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CO_2 Offshore Storage in China: Research Review and Plan for Demonstration Project

在中国进行离岸封存：
研究回顾和示范项目计划

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Introduction

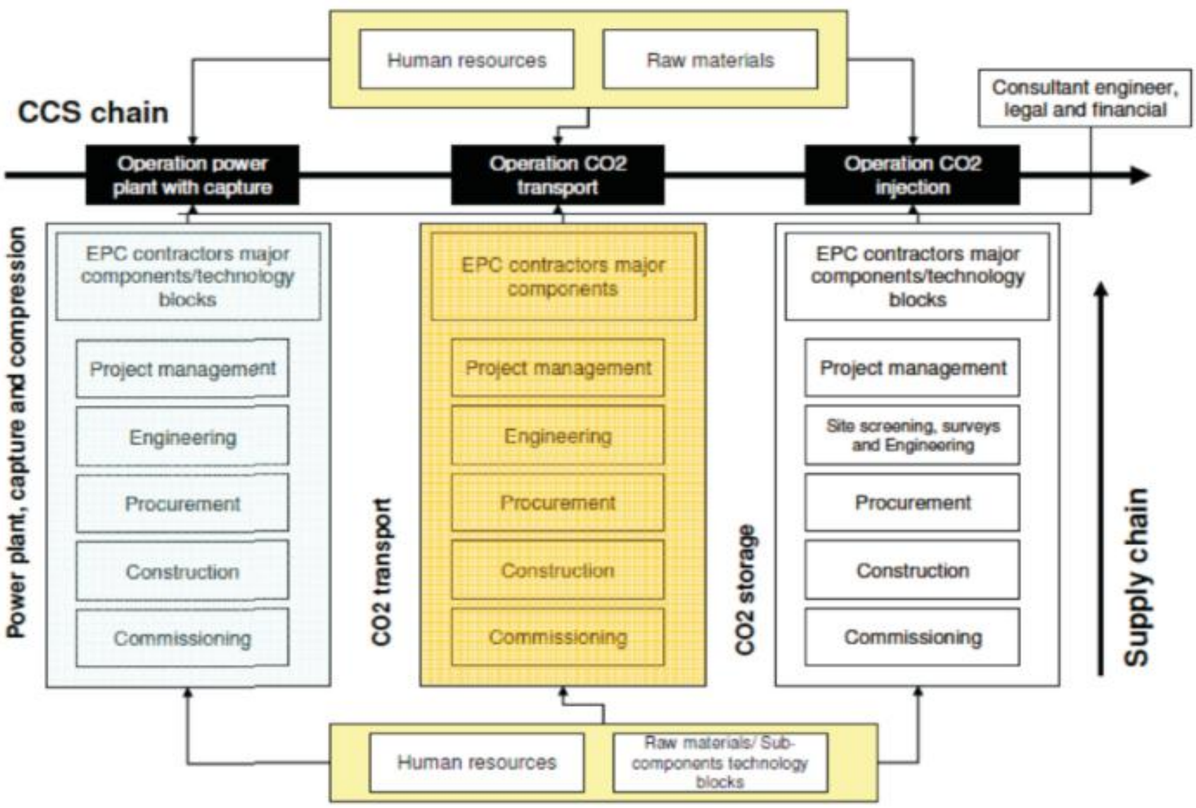
Background Information

Guangdong, as a province in southern China with a population of 106 million, is one of the first five low-carbon provinces in China and is hosting two pilot carbon markets (Guangdong and Shenzhen). The Guangdong provincial government recognizes the important role of Carbon Capture, Utilisation and Storage (CCUS) technologies in controlling greenhouse gas emissions. CCUS was highlighted as an important collaboration area in a joint-statement signed between the Guangdong Development and Reform Commission (GDDRC), and the UK Department of Energy and Climate Change (DECC).

Following the signing of the joint statement, the Guangdong CCUS Centre (hereinafter referred to as the Centre) was established in Dec 2013. The core goal of the Centre is to develop political, technical, industrial, financial and regulatory capacity to enable large-scale integrated CCUS demonstration projects in Guangdong.

The Centre, through GDDRC, invited China National Offshore Oil Corporation Group (CNOOC) to join the Centre, which it did in February 2014. The Centre and CNOOC Shenzhen jointly hosted the first offshore CO_2 storage workshop on 9-10 Dec 2014. Following the workshop, the Centre, with support from colleagues in CNOOC Shenzhen, drafted a 15-year work plan to support the development of a pilot capture, transport

Figure 1-1 Supply Chain of Carbon Capture and Storage Technology (IEAGHG, 2012:4)



and storage full chain project and to pave the way for a large-scale million tonne CCUS project in the province. The Guangdong project is critical to China's efforts to reduce GHGs from fossil power given the lack of onshore carbon storage potential in Southeast China. The Centre envisions that, if successful, Guangdong and the PRMB could serve as a hub for CO_2 in southeast China providing commercial scale offshore CO_2 storage opportunities for the region.

Supply Chain Related to Offshore CO_2 Storage

According to the current supply chain model **(Figure 1-1)**, CO_2 offshore geological storage would provide commercial opportunities for project development companies (e.g. oil and gas companies, professional CO_2 storage operators, utilities and transportation companies), EPC institutes, consulting companies, and relevant product and technology service companies. Apart from direct participation, the second tier of the supply chain would include major EPC and consulting companies providing reservoir and oil fields services, and relevant equipment and subsea and offshore engineering. The third tier suppliers would provide wider product and technology services. In addition, offshore CO_2 geological storage would provide new opportunities for the current engineering and financial service industries, such as qualification services (e.g. DNV GL has developed a recommended practice for CO_2 storage), insurance services (e.g. Zurich Insurance has developed a CO_2 geological storage insurance product).

The Value of Demonstrating Offshore CO_2 Storage in China

From the Chinese perspective, China's oil and gas, services and equipment manufacturing firms should widen their focus, and consider CO_2 storage as a service business and a future opportunity - instead of a pure environmental investment.

Developing and demonstrating CO_2 offshore storage has the following six strategic implications:

(a) Achieving a deep cut in greenhouse gas emissions;

(b) Contributing to marine economic development in China, and towards achieving the marine Silk Road agenda;

(c) Contributing to offshore engineering-related equipment manufacturing, services and advanced technology R&D, and reducing the cost of applying offshore technologies;

(d) Consolidating a potential offshore engineering and services industry hub, and increasing the export capacity and competitiveness of offshore engineering products;

(e) Offshore CO_2 storage helps large-scale infrastructure development and implementation;

(f) Chinese oil and gas companies will benefit from developing offshore oil fields.

The Aim of the Report

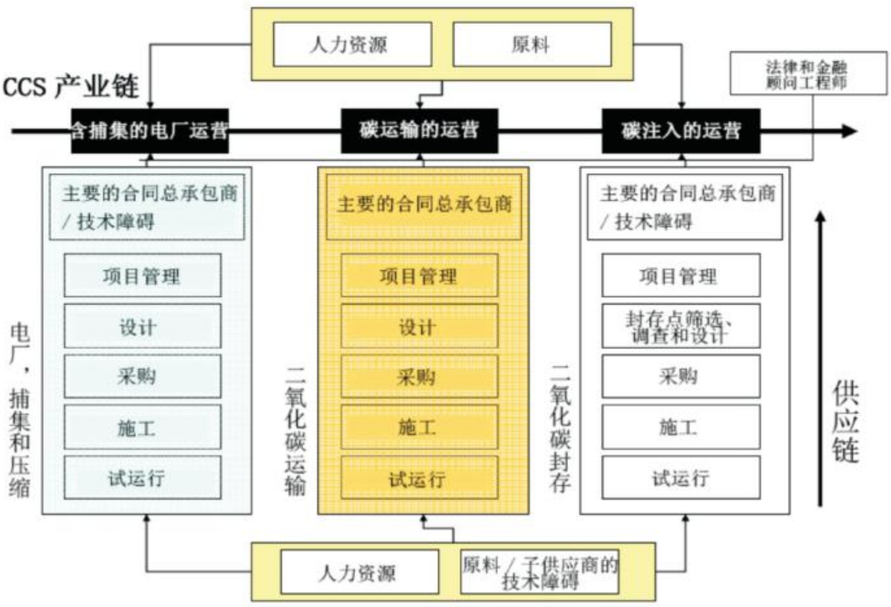
This report is a review of existing research, which reveals the selection of offshore storage demonstration site, identifies the potential to reuse injection infrastructures, and offers suggestions on offshore CO_2 storage research and demonstration in northern South China Sea. In addition, this summary will also help to select technically and economically suitable sites for storing 1 million tonne of CO_2 per year. The final aim of the report is to lay foundation for the pilot injection as well as Front End Engineering Design of Guangdong Offshore CCUS project (GOCCUS), to promote the construction and operation of GOCCUS project, and to kick-off an industry CO_2 offshore storage programme in northern South China Sea.

报告介绍

背景信息

拥有 1.06 亿人口的广东省是南中国首批（5 个省）列入低碳省份的地区之一，同时省内有两个（广东和深圳）试点碳市场。广东省政府重视碳捕集、利用与封存（CCUS）技术在遏制温室气体排放上的作用。广东省发改委（GDDRC）在与英国能源与气候变化部（DECC）签署联合声明时将 CCUS 划为重点合作领域。随后，中英（广东）CCUS 中心（于 2015 年 1 月正式注册为广东南方碳捕集与封存产业中心,以下简称为中心）在 2013 年 12 月成立。中心的核心目标是协调和推动省内 CCUS 相关的政治、技术、工业、金融和法规力量，以促进大型、完整的（捕集、利用和封存）CCUS 示范项目建立与发展。

图 1-1　CCS 技术的供应链（国际能源总署温室气体中心，2012：4）



2014 年 2 月，借助广东省发改委的正式沟通，中国海洋石油（CNOOC）接受中心邀请并成功成为中心成员单位。2014 年 12 月 9-10 日，中心与中国海洋石油深圳分公司共同举办了第一届二氧化碳封存研讨会。中心随后又在中国海洋石油深圳分公司同事的协助下起草了一份未来 15 年工作计划建议，来支持试点碳捕集、运输和封存全链条项目的开发，为省内大型百万吨级 CCUS 项目的发展奠定基础。由于中国南部地区陆上封存二氧化碳潜力匮乏，该项目对中国火电产生的温室气体减排有重要意义。中心预期，如果项目可以成功开展，广东及珠江口盆地将成为中国南部地区二氧化碳商业规模离岸封存的中心。

示范离岸二氧化碳封存涉及的产业链

根据目前二氧化碳运输与封存的供应链模式（**图 1-1**），二氧化碳离岸地质封存会为项目开发企业（包括石油与天然气公司、专门的封存公司、电力公司、运输公司）、承包机构和顾问公司，以及相关产品及技术服务公司带来新的商业机会。除了直接参与的企业，供应链的第二级包括主要承包商和顾问公司，涵盖盆地服务、油井服务、相关设备以及海底和海洋工程。第三级供应商包括更广泛的产品和技术服务。此外，二氧化碳离岸封存还会为许多现有的服务行业带来新的机会，包括认证服务（如挪威船级社积极投入 CCS 标准制定）、保险服务等。如苏黎士保险、瑞士再保险等保险公司与英国 CCS 协会合作，在 2012 年为二氧化碳封存所带来的产业机会进行过深入的评估。

在中国示范二氧化碳离岸封存的价值

对于中国而言，中国的海洋石油和天然气生产、服务和装备制造公司需要拓宽观念，把二氧化碳封存作为一项新兴的基础设施服务的产业，看作一个机会，而不是仅仅考虑为一项单纯的环保投资。

在中国开发和示范离岸封存技术有六点战略意义：

一是有利于大幅度降低温室气体排放；
二是有利于中国海洋经济的发展；
三是有利于海洋工程相关装备制造，服务和先进技术的研发，降低应用相关技术的成本；
四是有利于发展和巩固海洋工程和服务产业枢纽基地，增加海工产品出口能力和竞争力；
五是有利于大型基建项目的实施和开发；
六是有利于中国企业在海外开发油田。

本报告的目的和意义

该项目将会启动南海工业级碳封存项目的第一部分，其目的在于总结回顾已有研究，形成一份评估盖层质量的正式报告，确定注入平台再利用潜力，以及制定未来离岸碳封存工作的协调方案。在广东省进行离岸封存研究和示范活动的目的是为 25 万吨级碳试注做准备，并挑选出在技术和经济上都比较适合进行年均百万吨碳封存的场地，同时确定在南中国进行长期大规模碳封存的理想地点。

Selection of Offshore Storage Demonstration Site

CO_2 storage is an essential part of CCUS. Assessment has shown that the potential of CO_2 storage onshore Guangdong is limited, while large potential exists in offshore sedimentary basins in northern South China Sea *(GDCCSR-SCSIO, 2013)*[1]. Especially, the nearby Pearl River Mouth Basin has the effective storage capacity1 of ~300 $GtCO_2$ (Zhou et al., 2011). If 10% of this capacity may be used, the PRMB could store more than 300 years of Guangdong's current large point source emissions (Zhou et al., 2013). Offshore geological storage is the only viable option of CO_2 storage for Guangdong. It might be also the only viable option of CO_2 storage for southeastern China, where the onshore geological condition is similar to that of onshore Guangdong.

Offshore geological storage of CO_2 has numerous social, political, economic, and technical advantages with respect to onshore geological storage, especially for heavily populated areas *(Schrag, 2009)*. It has, however, an obvious disadvantage that the cost of offshore engineering and operation is usually much higher than the cost onshore. One possible way to reduce the cost is to reuse existing infrastructure and data of hydrocarbon production for CO_2 storage. If the existing installations, such as platform, well, pipeline, and other equipment may be retrofitted into CO_2 service, and existing may be used in site characterization and injection planning, then the capital cost of CO_2 storage may be reduced, and the construction time may be also shortened.

[1] Following the definition of CSLF (2007), the effective storage capacity is a portion of the theoretical storage capacity constrained by the storage efficiency factor, which represents a suit of geological and engineering limitations.

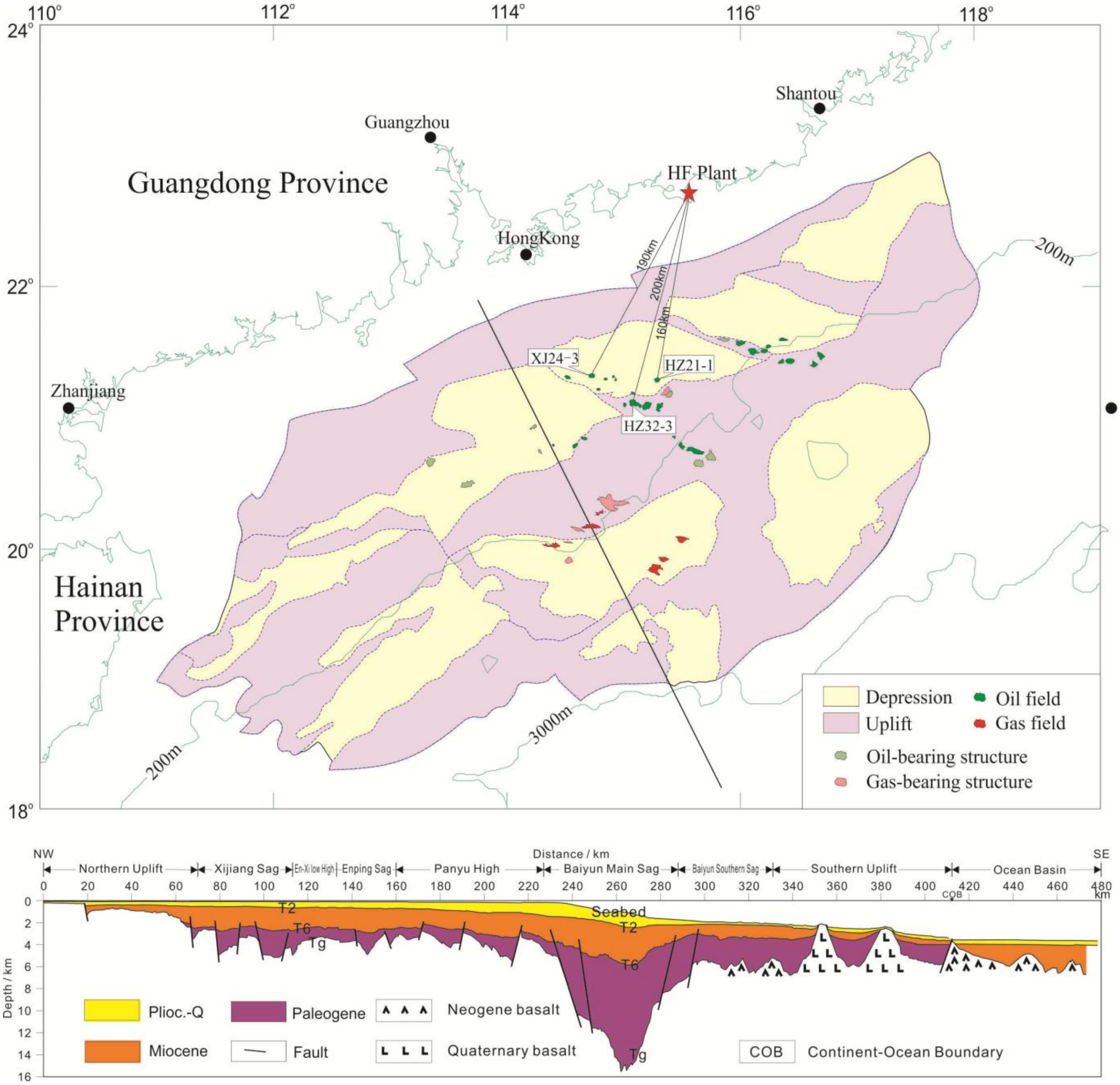
In order to find CO_2 storage site for the first full-chain offshore CCUS project in Guangdong Province, we examined 16 producing oil fields in the Pearl River Mouth Basin offshore Guangdong. At first, we eliminated from consideration the fields having good hydrocarbon potential that will not be depleted in the next 10 years. Then the CO_2-EOR potential was analyzed based on simple comparison with West Texas and UK continental shelf. Finally the remaining fields were screened and ranked with a scoring table based on published data on production status, trap, reservoir and caprock geology, and potential for infrastructure reuse. On this basis three fields, the HZ21-1, HZ32-3, and XJ24-3 were selected as candidate sites. Their advantages and disadvantages or knowledge gaps for CO_2 storage were discussed. Suggestions for further work to fulfil the knowledge gaps in order to make final selection were proposed.

Data and procedures

The Pearl River Mouth Basin (PRMB), with total area of ~200 000 km^2, is the largest sedimentary basin in the northern South China Sea **(Figure 2-1)**. The PRMB has experienced extensive geological survey and hydrocarbon exploration since the 1970's. Source rocks are mainly Eocene lacustrine mudstones and Oligocene coal-bearing rocks, and reservoirs are found mainly in Neogene marine clastic and carbonate rocks, and in Upper Oligocene alternative continental-marine beds. So far 30 oil fields have been found, most of them are small with proved reserve <60 million tonnes (<438 million barrels), only the LH11-1 field has proved reserve of 155 Mt (1.13

billion barrels) (Zhu et al., 2008; Zhu and Mi, 2010). Some small gas fields are also found in the Wenchang Sag of the Zhu-3 depression. According to 2008 assessment (MLRC et al., 2008), the PRMB has OOIP ("geological reserve" is Chinese nomenclature) 2.2 billion tonnes (16 billion barrels) and OGIP is 743 billion m^3. The proved oil reserve is 0.58 billion tonnes (4.2 billion barrels), and proved gas reserve is 58.6 billion m^3. These numbers indicate that the exploration in the PRMB is immature; with only 26% OOIP and 8% OGIP have been proved by 2008. In recent years several large gas fields have been found from the deepwater Baiyun Sag of the Zhu-2 depression, and crude oil reserves have been enlarged successfully for many producing fields.

