basin[10]. The location of this cross-section is shown in Fig. 3.

In addition to the deep saline aquifers and depleted oil and gas reservoirs located within the Beibu Gulf Basin, the basalts on the Leizhou Peninsula and Hainan Island, collectively referred to as "Leiqiong Volcanic Rock," also contain significant potential for carbon sequestration. The Leiqiong Volcanic Rock extends over an area of approximately 8,000 m^2, with the Leizhou Peninsula comprising 3,900 m^2 and the northern region of Hainan Island accounting for about 4,100 m^2 [12]. To date, 177 volcanoes have been identified within this area[12]. The geological activity of the Leiqiong Volcanic Rock spans from the Mid Cretaceous to the Holocene (from about 100 million years ago to 10,000 years ago)[13]. Its formation is linked to the expansion of the Beibu Gulf Basin and crustal thinning, which caused mantle material to rise and trigger volcanic eruptions. The volcanic activity peaked during the Middle Pleistocene (780,000 to 130,000 years ago) and then calmed down by the Holocene[13]. The last volcano eruption occurred in Hainan was the Maanling Volcanic Cluster, which was approximately 8,000 years ago, during the Holocene epoch[14].

Carbfix and Tencent have undertaken a preliminary assessment of the storage potential of these basalt formations. The results indicate that the regional carbon storage capacity ranges from 21 to 341 $GtCO_2$[15]. A study conducted by the SCSIO further reveals that the carbon storage potential of the basalts on the Leizhou Peninsula is estimated to be in the range of 1.9 to 45.9 $GtCO_2$[16]. However, geological survey data of the region show that the basalt is mostly buried less than 300 m deep due to its recent formation. Currently, exploration work for basalts at depths exceeding 300 m is limited. The shallow burial depth of the basalt raises concerns regarding whether its thickness and depth are sufficient to meet the construction requirements for basalt carbon sequestration technology. This issue represents one of the key areas where future research and investigation are warranted.

12 Tao Kuiyuan. Leiqiong Global Geopark in China[J]. Resources Survey and Environment, 2007, 28(3):5. DOI:10.3969/j.issn.1671-4814.2007.03.010.

13 Huang Zhenguo, Cai Fuxiang, Han Zhongyuan. Quaternary Volcanoes of Leiqiong [M]. Beijing: Science Press, 1993.

14 Bai Zhida, Xu Debin, Wei Haiquan, et al. Division of Quaternary Volcanic Activity Stages in the Maanling Area, Northern Hainan[J]. Seismology and Geology, 2003, 25(B12):9. DOI:10.3969/j.issn.0253-4967.2003.z1.003.

15 Carbfix and Tencent, Pre-feasibility screening study for CO_2 mineral storage potential in China [R], 2021

16 Pengchun LI, Jinglian J, Jinhui C, et al. Assessment of carbon dioxide mineralization sequestration potential of volcanic rocks in Leizhou Peninsula, Guangdong Province, China[J]. Geological Journal of China Universities, 2023, 29(1): 76.

05

Strategic Considerations for CCUS Cluster Deployment

The emission sources in the energy and industrial sectors around the Beibu Gulf Basin exhibit notable clustering features. These sources are mainly in Zhanjiang (Guangdong), Beihai, Fangchenggang, Qinzhou (Guangxi), and Haikou, Danzhou (Hainan), near port areas, providing favourable conditions for the layout of CCUS clusters. Based on this distribution, this study proposes to establish six CCUS clusters around the Beibu Gulf Basin, namely: Zhanjiang and Maoming-Yangjiang in Guangdong, Qinzhou-Fangchenggang and Beihai in Guangxi, and Haikou-Chengmai and Yangpu in Hainan.

In west Guangdong, Zhanjiang is the central city and an important base for steel and petrochemical industries. There are over 10 large CO_2 emission sources situated around the city centre of Zhanjiang, with annual emissions exceeding 30 Mt. A pipeline approximately 60 km long is required to transport CO_2 from Zhanjiang to the eastern part of the Beibu Gulf Basin. The scale of the CCUS cluster can significantly reduce the cost of CCUS implementation in Zhanjiang. In Maoming and Yangjiang, CO_2 emission sources are more dispersed compared to other cities in the region. A CO_2 transport and storage system is necessary to connect the seaside emission sources, while inland emission sources will require additional pipelines or the use of tanker truck to transport CO_2 to the seaside CO_2 pipeline terminal.

