A long-term strategic plan of offshore CO₂ transport and storage in northern South China Sea for a low-carbon development in Guangdong province, China

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\textbf{A B S T R A C T}

Strategic regional planning is an important step towards a successful CCUS development. This paper is the first effort of proposing a development plan of offshore CO₂ storage and transport for Guangdong in 2030 and 2050. We attempt to make an ambitious and achievable plan. The cluster-hub model of sources and sinks is adopted, and reuse of existing infrastructures is preferred. The targets of CCUS in Guangdong by 2050 are around 2040 and 6 Gtpa CO₂ in 2050 and 2014). To meet the 2 °C scenario, the world needs to capture and store their energy security (GCCSI, 2016). Without CCS, the cost of mitigation would more than double, and capture and storage is a principal or the only choice for CO₂ storage, because onshore storage capacity is small and/or the land is heavily occupied, and there is large storage capacity under the seabed near the large offshore Norway, and a number of other projects are in construction or planning in the world. The large potential of offshore CO₂ storage has been confirmed for the northern Atlantic continental shelves (Halland and Riis, 2014; Pale Blue Dot Energy and Axis Well Technology, 2016), US offshore (Eccles and Pratson, 2013; Meckel et al., 2014); Australia offshore (Borissova et al., 2013; Pale Blue Dot Energy and Axis Well Technology, 2016).

In China, CCUS is used to replace CCS in the sense of emphasizing operation or under construction sits at ~40 Mtpa (10⁶ tons per year), there is a lot of ground to make up (GCCSI, 2016).

CO₂ geological storage is an essential component in the CCS chain (IPCC, 2005). In many parts of the world, such as Western Europe, Australia, US Gulf Coast, Japan, and southeastern Asia, offshore CO₂ storage is a principal or the only choice for CO₂ storage, because onshore storage capacity is small and/or the land is heavily occupied, and there is large storage capacity under the seabed near the large CO₂ emission sources along the coast. Offshore CO₂ storage has been successful in the Sleipner and Snøhvit projects offshore Norway, and a number of other projects are in construction or planning in the world. The large potential of offshore CO₂ storage has been confirmed for the northern Atlantic continental shelves (Halland and Riis, 2014; Pale Blue Dot Energy and Axis Well Technology, 2016), US offshore (Eccles and Pratson, 2013; Meckel et al., 2014); Australia offshore (Borissova et al., 2013; Pale Blue Dot Energy and Axis Well Technology, 2016).

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the importance of CO2 utilization. CCUS has been included in the 13th Five-year Plan for Energy in China. CO2-EOR as a major form of CCUS has been implemented in several major oil producing sedimentary basins. In 2016 there are 8 large-scale CCUS projects in planning, construction or operation in China. In particular, the Yanchang project in Shanxi province is to be the first 1 Mtpa integrated CCUS project over Asia by 2020 (GCCSL, 2016). The CO2 storage suitability and capacity in Chinese offshore sedimentary basins were evaluated as a part of the national evaluation program (Gao et al., 2005). The estimated effective storage capacity in 9 main offshore sedimentary basins is 573 GtCO2, which is about half of the estimated capacity in 23 main onshore basins (1300 GtCO2) (ADB, 2015). The majority of the storage capacity is in saline formations. The oil and gas fields have the storage capacity of 4 GtCO2 offshore and 32 GtCO2 onshore respectively, 2.5% or less of the total. By adopting CO2 enhanced recovery, the storage capacity in oil and gas fields will be enlarged meanwhile producing incremental oil and gas, which will be important to China given the need to maintain domestic oil supply.

Guangdong is the largest provincial economy and one of the five low-carbon pilot provinces in China. The necessity and feasibility of CCUS in Guangdong have been confirmed by a study from 2010 to 2013 (Zhou et al., 2011). The 2010 CO2 emission of the province was 510 Mtpa, in which about half was from large point sources (LPSs) of power and industry (power 207 Mtpa, petrochemical 34 Mtpa, steel 12 Mtpa) (GDCCSR-GIEC, 2013). The study also shown that the storage capacity is limited onshore Guangdong, while the Pearl River Mouth Basin offshore Guangdong has very large effective CO2 storage capacity (GDCCSR-SCSIO, 2013). As most LPSs in Guangdong are distributed along the coast, the source-sink matches can be made within 300 km distance (GDCCSR-GIEC, 2013). Thus offshore storage is recognized as the primary form of CO2 storage for Guangdong (Li et al., 2013a; Zhou et al., 2012). In 2013, the UK-China (Guangdong) CCUS Center was established for promoting CCUS development in Guangdong. In 2015, the Guangdong Offshore CCUS Project is included as one of six US-China Climate Change Working Group (CCWG) projects.