Figure 2-1 **Simplified geological map and cross section AA' of the Pearl River Mouth Basin.** Locations are indicated for the Haifeng Power Plant (HF Plant), and the three candidate oil fields.



In this desktop study we screened 16 producing oil fields in the PRMB for their suitability for CO_2 storage. The geological, petroleum, and production data of these fields up to 2005 or 2007 are published in Zhu et al. (2010) and CNOOC (2011). We used mainly the data from these publications as basis for our study, but the production data were partially updated to the end of 2010.

As the PRMB is still in the stage of active hydrocarbon exploration and production, it is important not to hinder the hydrocarbon development by CO_2 storage activities. Keeping this as a principal, our screening was conducted with the following criteria: the possibility of earlier depletion, the potential of CO_2-EOR, the effective storage size including ambient saline aquifers, reservoir properties, containment qualities (caprock, fault, well leakage), reusable existing facilities, and other technical and economical factors (source-sink distance, water depths, etc.).

Scoring and ranking producing oil fields for CO_2 storage suitability

With the data and method described in the last section, our screening was performed in the following steps:

1) Eliminating the fields having large remaining crude oil or having high expectation of reserves growth and thus do not have the possibility of depletion within 10 years. This was made by discussion with CNOOC experts in reservoir department;

2) Ranking the short-listed fields using constructed database and scoring table;

3) Search all the 16 producing oil fields for the field(s) having significant saline aquifers above producing oil reservoirs based on core records, well logs, and multichannel seismic profiles;

4) Analyze the advantages and disadvantages of high-scored fields based on all available data, and identify the knowledge gaps in making the selection.

It should be noted that in the Step 3 the high-remaining oil potential fields are also considered, and the selected field(s) are not joint the scoring and ranking process in Step 2. These are because we are interested in the saline formations, thus the evaluation criteria are different from those the oil reservoirs are to be used in CO_2 storage.

After the first step, 7 oil fields were selected From the 16 oil fields in the PRMB. For these fields we compiled a database using mainly published data as but updated to end of 2010 with additional data from CNOOC. Then as the second step a scoring table **(Table 2-1)** was designed for ranking the suitability of these oil fields for CO_2 storage. The potential of CO_2-EOR should be an important factor, but it has not been included in the table because no detailed evaluation has been conducted for individual fields. The resulted scores for the selected 7 oil fields are listed in **Table 2-2**. We found that the data on caprock are mostly missing, and several indexes are uniform over the fields and thus have no effect on the scoring. The most variant and thus influential indexes are OOIP, potential for reserve growth, reservoir quality, trap dimension, and the possibility of reusing existing infrastructure. After this step, the HZ32-3 and HZ21-1 fields having the highest total scores are selected.

Table 2-1 Scoring scheme for the suitability of oil fields to CO_2 geological storage

Index Type	Weight	Index	Weight	Score				
				Good (9)	Fair (7)	Ordinary (5)	Poor (3)	Bad (1)
Production status	0.2	Production time(a)	0.1	>20	20~>15	15~>10	10~>5	<5
		OOIP (Mt)	0.2	>20	20~>15	15~>10	10~5	<5
		Portion of recovery (%)	0.2	>90	90~ >70	70~ >50	50~30	<30
		Potential for reserves growth	0.4	Limited	Minor	Unclear	High	Very high
		Water content (%)	0	100~ >95	95~ >90	90~ >80	80~ >70	< 70
Reservoir condition	0.25	Total thickness (m)	0.2	100~ >70	70~ >50	50~ >30	30~ >10	10
		Top depth (m)	0.2	1200~1500	1500~2000	2000~2500	2500~3000	>3000
		Effective porosity (%)	0.2	>25	25~ >20	20~ >10	10~5	<5
		Effective permeability (mD)	0.2	>500	500~ >300	300~ >200	200~50	<50
		Horizontal continuity	0.1	Good	Fair	medium	Poor	Bad
		Geothermal gradient (°C/km)	0.1	<30	30~ <34	34~ <37	37~ <40	>= 40
		Pressure coefficient	0.1	<1.05	1.05~<1.1	1.1~<1.15	1.15~1.2	>1.2
Caprock	0.25	Top caprock maximum thickness (m)	0.3	>100	100~ >70	70~ >50	50~20	<20
		Open fault	0.2	No	Minor	Medium	Common	Abundant
		Lateral continuity	0.2	Good	Fair	medium	Poor	Bad
		Breakthrough pressure (MPa)	0.1	>10	10~ >5	5~ >3	3~ 1	< 1
		Lithology	0.2	Tight mudstone Tight evaporite	Mudstone or evaporite	Silty mudstone	Muddy siltstone, limestone	Siltstone, fractured limestone
Trap	0.1	Type	0.2	Large dome	Dome	Faulted nose/ drag anticline	Faulted block	Lithological
		Height (m)	0.3	>40	40~ >30	30~>20	20~10	<10
		Area (km^2)	0.3	>20	20~ >15	15~ >10	10~5	<20
		Fault activity	0.2	No fault	One major fault inactive	Several fault, inactive	Several fault, active	Several fault, highly active
Others	0.2	Re-use of infrastructure	0.5	Favorable	Reasonable	Possible	Difficulty	Impossible
		Water depth (m)	0.3	<100	100~ <200	200~ <300	300~ 500 m	>500
		Distance to CO_2 source (km)	0.2	<50	50~ <150	150~ <200	200~300	>300

Table 2-2 Scoring results for selected seven oil fields. (For each field the first and second columns are score and weighted score respectively.

Type	Index	Weight	HZ32-3		HZ32-2		HZ32-5		HZ21-1		XJ24-1		HZ19-3		HZ19-2	
Production	Production time	0.02	7	0.14	7	0.14	5	0.10	9	0.18	7	0.14	3	0.06	3	0.06
	OOIP	0.04	9	0.36	3	0.12	3	0.12	3	0.12	3	0.12	1	0.04	1	0.04
	Portion of recovery	0.04	7	0.28	7	0.28	7	0.28	9	0.36	5	0.20	7	0.28	5	0.20
	Potential for reserves growth	0.08	3	0.24	3	0.24	3	0.24	9	0.72	3	0.24	9	0.72	9	0.72
	Water content	0	3	0.00	5	0.00	5	0.00	5	0.00	9	0.00	5	0.00	7	0.00
Reservoir	Total thickness	0.05	5	0.25	3	0.15	3	0.15	3	0.15	7	0.35	5	0.25	9	0.45
	Top depth	0.05	7	0.35	5	0.25	7	0.35	3	0.15	5	0.25	3	0.15	1	0.05
	Porosity	0.05	7	0.35	7	0.35	7	0.35	5	0.25	7	0.35	5	0.25	5	0.25
	Permeability	0.05	9	0.45	9	0.45	9	0.45	5	0.25	7	0.35	7	0.35	3	0.15
	Lateral continuity	0.025														
	Geothermal gradient	0.025	7	0.18	7	0.18	7	0.18	7	0.18	7	0.18	7	0.18	7	0.18
	Pressure coefficient	0.02	9	0.18	9	0.18	9	0.18	9	0.18	9	0.18	9	0.18	9	0.18
Caprock	Top caprock maximum thickness	0.075														
	Open fault	0.05														
	Lateral continuity	0.05														
	Breakthrough pressure	0.025														
	Lithology	0.05														
Trap	Type	0.03	9	0.27	9	0.27	9	0.27	9	0.27	5	0.15	7	0.21	7	0.21
	Height	0.045	9	0.41	9	0.41	5	0.23	5	0.23	7	0.32	9	0.41	7	0.32
	Area	0.045	9	0.41	3	0.14	7	0.32	5	0.23	1	0.05	1	0.05	1	0.05
	Fault activity	0.03	9	0.27	9	0.27	9	0.27	9	0.27	9	0.27	9	0.27	9	0.27
Others	Re-use of infrastructure	0.075	5	0.38	5	0.38	7	0.53	9	0.68	5	0.38	7	0.53	7	0.53
	Water depth	0.045	7	0.26	7	0.26	7	0.26	7	0.26	7	0.26	7	0.26	7	0.26
	Source-sink distance	0.03	5	0.19	5	0.19	5	0.19	5	0.19	5	0.19	5	0.19	5	0.19
Total score		1.00		4.95		4.24		4.45		4.65		3.96		4.36		4.09
Order				1		5		3		2		7		4		6

In the step 3, the XJ24-3 field was found having thick (>400 m) saline aquifers above the oil reservoirs. These saline aquifers can be traced laterally to adjacent oil fields and overlain by thick caprocks according to seismic profiles and well logging data. Thus the XI24-3 field is also selected as a candidate site.

Finally we analyzed the these three fields as the primary candidate sites for the first CO_2 storage demonstration project. The locations of these fields are shown in **(Figure 2-1)**. Major features of these candidate sites, based mainly on the data published in Zhu and Mi (2010) and CNOOC (2011), are listed in **Table 2-2** and discussed in this section. The theoretical CO_2 storage capacity of these fields, listed in the last but three row of **Table 2-3**, was estimated simply by volume replacement of recoverable oil reserves with supercritical CO_2, where the density of CO_2 estimated from the density/depth curve of northern PRMB in Figure 6 of Zhou et al.(2011).

Table 2-3 Main features of the selected candidate sites (Data source: Zhu and Mi (2010) and CNOOC (2011); data deadline by end 2007 or 2005 unless specified.)

Site	HZ21-1	HZ32-3	XJ24-3
Time of production start	1990	1995	1994
Proved oil reserve (Mt)	15.8	29.7	30.1
Recoverable oil reserve (Mt)	7.9	20.3	28.9
Recovery by 2010 (%)	88.7	91.8	44.4
Potential of reserves growth by 2014	Limited	Good	Good
Water content (%)	98.5	65.6	88
Number of reservoir layers	8	8 (one main layer with 75% reserve)	21
Reservoir total thickness (m)	26	30.4	16.6
Oil column height (m)	9.0~23.0	10.5~42.0	18.9~65.5
Reservoir top depth (m)	2821~3001	1955~2280	1872~2317
Reservoir effective porosity (%)	12.8~16.6	18.0~22.8	17.1~24.6
Reservoir effective permeability (mD)	68~317	247~2729	54~1982
Reservoir original pressure (MPa)	28.6~29.8	19.8~24.1	18.8~23.7
Reservoir lithology & facies	Sandstone Littoral to delta front	Sandstone Littoral to delta front	Sandstone Littoral to deltaic
Reservoir faults	No	No	Yes
Trap type	Draping anticline	Draping anticline	Draping anticline
Trap height (m)	11.5~23.0	12.2~46.0	35~64
Trap area (km^2)	10.5	23.6	14.5
Caprock thickness (m)	>75		
Caprock fracture	One fault concealed		
Caprock continuity	Good		
Geothermal gradient (℃/km)	33.3	31	29.7
Existing infrastructure	4-leg jacket with 15 slots, gas processing platform, pipeline to land	4-leg jacket with 12 slots	8-leg jacket with 24 slots
Number of Wells	15	22	16
Water depth (m)	116	110	99
Distance to CO_2 source in Haifeng (km)	160	200	190
CO_2 storage capacity*（Mt）	5.7	13.7	16.2
Advantages	1)Oil production is close to the limit 2)More reusable infrastructure including gas processing platform, pipeline to coastal terminal, CO_2-resistant components	1)Large capacity 2)Several adjacent oil fields favorable to capacity expansion 3)High reservoir relief that is favorable to “Next-generation” CO_2-EOR	Thick saline aquifer (280m net thickness) above oil reservoirs.
Disadvantages	Relatively small and deep aquifers	Possible interference to oil production	Seal quality for the upper saline aquifers is uncertain

* CO_2 storage capacity is estimated simply by volume replacement of recoverable reserves of oil with supercritical CO_2.

Discussion on the candidate sites

The HZ21-1 oil & gas field

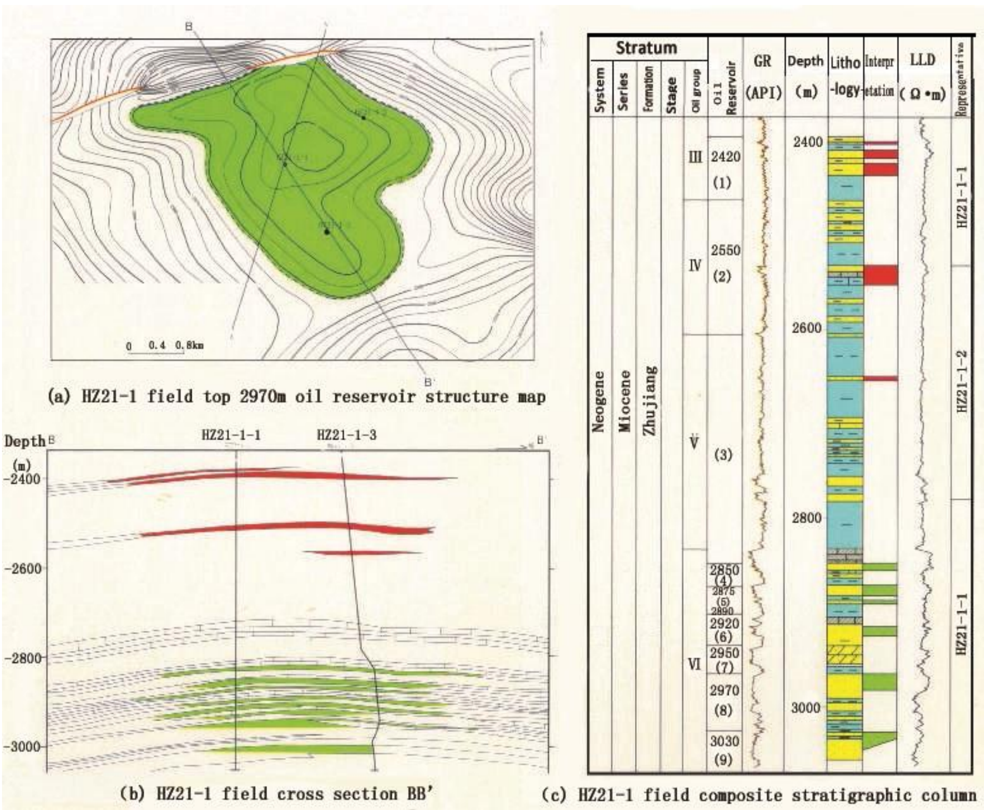
The HZ21-1 field is the first producing oil field and the only field now producing both oil and gas in the PRMB. It started oil production in 1990 and gas production in 2004.

This field is a draped dome of 10.5 km^2 in area **(Figure 2-2)**. There are 8 oil reservoirs at depths of 2820~3010 m and 2 gas reservoirs at depths of 2350~2540 m below seafloor. Reservoirs are uppermost Oligocene Zhuhai Fm. to Lower Miocene Zhujiang Fm. sandstones of littoral to delta-front/neritic facies. The oil reservoirs have single-layer average thickness 3.8~40.2 m, porosity 13.3~17.3%, and permeability 4.2~867 mD. The gas reservoirs are of thickness 25~42 m, porosity 9.5~18.1%, and average permeability 187 mD.

The crude oil produced from the field is of low density, low viscosity, and low sulphur content. On the formation level the crude oil has density 0.641~0.727 g/cm^3, viscosity 0.33~0.74 mPa·s, and soluble gas content 44~178 m^3/m^3. The gas reservoirs are condensate saturated and contain 76.6% CH_4 and 2.4% CO_2. The reservoirs are in normal pressure system and have strong lateral or bottom aquifer support. At the early stage of oil production it was observed that in major reservoirs the water volume was 100~200 times of oil volume, and the formation pressure reduced only 0.07~0.124 MPa for producing 1% reserve. Thus the water flood was regarded as unnecessary, and the planned water injection well was turned into an oil production well since then.

The quality of caprocks in the ZH21-1 field was evaluated by well-log analysis (Chen et al., 2007). The 75m thick caprocks at 2676~2850 m directly overlying oil reservoirs have average effective porosity 2%, permeability <0.02 mD, and breakthrough pressure as large as 20 MPa. The traps of the ZH21-1 field are cut by only one fault in its northern edge. This fault is a

Figure 2-2 **The HZ21-1 oil/gas field**
from Zhu and Mi, 2010). (a) Structure map of the top 2970m oil reservoir. (b) Cross section showing the oil (green) and gas (red) reservoirs. (c) Composite stratigraphic column.



sealing fault as evaluated by CNOOC experts. Thus the containment of the ZH21-1 field is good.

The HZ21-1 field has proved reserves of 15.75 Mt oil, 2056 Mm^3 soluble gas, and 6735 Mm^3 natural gas. The estimated recoverable reserves are 7.9 Mt oil, 1281 Mm^3 soluble gas, and 5400 Mm^3 natural gas. By the end of 2010, the total production was 7.0 Mt oil, 1262 Mm^3 soluble gas, 3822 Mm^3 natural gas, and 0.6 Mt condensates. By now the oil production is regarded as close to the limit, and a small gas production is continued to generate energy for this and nearby platforms.

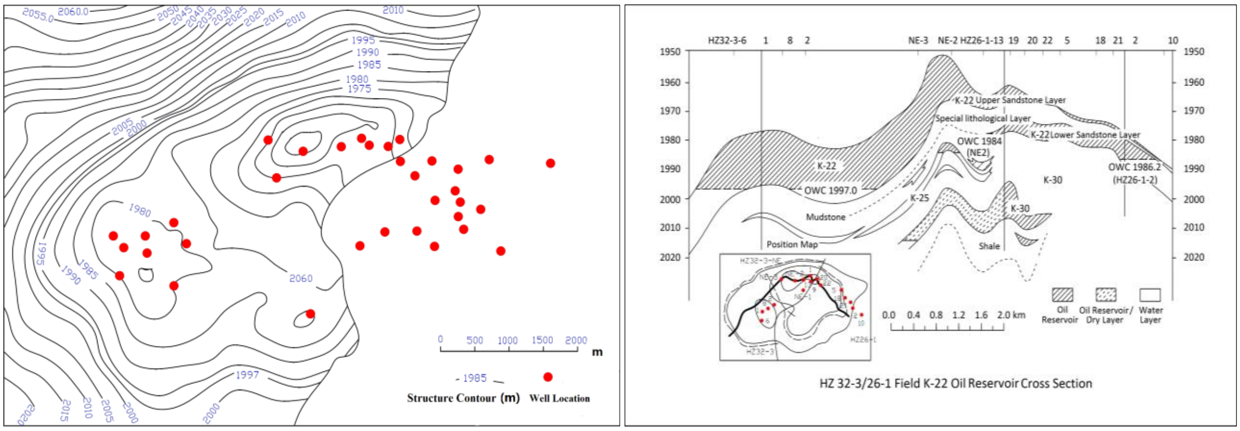
The theoretical CO_2 storage capacity of the HZ21-1 oil reservoirs, estimated simply by volume replacement of recoverable reserve of oil with supercritical CO_2, is only 5.7 Mt. As the planned demonstration project needs at least 20 Mt CO_2 storage capacity, the use of ambient saline formations for CO_2 storage is essential. In order to estimate if the oil reservoirs in the HZ21-1 field can accommodate CO_2 injection at a rate of 1 and 2 Mtpa (million metric tonne per year) for 20 years, a primary CO_2 injection modeling has conducted using the ECO2N module of the TOUGH2 computer program and based on the thickness, porosity, and permeability data from one well (Li et al., unpublished report). Results shown that the maximum pressure buildup at 500 m from the injection point was only 2.3% of the original formation pressure, and the maximum CO_2 plume dispersion after 100 years was only 4.5 km to the southeast. These suggest it is possible for the HZ21-1 oil reservoirs serving as the storage site for the planned demonstration project.