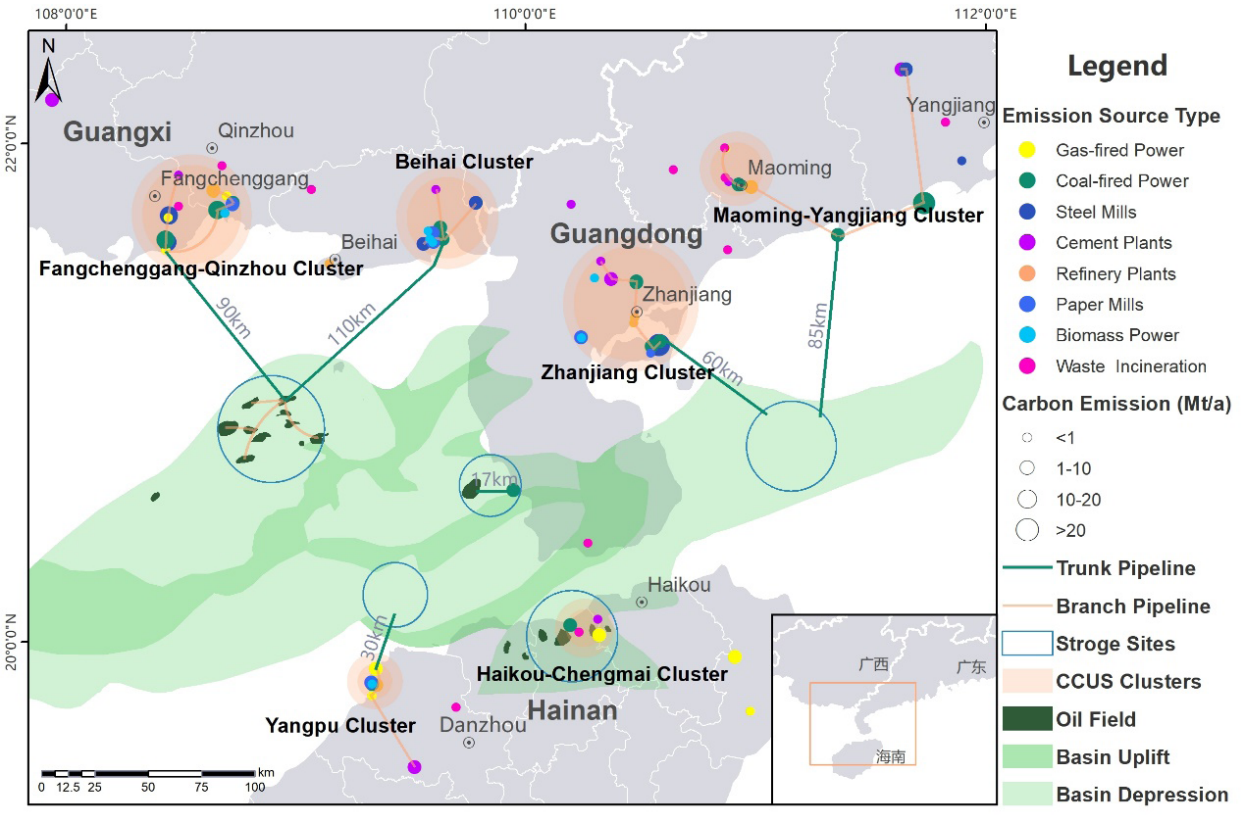


Fig. 5 Proposed CCUS Cluster Planning Around the Beibu Gulf Basin

In Guangxi, Qinzhou and Fangchenggang form an important industrial cluster due to their adjacent locations and highly concentrated emission sources. Emissions from this cluster primarily originate from the energy and steel industries, with an annual total of nearly 60 million tonnes of CO_2. The emission sources in Beihai are also concentrated around the port area, with the cluster's annual total emissions controlled within 20 million tonnes. The potential CO_2 storage areas are located in the Weixinan Graben in the northeast of the Beibu Gulf Basin. CO_2 storage capacity of the oilfield in the Weixinan Graben is only in the million-tonne range, so large-scale CO_2 storage in saline aquifers is necessary. Overall, the highly concentration of CO_2 emission sources in Qinzhou, Fangchenggang, and Beihai presents advantageous circumstances for the establishment of extensive CCUS clusters and the advancement of related industries.

Located in Hainan Province, the Haikou-Chengmai Cluster emits on a relatively smaller scale compared to the CCUS clusters in Guangdong and Guangxi, with annual emissions amounting to just a few million tons. Within a 10-kilometer vicinity of the emission sources near Haikou and Chengmai, lies the Fushan Oilfield of China National Petroleum Corporation. The oilfield aims to achieve a CO_2 injection capacity of 300,000 tons annually by 2025.

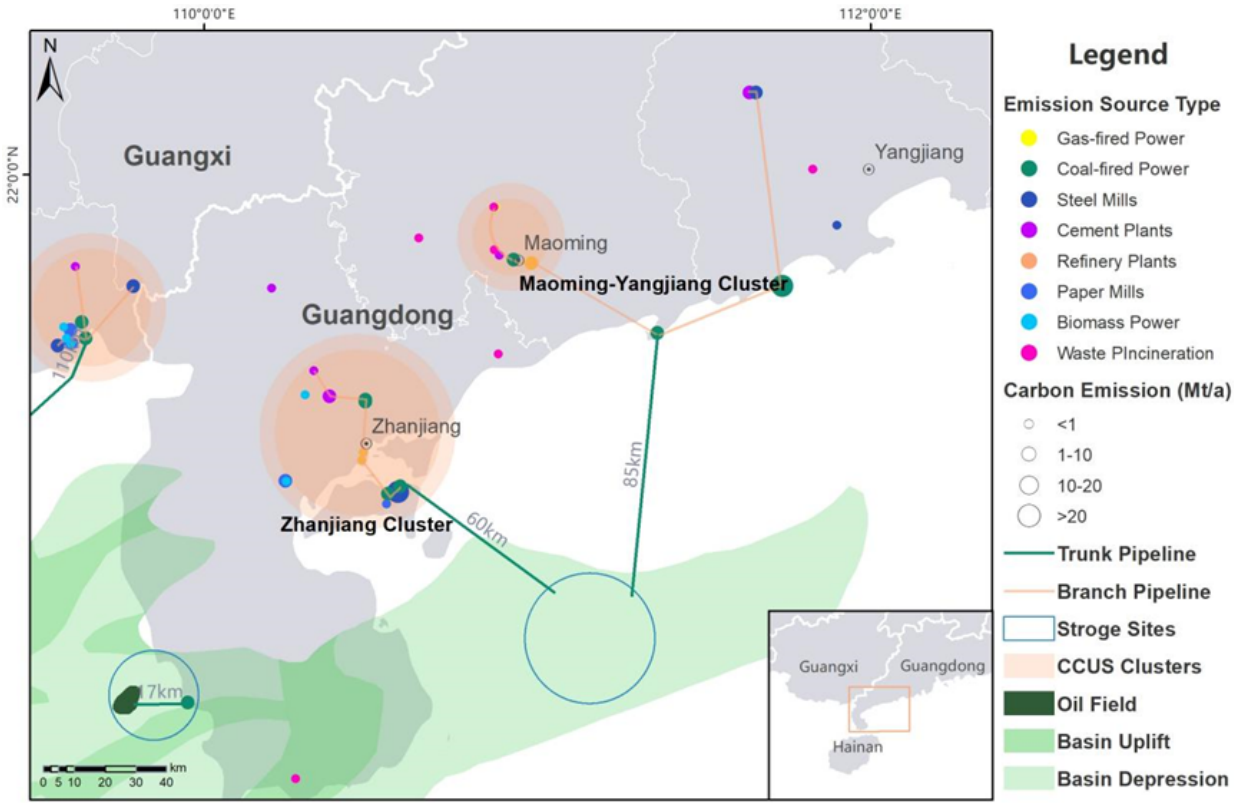


Fig. 6 Proposed CCUS Cluster layout for Zhanjiang, Maoming and Yangjing cities in west Guangdong

The Haikou-Chengmai Cluster is situated in an area with satisfactory onshore storage conditions, where depleted oil and gas fields and saline aquifers provide abundant carbon storage capacity for the cluster's emission sources. Additionally, the region's well-developed volcanic basalt offers additional potential for carbon dioxide sequestration. Given these circumstances, the Haikou-Chengmai Cluster is expected to primarily rely on onshore storage methods in the future, distinguishing it markedly from other clusters in the Beibu Gulf Basin. Onshore storage offers advantages such as short transport distances and low storage costs. However, it is crucial to note that onshore storage requires substantially high safety requirements. Therefore, more stringent safety standards and monitoring measures must be established to ensure the smooth implementation of future carbon dioxide storage efforts in the Haikou-Chengmai Cluster.