In 2016, the Asian Development Band (ADB) set up a special fund to support the capacity building of the UK-Chine (Guangdong) CCUS Center and to complement the Guangdong Offshore CCUS Project (GCCUS) (ADB, 2016). The general timetable for the GCCUS project is specified as those in Table 1.

While working on the feasibility study of GCCUS, the Guangdong CCUS team is also preparing for the long-term and large-scale greenhouse gas reduction stages beyond the GCCUS project. This paper presents a development plan of offshore CO2 storage and transport for Guangdong in 2030 and 2050 as part of the effort.

2. General geography and geology of Guangdong and offshore

Guangdong Province of South China is located in subtropical zone, with a land area of 180,000 km². Morphologically the province consists of the Pearl River Delta and coastal zones in the south, the E-W-running mountain range in the north, and low mountains and terraces in the west and east. The middle and lower reaches of the Pearl River form a network through the province and enter the South China Sea at the river mouth near the city of Hong Kong (Fig. 1).

Geologically the Guangdong province belongs to the Caledonian Fold Belt of the South China Block. The tightly folded basement consists of Proterozoic and Lower Paleozoic metamorphic rocks. The overlying platform cover consists of Devonian to Middle Triassic clastic and carbonate strata, which was folded and uplifted during the Indosinian Orogeny. Large-scaled granitic intrusions and volcanic eruptions occurred during the Mesozoic Yanshannian Orogeny.

Inland Guangdong, sedimentary basins developed in Cretaceous and Tertiary periods. Studies shown (GDCCSR-SCSIO, 2013) that these are small fault-blocked basins filled with fluvial-lacustrine and volcanic sediments containing poor reservoirs. Only two basins have individual area over 2000 km². Among these the Sanshui Basin is the only oil-bearing basin, located in the densely-populated Pearl River Delta, and has only 20 MtCO2 effective storage capacity. The Maoming Basin to the west produced oil shale (Fig. 1). Thus there is little storage potential onshore Guangdong.

Offshore Guangdong there exist five large sedimentary basins in the northern South China Sea (Fig. 1). These are petroliferous basins filled with thick Cenozoic sediments, which contain high-quality reservoirs and cap rocks favorable for CO2 storage. Among these basins, the Pearl River Mouth Basin (PRMB) is the largest, with 200,000 km² area and thick sediments (up to > 6 km in shelf areas and > 14 km in slopes). Oil production started in 1990 and maintained about 10 million tons per year since 1996. The oil fields are distributed in clusters, thus the production was organized in clusters to improve efficiency. The 2008 estimation of geological resources in the PRMB is 2.2 Gt crude oil. Since then several new gas fields have been discovered in the deepwater areas.

The geological conditions and the CO2 storage capacities in the sedimentary basins offshore Guangdong have been evaluated (GDCCSR-SCSIO, 2013). The Tertiary strata, especially the Upper Oligocene and Lower to Middle Miocene strata, contain thick and high quality aquifiers and are capped by regional or local seals. These strata are of mainly neritic and deltaic facies and thus have good lateral continuity. The region is tectonically relatively stable with sparse earthquakes mainly at the edges of the basins. The PRMB has the effective CO2 storage capacity of more than 300 GtCO2, in which 77 GtCO2 (P85 probability level) resides in the shallow water areas (mostly < 200 m water depth). As PRMB is the basin most proximal to the coastal Guangdong where most LPSs of CO2 emission are located, it was concluded that offshore CO2 storage will be the major form of CO2 storage for Guangdong, and the most favorite areas are the shallow areas of the PRMB (GDCCSR-SCSIO, 2013).

3. Status of CCUS development in Guangdong

The first CCUS project in Guangdong (the GDCCUSR project) was conducted in 2010–2013 with the financial support from the UK Strategic Prosperity Fund and GCCSI funding, with the recognition of National and Guangdong provincial Development and Reform Commissions. In this project the total emission and major point sources

Table 1

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* FEED: Front End Engineering Design.
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