The oil reservoirs in the HZ21-1 field have several advantages for being used in CO_2 storage: 1) In the field conventional oil production is close to the limit, thus it is possible to apply CO_2-EOR or CO_2 storage in near future years. 2) The field has gas-processing platform and CO_2-resistant components and thus is more favorable to be retrofit for CO_2 services, as discussed in Chapter 3 of this report. 3) A pipeline from HZ21-1 to the coastal terminal at Zhuhai is spare and may be available for CO_2 transportation. A major concern for CO_2 storage in the HZ21-1 field is whether the storage size is large enough for the demonstration project. Although our preliminary modeling indicated it can accommodate 20 years CO_2 injection at 2 Mtpa rate, this needs to be confirmed by further detailed study using all the available data.

The HZ32-3 oil field

The HZ32-3 oil field is a draped anticline developed above a granitic basement high. The oil-bearing strata pinch out to the northeast, so the field has combined structural and stratigraphic traps **(Figure 2-3)**. There are 11 oil reservoirs occurring at depths 1955~2280 m below seafloor. They are made of uppermost Oligocene to lower Lower Miocene lithic feldspar arenite with deltaic to littoral facies. A unique character of this field is that 81% of its reserve comes from one single reservoir K-22, which is a sandstone layer in the Lower Miocene Zhujiang Fm., made of thick coarse sandstone deposited in braded channels of deltaic plain. The layer has average porosity 25%, average air permeability 2729 mD, effective thickness 18.6 m, oil column height 42 m, and oil/water contact (OWC) at 1997 m. The K-22 reservoir pinches out to the east.

Figure 2-3 The structure map (a) and cross section (b) of the HZ32-3 oil field in the Pearl River Mouth Basin (From CNOOC, 2011).



(a) (b)

The oil production in the HZ32-3 field started in 1995. By 2010 its proved reserve was 29.7 Mt, and total production was 18.6 Mt. At formation level the crude oil has density 0.759~0.818 g/cm^3, viscosity 0.75~4.39 mPa·s. There is no gas layer but small amount of dissolved gas.

The advantage of the HZ32-3 field is its relatively large OOIP suggesting a larger CO_2 storage capacity (13.7 Mt CO_2, more than 2 times of that in oil reservoirs of HZ21-1, see Table 2-3). The large thickness and high relief of the K-22 reservoir may be advantageous for the application of "Next-generation" CO_2-EOR. Another advantage of the HZ32-3 field is that it resides in a belt of several adjacent fields and thus is easy to expand its storage capacity. The distances from the HZ32-3 platform to the HZ32-2 and HZ26-1 platforms are only 5.6 km and 4.8 km respectively. In comparison, the distances from these platforms to the HZ21-1 platform are 25 km. The major concern for the CO_2 storage in the HZ32-3 field is the oil company might be afraid of obstructing its oil exploration by CO_2 storage activities.

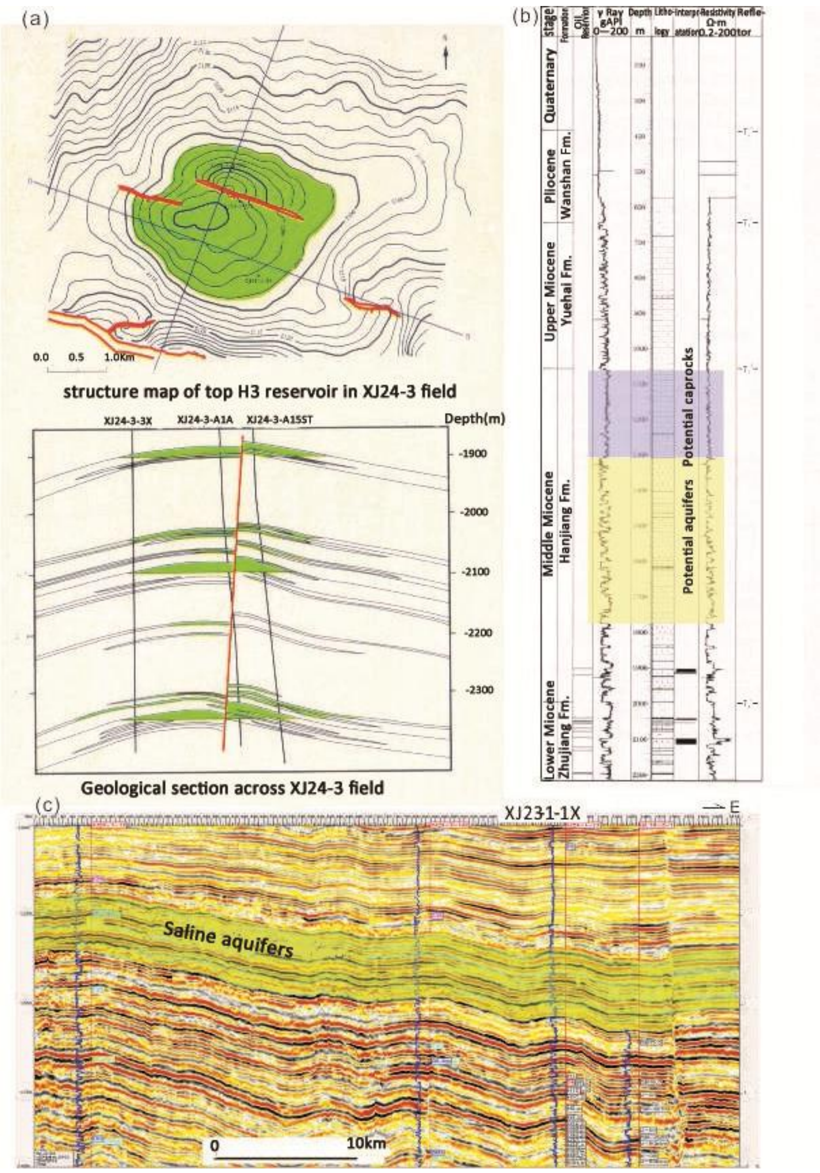
The XJ24-3 oil field

The XJ24-3 field is also a draped anticline developed above basement high. It has 21 oil reservoirs at depths 1872~2317 m below seafloor, composed of deltaic and littoral sandstones in middle to upper portion of the Lower Miocene Zhujiang Fm. and lower portion of the Middle Miocene Hanjiang Fm. The reservoirs have average porosity 17~25%, effective permeability 54~1982 mD, single-layer thickness <1~22.4 m. The oil production started in 1994 from the XJ24-3 field. Its proved reserve was 30.4 Mt, and total production was 19.8 Mt by 2010. At formation level the crude oil has density 0.796~0.869 g/cm^3, viscosity 2.3~12.4 mPa·s. These are ultra-low saturated oil reservoirs without gas cap or gas intra-layer. The amount of dissolved gas is lower than 1 m^3/m^3.

In recent years the XJ24-3 oil field has shown significant potential of reserves growth. Therefore at the present we are considering only the saline aquifers for CO_2 storage. From well logs we found above the oil reservoirs a >400 m thick sandy section in the lower and middle Hanjiang Fm (Middle Miocene). The net thickness of sandstones in this section is as large as 280 m **(Figure 2-4b).** using seismic profiles, this sandy section may be traced at least 40 km long in E-W direction (Fig. 2-4c). If these saline aquifers can be used to store CO_2, the storage capacity will be very large, and the infrastructure of the XJ-24-3 oil field might be used to reduce the storage cost. However, although well log curves show that there is about 200 m thick caprock section in the upper Hanjiang formation, at present we have no data on the sealing quality of these caprocks. Because the XJ24-3 field is located close to the paleo-Pearl River mouth, its sediments are thought to be relatively coarse indicating seal risk. In addition, seismic profiles indicate there are faults cutting through both saline aquifers and caprocks. The leakage along faults is also an important concern.

In summary the main possibility for storage demonstration at XJ24-3 is in overlying saline aquifers, rather than in depleted oil/gas reservoirs. This is a different storage proposition with major uncertainties and risk around storage characteristics and containment. Extensive work and probably new data acquisition and new appraisal wells are required to address these unknowns and to progress this option.

Figure 2-4 **The XJ24-3 oil field:** (a) Structure map and cross section (Zhu and Mi, 2010); (b) The composite stratigraphic column showing the sandy saline aquifers (in yellow) and caprocks (in violet) in Middle Miocene Hanjiang Fm.(CNOOC, 2011); (c) A multi-channel seismic profile showing the areal extend of the sandy saline aquifers (From CNOOC).



Conclusions and Suggestions on Site Selection

Previous works demonstrated that the potential CO_2 storage sites for Guangdong Province reside offshore in the Pearl River Mouth Basin (PRMB). The cost of offshore CO_2 storage will be reduced if existing infrastructures for oil/gas exploration may be reused for storage. In order to find a suitable storage site for the first full-chain offshore CCUS project in Guangdong, we examined and ranked 16 producing oil fields in the PRMB based on published data for their potential of early abandonment, potential of CO_2-EOR application, suitability in geological conditions, and possibility of reuse infrastructure for CO_2 injection and transportation.

Three fields, the HZ21-1, HZ32-3, and XJ24-3, were short-listed from our screening. Their major features are reviewed in this report. In summary, each site has its own advantages and knowledge gaps. The HZ21-1 field is advantageous in its possible earliest abandonment and higher potential of infrastructure reuse, but if its storage capacity is large enough for the demonstration project needs to be confirmed. The HZ32-3 field has relatively higher storage capacity and CO_2-EOR possibility, but its oil production is still active and may not want to be interfered by CO_2 activities. The XJ24-3 is also in active oil production, we are interested in using the saline aquifers above oil reservoirs for CO_2 storage. These saline aquifers have large thickness and areal extend, which imply a large storage capacity, but the quality of containment is uncertain at present. Taken into account of all these pros and cons, at present we feel that the HZ21-1 field is the most favourable site for CO_2 storage demonstration. The importance of HZ32-3 might increase if the potential of CO_2-EOR is regarded as large by further works. The feasibility of saline aquifers in the XJ24-3 requires much more work to confirm.

In order to make final decision, the major knowledge gaps need to be resolved. The following works are suggested to be the most urgent:

1) To assess the dynamic and ultimate CO_2 storage capacity in each of these field to see if it is sufficient for injecting 1 $MtCO_2$ annually for 20 years (or 2 $MtCO_2$ annually for 10 years) as requested by the planned Haifeng full-chain offshore CCUS project and to see how large is the potential of further extension. The injection modeling is needed based on updated reservoir models and parameters accumulated in oil production activities. As the oil fields in concern are small and do not have enough CO_2 storage capacity, the storage capacity in saline aquifers downdip of or underneath producing horizons need to be considered in the assessment.
2) To evaluate the technical potential and economic viability of CO_2-EOR in these fields. If CO_2-EOR is viable, then the CO_2 injection may be started before the field depletion.
3) To evaluate the containment effectiveness of these fields by examining the leakage risk through caprocks, faults, and existing wells. This will be done through examining existing geological, geophysical, and geochemical data, through additional well sample tests, as well as through dynamic modeling.

After these studies, it is expected that one site will be finally selected, and the process of CO_2 storage will proceed further to the steps of site characterization and front-end engineering design.

离岸封存示范场地的筛选

CO_2 地质封存是 CCUS 的不可缺少的组成部分之一。过去的工作已查明广东省陆上缺乏 CO_2 封存条件，而在南海北部的大型沉积盆地中却有着巨大的 CO_2 封存潜力(GDCCSR-SCSIO，2013)，其中在邻近广东省的珠江口盆地的 CO_2 有效封存容量[2]就可以为广东省提供未来 300 多年内大型点源按 2010 年水平排放 CO_2 的封存场地(Zhou et al., 2011; 2013)。因此离岸地质封存是广东省实现 CO_2 封存的唯一可行方式。由于中国东南部的地质和土地利用条件与广东省类似，离岸地质封存也可能是中国东南部实现 CO_2 封存的唯一可行方式。

与CO_2 陆上、特别是与人口稠密地区的CO_2地质封存相比，CO_2离岸地质封存有不占用土地、不会影响饮用水资源、环境风险较小等优越性；但也有建设和运行成本较高的缺点。降低成本的一个有效途径是利用现有的油气勘探的资料和设备。如果现有的资料可用于CO_2封存的选址和工程设计，如果现有的平台、钻井、管线等设备经适当改造后可用于CO_2 地质封存和运输，则离岸封存的基建成本不仅会显著降低，而且建设工期也会缩短。因此，为示范工程选择CO_2封存场地时，我们首先考虑利用现有的油气田。

现有油气田用于CO_2封存有三种方式：一种是在油气开发的晚期开展CO_2驱油（即CO_2-EOR），另一种是在油气田枯竭之后开展纯粹的CO_2封存；这两种方式都要利用油气开发后遗留的空间来封存CO_2。第三种方式是利用油气田的设备将CO_2封存到油气田附近的咸水层中；这种方式不涉及油气藏空间的利用，因此可在油气生产的同时进行，如挪威海外的Sliepner气田。三种方式有各自的适用条件；一般来说应该首先考虑油气田是否适用于第一种方式，因为若能实施CO_2-EOR，就可在封存CO_2的同时也提高石油的采收率，实现了CO_2的经济利用。

为了给广东省首个全流程离岸 CCUS 项目寻找封存场地，我们对珠江口盆地的 16 个生产油田进行了筛选。首先将油气勘探潜力较大、在今后十年内不会废弃的 9 个油田列入“不考虑”的范围，然后采用与美国德克萨斯州西部和北海大陆架油田进行类比的方法初步评价了珠江口盆地油田开展 CO_2 驱油（即 CO_2-EOR）的可行性，最后根据已发表的资料对剩下的 7 个油田根据已发表的油田的开发状态、圈闭、储层和盖层的地质条件、以及现有设施可利用与 CO_2 充注的程度等资料进行了封存适宜性评分排队。在这些分析的基础上，选择了 HZ21-1、HZ32-3、XJ24-3 这三个油田作为候选封存场地，讨论了它们用于 CO_2 地质封存的优缺点及待查明问题，提出了下一步工作的建议。

资料和方法

珠江口盆地面积约20万平方公里，是南海北部最大的沉积盆地，自上世纪70年代以来在该盆地进行了大规模的地质调查和油气勘探（**图2-1**）。盆地中的油气源层主要是始新统湖湘泥岩和渐新统含煤岩系，储层主要是新近系海相碎屑岩和碳酸盐岩。迄今已发现30个油田，多数为小型油田（探明储量小于6千万吨），仅LH11-1油田较大，有探明储量1.55亿吨(朱伟林 et al.，2010)。在珠三坳陷的文昌凹陷还发现若干小型气田。根据2008年的新一轮资源评价(国土资源部 et al.，2008)，珠江口盆地的地质储量为22亿吨石油、7430亿方天然气；而探明储量仅为5.8亿吨石油和586亿方天然气，分别占地质储量的26%和8%，可见珠江口盆地的勘探

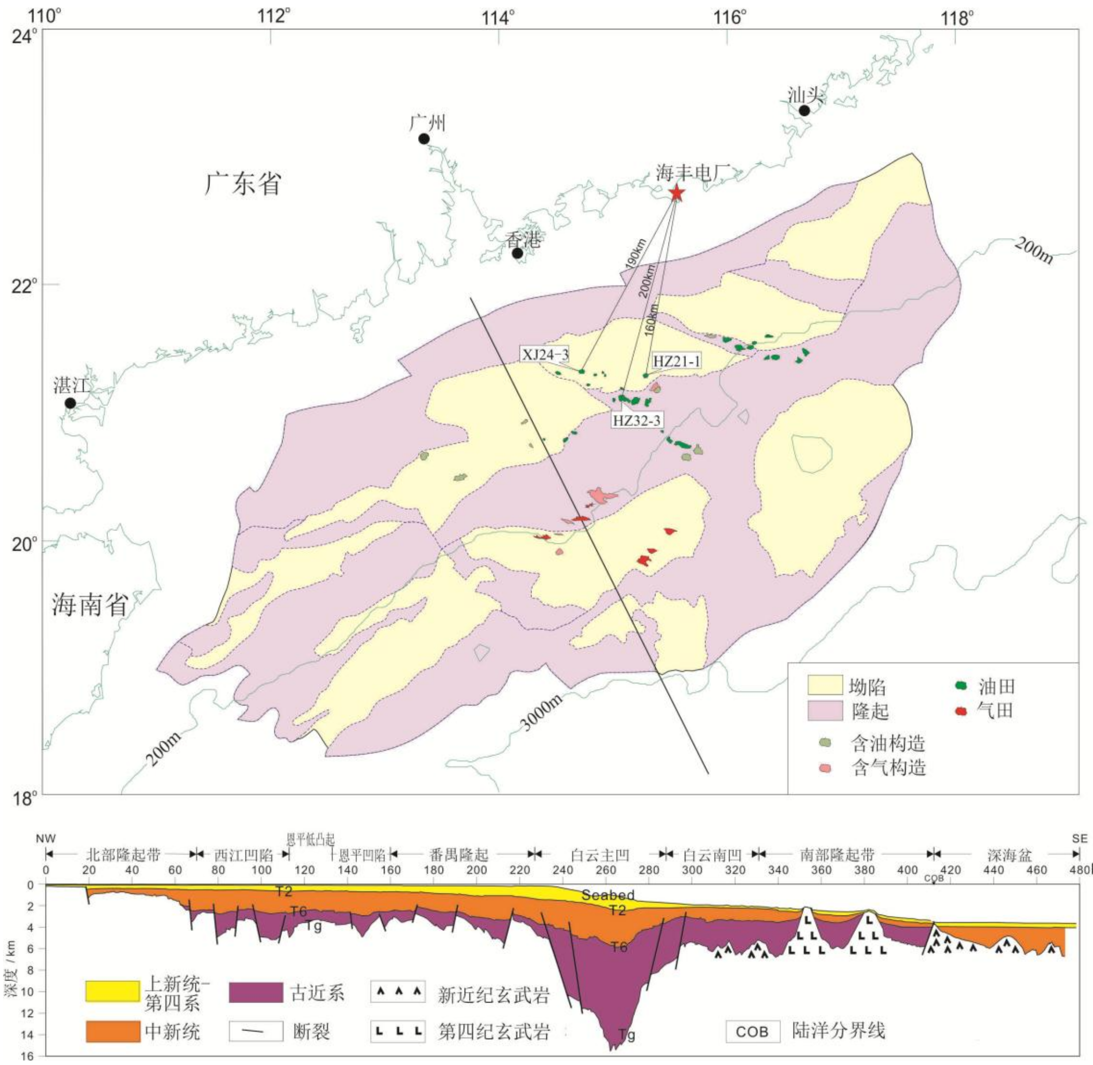
[2] 据碳封存领导人论坛（CSLF，2007）的定义，CO_2有效封存容量指具备一定地质和工程条件的那部分理论封存容量（孔隙体积），由理论容量与封存有效性系数的乘积来估算。