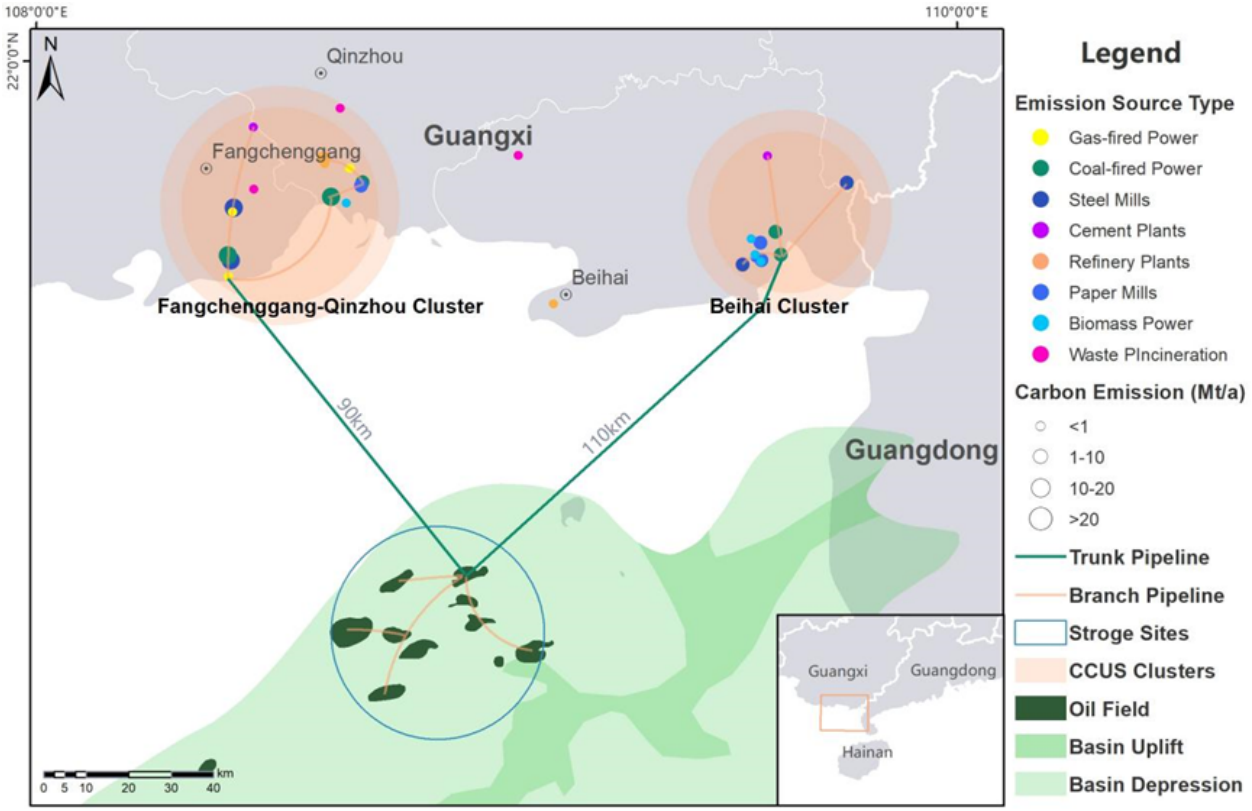


Fig. 7 Proposed CCUS Cluster layout for Beihai, Qinzhou and Fangchenggang cities in south Guangxi

The Yangpu Cluster is located in Danzhou City, Hainan Province, with the main sources of carbon emissions concentrated in the Yangpu Economic Development Zone, primarily originating from the petrochemical and power industries. Its geographical proximity to the Maichen Graben in the Beibu Gulf Basin presents an opportunity to construct a CO_2 transportation pipeline, stretching from the Yangpu Petrochemical Zone to targeted regions, for the purpose of implementing carbon sequestration projects. The pipeline is expected to be approximately 30 to 50 kilometers in length. Given that the Yangpu Economic Development Zone is a rapidly developing emerging industrial area, it is important to start Pre-FEED study on CO_2 capture, transportation, and sequestration projects and to pre-plan the land for CCUS facilities. This strategic approach is vital for minimizing the future emission reduction costs of CCUS technologies.

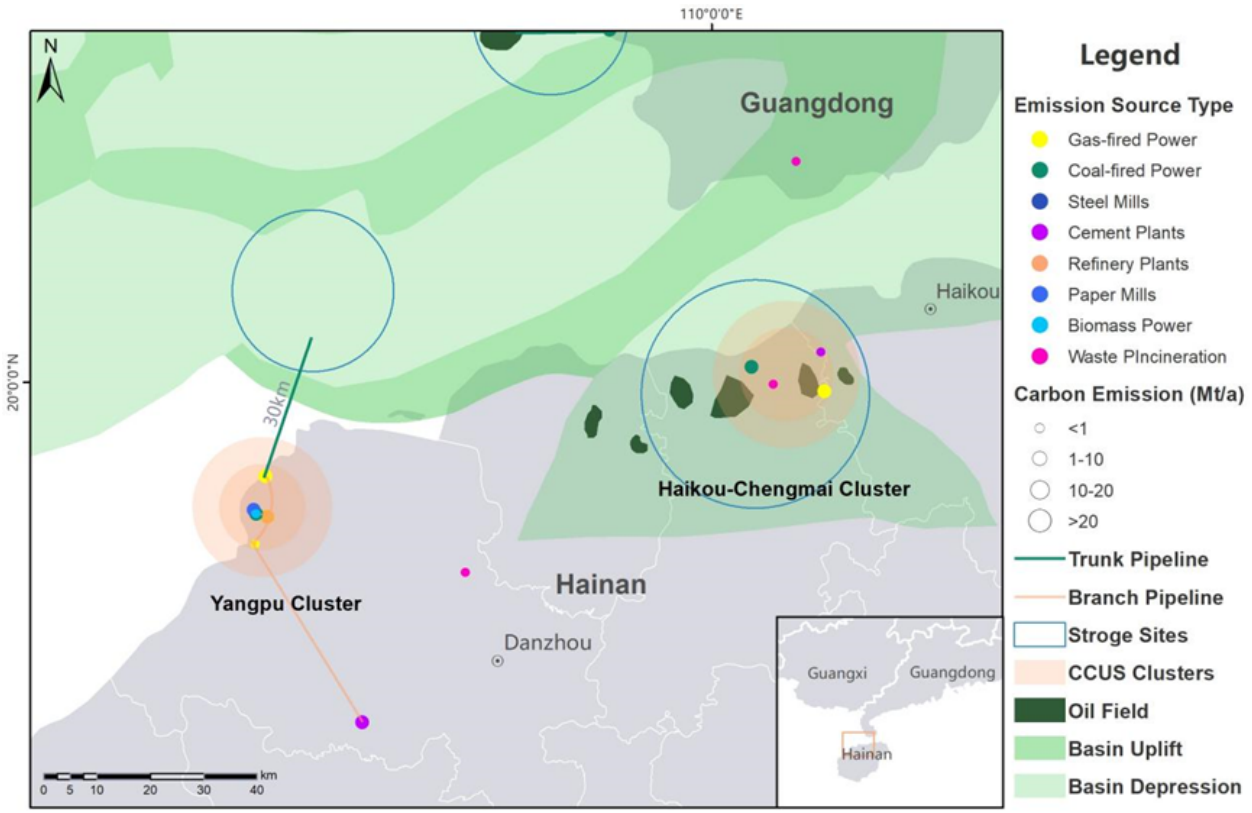


Fig. 8 Proposed CCUS Cluster layout for Haikou, Chengmai and Yangpu in North Hainan



The Huaxia Yangxi Power Plant, with a capacity of 5000 MW, is located on the coastline of Yangjiang city, Guangdong Province. It is the largest power plant situated near the Beibu Gulf.



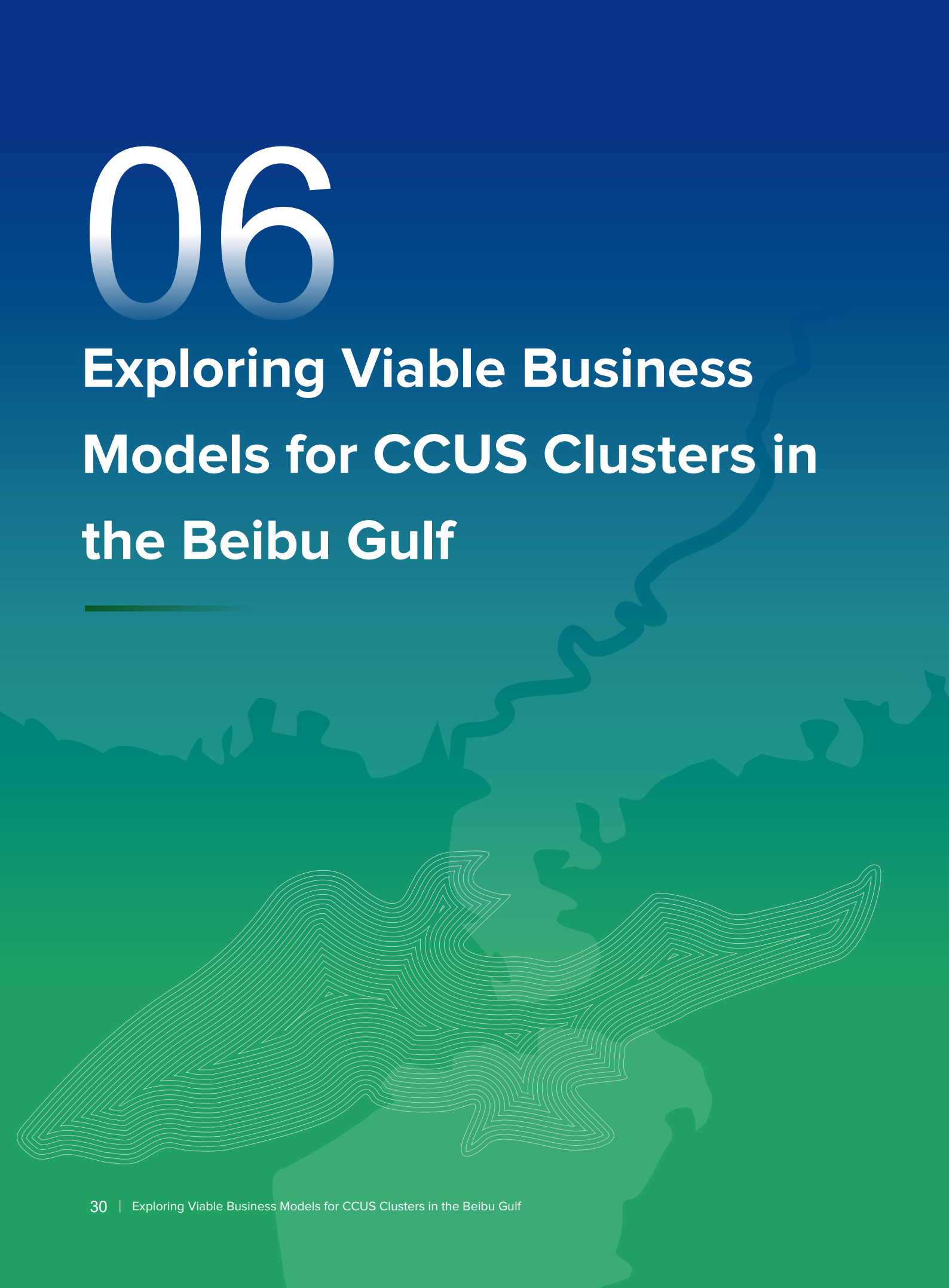
Sinopec Hainan Refining & Chemical Plant within the Yangpu Economic Development Zone. (Photo source: Sinopec)



The petrochemical industry park of Yangpu Economic Development Zone, Hainan.

06

Exploring Viable Business Models for CCUS Clusters in the Beibu Gulf



6.1 Business Model of CCUS Clusters

CCUS cluster projects typically entail significant capital investment and necessitate extensive collaboration across multiple industrial sectors and numerous enterprises. Drawing on global experiences in developing CCUS clusters, particularly in Europe and North America, governments assume a critical leading role during the initial planning and implementation phases of such projects. By formulating comprehensive regional strategic development plans and introducing supportive policy frameworks—including financial subsidies, tax incentives, and risk-sharing mechanisms—governments can substantially reduce the financial burden on private sector participants. This, in turn, enhances the willingness and capacity of various stakeholders to engage in CCUS deployment, while also improving the overall economic viability and long-term sustainability of cluster-based CCUS projects.

Comprehensive analysis of global CCUS cluster case studies reveal three predominant business models evolving across developmental phases[17]:

(1) Transport and Storage (T&S) Operator Model: In this model, specialised operators take full responsibility for CO_2 transport and geological storage within the CCUS value chain. By integrating hub, transport, and storage infrastructure, the T&S Operator Model streamlines coordination among different stakeholders—capture, transport, and storage—reducing complexity and accelerating deployment during the early stages of CCUS cluster development. This enhances overall system efficiency and scalability. This approach has become the preferred structure for several large-scale CCUS projects in Europe. Notable examples include: the UK's East Coast Cluster, where the Northern Endurance Partnership (a consortium of bp, Equinor, and TotalEnergies), serves as the T&S Operator; the UK's HyNet Cluster, with Eni serving in the T&S role; the Netherlands' Porthos Project, operated by a T&S entity formed by EBN, Gasunie, and the Port of Rotterdam Authority; and Norway's Northern Lights Project, managed by Northern Lights JV—a consortium comprising Equinor, Shell, and TotalEnergies.