程度还较低。不过，自2008年以来在盆地深水区的珠二坳陷白云凹陷陆续发现若干大型天然气田，对陆架区的已生产油田进行深入勘探扩大储量也取得显著效果。

本报告对珠江口盆地的16个生产油田的CO_2封存适宜性进行了初步评价。数据来源除特别注明以外均来自朱伟林等（2010）和(朱伟林 et al., 2010; 编纂委员会, 2011)，数据截止日期分别为2005年和2007年，油田的生产数据更新到2010年。

由于珠江口盆地目前还处于积极进行油气勘探开发的时期，不能因CO_2封存活动而妨碍油气勘探开发。在此原则下，我们对珠江口盆地现有油田的CO_2封存适宜性评估考虑了以下因素：油田生产状况即早期（十年内）枯竭的可能性、CO_2-EOR的潜力、油藏和邻近咸水层的有效封存容量、圈闭和油藏的特性、封闭条件（盖层、断层、钻井泄漏）、已有设备的可利用程度、以及其他的技术和经济因素（源汇距离、水深等）。

图 2-1 珠江口盆地地质简图和地质剖面图。示三个候选封存场地和海丰电厂的位置。



生产油田的 CO_2 封存适宜性评分和排队

根据上述资料和方法，对珠江口盆地现有油田的筛选工作按以下步骤进行：

1) 咨询中海油专家的意见，删去那些剩余原油比例大或储量增长潜力大，在未来十年之内枯竭的可能性不大的油田。
2) 设计一个油田对 CO_2 封存的适宜性评分表，对留下的油田进行评分和排队。
3) 对所有 16 个生产油田，根据钻孔、测井和多道地震资料寻找在油藏上方有一定规模咸水层的油田。
4) 根据现有的资料，分析得分较高的油田的 CO_2 封存有利和不利条件，明确尚需进一步调查的问题。需要指出的是，在第 3 步中也考虑了在未来十年之内枯竭的可能性不大的油田，而且所选出的油田不参加第 2 步的评分和排队，这是因为 CO_2 封存将利用油田上方的咸水层，其评价方式与利用油藏本身的情形不同。

经过第一步后从珠江口盆地的 16 个生产油田中选择了 7 个油田，然后按第二步对这些油田建立了数据库，并设计了一个油田对 CO_2 封存的适宜性评分表，见表 2-1。表中没有列入非常重要的一项“CO_2-EOR 潜力”，这是因为迄今尚未对这些油田进行 CO_2-EOR 潜力的详细评估。7 个油田的得分见**表 2-2**，其中关于盖层的数据大多缺失因而没有打分，有几项在各油田的得分相同因而没有影响，对排队起重要作用的项是得分变化最大的项，有地质储量、储量增长潜力、储层质量、圈闭大小、以及设备可利用程度。执行第二步以后，HZ32-3 和 HZ21-1 这两个油田得分最高。

表 2-1 油田对 CO_2 地质封存的适宜性评分表

指标类型	权重	指标	权重	评分				
				优秀（9）	良好（7）	一般（5）	较差（3）	差（1）
生产状态	0.2	投产时间（年）	0.1	>20	20~>15	15~>10	10~>5	<5
		地质储量（Mt）	0.2	>20	20~>15	15~>10	10~5	<5
		采出比例（%）	0.2	>90	90~>70	70~>50	50~30	<30
		扩大潜力	0.4	有限	较小	不明	大	很大
		含水率（%）	0	100~>95	95~>90	90~>80	80~>70	< 70
储层条件	0.25	总厚度（m）	0.2	100~>70	70~>50	50~>30	30~>10	10
		高点埋深（m）	0.2	1200~1500	1500~2000	2000~2500	2500~3000	>3000
		孔隙度（%）	0.2	>25	25~>20	20~>10	10~5	<5
		渗透率（mD）	0.2	>500	500~>300	300~>200	200~50	<50
		横向连续性	0.1	优秀	良好	中等	较差	很差
		地温梯度（℃/km）	0.1	<30	30~<34	34~<37	37~<40	>= 40
		压力系数	0.1	<1.05	1.05~<1.1	1.1~<1.15	1.15~1.2	>1.2
盖层条件	0.25	总厚度（m）	0.3	>100	100~>70	70~>50	50~20	<20
		开放断裂	0.2	无	少量	中等	常见	大量
		横向连续性	0.2	Good	Fair	medium	Poor	Bad
		突破压（MPa）	0.1	>10	10~>5	5~>3	3~1	< 1
		岩性	0.2	致密泥岩 致密蒸发岩	泥岩/蒸发岩	粉砂质泥岩	泥质粉砂岩,	有裂隙的粉砂岩 limestone
圈闭条件	0.1	类型	0.2	大型穹窿	穹窿	断鼻/牵引背斜	断块	岩性
		高度（m）	0.3	>40	40~>30	30~>20	20~10	<10
		面积（km²）	0.3	>20	20~>15	15~>10	10~5	<20
		断裂活动性	0.2	无断裂	一条断裂，不活动	若干断裂，不活动	若干断裂，活动	若干断裂，强活动
其他	0.2	设备可利用程度	0.5	高	中等	可能	较困难	不可能
		水深（m）	0.3	<100	100~<200	200~<300	300~500 m	>500
		源汇距离（km）	0.2	<50	50~<150	150~<200	200~300	>300

表 2-2 七个油田的评分结果

类型	参数	权重	HZ32-3		HZ32-2		HZ32-5		HZ21-1		XJ24-1		HZ19-3		HZ19-2	
生产状态	投产时间	0.02	7	0.14	7	0.14	5	0.10	9	0.18	7	0.14	3	0.06	3	0.06
	地质储量	0.04	9	0.36	3	0.12	3	0.12	3	0.12	3	0.12	1	0.04	1	0.04
	采出比例	0.04	7	0.28	7	0.28	7	0.28	9	0.36	5	0.20	7	0.28	5	0.20
	扩大潜力	0.08	3	0.24	3	0.24	3	0.24	9	0.72	3	0.24	9	0.72	9	0.72
	含水率	0	3	0.00	5	0.00	5	0.00	5	0.00	9	0.00	5	0.00	7	0.00
储层条件	总厚度	0.05	5	0.25	3	0.15	3	0.15	3	0.15	7	0.35	5	0.25	9	0.45
	高点埋深	0.05	7	0.35	5	0.25	7	0.35	3	0.15	5	0.25	3	0.15	1	0.05
	孔隙度	0.05	7	0.35	7	0.35	7	0.35	5	0.25	7	0.35	5	0.25	5	0.25
	渗透率	0.05	9	0.45	9	0.45	9	0.45	5	0.25	7	0.35	7	0.35	3	0.15
	横向连续性	0.025														
	地温梯度	0.025	7	0.18	7	0.18	7	0.18	7	0.18	7	0.18	7	0.18	7	0.18
	压力系数	0.02	9	0.18	9	0.18	9	0.18	9	0.18	9	0.18	9	0.18	9	0.18
盖层条件	总厚度	0.075														
	开放断裂	0.05														
	横向连续性	0.05														
	突破压	0.025														
	岩性	0.05														
圈闭条件	类型	0.03	9	0.27	9	0.27	9	0.27	9	0.27	5	0.15	7	0.21	7	0.21
	高度	0.045	9	0.41	9	0.41	5	0.23	5	0.23	7	0.32	9	0.41	7	0.32
	面积	0.045	9	0.41	3	0.14	7	0.32	5	0.23	1	0.05	1	0.05	1	0.05
	断裂活动性	0.03	9	0.27	9	0.27	9	0.27	9	0.27	9	0.27	9	0.27	9	0.27
其他	设备可利用程度	0.075	5	0.38	5	0.38	7	0.53	9	0.68	5	0.38	7	0.53	7	0.53
	水深	0.045	7	0.32	7	0.32	7	0.32	7	0.32	7	0.32	7	0.32	7	0.32
	源汇距离	0.03	5	0.15	5	0.15	5	0.15	5	0.15	5	0.15	5	0.15	5	0.15
总得分		1.00		4.95		4.97		4.26		4.47		4.67		3.98		4.38
排队次序				1		5		3		2		7		4		6

在第三步，我们发现 XJ24-3 油田的油藏上方有厚逾 400 米的咸水层，并可沿走向追索到相邻的油田；根据测井剖面分析，在该厚层咸水层之上有较厚的盖层。因而我们将 XJ24-3 油田也纳入候选封存场地之列。

最后一步，我们根据现有资料进一步分析了三个候选封存场地 HZ21-1、HZ32-3 和 XJ24-3 对实施 CO_2 封存的有利和不利条件。三个场地的位置见图 2-1，所考虑的主要参数见表 2，其资料来源除特别注明之外均来自朱伟林和米立军（2010）和编纂委员会（2011）。表中倒数第三行所列的 CO_2 封存容量为作者采用体积置换法（用超临界 CO_2 替代

石油可采储量）所作的粗略估算，其中 CO_2 密度读自 Zhou et al.(2011)图 6 中的珠江口盆地北部 CO_2 密度/深度曲线。以下对各个场地的特征做进一步的讨论。

表 2-3 候选封存场地的主要特征。数据来源主要为朱伟林和米立军（2010）和编纂委员会

候选场地	HZ21-1	HZ32-3	XJ24-3
投产时间	1990	1995	1994
石油探明储量（Mt）	15.8	29.7	30.1
石油可采储量（Mt）	7.9	20.3	28.9
至 2010 年已采（%）	88.7	91.8	44.4
2014 估计增产潜力	有限	良好	良好
含水率（%）	98.5	65.6	88
油层层数	8	8（一个主力油层）	21
油层总厚（m）	26	30.4	16.6
油柱高度（m）	9.0~23.0	10.5~42.0	18.9~65.5
油层高点埋深（m）	2821~3001	1955~2280	1872~2317
油层有效孔隙度（%）	12.8~16.6	18.0~22.8	17.1~24.6
油层有效渗透率（mD）	68~317	247~2729	54~1982
油层原始压力（MPa）	28.6~29.8	19.8~24.1	18.8~23.7
油层岩性岩相	砂岩，滨海至三角洲前缘	砂岩，滨海至三角洲前缘	砂岩，滨海至三角洲
油层断裂	无	无	有
圈闭类型	披覆背斜	披覆背斜	披覆背斜
圈闭高度（m）	11.5~23.0	12.2~46.0	35~64
圈闭面积（km^2）	10.5	23.6	14.5
顶部盖层总厚（m）	>75		
盖层断裂	一条封闭断裂		
盖层侧向连续性	好		
地温梯度（℃/km）	33.3	31	29.7
现有设备	4 腿钻井架，15 个井槽，另有天然气处理平台，海底管线至岸上终端	4 腿钻井架，12 个井槽	8 腿钻井架，24 个井槽
钻井数	15	22	16
水深（m）	116	110	99
至海丰电厂的距离（km）	160	200	190
CO_2 封存容量*（Mt）	5.7	13.7	16.2
有利条件	3)油田开采接近极限 4)较多可利用设备，如 天然气处理平台、至岸上终端的海底管线、抗 CO_2 腐蚀的设备部件等	4)容量较大 5)主力油藏起伏较大，有利于下一代 CO_2-EOR 6)容易与邻近油田联合开发	油藏之上有巨厚咸水层(净厚 280m)可供. CO_2 封存
不利条件	容量较小、埋深较大	可能干扰油田生产	咸水层之上的盖层质量未知

* CO_2 storage capacity is estimated simply by volume replacement of OOIP with supercritical CO_2.

候选封存场地讨论

本节讨论的资料来源除特别注明之外均来自朱伟林和米立军（2010）和编纂委员会（2011）。

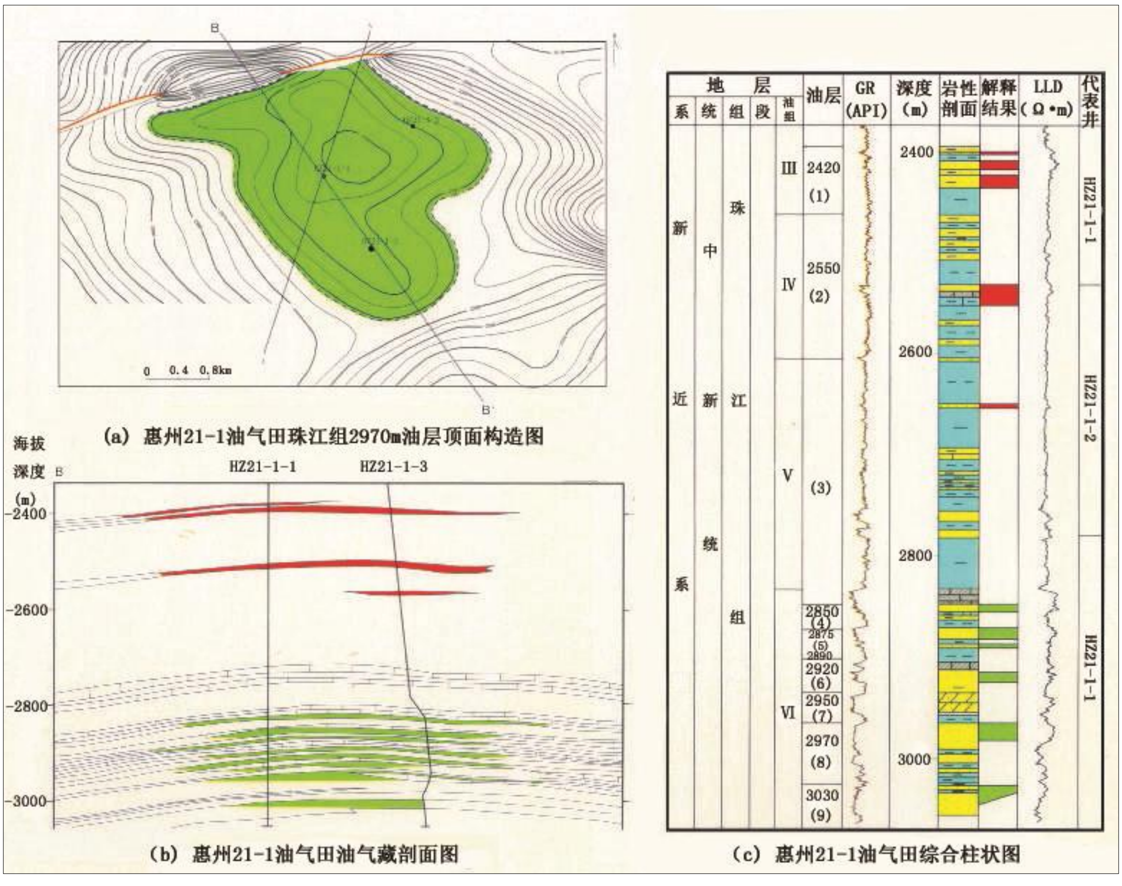
HZ21-1 油气田

HZ21-1 油气田是珠江口盆地的第一个生产油田，也是盆地中迄今唯一的同时生产石油和天然气的油气田。其石油开采于 1990 年开始，天然气开采于 2004 年开始。

油气田的构造为一个近等轴状披覆背斜，面积 10.5 km^2 **(图 2-2)**. 8 个油层的高点埋深为 2820~3010 m，2 个气层的高点埋深为 2350~2540 m。油层由渐新统珠海组顶部至下中新统珠江组下部的滨海相至三角洲前缘/浅海相砂岩组成，单层平均厚度 3.8~40.2 m，孔隙度 13.3~17.3%，渗透率 4.2~867 mD. 气层平均厚度 25~42 m，孔隙度 9.5~18.1%，平均渗透率 187 mD.

图 2-2 **HZ21-1 油气田**

自朱伟林和米立军，2010)。 (a) 2970m 油层顶部构造图；. (b) 地质剖面，示油层（绿色）和气层（红色）； (c) 综合地层柱状图。



原油具低密度、低粘度、低硫特征。地层原油密度 0.641~0.727 g/cm^3，粘度 0.33~0.74 mPa·s， 溶解气含量 44~178 m^3/m^3。气层中凝析油饱和，含 76.6% 的 CH_4 和 2.4% 的 CO_2。地层压力系统正常，边水和底水能量充足。在油田开发初期测得主力油层的含水体积是含油体积的 100~200 倍，每开采 1%石油储量所引起的油层压力下降仅为 0.07~0.124 MPa，因而认为水驱没有必要，从此将原来设计的注水井一律改为生产井。

对 ZH21-1 油气田的盖层和隔层的质量进行了样品测试和测井资料分析(陈建亮 et al., 2007)。直接覆盖在油层上方的盖层厚 75 m（埋深 2676~2850 m），平均有效孔隙度 2%，有效渗透率 <0.02 mD，突破压高达 20 MPa。ZH21-1 油田范围内仅有一条断裂，位于油田的北部边缘（**图 2-**

2），据石油公司专家评估为封闭断裂。因此，ZH21-1 油气田的封闭条件优良。

HZ21-1 油气田的探明地质储量是石油 15.75 Mt（百万吨），溶解气 2056 Mm^3（百万方），天然气 6735 Mm^3。2010 年底的估计开采储量为石油 7.9 Mt，溶解气 1281 Mm^3，天然气 5400 Mm^3。至 2010 年底的累计产量为石油 7.0 Mt，溶解气 1262 Mm^3，天然气 3822 Mm^3，0.6 Mt 凝析油。目前，该油气田的石油生产已被认为接近极限，而天然气仍在小规模开采，供相邻各平台的发电之用。