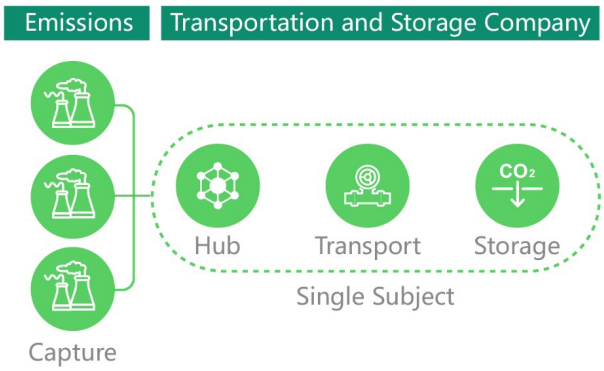


Fig. 9 Schematic of the Transport & Storage Operator Model

17 Fattouh, B., Muslemani, H. and Jewad, R. (2024) Capture Carbon, Capture Value: An Overview of CCS Business Models. OIES Paper: CM08. Oxford: Oxford Institute for Energy Studies.

(2) Segmented Responsibility Sharing Model: This model is characterised by a clear division of roles among various stakeholders across different stages of the CCUS value chain (Fig. 10). At the core of this framework lies an independent hub, which serves as a central node for CO_2 aggregation and redistribution. This hub functions as an intermediary within the system, enabling multiple downstream transport and storage operators to provide competitive and complementary services. To date, no fully operational CCUS cluster has implemented this model in practice. However, it is regarded as a more mature structure that allows emitters greater flexibility in selecting transport and storage providers based on cost efficiency, service quality, and technical compatibility. An illustrative example can be found in the Humber region of the UK's East Coast Cluster, where Immingham serves as a hub along the planned route of two parallel transport and storage systems: one operated by Harbour Energy (the Viking Carbon Transport and Storage system) and another managed by the Northern Endurance Partnership. Furthermore, the second phase of the UK's CCUS development strategy outlines a policy vision for introducing a new process for the allocation of economic licences for CO_2 transport and storage[18]. Such a mechanism aims to expand the pool of available transport and storage operators, thereby strengthening systemic flexibility and operational efficiency.

(3) Free Market Model: In this model, capturers have the flexibility to choose among multiple hub, transportation and storage service providers (Fig. 11). All participants make decisions based on market demand and price signals, achieving optimal resource allocation. This model reflects a high-level development of the CCUS cluster, a competitive market in the carbon transport and storage sector. Capture projects would have the potential to access multiple storage sites through multiple transport modes, enhancing both flexibility and scalability. The entire system operates independently of direct governmental intervention, with market mechanisms serving as the principal coordinating force.

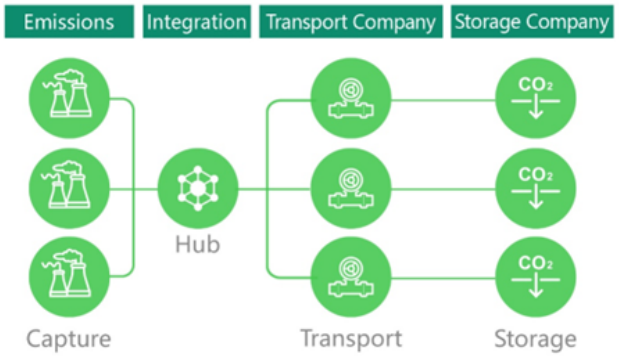


Fig. 10 Schematic of the Segmented Responsibility Sharing Model

18 Department for Energy Security & Net Zero (2023) Carbon Capture, Usage and Storage: A Vision to Establish a Competitive Market. London: Crown Copyright. Available at: https://www.gov.uk/government/publications (Accessed: [10 June 2025]).

Within the framework of the abovementioned business models, governments can employ diversified financial incentive measures to promote the development of CCUS cluster projects. These include funding for preliminary planning and research, one-time subsidies for investment costs, regular subsidies for operating costs, tax incentives, and the establishment of a carbon price guarantee mechanism (where the government provides subsidies to compensate for the difference when the carbon market price falls below a preset benchmark value).

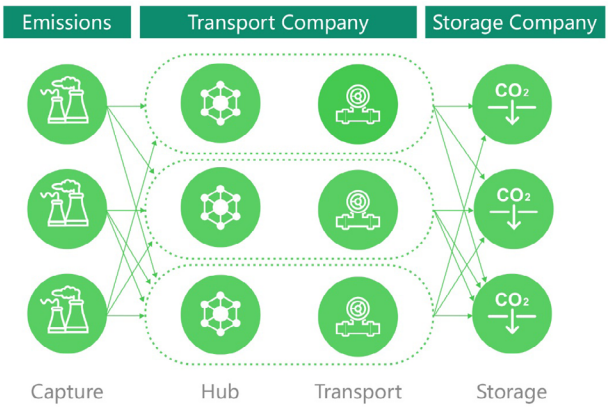


Fig. 11 Schematic of the Free Market Model



6.2 Proposed Business Models for CCUS Clusters in the Beibu Gulf Region

In the absence of robust carbon pricing mechanisms and explicit regulatory frameworks, the formulation of viable business models for both carbon emitters and developers of carbon transport and storage infrastructure becomes a formidable challenge. To address this multifaceted challenge, support must be provided in a multitude of forms, tailored to the specific needs of each stage in the lifecycle of CCUS projects—from its inception and development, through to implementation and sustained operation. Such support could encompass financial incentives, technical assistance, regulatory guidance, and market facilitation measures.

It is essential to recognise that CCUS clusters evolve through distinct developmental stages, each with its own unique set of requirements and challenges. For the purpose of this discussion, we classify these stages into two phases: the cluster incubation stage and the cluster maturity stage. In the subsequent sections, we will focus on the Beibu Gulf Basin region and discuss business models specifically advised for these stages, aiming to foster the sustainable growth and widespread adoption of CCUS in the region.

6.2.1 Cluster Incubation Stage

During this stage, the market mechanism is immature, and the commitment and actions of governments in promoting CCUS clusters are of paramount importance. From a global perspective, government policies supporting the early-stage CCUS industry exhibit considerable diversity, with significant variations in policy mechanisms among countries.

In North America, both the governments of the United States and Canada currently provide tax credit support for CCUS projects, offering universal assistance to the entire CCUS sector. In the United States, the government has established a comprehensive support framework for nationwide CCUS projects through the Inflation Reduction Act (IRA) and the Section 45Q of Internal Revenue Code (Table 6). Specifically, for point-source capture and dedicated geological storage projects, the US government offers a tax credit of US$85 per tonne to incentivize the relevant projects. In Canada, the government introduced a tax credit policy for CCUS projects in 2024. For eligible CCUS project capital expenditures incurred until 2030, 50% of the investment costs for carbon capture and 37.5% of the costs for transportation and storage infrastructure are eligible for tax credits (Table 6). Furthermore, the Government of Alberta

in Canada has also launched the Alberta Carbon Capture Incentive Program (ACCIP). This program stipulates that for new eligible CCUS project capital expenditures, a grant of 12% will be provided, further promoting the commercialisation process and industrial upgrading of CCUS technologies in the province.