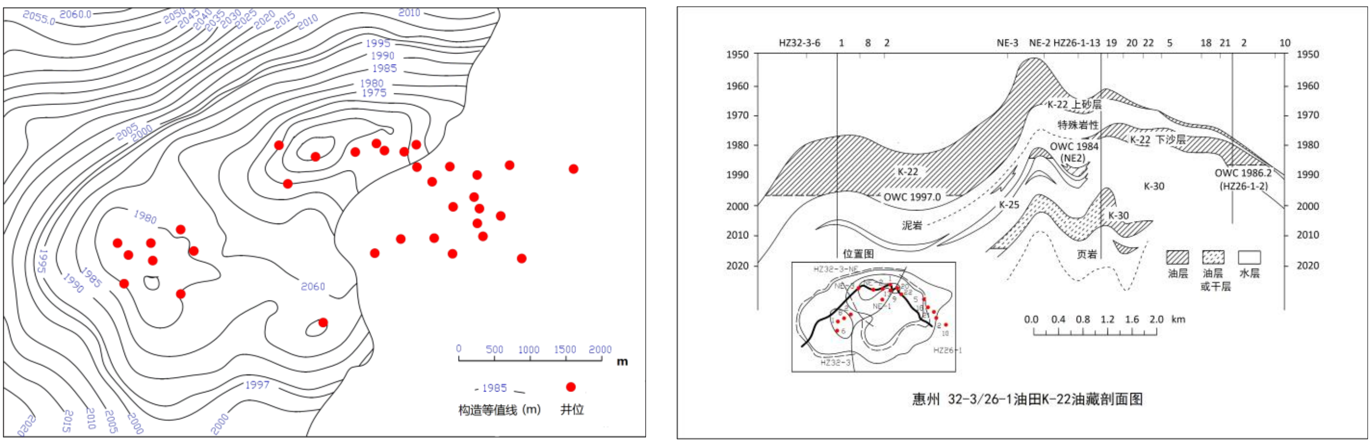
假设所有的可采原油储量都可用于封存 CO_2，则采用简单的体积置换法粗估 HZ21-1 油藏的 CO_2 理论封存容量为 5.7 Mt，远小于示范项目所需要的 20 Mt CO_2，因此利用油藏邻近的咸水层是必须的。李鹏春等（未公开的报告）用 TOUGH2 程序的 ECO2N 模块对 HZ21-1 的油藏进行了 CO_2 充注的初步模拟，采实际厚度和一口井的孔隙度、渗透率数据，分别模拟了以速率 1 和 2 Mtpa（百万吨/年）CO_2，充注十年的情景。结果是：在离充注点 500 m 处的最大压力增高为原始地层压力的 2.3%，100 年后 CO_2 的最大迁移距离为向东南方 4.5 km。因而模拟结果表明 HZ21-1 油藏的 CO_2 封存容量足以支持示范项目的 CO_2 封存。

HZ21-1 的油藏作为示范项目的 CO_2 封存场地有若干突出优点：1）传统方式的原油开采已接近极限，因此具有早日开展 CO_2-EOR 或 CO_2 封存的可能。2) 在现有设备的改造方面有比其他油田都优越，如：除了油气生产平台之外还有一个天然气处理平台，有抗 CO_2 腐蚀的设备器件，有海底管道从油田直达位于广东海岸的珠海终端等，这些有利条件不仅能降低改造难度和成本，而且能缩短工期；详见本报告第三章。HZ21-1 的油藏作为 CO_2 封存场地的主要疑问是其封存容量较小，虽然初步模拟认为它能满足示范项目的 CO_2 封存需要，但还需要利用所有资料进行详细的模拟来进一步确认。

HZ32-3 油田

HZ32-3 油田是一个位于花岗岩基底高之上的披覆背斜，含油层系向北东方向尖灭，因而形成构造-地层复合圈闭（图 2-3）。含 11 个油层，埋深 1955~2280 m，由渐新统顶部到下中新统下部的三

图 2-3 珠江口盆地HZ32-3油田构造图(a)和地质剖面图(b) (自编纂委员会，2011)。



(a) (b)

角洲-滨海相含岩屑长石砂岩组成。该油田的最大特点是 81%的储量来自一个主力油层 K22，它是位于下中新统珠江组中的厚层粗砂岩，沉积于三角洲平原的辫状河环境，向北东方向尖灭，平均孔隙度 25%，平均空气渗透率 2729 mD，有效厚度 18.6 m，油柱高度 42 m，油水界面（OWC）深度 1977 m。

HZ32-3 的石油生产开始于 1995 年，在 2010 年其探明石油储量为 29.7 Mt，累计产量 18.6 Mt。地层原油密度 0.759~0.818 g/cm^3，粘度 0.75~4.39 mPa·s，含少量溶解气，但无气层。

HZ32-3 作为 CO_2 封存场地的优点是容量较大；按石油可采储量的体积换算得到的 CO_2 封存容量为 13.7 Mt，是 HZ21-1 油藏的两倍以上（**表 2-3**）。其主力油层 K22 的大厚度和高起伏可能有利于实施“下一代”CO_2-EOR。另一个优点是该油田位于油田带中，因而便于与其他油田联合而扩大封存容量。HZ32-3 的平台距 HZ32-2 和 HZ26-1 的平台仅 5.6 km 和 4.8 km，而与 HZ21-1 平台则相距 25 km。对 HZ32-3 的主要顾虑是怕影响石油开采活动。

XJ24-3 油田

XJ24-3 油田也是一个发育在基底高之上的披覆背斜，含 21 个油层，含油段埋深 1872~2317 m，位于下中新统珠江组中-上部和中中新统韩江组下部。 砂岩储层的平均孔隙度 17~25%，有效渗透率 54~1982 mD，单层厚度<1~22.4 m。石油生产开始于 1994 年，到 2010 年底其探明储量为 30.4 Mt，累计产量为 19.8 Mt。储层原油密度 0.796~0.869 g/cm^3，粘度 2.3~12.4 mPa·s。油层具有超低的饱和度，无天然气顶或夹层，溶解气浓度低于 1 m^3/m^3。

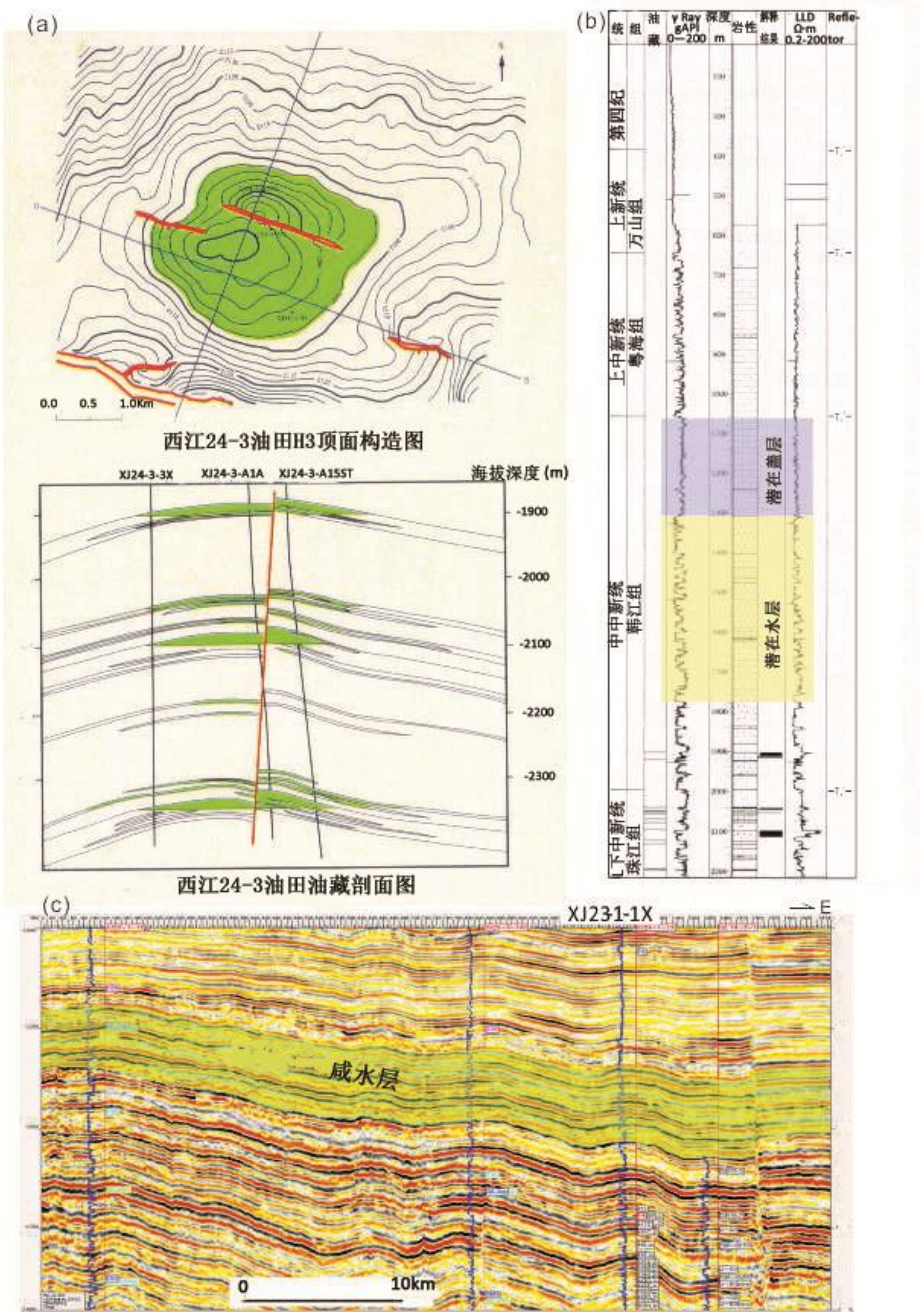
近年来 XJ24-3 油田表现出良好的储量增长潜力，因此目前我们仅考虑利用其咸水层来封存 CO_2。测井资料显示在其含油层系的上方即中中新统韩江组中-上部有厚度超过 400 m 的富砂层，其中砂岩的净厚度达到 280 m（**图 2-4b**）。从多道地震剖面可见该层在东-西方向上可追索到 40 km 以上（**图 2-4c**）。如果这个咸水层能用于封存 CO_2，其封存容量将会非常大；而 XJ24-3 油田的生产平台有可能被利用而降低封存成本。

但是，虽然测井曲线显示在韩江组上部有厚约 200 m 的盖层，目前我们还没有掌握关于这套盖层质量的数据。由于 XJ24-3 油田的地理位置靠近古珠江河口，其沉积物可能会粗一些。而且，地震剖面显示有断层切穿油层和盖层；油层中溶解气浓度低，没有天然气顶或夹层，是否说明其盖层封闭性较差？ 这些问题都有待回答。

总之，XJ24-3 油田中的 CO_2 可能封存机会在其上覆咸水层，这与枯竭油气田的 CO_2 封存条件完全不同，现有资料更少，关于储层特点和封闭条件的不确定性更多。确定这个封存场地需要进行大量工作，甚至包括采集新的数据和打新的评价钻井。

图 2-4 珠江口盆地 XJ24-3(a)油田构造图和剖面图

自朱伟林和米立军, 2010); (b) 综合地层柱状图，示中中新统韩江组中的砂质咸水层（黄色）和盖层（紫色）(自编纂委员会, 2011); (c) 多道地震剖面，示砂质咸水层的延伸情况(自 CNOOC)。



结论和建议

以前的工作已表明，广东省实施 CO_2 封存的潜在场地将在南海北部的珠江口盆地内，而降低离岸 CO_2 封存成本的一个有效途径是利用现有油气田的设备。为了给广东省首个全流程离岸 CCUS 项目选择封存场地，我们根据已发表的资料对珠江口盆地的 16 个在生产油田进行了 CO_2 封存适宜性筛选，主要考虑因素是油田近期废弃的可能性、CO_2-EOR 潜力、地质条件的适宜性、以及油田设备再利用于 CO_2 充注和运输的可能性。

经过筛选，HZ21-1, HZ32-3, and XJ24-3 这三个油田被选为 CO_2 封存的候选场地，在本报告中对它们进行了分析讨论。总的来说，三个场地各有自己的优缺点以及需要进一步研究的问题。HZ21-1 油气田的主要优点是早期废弃的可能性大、油田设备可利用的程度高，但目前对其封存容量是否能满足示范项目还没有把握。HZ32-3 油田有相对较大的封存容量和 CO_2-EOR 可能性，但其石油生产尚在积极进行，可能不希望受 CO_2 封存活动所干扰。XJ24-3 油田也处于积极勘探开发的阶段，我们关注的是利用油层上方的咸水层来进行 CO_2 封存。该咸水层厚度大，分布面积大，意味着巨大的封存容量，但目前我们不确定其盖层和断层的封闭性如何。

综合考虑上述优缺点，目前我们倾向于认为 HZ21-1 的油藏对于实施示范项目最为有利；其次为 HZ32-3 油田，如果通过今后的工作证明其具有 CO_2-EOR 的可行性，则其重要性会增加；最后是 XJ24-3 油田，其上覆咸水层用于 CO_2 封存的可能性需要较多的后续工作来辨识。

为了最终选出一个封存场地，上述重要的知识缺欠尚需通过进一步的工作来填补，以下工作被认为是最为迫切的：

1) 评估 HZ21-1 和 HZ32-3 的动态及最大 CO_2 封存容量，以判断各个油田是否能够满足所计划的海丰全流程离岸 CCUS 项目，即以每年 1 Mt CO_2 的速度注 20 年，或以每年 2Mt CO_2 的速度注 10 年，并估计其进一步扩大封存量的潜力。需要利用石油公司在长期生产实践中积累的并且更新的全部油藏和盖层资料进行 CO_2 充注模拟。由于这些油田规模较小，可能不具备足够的封存容量，因此评估时还需将油层下倾方向和下伏的咸水层考虑在内。

2) 评估在这些油田实施 CO_2-EOR 的技术和经济可行性。如果可行，CO_2 的充注就可在油田枯竭之前开始。

3) 评估 HZ21-1 和 HZ32-3 油藏以及 XJ24-3 顶部咸水层的密封性，检查其盖层、断裂及现有钻井发生 CO_2 泄漏的可能性。这种评估需要充分利用现有的地质、地球物理和地球化学资料、进行必要的补充采样和样品测试、以及通过进行充注的动态模拟。

通过这些工作有望最终选择一个封存场地，之后就会进入对封存场地的细致描述和前端工程设计阶段。

Potential of Reuse Existing Infrastructure: Preliminary Finding

For offshore CO_2 geological storage, the cost of building and operating marine engineering facilities is higher than onshore. If offshore facilities for oil and gas production can instead be utilized for CO_2 storage, the initial cost of constructing the project would be greatly reduced. Therefore, further survey and assessment should be made on the feasibility of utilizing exiting offshore engineering equipment in producing oil/gas fields for CO_2 storage, which will be very significant for development of offshore CCS. In this chapter, using the HZ21-1 oil and gas field as the candidate storage site, exiting oil and gas production facilities will be surveyed and analysed and the feasibility of reusing these facilities for CO_2 transportation and storage will be assessed.

After depletion, some third party oil and gas processing infrastructure might still be reusable and existing data could be used for CO_2 storage evaluation. Therefore, knowing when the hydrocarbon fields will be depleted is a critical factor in achieving cost reduction for demonstration CO_2 offshore storage. Other factors which need to be taken into account include time expectation, pipeline status, commerciality, safety, performance, monitoring, etc.

In the PMRB there are 16 hydrocarbon fields in production, 14 platforms and 1 natural gas processing platform, and other infrastructure such as pipelines and floating production storage and offloading (FPSO) vessels **(Figure 3-1)**. Preliminary research has been carried out on the oldest platform of the oilfield HZ21-1, which began production in 1990. The designed lifetime of the platform was 10 years, but extensive retrofits for extending the lifetime by another 10 years were carried out in 2004 and 2013, and a natural gas procession platform was built in 2005. Some components of this infrastructure were built as CO_2-resistant. Preliminary evaluation suggests

Figure 3-1 Sketch map of Existing Oil and Gas Field Infrastructure in the Pearl River Mouth Basin

that it is feasible to retrofit the facilities in HZ21-1 for CO_2 storage.

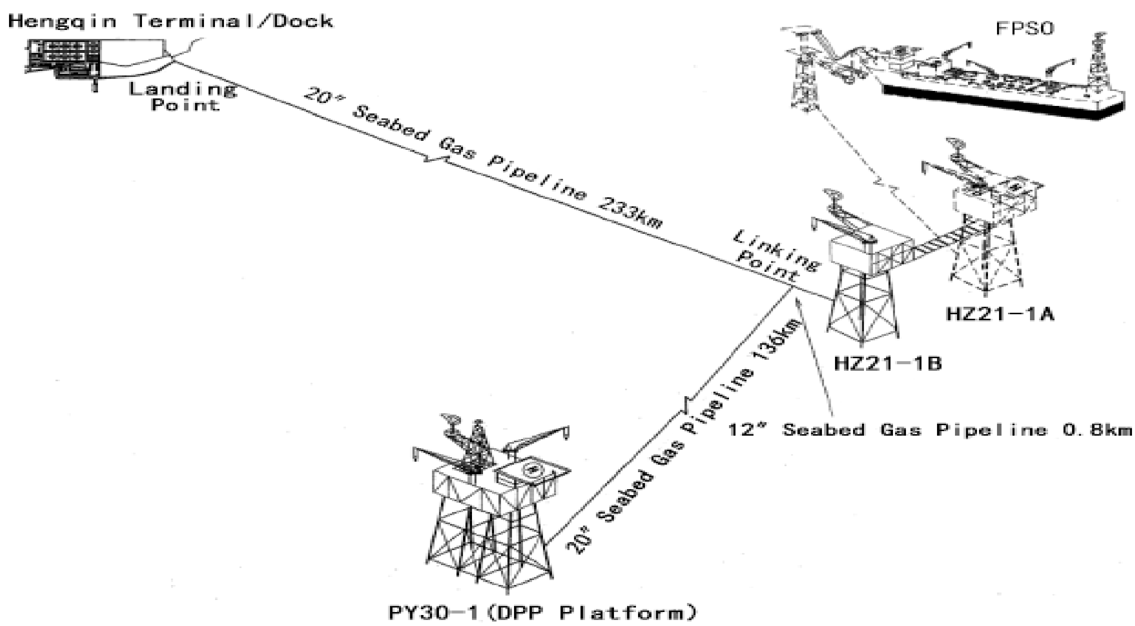
Status of Huizhou Oil and Gas Fields

HZ21-1 Oil and Gas field is the first small offshore marginal field developed cooperatively with ACT group in the area with > 100m seawater depth. Geographically, the field is located on the continental shelf of the Guangdong Province, South China. It is about 160 km southeast of Hong Kong, and about 170 km away from the nearby power plants and other large-scale carbon emission point sources located in Huizhou Daya Bay. The average water depth is 116 m, and the seabed terrain is flat. The area has a subtropical marine climate, the highest air temperature is 36 °C, the lowest is 6 °C, the annual average is 21.1-26.4 °C, the surface seawater temperature varies between 15-29 °C, and the bottom seawater temperature between 8.3-28 °C. The largest earthquake acceleration is 98 cm/s^2. There is an average of 10 typhoons a year. The surface current velocity is 21m/s, and the bottom 1.1m/s.

The whole development system of "*wellhead platform + FPSO + singlepoint mooring*" has been adopted, which contains one offshore wellhead platform and an FPSO system. The offshore platform is provided with a well drilling and servicing unit, accommodation module, primary gas-liquid separation device, gas compression equipment, a power distribution unit, pump, torch, and other support equipment. An oil carrier is provided with oily water separating, sewage disposal, electric power generation, water injection, crude oil storage and transportation equipment. The FPSO is connected to the platform by three seabed pipelines and one power cable. The field entered into production in September 1990. The platform is provided with 15 well slots which had been fully used. There are 10 design production oil wells, 1 gas well, and 1 water injection well which was subsequently converted into a production well. At present, there are 6 oil wells and 5 gas wells in production.

The HZ21-1 gas field was developed jointly with the

Figure 3-2 Schematic diagram of development and production facilities in HZ21-1 oil and gas field (Deng et al., 2010)



PY30-1 gas field in April 2003. A new platform for natural gas treatment, HZ21-1B, was built in 2005. This platform is located to the west of HZ21-1A. The two platforms were connected by a trestle bridge. The equipment on the HZ21-1B platform consists mainly of gas production and treatment facilities, such as systems for separating and cooling natural gas, compression, and compression recovery systems, a dehydration and triethylene glycol reproduction system, and remote monitoring and measuring instruments. The HZ21-1B platform receives and dehydrates natural gas produced by a well on platform A. The gas is then transported by seabed pipeline (with diameter of 12in and length of 800m) to where it connects with the pipe containing gas from the PY30-1 field, and then both gases are transported together by seabed pipeline (with diameter of 20in and length of 233km) to the terminal treatment plant on Hengqin Island, Zhuhai city **(Figure 3-2).**

The Potential to Reuse Facilities for CO_2 Offshore Transportation

Currently pipeline and ship are the main operational and proposed offshore CO_2 transportation systems. The pipeline transport of CO_2 could be either onshore or offshore, has been demonstrated as being the most effective method for large-scale and long-term CO_2 transport. In theory, exiting natural gas transmission pipelines, either onshore or offshore, can be reused for CO_2 transport. However, the different thermodynamic properties of CO_2 and natural gas along the process chain should be considered. The feasibility of reusing transportation infrastructure should be assessed. Ship transport is usually better for transport solutions requiring flexibility in terms of storage locations and/or transport durations. Consequently ship transport may be feasible for test injections and early large-scale demonstration projects. Compared to pipeline transport, shipping requires less initial capital investment, and might be less expensive for very long distance transport, for example >300km. The two transport solutions have different advantages and disadvantages depending on the transport volume, distance, geographic conditions, demands for flexibility, and the timing of investment decisions.

A single offshore pipeline transports the gas produced from the PY30-1 and HZ21-1 gas fields to the treatment terminal plant on Hengqin Island, Zhuhai city. The pipeline was designed for natural gas/condensate multiphase transportation. Because the the natural gas contains some CO_2 and H_2S the pipeline is mainly made of X65 steel and is partly corrosion resistant. Consequently X65 steel could be used as a subsea pipeline in CO_2 transportation with the addition of a corrosion inhibitor. The seabed pipeline of the HZ21-1 gas field has been in service for many years, and it’s operating state and degree of corrosion are unclear, which need further assessment. As proposed by a CNOOC expert, the state of pipeline is being checked and assessed, and the results will be useful for assessing whether it can be reused for the CO_2 project.

Ship transportation of CO_2 has been taking place for nearly 20 years, although at small scale for industrial and alimentary purposes. For example, the four existing CO_2 carriers in the European North Sea are each around 1500m^3, which carry the cargo at 15-30bar and around -30°C. However these ships are not suitable for large scale transport of CO_2. Liquid petroleum gas (LPG) carriers can be classified into three main categories: pressurized, semi-pressurized and fully refrigerated. The semi-pressurized ships are usually designed for a working pressure of 5-7 bar and operate at low temperatures (-48 °C for LPG, and -104°C for ethylene). This is the most frequent type of ship for LPG transport with a capacity up to nearly 20000m^3. Such vessels have normally two to six tanks, and each tank may have a capacity of 4500m^3. It may be possible to rebuild existing LPG ships as a combined LPG/CO_2 semi-refrigerated ship with a total capacity of 20000m^3 (Aspelund et al., 2006). However, no case study has yet been conducted on retrofitting an LPG ship for CO_2 transport in South China Sea, and it is essential as a next step to discuss the possibility of LPG ship retrofit for CO_2 transportation with shipyards and ship owners such as Jiangnan shipyard with 30,000 tonne plus ship building capacity.

Platform Retrofit and Reuse Potential

HZ21-1A is a simple wellhead platform. It's jacket is a double oblique type steel frame with 4 legs, which is formed by 4 king piles with a diameter of 60in and 8 skirt piles with a diameter of 72in. The top of the jacket is 18.9×18.9m, and the bottom 54.9x54.9m, total length 121.82m, weight 6011t. It was designed with a 15 years life and can meet the conditions and parameters of a once-in-a-century sea state. The platform is divided into main deck, working deck, life deck and cellar deck. The area of the main deck is 30.5×30.5m, located 26.8m above sea level. Drilling machinery, a well servicing unit, life module, helipad, flare boom and crane are arranged on the platform. The life deck is divided into four layers and its life support facilities can accommodate 50 platform staff. The area of the working deck is 30.5×30.5m, located 19.8m above sea level. All production facilities are arranged on the platform: production manifold, oil transfer pump, torch head, separator, production test separator, deck crane, high pressure gas separator, instrument air supply and regeneration device, pig receiving/sending device, chemical reagent injection system and drilling service lever block (including separator, mud pump, water tank), etc. The cellar deck is 5.2m×9.5m, located 2.42m below the working deck. All discharge devices (including open and closed systems) and storage tanks are arranged on this deck. Facilities on the platform include: instrument /instrument air and public air system, diesel oil, chemical agent injection system, crane and equipment operating system as well as emission system (including daily fresh water, sea water system, water drilling system, and sewer and sewage systems). Platform B is west of HZ21-1A, and the two platforms are connected by a bridge. Facilities on Platform B includes: gas production separation and cooling system, gas production compression system, gas recovery compression system, natural dehydration and triethylene glycol in-production system and remote monitoring and transferring gas meter.

HZ21-1A platform was built in 1990 with a design life of 10 years, and its jacket with a design life of 15years. The service lives were extended twice by 10 years in 2004 and 2013, so 9 years of working live remains. HZ21-1B platform was newly built in 2005 for natural gas processing. Consequently both platforms have sufficient remaining lives for reuse to be considered. In terms of **function**, HZ21-1A has the function of drilling, workover and oil and gas production. At present, it not only serves the production of HZ21-1 oil and gas fields but also provides drilling operations for oil-gas exploration in the surrounding target areas. Consequently it can satisfy the operation requirements of the CO_2 injection project such as well drilling, completion, and workover. Regarding **availability**, the platform is still carrying on normal oil-gas production, and the production manifold on platform A is being used in crude oil production, so it is possible to take advantage of these pipes only after crude oil production has stopped. HZ21-1 has stopped providing natural gas for Zhuhai terminal, so the unused natural gas compression system on platform B could be used for CO_2 compression. The gas lift wells and pipelines of HZ21-1 field can be used for CO_2 injection. The old gas lift process is highly suitable for reuse. In regard to the material of **pipes and tubes**, the existing manifolds are mainly made of pipe of American standard ASTM, such as A106, Gr B, A312 TP 316L, and APL-5LX-46 steels, which are all typical seamless steel tube materials and highly likely to be suitable for CO_2 transport and injection. However, the pipeline operations need further evaluation.

Though both platforms A and B are now dealing with the fluid from the wellhead, if it is to be utilized for CO_2 injection, platform B may need further analysis in relation to CO_2 transport and injection processing – which is similar to natural gas processing.

However, the following changes are required:

(1) For shipping, an appropriate offshore unloading system and pipelines need to be build according to the conditions of the platform, to transport the carbon dioxide from the storage tank on the ship to the platform;

(2) New pressure controlling valves need to be installed to maintain the carbon dioxide conveyed to the pipeline on the platform in a single high density phase;

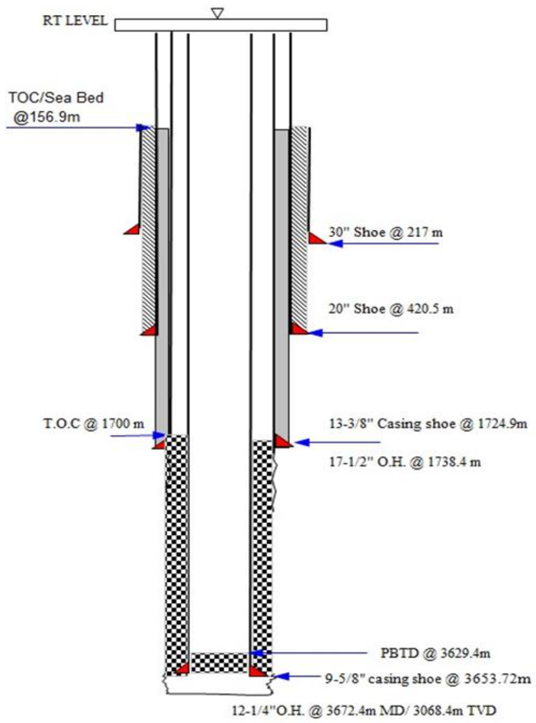
(3) The original separator should be replaced with a new carbon filter to make sure the injected CO_2 contains no impurities which could plug up the injection layers;

(4) Isolation valves should be added to the wellhead to prevent CO_2 returning from the wellbore to the platform.

Reuse of Wells

All development wells were pre-drilled through the well slots on the seafloor chassis in the HZ21-1 oilfield. After drilling, the wellhead on the chassis was connected back to the production platform. The chassis of the HZ21-1 oilfield is an integral one covering 15 seafloor wellheads and is supported and fixed by three 30in pile pipes. At present, 15 well slots have all been used up. Taking HZ21-1-10 as an example, it has a typical four-section casing well structure **(Figure 3-3)**. It was completed by the semi-submersible drilling platform named South China Sea 5 in April 12, 1989 and it's drilling depth is 3672.4m (TVD:3068.4 m). After the HZ21-1A platform was built, it was tied-back to the wellhead with 20in, 13-3/in and 9-5/8in casings. In terms of its reuse potential for CO_2 storage, the **casing materials** of the

Figure 3-3 Structure diagram of HZ21-1-10 well in HZ21-1 field (from CNOOC)



wells in HZ21-1 field are commonly N80 steel, which has poorer CO_2 corrosion resistance and a higher risk of local corrosion; the **oil well cement** in HZ21-1 oilfield is G grade cement, which can be used for CO_2 injection well cementing, but has poorer CO_2 corrosion resistance; the materials of the **production tubing** in HZ21-1 oilfield are commonly L80-13Cr steel. 13Cr steel has better corrosion resistance for CO_2 and therefore can be used in a CO_2 injection project.

现有基础设施再利用潜力：初步分析结果

对于离岸封存而言，由于海洋工程设施建设和运行成本都比陆上高很多，因此寄希望于在不影响油气正常生产条件下，尽可能利用海上已有的油气田开发设施进行 CO_2 注入封存，从而大幅降低初始工程建设成本，因此，离岸设施能不能利用于 CO_2 注入封存工程的可行性亟待开展评价和研究。本章节以广东省近海惠州 21-1 油气田作为待选离岸封存场地，对油气田设施是否能够利用于 CO_2 运输和封存工程进行初步分析，以期为示范项目的前期试注和前端工程设计做准备。

油气田枯竭之后，一些第三方油气生产与加工基础设施有可能可以重复利用于 CO_2 注入封存，现有的数据也可用于碳封存评估。因此，了解油气田何时枯竭对于减少离岸碳封存示范的成本至关重要。其它还需要考虑的因素包括时间预期、管道现状、商业性、安全性、绩效、监测等。

珠江口盆地浅水区现有 16 个在生产油田，有 14 个生产平台和 1 个天然气处理平台，还有管道、浮式生产储卸油装置等设备（图 3-1）。对其中于 1990 年投产的最老油田 HZ21-1 的生产平台进行了初步调查。该平台设计寿命 10 年，但在 2004、2013 年进行了两次延长 10 年寿命的改造，在 2005 年还增建了天然气处理平台，有些设备具有抗 CO_2 腐蚀的性能，初步研究认为具有经改造后再利用于 CO_2 充注的可能性。

图 3-1 现有珠江口盆地石油与天然气田基础设施示意图

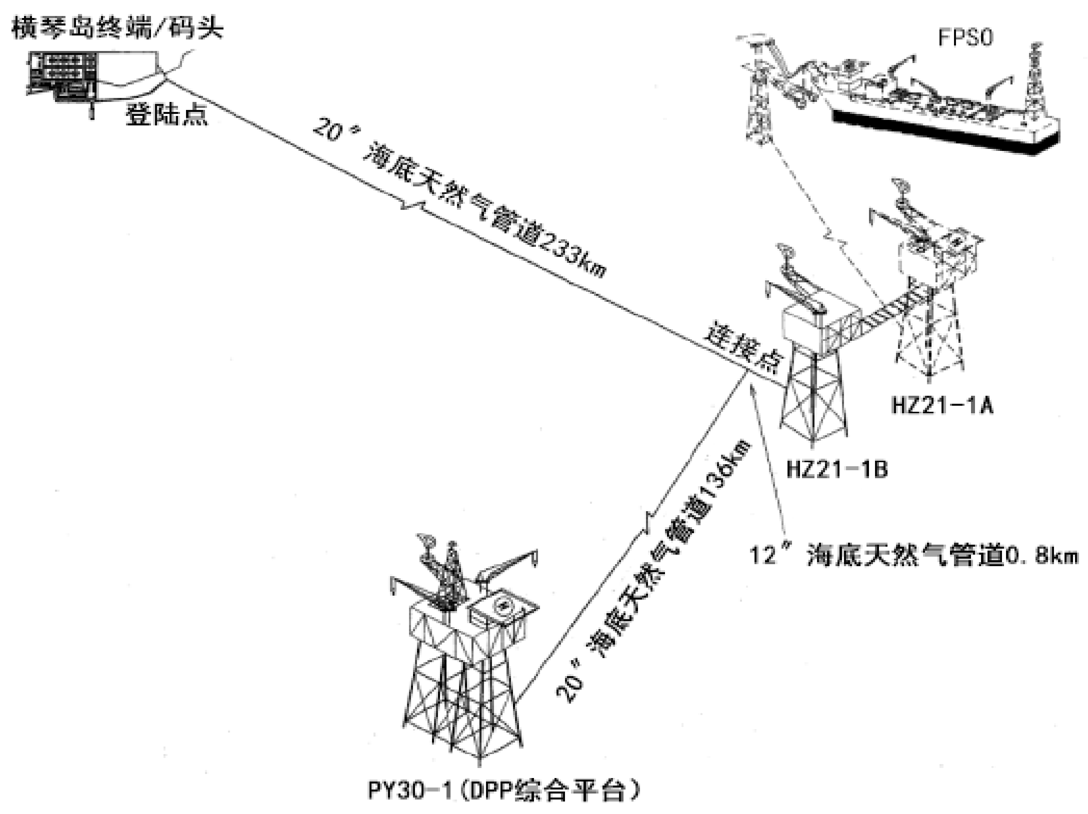
惠州油气田的基本状况

惠州 21-1 油气田是我国离岸与 ACT 集团合作开发的第一个水深超过 100 米的小型边际油气田，水深 116m，年平均气温 7~36 °C，最大地震加速度 98cm/s^2，台风年平均数 10 次。海流速度：表面流 2.1m/s，海底流 1.1m/s；海水温度：海面 8~34 °C，海底 15~17 °C。

惠州油田采用“井口平台+浮式生产储卸油装置（FPSO）+单点系泊”的全海式开发方案，包括一个井口平台和一艘生产储油轮/单点系泊系统。平台上设有可用于辅助船钻井的钻、修井机、生活模块、初级气液分离设备、气体压缩设备、配电装置以及泵、火炬和支持设备等。游轮上设置油水分离、污水处理、发电、注水和原油储存外输设备等。FPSO 与平台之间由三条海底管线和一条动力电缆相连。油田于 1990 年 9 月投产。平台共有 15 个井槽，设计生产井 10 口，气井 1 口，注水井 4 口（后转为开发井）。

2003 年 4 月惠州 21-1 气田与番禺 30-1 气田进行联合开发，于 2005 年新建了惠州 21-1B 平台作为天然气处理平台。该平台位于惠州 21-1A（原惠州 21-1）平台西侧，通过栈桥将两个平台连接起来。上部设施包括：天然气生产分离和冷却系统、天然气生产压缩系统、天然气回收压缩系统、天然脱水和三甘醇再生产系统以及远程监测交接气体计量仪。来自惠州 21-1A 平台上气井产出的天然气在此进行脱水，后经 800m*12in 的海底管道输送至连接处与来自番禺 30-1 气田的天然气汇合，再经过 233km*20in 的海底管道输送至珠海横琴岛的终端处理厂（图 3-2）（刘宝和等，2011）。

图 3-2　惠州 21-1 油气田开发生产设施示意图(邓晓辉等, 2010)



现有设备再利用于二氧化碳离岸运输的潜力

离岸二氧化碳运输包括管道和船舶运输两种方式。无论是陆上还是海上，二氧化碳管道运输方式已经被证实是大规模长距离运输的有效方式。理论上，现有的离岸或陆上的天然气输送管道都有可能被用来运输二氧化碳，但在整个过程链条中必须考虑二氧化碳不同于天然气的化学和热力学性质，对管道进行再利用可行性评价。船舶运输方式比较灵活，可以应对二氧化碳封存地点和持续时间等，因此可能适用于试注和早期示范项目。与管道运输相比，船舶运输所需的首次投资额度较少，如果运输距离超过 300km，它有可能比管道运输更经济。根据运输量、运输距离、地理条件、灵活性需求、投资决策时间等不同需求，管道和船运有其不同的优势和劣势，因此需要根据项目具体情况选择合适的运输方式。

珠江口盆地目前只有一条运输天然气的海底管线，将位于南海珠江口盆地流花 07 自营区块的 PY30-1 气田产出的天然气在平台上经脱水处理合格后与脱水后的凝析油混合进入外输管道，并在 HZ21-1B 平台附近与 HZ21-1B 平台生产的天然气混合，然后输往珠海天然气终端处理。该管线材料为 API 5L X65 钢设计入口组份含约 6%CO_2 可见，该海管具有一定的防腐蚀性（邓晓辉等，2010）。因此，结合缓蚀措施，X65 钢海底管道可以用于输送 CO_2。由于惠州 21-1 气田管道已经服役多年，目前的管道运行状态和腐蚀程度等还不清楚，需要进一步进行评价。据中国海洋石油深圳分公司专家介绍，目前他们正在开展海管评价工作，其结果将为开展利用海管输送 CO_2 可行性评价提供基础数据资料。

二氧化碳船舶运输已经发展近 20 年，不过船舶规模都比较小，主要运输工业和食品用途的二氧化碳。例如在欧洲北海有四艘二氧化碳运输船，每艘约 1500m^3，压力 12-30bar，温度约-30 °C。但这些船舶不合适于大规模的二氧化碳运输。在全压、半压和全冷冻三种液化气运输船舶中，半压的液化气（LPG）船设计压力一般为 5-7bar, 工作温度也很低，其运输液化气的工作温度为-48 °C，运输甲烷的温度为-104 °C。该类 LPG 船一般具有 2-6 个储罐，每个储罐储存能力为 4500m^3，船舶总运输 LPG 的能力可达 20000m^3。因此，该类 LPG 船可以改装成为具有 20000m^3 运输能力的 LPG/CO_2 联合运输船 (Aspelund 等, 2006)。本研究尚未对中国南方的 LPG 船舶改造进行研究，下一步需要与主要造船厂和船东探讨改造潜力，如具备 30000 吨以上船舶制造能力的江南造船厂。