In Europe, several countries are increasingly recognising the indispensability of CCUS in achieving net-zero emission targets and are providing increasingly robust policy support to CCUS projects, each with its own unique characteristics, markedly different from those in North America. In the United Kingdom, Norway, the Netherlands, and Denmark, governments have issued clear policies providing financial subsidies for the investment and operational costs of large-scale CCUS projects and CCUS clusters. Germany and France have also released national strategies on CCUS, both mentioning the future adoption of Carbon Contracts for Difference (CCfDs) to subsidise CCUS (detailed policies for each country are available in Table 6).

The subsidy mechanisms in European countries exhibit two distinct characteristics. Firstly, they predominantly adopt a competitive approach, wherein project proposals submitted by enterprises compete for government funding. The funding scheme is designed aiming at maximising competition for funding to achieve the highest possible carbon reductions at the lowest possible cost. Secondly, funding for projects provides a financial safety net for project profitability. Regarding the first point, for instance, the UK government solicits CCUS cluster proposals from various regions and, after comprehensive evaluation, selects four CCUS clusters or carbon dioxide transportation and storage projects for funding. Future government funding will be primarily allocated to projects within the designated CCUS clusters, with the specific level of support and terms determined on a case-by-case basis through negotiations between enterprises and the government. Similarly, in the Netherlands and Denmark, each round of CCUS funding is awarded through open tendering and competitive selection processes. Concerning the second characteristic, countries such as the UK, France, and Germany have introduced Carbon Contracts for Difference (CCfDs). This mechanism is employed to compensate for potential profitability shortfalls in CCUS projects, given that future carbon market prices may be insufficient to cover the full costs of such projects. By procuring CCfDs, governments aim to mitigate the financial risks associated with the projects' profitability.

Table 6 Overview of Current Policies for Nurturing CCUS Clusters in Various Countries

No.	Country	Supporting Policy Content
1	United States	The Inflation Reduction Act (IRA) and the Section 45Q of Internal Revenue Code offers substantial incentives for CCUS projects, including: • Point-source capture & dedicated storage: US$85/tonne • Point-source capture & EOR/utilization: US$60/tonne • DAC & dedicated storage: US$180/tonne
2	Canada	• In June 2024, legislation was enacted as part of Bill C-59 to implement the CCUS Investment Tax Credit (ITC) within the Income Tax Act. The following tax credit rates will apply to eligible CCUS project capital expenditures incurred between 2022 and 2030: 60% for DAC, 50% for capture methods excluding DAC, and 37.5% for carbon transportation, storage, and utilization. From 2031 to 2040, the ITC credit rates for all projects will be halved[19]. • Alberta Carbon Capture Incentive Program （ACCIP）will provide a grant of 12% for new eligible CCUS capital costs.[20]
3	United Kingdom	• The UK's Spring Budget 2023 confirmed up to £20 billion funding for CCUS over the next 20 years. • The UK government, after evaluating various proposals, has chosen to fund two CCUS clusters （East Coat & HyNet） and two CO_2 transport & storage projects (Acorn&Viking). • Industrial Carbon Capture (ICC) Contract: For carbon capture projects, the government will offer incentives via the Industrial ICC Contract, which provides revenue support based on the amount of CO_2 captured. This revenue support will help cover capital expenditures, operating costs, as well as CO_2 transport and storage expenses, depending on payment terms agreed upon in the contract[21]. • Revenue Support for Transport and Storage Company (RSA): The government supports CO_2 Transport and Storage Company (T&SCo) through the Revenue Support Agreement (RSA) in two ways: it compensates for revenue shortfalls if actual revenue doesn't meet the allowed standard, and covers operating expenses and asset depreciation due to delays in user connections[22].

19 Canada Revenue Agency. (n.d.). Carbon Capture Investment Tax Credit. Retrieved from https://www.canada.ca/en/revenue-agency/services/tax/businesses/topics/corporations/business-tax-credits/clean-economy-itc/carbon-capture-itc.html on [Accessed on 19/12/20242023-10-05].

20 Alberta Government. (n.d.). Alberta Carbon Capture Incentive Program. Retrieved from https://www.alberta.ca/alberta-carbon-capture-incentive-program

21 Department for Energy Security and Net Zero. Carbon Capture, Usage and Storage. Industrial Carbon Capture business models Update for Track-1 Expansion and Track-2[EB/OL]. (2024-04). https://www.gov.uk/government/publications/carbon-capture-usage-and-storage-ccus-business-models.

22 Department for Energy Security and Net Zero. Carbon Capture, Usage and Storage: An update on the business model for Transport and Storage - explanatory note and indicative heads of terms [R]. 2023.

4	Norway	The Norwegian government has signed **State Support Agreements** with companies participating in the Longship Project. Under these agreements, the Project will receive direct grants including: (i) investment aid, which covers a portion of the projects' CAPEX, and (ii) operating aid, covering a portion of the projects' OPEX[23]. In addition, the aid also includes compensation for CO_2 leakages and CCS full-chain related risks. Investment aid will be provided from the Project's initiation until the completion of the facilities, while operating aid will be granted for a 10-year period following the facilities' completion[5]. The funding will be allocated annually through the Norwegian State Budget. The total estimated cost of the Longship Project is approximately NOK 30 billion (~USD 2.62 billion), with the government's share of the costs estimated at NOK 20 billion (~USD 1.75 billion)[24].
5	Netherlands	The Sustainable Energy Transition Subsidy Scheme (SDE++) bridges the gap between the European Union's Emissions Trading System (ETS) and the costs of CCUS by compensating for the difference between the cost and market value of CCUS technology. A CCUS project is more likely to receive subsidies if it can achieve CO_2 capture and storage at a lower cost. The application process for SDE++ subsidies in 2024 is divided into five tiers, with subsidy levels of 75, 150, 225, 300, and 400 €/tonne CO_2, respectively[25].
6	Denmark	The Danish Government provides funding for CCUS projects: • In May 2023, the first fund, amounting to DKK 8 billion (approximately USD 1.1 billion), was awarded to Ørsted. This allocation will enable Ørsted to capture and store 430,000 tonnes of CO_2 annually from 2026 onwards for a duration of 20 years, sourced from wood chip- and straw-fired power stations[26]. • In May 2024, the fund for negative CO_2 emissions (NECCS fund), totalling DKK 2.5 billion (approximately USD 0.35 billion), contracted three companies to capture and store 160,350 tonnes of biogenic CO_2 annually from 2026 to 2032[27]. • In October 2025, the Danish Energy Agency announced a new tendering procedure to allocate DKK 28.7 billion (approx. USD 4.0 billion) to CCS projects. This is the third fund for promoting CCS deployment in Denmark, disbursed over 15 years, expected to reduce CO_2 emissions by 2.3 Mtpa from 2030[28].