平台再利用和改造的潜力

惠州 21-1A 平台是一个简易井口平台。导管架是一座双斜式 4 腿钢架，由 4 根直径为 60in 的主桩和 8 根直径为 72in 的裙桩组成。导管架顶面为 18.9*18.9m，底面为 54.9*54.9m，总长 121.82m，重 6011t。导管架按平台设计寿命 15 年进行设计，并满足百年一遇的海况条件和参数。平台分为主甲板、工作甲板和底层甲板。主甲板面积 30.5*30.5m，位于海平面以上 26.8m。甲板上布置钻机、修井机、生活模块及直升机坪、火炬臂及吊车。生活甲板分为 4 层，可容纳 50 位平台工作人员生活及配套设施。工作甲板面积为 30.5*30.5m，位于海平面以上 19.8m 的高度。甲板上布置了所有的生产设施：生产管汇、输油泵、火炬头、生产分离器、测试分离器、甲板吊机、高压燃气分离器、仪表风供给及再生装置、清管器接收/发送装置、化学试剂注入系统、钻井服务撬块（包括分离器、泥浆泵、水罐等）等。底层甲板面积为 5.2m×9.5m，位于工作甲板以下 2.42m。甲板上布置了所有排放装置（包括开放式系统和闭式系统）及储罐。平台上的公共设施包括：仪表/仪表风和公共用风系统、柴油系统、化学剂注入系统、吊车及设备操作系统以及排放系统（包括生活用淡水、海水系统、钻井水系统、排污系统及下水道系统）。惠州 21-1B 平台位于惠州 21-1A 平台的西侧，通过栈桥将两个平台连接起来。上部设施主要包括：天然气生产分离和冷却系统、天然气生产压缩系统、天然气回收压缩系统、天然脱水和三甘醇在生产系统以及远程监测交接气体计量仪（刘宝和等，2011）。

HZ21-1A 建于 1990 年，设计寿命 10 年，导管架设计寿命 15 年。曾在 2004 年和 2013 年进行了两次延长寿命 10 年的改造，因此目前运行寿命还剩余 9 年。HZ21-1B 平是在 2005 年新建的天然气处理平台，因此，从平台的运行寿命来看，两个平台是可以利用的。在功能方面：HZ21-1A 平台具有钻井、修井及油气生产功能，目前除了服务于惠州 21-1 油气田的生产任务外，还为周边目标区的油气勘探提供钻探作业服务。因此 HZ21-1A 可以满足 CO_2 注入工程所需的钻完井、修井等作业功能。从 CO_2 注入处理可用性考虑，由于平台目前还进行着正常的油气生产活动，A 平台上的生产管汇都在利用于原油生产，因此只有在原油生产停止后，才有可能利用这些管线。由于 HZ21-1 已停止向珠海终端供气，因此 B 平台上闲置的天然气压缩系统有可能用来进行二氧化碳压缩处理。HZ21-1 有气举井，注气流程管线有可能利用于注入二氧化碳。旧的气举工艺流程利用可行性比较高。管材方面，现有的管汇材料一般采用的是美国标准 ASTM 的管材，如 A106 Gr B，A312 TP 316L，API-5L Gr B，API-5LX-46，都属于较为典型的高温高压作用条件的无缝钢管材料，利用于 CO_2 注入输送的可能性比较高，但需要重新对管线运行状况进行进一步评估。

虽然目前的 A、B 平台都是处理来自井口的流体，但是如果利用其进行二氧化碳注入，还可能需要对 B 平台进行评估，以考虑二氧化碳运输和充注过程的需要，类似于天然气处理工艺。

需要进行以下几方面的改造：

（1）如果采用船舶运输，需要根据平台情况建设合适的卸载系统及和管线，将船舶储罐中的二氧化碳输送至平台；

（2）B 平台甲板上需要安装新的压力控制阀，以控制输送至平台上管线内的二氧化碳为单独高密度相；

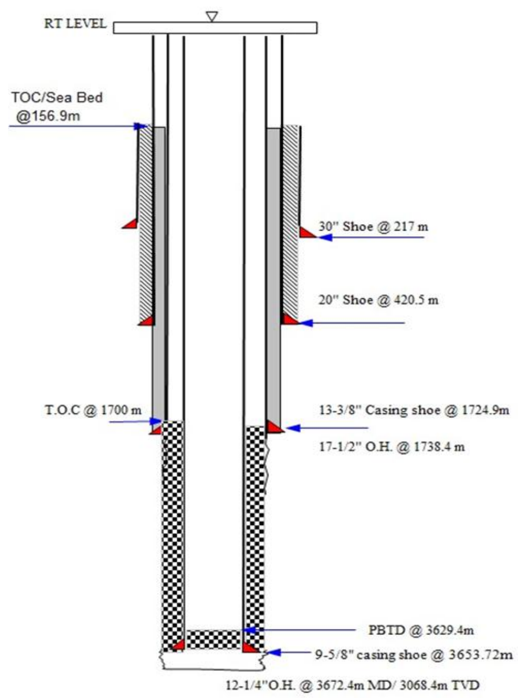
（3）原分离器需要更换，安装新的二氧化碳过滤器，以保证注入的二氧化碳不含能堵塞注入层位的杂质；

（4）井口增加隔离阀，防止二氧化碳从井筒返回至平台。

油井再利用

惠州 21-1 油田是通过海底底盘上的井槽预钻全部开发井，完钻后，再将底盘上的井口回接到生产平台上。惠州 21-1 油田底盘为 15 孔海底井口整体式底盘，由三根 30in 桩管支撑固定底盘。目前 15 各井槽全部用完（刘宝和等，2011）。以 HZ21-1-10 为例，可以看到为典型的四段式套管井身结构（**图 3-3**）。该井是由南海 5 号于 1989 年 4 月 12 日完钻的，完钻井深 3672.4m（TVD: 3068.4m）。HZ21-1A 平台建好后，回接 20in 套管、13-3/in 套管和 9-5/8in 套管到井口。惠州 21-1 油气田采用预钻井回接平台井口完井方法，用的是 Cameron 水下回接系统。在二氧化碳注入可利用方面，目前惠州 21-1 油田套管材料普遍为 N80 钢，CO2 耐腐蚀性较差，发生局部腐蚀的风险较高；惠州 21-1 油田钻井固井水泥为“G”级油井水泥，普通 G 级水泥可以用于 CO_2 注入井的固井，但耐 CO_2 腐蚀性较差；目前惠州 21-1 油田采用的生产管柱材料普遍为 L80-13Cr 钢级、13Cr 钢具有较好的 CO_2 耐腐蚀性，可以用于 CO_2 注入。

图 3-3　惠州 21-1 油气田 HZ21-1-10 井井身结构示意图



Recommendation for Offshore CO_2 Storage Research and Demonstration in Northern South China Sea

General timetable for Guangdong Offshore CCUS Project

The offshore CO_2 storage research and demonstration in northern South China Sea is an integral part of the Guangdong Offshore CCUS Project. Therefore, the timetable of the Storage R&D should follow the general timetable by Guangdong CCUS Center for the Guangdong Offshore CCUS Project. This general time table consists of four stages, as listed in **Table 4-1**.

Feasibility Studies for offshore CO_2 Storage

As indicated in **Table 4-1**, in the stage of feasibility study from 2015 to 2017 there are three tasks for the Storage R&D: Site selection, site characterization, and design for test CO_2 injection.

Table 4-1 General timetable for the Guangdong Offshore CCUS Project

Stage	Feasibility stud (2015-2017)	FEED[1] (2018-2020)	Demo project (2021-2025)	Commercial-scale CCUS project (2026 and later)
Capture	Develop a 70,000 t/a testing platform	FEED of demo capture	Construction & operation of demo capture	FEED, construction & operation
Transport	Transport type selection & design	FEED of demo transport	Construction & operation of demo transport	FEED, construction & operation
Storage	Site selection, characterization, design for test injection	Test CO_2 injection; FEED of demo CO_2 injection	Construction & operation of demo injection	Monitoring of demo injection site; FEED, construction & operation

1] FEED: Front End Engineering Design

Studies for storage site selection

Previous work has demonstrated that the best sites for CO_2 storage in Guangdong are in the shallow water area of the Pearl River Mouth Basin (PRMB), northern South China Sea. As discussed in Chapter 2 of this report, three most favourable hydrocarbon fields have been selected from this basin as the candidates for the first offshore CO_2 storage demo project. These candidate sites are tentatively arranged in the order of favourability as HZ21-1, HZ32-3, and XJ24-3. The next step is to carry out further researches on these sites in order to select one site finally. The following studies are suggested:

1. The effectiveness of containment.

Although existing hydrocarbon fields can demonstrate the effectiveness of the caprock for restraining hydrocarbons, CO_2 has a better penetrating capacity than oil and natural gas. Therefore, further commercial quality investigations are required for the effectiveness of the caprock against CO_2. In addition, the leakage risk along faults and existing wells need to be evaluated. The following studies need to be done:

1) The lithology, thickness and lateral continuation of the caprock will be estimated based on information deriving from cores, well logging and seismic data.
2) Rupture pressure and capillary breakthrough pressure of the caprock will be analysed from the compilation of the previous data and more sample tests. It may be necessary to try to obtain new well samples
3) The sealing characteristic of the faults in the vicinity of the candidate fields will be analysed using geological, geophysical, and geochemical information.
4) The leakage risk along existing wells will be evaluated along with the evaluation forre-using existing infrastructure.

2. The capacity and injectivity of reservoirs based on injection simulation.

Previous work has simulated injection only for the HZ21-1 field using information from one well only. For a more reliable assessment, all the available data on the reservoirs, caprocks, faults and well loggings of the fields HZ21-1 and HZ32-3 will be used in the simulation to obtain the following information:

1) The maximum storage capacity of each field under the constraint of no leakage;
2) The CO_2 injectivity, including the optimum rates of CO_2 injection, the pressure build up, and the dispersion of CO_2 plume.

The modeling for the top saline formations in the XJ24-3 field will be conducted only after its caprock sealing quality has been confirmed.

3. The re-use of existing infrastructure

It includes the following aspects:

1) The feasibility of the re-use of the platform and installations for CO_2 injection preparation (temperature and pressure adjustment) and for storage, and a suitable retrofit scheme;
2) The feasibility of the re-use of the wellbores, a suitable retrofit scheme, and the risk of leakage along active and abandoned wells;
3) The feasibility of the re-use of pipelines and other equipment, and a suitable retrofit scheme.

4. The final selection of storage site.

According the conclusions of the above studies, the best storage site will be chosen for test CO_2 injection and demonstration CO_2 storage.

Storage site characterization

The studies for site characterization are highly site specific and will be proposed after the site selection is finalized.

Design of test CO_2 injection

As offshore CO_2 injection has not been conducted in the northern South China Sea to date, a test injection of several thousands tones or more of CO_2 at the selected storage site is considered necessary for testing the retrofitted equipment and various injection scheme, for refining formation data, and for gaining technical confidence in offshore CO_2 storage under the geological, geographical, and engineering conditions of the northern South China Sea. All these would be helpful to a successful demonstration project. The test injection design shall include monitoring techniques and at least one appraisal well (may use existing well).

南海北部离岸 CO_2 封存研究和示范建议

广东省离岸 CCUS 项目总时间表

南海北部离岸 CO_2 封存研究和示范是广东省离岸 CCUS 项目的组成部分之一，因此封存 R&D 应该服从广东省离岸 CCUS 项目的总时间表的要求。这个总时间表可分为 4 个阶段，见**表 4-1**.

表 4-1　广东省离岸 CCUS 项目总时间表

阶段	可行性研究 (2015-2017)	前端工程设计 (2018-2020)	示范工程 (2021-2025)	商业规模 CCUS (2026 及以后)
捕集	70,000 吨/年捕集中试平台建设和运行	示范工程的捕集前端工程设计	示范工程的建设和运行	商业工程的设计、建设和运行
运输	运输方式选择和设计	示范工程的运输前端工程设计	示范工程的建设和运行	商业工程的设计、建设和运行
封存	封存选址；场地详查；CO_2 试注设计	试注；示范工程的封存前端工程设计	示范工程的建设和运行	商业工程的设计、建设和运行

离岸 CO_2 封存的可行性研究

如表 4-1 所示，在 2015 到 2017 年的离岸 CO_2 封存的可行性研究阶段要进行三项工作：封存选址、场地详查、CO_2 试注设计。

封存选址有关研究

前期研究已论证了广东省实施 CO_2 封存的最佳场地在南海北部珠江口盆地的浅水区内，而利用生产油田的资料和设备有利于降低封存成本。本报告的第二章已说明，经过对珠江口盆地的浅水区 16 个生产油田的分析，为广东省离岸 CCUS 项目选出了三个油田作为候选封存场地，并初步按其优先程度排队为 HZ21-1、HZ32-3、XJ24-3。下一步就是要对这些候选场地做进一步的研究，以最终确定一个封存场地。所建议的研究内容如下：

1. 场地密封性

虽然油藏的存在证明了盖层对封闭石油的有效性，但由于 CO_2 的穿透能力要大于石油和天然气，还是要进行满足工程质量要求的研究，以查明盖层对 CO_2 的封闭能力。另外，沿断裂和已有钻井的 CO_2 泄漏风险也需要评估。为此需做以下工作：

1) 根据钻井岩心、测井及地震资料估计盖层的岩性、厚度和横向连续性。

2) 根据前人资料和新的样品测试分析盖层的破裂压和毛细突破压；为此可能需要采集新的钻井岩心样品。

3) 根据地质、地球物理和地球化学资料评估油田内部和附近断裂的封堵性。

4) 评估已有钻井的 CO_2 泄漏风险；将与现有设备再利用可行性研究同时进行。

2. 场地封存容量和充注性的模拟

前期工作仅利用一口井的资料对 HZ21-1 的油藏进行了 CO_2 充注模拟。为了提高模拟结果的可信度，需要利用关于油藏、盖层、断裂和测井的所有资料，对 HZ21-1 和 HZ32-3 的油藏进行 CO_2 充注模拟，以获得该两个油田的下列资料：

1) 在不发生泄漏的前提下的最大 CO_2 动态封存容量。

2) CO_2 的充注性，包括 CO_2 的最佳充注速度、压力增高情况和 CO_2 扩散范围等。

对 XJ24-3 油田顶部咸水层的 CO_2 充注模拟仅当其盖层的质量得到肯定以后才考虑进行。

3. 现有设备可利用性评估

1) 现有平台及其设备再利用于 CO_2 的充注准备（温度和压力的调节）以及 CO_2 的封存充注的可行性及改造的初步方案；
2) 现有钻井再利用于 CO_2 充注的可行性、改造的初步方案及沿在用和废弃钻井发生 CO_2 泄漏的风险；
3) 现有管线及其他设备再利用于 CO_2 运输或充注的可行性及改造的初步方案。

4. 封存场地的最终选择

根据以上研究的结果，选择最佳的场地作为 CO_2 试注和封存示范的场地。

封存场地详查

封存场地详查的方案随封存地的不同会有较大变化，因此必须在场地选择完成之后才能提出建议。

CO_2 试注的初步方案

由于南海北部至今尚未进行过 CO_2 充注，我们认为在所选的封存场地进行几千吨或更多 CO_2 的试是很有必要的。通过试注将检验经改造的设备的功能，将试验和改进充注方案，将采集更多的储盖层参数和改进储盖层模型，将培训有关技术人员，增强我们在南海北部的地质、地理和工程条件下实施 CO_2 封存的信心。所有这些都将有助于下一步成功地进行示范工程的设计和施工。

CO_2 试注的方案随场地而不同，只有在场地选择完成之后才能设计。试注方案必须包含监测内容和技术，至少有一个评价井（可用已有钻井）。

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Appendix

附件

System: Scientific Research Management Number: 2015-RM-01-01	Version: A Modified Number：0 1□2□3□4□5□
体系名称：科研管理 编　　码：2015-RM-01-01	版　　本：A 修 改 码：0 1□2□3□4□5□

Interim Procedures of Carbon Dioxide Capture and Offshore Storage Demonstration Projects Management (Draft)

二氧化碳捕集及离岸封存示范应用研究科研项目管理暂行办法(草案)

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Interim Procedures of Carbon Dioxide Capture and Offshore Storage Demonstration Projects Management (Draft)

1. Aim

The aim of the regulation is to make the management of research projects under Guangdong CCUS Centre (hereinafter referred to as Centre) more standardized and scientific, and to specify the working requirements and procedures on the project initiation management, process management, funds management and acceptance management, in association with the requirements of carbon dioxide capture and offshore storage related technologies development.

2. Range of Application

Research projects implemented by the Centre and projects the Centre is involved in.

3. Basis of Compilation

3.1 The National Program for Long- and Medium-Term Scientific and Technological Development Plan (2006-2020).

3.2 Interim Provision of National Science and Technology Major Project (No. 453(2008) issued by the Ministry of Science and Technology of China)

3.3 Regulation on National Science and Technology Major Project of CNOOC (No. 622 (2011) issued by Risk Office of CNOOC)

3.4 Programme on Deepening Science and Technology Reform Plan (projects, funds, etc.) of the Centre Government (No. 64 (2014) issued by the State Council)

4. Major Risks

4.1 Research projects do not meet the requirements on scientific and technological plans of the Centre, so cannot efficiently support its development.

4.2 Research projects cannot solve key technical issues restricting the development of the Centre, due to no achievements as expected.

4.3 Audit risks resulted from inappropriate fund use for research projects.

4.4 Risks of academic misconduct behaviours due to non-standardized management of research projects

5. Specification

5.1 **The Centre** refers to Guangdong CCUS Centre.

5.2 **Research projects** refer to all of scientific and technological projects that the Centre initiates, organizes and involves in.

6. Assignment of Responsibility

6.1 The Centre

Conducting research projects is the important part of the Centre's work, including:

a) To set up and revising management systems of research projects of the Centre and supervise them to be implemented.

b) To organize the drawing up of annual plans and budgets of research projects and to supervise them to be implemented.

c) To organize the initiation, implementation and check and acceptance management of research projects.

d) To solve major problems during the implementation of research projects.

e) To summarize the management of research projects.

6.2 Advisory Board of the Centre

As the top scientific and technological regulatory agency, Advisory Board of the Centre has the power to make decisions on the professional development plans, research development plans, annual research plans and their adjustment, and to supervise the setting up of research projects and technical supporting points and their adjustment, the outsourcing examination and approval, acceptance of projects and achievement appraisal. The duties are:

a) To keep up with tendencies of CCS development home and abroad and related technical requirements, and bring up corresponding countermeasures and advice.

b) To examine scientific and technological development plans and technology introduction and retrofit programme of the Centre, and to provide opinions on major technical issues for the leadership for reference.

c) To organize in demonstrating the initiation of research projects and examine and approve implementation departments, groups, the recommended project principals, examine and verify contracts that are delegated to other institutions and annually examine execute progress, examine production quality of research projects, inspect, appraise and check outputs for medium-term, and assist researchers to solve technical difficulties in the process of production.

6.3 Undertakers of Research Projects

Undertakers of research projects is the ones responsible for the implementation, who is responsible for achieving targets, accomplishing research tasks, breaking through key technologies, managing funds and intellectual property and keeping confidentiality. Their tasks are:

a) To identify the project principles and build up the project team.

b) To organize and implement the project, and collecting fund the project needs and providing related support for the implementation.

c) To complete the initiation report, the implementation report and the check and acceptance report.

d) To audit budgets, manage process and inspect the project of outsourcers, meanwhile assist in reviewing qualification and signing contracts of outsourcers.

e) To apply and extend outputs of the project.

f) To manage intellectual property and keep confidentiality for outputs of the project.
g) To assist in conducting internal audit on fund use for the project.

6.4 The Research Project Principals

The project principals should take charge of managing, organizing and implementing the project, who should be dedicated to it for more than 70% of service time. The responsibilities include:

a) To organize in drawing- up of the execute plan, and organizing resources to implement it.
b) To organize in making budgets for project fund and coordinating other fees.
c) To organize in screening and recommending outsourcers, auditing their budgets, managing the quality in the process of the outsourcing project, and checking it with the undertaker.
d) To accept supervision and inspection on the process of the project from the Centre and related departments in Guangdong and China.
e) To complete related reports on the initiation, implementation and acceptance of the project.
f) To take part in big events on the initiation demonstration, process review and acceptance of the project and give a report.
g) To give a report on big events and their adjustment in the implementation process.
h) To organize in financial statement and submit the financial statement report.
i) To take charge of the use, registration and protection of intellectual property.
j) To collect and archive documents on scientific and technological projects.
k) To conduct trials and complete post-assessments on application and transition of fruits to productivity after the project.

7. Management Requirements

a) To follow the principle of combining the Centre with other agents in the management of research projects, which means the initiation, implementation, check and acceptance, and funds allocation will be governed by the Centre in conformance with its management systems and requirements.
b) To stick to the principle that experts take part in decision-making, which implies the ways to review by industrial expert teams is to make decisions in key points during the initiation, implementation, and check and acceptance.
c) To implement whole process management on research projects, that is to say, the whole process such as the initiation, implementation and check and acceptance of projects should be operated in the Centre's management system of research projects, and make it specific for managing responsibilities and procedure requirements in technical decision-making and major measures.
d) To adhere to the principle that fund use for research projects should be covered in their process management and the focus is to improve the audit and verification of budgets and financial statement.

7.1 Requirements on the initiation management

a) A research project is proposed by demanders/ project teams/ project partners, and the application including annual budgets, projects' construction budgets and outsourcers' selection should be submitted to the Centre.
b) Advisory Board of the Centre is responsible for demonstrating the initiation of research projects, reviewing the application submitted by demanders/ project teams/ project partners, and providing advice. After approved by the Advisory Board, the project is allowed to be initiated and applied.
c) After the initiation is approved, the project team should submit the application form to the financial department of the Centre, so as to keep track of fund use.

7.2 Requirements on the implementation management

a) All research projects demonstrated and approved by the Advisory Board should be operated in accordance with related management rules of the Centre.
b) Before the implementation of all outsourcing projects, proposals on the research tasks and the initiation should be submitted to the Advisory Board and all of those could be implemented after the Board's approval.
c) The operation of all outsourcing projects, including tasks, contractors, value and period of the contract, should be conducted within the framework approved by the Advisory Board on the basis of following the rules on the Centre's procurement management.
d) The project team could select and employ leading experts if necessary, who must be approved by the Centre's leadership. Those authoritative expert experts, who should be familiar with the state of development in a field the project belongs to, are required to have the ability to make comprehensively analysis and judgement in technical, economic, market and industrial policies, whose basic responsibility is to participate in the whole project or some of them and to help the leader with technical roadmaps. The costs are covered in funds of the project.
e) The project team makes quarter and annual reports on the process. If there are situations where such changes in targets, research subjects, the leader, and key technical schemes and irresistible factors have significant effects on the implementation, report to the Advisory Board in time and wait for its response.
f) In the process of implementation, mid-term outcome review should be organized according to specific requirements.
g) If the project period needs to be extended, the project team should submit the written application to the Advisory Board and wait for its official response to allow for implementation.

7.3 Requirements on fund management

a) Research project fund management from Guangdong province, national departments and institutional investors, should abide by related rules.
b) Research project funds cover such expenses for technology introduction (expenditures in equipment purchase or manufacturing trials included), operation (including material expenses, experimental expenses, costs in fuel and power, data or document expenses, expenses for initiation demonstration/ mid-term review/ assessment/ acceptance meetings, expenses for consultancy and review paid for experts, travel expenses, expenses for expert employment, costs in publishing or intellectual property matters), outsourcing, tests and collecting data sent out

to other agents, academic exchange and collaboration with organizations home or aboard, shared personnel costs, shared costs in building or equipment lease or depreciation costs, matching budgets of supporting projects and other expenses.

c) Rigid control over the budget breakdown system should be conducted for research projects: WBS needs to be set up in SAP for auditing the budget breakdown based on different grades according to detailed budgets, and online budget breakdown and total sums are controlled at the same time, so that actual breakdown and total sums beyond the budget could be avoided.

d) Rigid control over total budgets for research projects: IO needs to be built up in SAP for trace management, through which rigid control over online total budgets can be conducted in a way that expense controllers of different projects control the budget of each project in order to avoid the overrun of actual breakdown and total sums.

e) As for expenses for meetings and business trips in the project implementation, supporting documents for claim should be provided according to the classification of claim.

7.4 Requirements on acceptance management

7.4.1 Research projects are accepted by the Advisory Board at first, and then organized by Guangdong province, national departments and institutional investors for acceptance.

7.4.2 Centred on contents specified in the mission statement and testing goals in it, the acceptance of the project makes objective assessment for research subjects, achievements, major technical innovation, application effects on economic and social benefits, organizational management and documents and data.

7.4.3 Acceptance procedures

a) Acceptance of the project needs to be accomplished in half a year after completing the contract, meanwhile the project team should complete all reports in time.

b) The project principals should submit the acceptance application and related materials to the Advisory Board ahead of 30 days at the end of the contract period after accomplishing the technological research and development summary through the verification of undertakers. These materials for expert’s review include: the contract, the technological research and development report, the fruit application report, patent forms, technical standards of the fruit application, basic data on the list of fixed assets like purchased instrument and equipment in a book form, outcomes in a certain form (like machine models and samples) and financial statement.

c) The Advisory Board gives an official response to the acceptance application, and then organizes experts to conduct the acceptance. The expert team consists of technical experts and related administrative staff, generally more than 7 experts in total, in which all stakeholders that are involved in the accepted project should be excluded.

d) Experts involved in the acceptance should be those who take part in the initiation demonstration.

e) The head of the expert team is commissioned to organize the project acceptance. All experts listen to the leader's report which generally contains but is not restricted to project review (research targets, research subjects, key technologies and indicators for performance appraisal), contract process, major achievements and application, significant technical innovation, intellectual property use and its protection, fund use and problems and corresponding advice.

f) The expert team brings forward opinions and conclusions that can be divided into approval, reconsideration and disapproval on the acceptance after listening to all the acceptance report and reviewing all related data. The projects approved by the expert team should be reported to the Centre for permission of completion. Those that need reconsideration or are not approved should be respectively rectified and improved in three months and half a year and then apply for acceptance again. If some of them are still not approved by the team, their undertakers and principals would be asked to take responsibility.

g) The project principals should be responsible for the authenticity and reliability of acceptance reports, documents, data and conclusions. In the meantime, the project acceptance committee should be responsible for the authenticity of acceptance results or assessments, in addition, protect its intellectual property and keep it confidential.

7.4.4 Archiving documents of the project

a) The undertaker takes all documents back on the basis of confidentiality rules after project acceptance.

b) The undertaker should sew all documents of project fruits into bound volumes according to related standards, with such notes as "Results of Research Project owned by Guangdong CCUS Centre","Project No.","Outsourcing Contract No.","Internal Confidential Documents" in the cover pages of project working reports and technical reports.

c) All project documents should be made in an electronic version and a disc version with printed tags and contents for two copies, one archived in Guangdong government/ national departments/ institutional investors, and the other in the Centre along with paper-based documents.

d) Physical information, software and products should be turned over and registered in the assets own by the Centre. The project principals submits related information to related people for registration.

7.4.5 Achievements of research projects should be registered.

8. Post-project Assessment

After completing the acceptance, the undertaker is the subject to be responsible for the transition and application of project results, while the the project principals are the first responsible body for this process. A post-project assessment is an essential way to assess the project principals and the outsourcing contractors. The Centre will make an assessment for them in stages.

9. Supplementary provisions

The Centre has the right to answer for the illustration of the regulation.

The regulation will be implemented from the date of release.

二氧化碳捕集及离岸封存示范应用研究
科研项目管理暂行办法(草案)

1. 目的

为了加强广东南方碳捕集与封存产业中心(以下简称中心)科研项目规范化、科学化管理，明确科研项目的立项管理、过程管理、经费管理和验收管理的工作要求与程序，结合二氧化碳捕集及离岸封存科技发展的需求，制定本管理办法。

2. 适用范围

广东南方碳捕集与封存产业中心及其参与的科研项目。

3. 编制依据

3.1 《国家中长期科学和技术发展规划纲要（2006—2020 年）》。

3.2 《国家科技重大专项管理暂行规定》(国科发计【2008】453 号)。

3.3 《中国海洋石油总公司国家科技重大专项实施管理办法》（海油总风险办【2011】622 号）。

3.4 《关于深化中央财政科技计划（专项、基金等）改革的方案》(国发【2014】64 号)。

4. 主要应对的风险

4.1 科研项目不符合中心科技规划要求,无法有效支持中心产业发展；

4.2 科研项目未取得预期成果,未能解决制约中心发展的关键技术问题；

4.3 科研项目资金使用不符合规定而导致审计风险；

4.4 科研项目管理不规范，导致学术和学风不正的风险。

5. 释义

5.1 中心指广东南方碳捕集与封存产业中心

5.2 科研项目指中心自行立项、组织承担和参与的各类科技项目。

6. 职责分工

6.1 广东南方碳捕集与封存产业中心

开展科研项目是广东南方碳捕集与封存产业中心的重要工作,主要职责如下：

一、 制订或修订中心科研项目管理制度并监督实施；

二、 组织编制中心科研项目年度计划与费用预算，并监督预算执行；

三、 组织科研项目的立项、实施和验收等管理工作；

四、 协调解决科研项目实施中出现的重大问题；

五、 总结中心科研项目管理工作。

6.2 中心顾问委员会

中心顾问委员会是中心最高科技管理机构，对中心的专业发展规划、科研发展规划、年度科研计划及其调整、科研项目和技术支持点的设立和调整以及科研项目外协审定、项目验收、成果鉴定等事宜拥有决策和监督实施的权力。其职责如下：

一、 跟踪掌握国内外碳捕集与封存技术发展趋势和碳捕集与封存的技术需求，提出相应的对策和建议；

二、 审定中心科技发展规划及技术引进和改造方案，为中心领导决策重大技术问题提供参考意见；

三、 组织科研项目的立项论证，审批项目承担部门/项目组/机构/单位推荐项目负责人、项目责任人；审核科研项目的外委合同、检查项目年度执行情况；检查科研生产质量，对科研项目成果进行中期检查、评估及验收，协助科研人员解决科研生产中的技术难题。

6.3 科研项目承担单位

科研项目承担单位是项目实施的责任主体，负责项目既定目标的实现、研究任务的完成、关键技术的突破、经费管理及知识产权管理和保密等工作。其职责如下：

一、 负责落实项目负责人、组建项目组；

二、 负责项目的组织实施，落实配套经费及项目实施的相关支撑条件；

三、 负责项目立项、实施与验收报告的编写；

四、 负责项目外委单位的预算审查、过程管理和验收；同时协助对外委单位的资质审查和合同签订；

五、 负责项目成果的应用及推广；

六、 负责科技成果的知识产权管理及保密等工作；

七、 负责协助项目经费使用情况的内部审计。

6.4 科研项目负责人

科研项目负责人具体负责项目管理组织实施，对项目承担单位负责。项目负责人投入项目的工作时间应达到 70%以上。其职责如下：

一、 负责组织编制项目实施方案，并组织实施；

二、 负责组织项目经费预算的编制和配套经费的协调；

三、 负责组织外委单位的筛选推荐、外委单位的预算审核及外委项目的全过程质量管理，会同项目承担单位组织完成对外委项目的验收；

四、 接受中心、广东省、国家有关单位等对项目执行情况的监督检查；

五、 负责项目立项、实施、验收等相关报告的编写；

六、 参加项目立项论证、过程审查和验收（结题）等重大活动并亲自汇报；

七、 报告项目执行中的重大事项及变更调整；

八、 负责组织科技项目财务决算工作，并出具财务决算报告；

九、 负责项目研发过程中的知识产权的使用、登记和保护；

十、 负责科技项目文档资料的日常收集保管和最终归档；

十一、进行项目试验、负责完成本项目完成后的后评估包括成果应用和成果向生产力的转化。

7. 管理要求

一、科研项目管理实行上下结合的原则。科研项目的立项、实施、验收及费用管理由中心管理，遵循中心的管理制度与工作要求；

二、坚持专家参与决策的原则。在科研项目的立项、实施和验收等关键节点的把关决策实行业内专家组评审的方式；

三、实行科研项目全过程管理。科研项目的立项、运行、验收等全过程应纳入中心科研管理体系下运作，并在技术决策与实施重大事项上明确管理责任和程序要求；

四、坚持科研项目经费管理纳入科研项目过程管理的原则。重点加强科研项目预算的审核与决算的审计工作。

7.1 立项管理要求

一、中心的科研项目由需求部门/项目组/机构等单位提出，并向中心提交项目建议（申请）书，包括：年度费用预算、项目依托工程预算、外委单位的选择意向等。

二、中心顾问委员会负责组织专家对中心科研项目的立项进行论证，审查需求部门/项目组/机构/单位提交的项目建议（申请）书，提出意见与建议。经过中心顾问委员会的审批同意，科研项目予以立项申报；

三、立项批准后，项目组需向中心计划财务部提交申请单，以便对项目经费进行跟踪管理。

7.2 实施管理要求

一、经中心顾问委员会论证，并批准的科研项目，按照中心相关管理规定执行。

二、中心科研项目所有外委项目的开展之前应向中心顾问委员会提交科研任务及外委立项建议书，经中心主管领导审批同意后予以执行。

三、中心科研项目所有外委项目的运作，包括：合同任务、招标合同方、合同金额、合同期限等都应在遵循中心采办管理规定的基础上，在经中心顾问委员会论证通过的框架内进行。

四、项目组根据需要可选聘项目指导专家，但须报中心领导审核。项目指导专家应熟悉项目所属专业的发展状况，具有较高的权威性，在技术、经济、市场、产业政策等方面有一定的综合分析判断能力。其基本职责是：全过程或部分参与项目研究；协助项目负责人完成技术路线的实施。其聘任费从项目经费中列支。

五、项目组按季度和年度上报科研项目进度报表。如遇目标调整、研究内容更改、项目负责人变更、关键技术方案的变更、不可抗拒的因素等对项目执行产生重大影响的情况必须及时向中心顾问委员会报告审批。

六、项目在实施过程中，应根据项目需求组织中间成果审查。

七、如果项目需要延期，项目组应向中心顾问委员会提出书面申请，得到正式批复后，才能予以执行。

7.3 经费管理要求

一、广东省/国家部委/投资机构等下达的科研项目经费由广东省/国家部委/投资机构等拨付，有关项目经费的管理按照相关管理规定执行。

二、中心科研项目经费包括如下内容：技术引进费（包括设备购置/试制费）、业务费（材料费、试验费、燃料及动力费、资料及文献费、项目论证/中期检查/评估/验收会议费、专家咨询/评审费、差旅费、聘用专家费、出版费/知识产权事务费）、外协/外委费、外送化验/资料处理费等、国际合作与国际、国内学术交流费、人员费（分摊费用）、房屋/设备租赁/折旧费等分摊费用、依托工程配套预算、其他费用。

三、针对科研项目实施预算细项系统刚性控制：依照任务合同书的预算明细，在 SAP 中建立 WBS 进行分层级项目细项核算，实施线上预算细项和总额控制，避免实际经费细项和总额超预算

四、针对科研项目实施预算总额刚性控制，在 SAP 中建立 IO 进行跟踪管理，通过 IO 实施线上预算总额刚性控制，由各项目费控人员控制分项预算，避免实际经费细项和总额超预算。

五、针对科研项目的会议费、差旅费报销，依据不同的报销类别提供报销支持文件。

7.4 验收管理要求

7.4.1 科研项目先由中心顾问委员会对项目进行验收，后由广东省/国家部委/投资机构等组织项目的验收。

7.4.2 项目验收围绕任务书约定的内容和确定的考核目标，对项目研究内容、取得的主要成果、主要技术创新、应用效果（经济和社会效益）、组织管理和文档资料等做出客观的评价。

7.4.3 项目验收程序如下：

一、项目验收工作要在合同完成后半年内完成，项目组应及时完成各类项目报告的编制;

二、项目负责人在完成技术、研发总结基础上，经项目承担单位核准，在合同结束 30 日前向中心顾问委员会提交验收申请和提交有关验收资料。包括：项目合同书；项目研发技术报告；项目成果应用报告、专利一览表和应用该项目成果的技术标准；购置的仪器、设备等固定资产清单等基本资料装订成册，以及一定形式的成果（样机、样品等）；财务决算报告，供验收专家组审查;

三、中心顾问委员会批复验收申请，由中心顾问委员会组织专家对项目进行验收；验收专家组由技术专家和有关管理人员组成, 总人数原则上不少于 7 人；凡参与被验收项目或与被验收项目有利害关系的人员应当回避，不参加验收专家组;

四、参加项目验收专家应与立项论证专家尽可能保持一致；

五、专家组组长受托组织项目验收，专家听取项目负责人汇报。汇报内容一般包括但不限于：项目概况（研究目标、研究内容、关键技术、考核指标等）、合同完成情况、取得的主要成果及应用、主要技术创新、知识产权的使用及保护情况、经费执行情况和存在问题与建议等;

六、验收专家组在听取项目验收报告并审查项目验收全部资料后，提出验收意见和验收结论。验收结论分为通过验收、需要复议和不予通过。通过验收专家组验收的项目报中心审批通过，项目将完成收尾工作，予以结束。需要复议和不予通过验收的项目应分别在 3 个月和半年内经认真整改后提出再次验收申请。再次验收未通过的项目，将追究承担单位和项目负责人的责任;

七、项目负责人应对验收报告、资料、数据及结论的真实性、可靠性负责。项目验收委员会应对验收结论或评价的准确性负责，应保护验收项目的知识产权和保守其技术秘密。

7.4.4 项目资料归档

一、验收会结束后，承担单位收回所有验收资料，依照保密要求统一处理。

二、通过验收后，承担单位将项目成果资料按标准装订成册。项目工作报告和技术研究报告封面应标注“广东南方碳捕集与封存产业中心科技项目成果”、“项目编号”、“外委合同号”以及“内部资料注意保密”等字样；

三、所有项目文档资料需整理出相应的电子文档,刻录光盘 2 份,打印标签及目录,一份报广东省/国家部委/投资机构等存档,另一份连同纸质资料提交给中心归档留存；

四、实物资料，软件、产品等应进行中心的资产移交登记，项目负责人提交相关信息给有关人员进行资产登记。

8. 项目后评估

项目完成验收后，项目承担单位是项目成果转化及应用的责任主体，项目负责人是项目成果转化及应用的第一责任人。项目后评估作为对项目负责人、外委承包商的重要考核途径，中心阶段性地对其进行评估考核。

9. 附则

本办法由广东南方碳捕集与封存产业中心负责解释。

本办法自发布之日起施。