23 EFTA Surveillance Authority, The Full-Scale CCS Project [R]. 2020.

24 State Support Agreements in Longship[EB/OL]. https://ccsnorway.com/state-support-agreements-in-longship/. (Accessed: [20 Dec 2024])

25 RVO. Apply for SDE - Subsidies & Financing. Available at: https://english.rvo.nl/subsidies-financing/sde/apply (Accessed: [14 Dec 2024])

26 Energistyrelsen. First tender for CCUS subsidy scheme has been finalized: Danish Energy Agency awards contract. [online] Available at: https://ens.dk/en/press/first-tender-ccus-subsidy-scheme-has-been-finalized-danish-energy-agency-awards-contract (Accessed: [9 Jan 2025])

27 Energistyrelsen. Three new CCS projects have been pledged support to capture and store biogenic CO_2. Ens.dk. Retrieved, Available at: https://ens.dk/en/press/three-new-ccs-projects-have-been-pledged-support-capture-and-store-biogenic-CO_2 (Accessed: [9 Jan 2025])

28 Energistyrelsen. Danish Energy Agency presses start button on billion-dollar tendering procedure for carbon capture. [online] Available at: https://ens.dk/en/press/danish-energy-agency-presses-start-button-billion-dollar-tendering-procedure-carbon-capture (Accessed: [9 Jan 2025])

7	Sweden	Sweden offers state aid for biomass-based CCS via auctions. The first auction ran from August to November 2024[29,30]. The total budget of the state aid scheme is €3bn ($3.2bn) for distribution in 2026-46, to be awarded through bidding by 31 December 2028[22]. Aid, covering both capital and operating costs, will be given for 15 years, starting when the first tonne of captured biogenic CO_2 is permanently stored[22]. Projects must store biogenic CO_2 within three years, with a possible two-year extension. Potential beneficiaries must be Swedish enterprises emitting biogenic CO_2 and implementing CCS projects with a capture capacity of over 50,000 t/yr. Beneficiaries can sell CCS credits, but these will be deducted from the aid to prevent overcompensation.
8	France	The French Government has outlined its national CCUS strategy, aiming to capture 4 to 8 million tonnes of CO_2 annually by 2030 and establish CCUS hubs within major industrial clusters by that same year[31]. To facilitate this, the government plans to offer financial support to industrial CCUS projects through 15-year Carbon Contracts for Difference (CCfDs). This support will be based on the difference between the carbon price and the costs associated with capture, transportation, and storage[32].
9	Germany	The German Government has released the key principles for a Federal Carbon Management Strategy, acknowledging that CCUS must play a role in achieving climate neutrality[33]. The draft of the Funding Guideline for Federal Support in Industry and Climate Action (FRL BIK) introduces a funding module for CCUS. Public funding for CCUS, where deemed necessary, will prioritize addressing hard-to-abate or impossible-to-abate emissions in industries such as the cement sector, as well as in the waste management industry. CCUS projects that significantly reduce unavoidable process emissions may be eligible for Carbon Contracts for Difference.

29 European Commission. Commission approves €3 billion Swedish State aid scheme to support the roll-out of biogenic carbon dioxide capture and storage. [online] Available at: https://ec.europa.eu/commission/presscorner/detail/en/ip_24_3583 (Accessed: [6 Feb 2025])

30 Argus, Swedish Energy Agency opens BECCS reverse auction. [online] Available at: https://www.argusmedia.com/zh/news-and-insights/latest-market-news/2602382-swedish-energy-agency-opens-beccs-reverse-auction. 2024. (Accessed: [6 Feb 2025])

31 The Directorate General of Enterprises. Deployment of Carbon Capture, Utilization, and Storage (CCUS) in France. [online] Available at: https://www.entreprises.gouv.fr/la-dge/actualites/deploiement-de-la-capture-du-stockage-et-de-la-valorisation-du-carbone-ccus-en (Accessed: [6 Feb 2025])

32 French Government. State of the art and perspectives of CCUS deployment in France[R] https://www.entreprises.gouv.fr/files/files/Actualites/2024/etat-des-lieux-et-perspectives-de-deploiement-du-ccus-en-france.pdf, 2024-07-01[2024-10-24].

33 Federal Ministry for Economic Affairs and Climate Action (BMWK). (2024). Key Principles of the Federal Government for a Carbon Management Strategy. Retrieved from https://www.bmwk.de/Redaktion/EN/Downloads/E/240226-eckpunkte-cms-en.pdf?__blob=publicationFile&v=2 (Accessed 7 January 2025).

6.2.2 Cluster Maturity Stage

The Cluster Maturity Stage is characterised by years of stable and safe operation of CCUS clusters. During this stage, the cost of CCUS is likely to decrease due to the learning-by-doing effect and the realization of economies of scale. The risks associated with CCUS projects will also undergo a significant reduction, attributed to the widespread validation and proven efficacy of the technology. On the other hand, the carbon market is forecasted to be more mature compared to the incubation stage of the cluster, potentially offering higher carbon prices that may enable CCUS projects to attain self-sustainability. However, market competition is likely to intensify as capture projects gain access to a variety of storage sites to choose from, and CCUS clusters compete to offer CO_2 transport and storage services.

The carbon market plays a crucial role in the self-sustainability of CCUS projects. At the moment, all carbon markets around the world do not have market mechanism to include the carbon emission reduction credits from CCUS projects. While there exist certain experiences worth emulating from the carbon markets of California, USA, and the carbon credit system of Alberta, Canada (Table 7), the operational experience in this area is still relatively constrained. This sector is poised for significant evolution in the coming years.

Table 7 Current Policies for Incorporating Carbon Credits of CCUS Projects in Global Emission Trading Systems

No.	Region/Country	Relevant Policy
1	California, United States	In the Low Carbon Fuel Standard (LCFS) of California: CCUS project operators eligible for carbon trading are divided into two categories: one is enterprises with mandatory compliance obligations, including refineries and oil/gas facilities, whose CCS projects must apply for emission reduction credits under specific plans. CCS rules set limits on project size, location, and timing. The other category is operators who join the LCFS carbon market by investing in CCS projects, without mandatory obligations, and sell emission reductions for economic benefits.
2	Alberta, Canada	In January 2023, Alberta's TIER system introduced two key components for carbon capture and storage (CCS) projects: Capture Recognition Tonnes and Sequestration Credits. Sequestration Credits represent emission offsets obtained through the geological sequestration of carbon dioxide. Capture Recognition Tonnes enable large emitters or opted-in facilities to convert their Sequestration Credits into tonnes, which can then be deducted from their net emissions, thereby reducing their reduction obligations under the TIER system.

Transitioning from this stage will necessitate new policies that reflect the evolving roles of the government and the private sector. CCUS clusters will transition from public funding support to a market-led economy. The government's role during this stage is to enhance regulations by:

- Introducing regulations that attract private investment into the market.
- Developing a plan for the smooth withdrawal of government funds and enabling the carbon market to support ongoing operations. It is essential to mitigate the impact of carbon market price fluctuations on the operation of CCUS clusters.
- Focusing on improving regulations to enhance the efficiency of CCUS cluster operations, such as adjusting access to CO_2 transport and storage infrastructure and introducing more competition into the market.
- Developing strategies for negative emission CCUS technologies, including biomass energy carbon capture and storage, and direct air capture.

A successful CCUS cluster at this stage would offer services at competitive prices within the region and sell low-carbon credits in national and international markets. From the authors' perspective, the Beibu Gulf region possesses prime conditions for CO_2 transport and storage in each cluster. Industries in other regions of South China may, to some extent, relocate to this region due to the lower cost of carbon emission reduction via CCUS. With CCUS, the entire region is poised to become an increasingly important industrial hub in South China under the carbon neutrality scenario.

07

Policy Suggestions



To facilitate the development of CCUS industry and clusters, the government is responsible for fulfilling three essential roles: 1) formulating an enabling regulatory and legal framework for CCUS, 2) bringing together entities involved in CCUS clusters, and, 3) most importantly, developing incentive mechanisms to kick-start early-stage projects. Among these, the third role presents the greatest challenge. On the other hand, firms are tasked with investigating cost-effective project plans that significantly reduce CO_2 emissions with minimal financial resources and maintaining communication with the government.

Given the pivotal role that governments play in promoting the development of CCUS industries, the following key policies are recommended for government consideration:

(1) Conduct research on medium- and long-term CCUS development planning

- Initiate studies on CCUS industry and cluster planning, addressing the selection of storage locations for CCUS clusters, the routing of pipelines, and the costs of CCUS. Outline the implementation timeline for CCUS projects and clusters up until the carbon neutrality target is achieved by 2060. Detailed planning will help reduce the emission reduction costs associated with CCUS.
- Based on CCUS planning study, setting regional CCUS targets to signal the governments' commitment for CCS as a mitigation technology.

(2) Explore CCUS business models tailored to local conditions

- Designate a department or establish an entity to coordinate activities across the CCUS value chain. For example, in Norway, the government established Gassnova, a state-owned company, to serve as the project integrator for the CCS Longship project.
- Consider and determine the coordination model among entities within the CCUS value chain. For instance, drawing from the experience of CCUS clusters in Europe, it may be advisable to classify participants into carbon emitters and transport & storage operators. Cost-effective mechanisms, such as companies developing low-cost CCUS project proposals and bidding for government funds, as well as Carbon Contracts for Difference (CCfDs), may be considered.
- Consider implementing a risk-sharing mechanism for long-term CO_2 liability. This could involve establishing an industry-wide insurance scheme or a regional fund to ensure the financial security related to long-term CO_2 liability.

(3) Establish a regulatory framework supporting the development of CCUS projects and clusters

- Develop a streamlined permitting process for carbon capture and storage projects.
- Facilitate coordination of financial support across various funding channels. Identifying synergies between national subsidies and

private investments for CCUS projects can help accelerate their implementation.

- Explore the establishment of coordinated management mechanisms between CO_2 storage spaces and oil/gas/mineral resources to prevent conflicts in subsurface resource utilization.
- Investigate institutional arrangements to gradually transfer the responsibility for long-term monitoring and regulation from project operators to government authorities after the completion of CO_2 injection and entry into the site closure phase.
- Establish a dedicated government fund or introduce insurance mechanisms to provide a risk backstop for major potential risks across the CCUS value chain, such as CO_2 leakage.
- Allocate research and development (R&D) funding to address the specific technical needs of local CCUS projects.
- Foster regional and international cooperation, for example, by collaborating with ongoing CCUS cluster projects in the UK, Norway, the Netherlands, and Denmark.
- Engage with provincial and national governments to propose the establishment of a CCUS cluster demonstration zone in the Beibu Gulf Basin.

08

Future CCUS Commercial Prospects in the Beibu Gulf Basin Region



The CCUS industry and clusters in the Beibu Gulf Basin are still in their early stages, with limited understanding of CCUS and a lack of detailed preliminary planning studies. Given China's commitment to achieving carbon neutrality by 2060, there is considerable work to be done and substantial commercial opportunities to be explored. These opportunities include the following aspects:

(1) Conducting planning and development studies for regional CCUS clusters and industries; undertaking Pre-FEED (Pre-Front End Engineering Design) and FEED (Front End Engineering Design) studies for large-scale CCUS projects.

(2) Implementing EPC (Engineering, Procurement, and Construction) projects for large-scale carbon capture facilities, constructing CO_2 transportation infrastructure, and procuring a significant amount of equipment.

(3) Procuring equipment for large-scale carbon capture projects, including CO_2 transport pipelines, ships, and offshore CO_2 injection facilities.

(4) Providing MRV (Measurement, Reporting, and Verification) services for emissions reductions achieved through CCUS projects.

Appendix

Acronyms

ACCIP	Alberta Carbon Capture Incentive Program
BECCS	Bioenergy with Carbon Capture and Storage
CAPEX	Capital Expenditure
CCfDs	Carbon Contracts for Difference
CCUS	Carbon Capture, Usage, and Storage
DAC	Direct Air Capture
EPC	Engineering, Procurement, and Construction
FEED	Front End Engineering Design
GPF	Global Partnership Fund
HEGSC	Hydrogeology and Environmental Geology Survey Center
IRA	Inflation Reduction Act
ITC	Investment Tax Credit
LCFS	Low Carbon Fuel Standard
MRV	Measurement, Reporting, and Verification
Mt	Million Tonnes
NECCS	Negative Emissions Carbon Capture and Storage
OPEX	Operating Expenditure
Pre-FEED	Pre-Front End Engineering Design
SCCS	Scottish Carbon Capture & Storage
SCSIO	South China Sea Institute of Oceanology
SDE++	Stimulering Duurzame Energieproductie en Klimaattransitie
T&S	Transport and Storage
TIER	Technology Innovation and Emissions Reduction
UKCCSRC	UK Carbon Capture and Storage Research Centre

About the UK-China (Guangdong) CCUS Centre

The UK-China (Guangdong) CCUS Centre is a non-profit organization established in 2013 under the guidance of the Guangdong Provincial Development and Reform Commission. It was jointly initiated by China Energy Engineering Group Guangdong Electric Power Design Institute, the UK Carbon Capture and Storage Research Centre (UKCCSRC), and the Scottish Carbon Capture & Storage (SCCS). The Centre is dedicated to advancing carbon capture, usage, and storage (CCUS) and other near-zero emissions technologies in China, supporting national efforts to reduce greenhouse gas emissions and address climate change.

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