



NZEC WP Reports

Regional Assessment of CO₂ Storage Potential in the Saline Aquifers of the Songliao Basin

Basin assessment of the Songliao Basin, report of the Near Zero Emissions Coal (NZEC) Project, Work Package 4

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Executive summary

Storage of carbon dioxide in deep saline aquifers offers the potential to contain CO₂ for geological time periods. The Songliao Basin with an area of 260,000 km² is one of the largest Jurassic-Cenozoic continental basins in north-eastern China. The geological characteristics including structure, stratigraphy, saline aquifers and seals of the Songliao Basin are described in this report. Suitable porous formations, namely the Qingshankou and Quantou are present at suitable depth for CO₂ to be in its highly dense phase. These are overlain by the impermeable shales and mudstones of the Yaojia Formation. The storage potential of the Qingshankou Sandstone Formation was calculated using a CSLF-based methodology (Bachu et al., 2007). The total regional theoretical storage capacity is about 69,160 Mt (million tonnes) CO₂, and the effective storage capacity is 691.6 – 6,916 Mt depending on the value of storage coefficient applied (1 – 10% respectively).

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1 Introduction

Storage of carbon dioxide in deep saline aquifers provides the opportunity to contain CO₂ for geological timescales. Large volumes of CO₂ can be stored in a saline formation if it is injected at temperatures and pressures suitable for CO₂ to be in its highly dense phase (above 31.1°C and 7.38 MPa). CO₂ stored in the dense phase occupies much less space in the subsurface and so would be desirable considering the large masses that need to be stored. As a general rule, a minimum depth of 800m is necessary for CO₂ to remain in its dense phase state, though the depth may vary according to the location of the reservoir and the subsurface temperature and pressure gradient of the formation.

The Songliao Basin is the most important oil-producing basin in China. It is located in northeastern China (Figure 1), covering an area of about 260,000 km². The Daqing Oilfield and the Jilin Oilfield are located in the northern and southern parts of the basin respectively.



Figure 1: Location of the Songliao Basin in China

2 Geological structure of the Songliao Basin

The Songliao Basin is one of the largest Jurassic-Cenozoic continental basins in China related to rifting processes. It consists of a central depression surrounded by basin margins.

A schematic map of the geological structure in the Songliao Basin and neighbouring areas is shown in Figure 2.

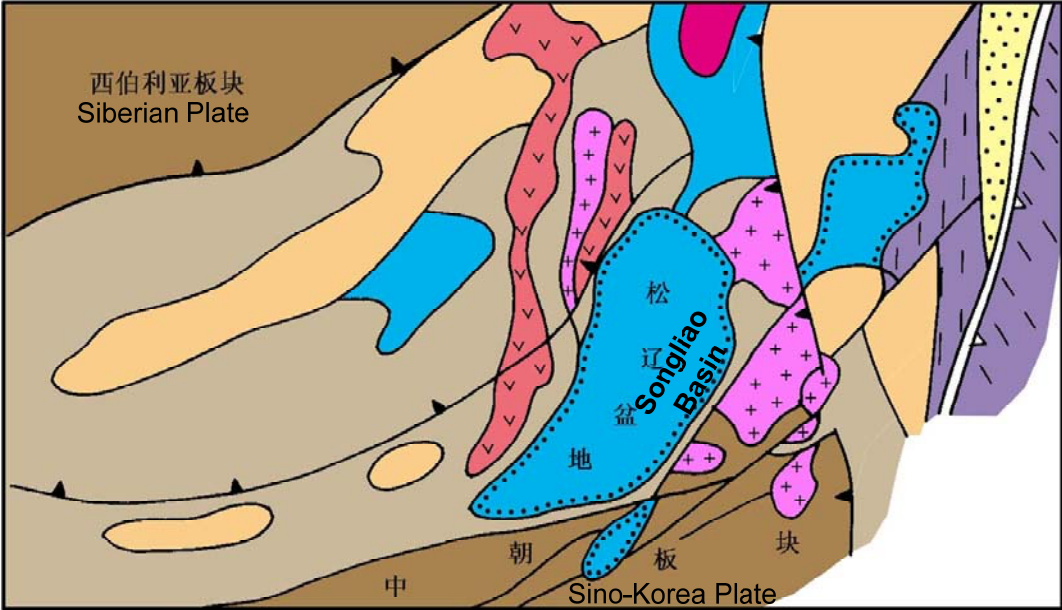


Figure 2: Schematic map summarising the geological structure of the Songliao Basin and neighbouring areas

3 Stratigraphy of the Songliao Basin

The stratigraphy of the Songliao Basin is dominated by Cretaceous fluvial and lacustrine rocks interlayered with volcanic and volcanoclastic rocks, which can be classified into five hydrostratigraphic units. These are shown in Figure 3; the Upper Jurassic to Lower Cretaceous formation, the Late Cretaceous Quantou Formation (K_2q), the Qingshankou Formation (K_2qn), the Yaojia Formation (K_2y) and the Nenjiang Formation (K_2n).

The Upper Jurassic to Lower Cretaceous sediments including the Denglouku Formation (K_1d), comprise calcareous shale, fine to coarse-grained sandstones deposited in fan-delta, deltaic and lacustrine environments. During the Upper Cretaceous, lacustrine environments prevailed in the Songliao Basin, interbedded shale, siltstone and sandstone were deposited in lacustrine and deltaic environments. Thick lacustrine sequences in the Qingshankou Formation (K_2qn) and Quantou Formation (K_2q) developed in the central part of each depression.

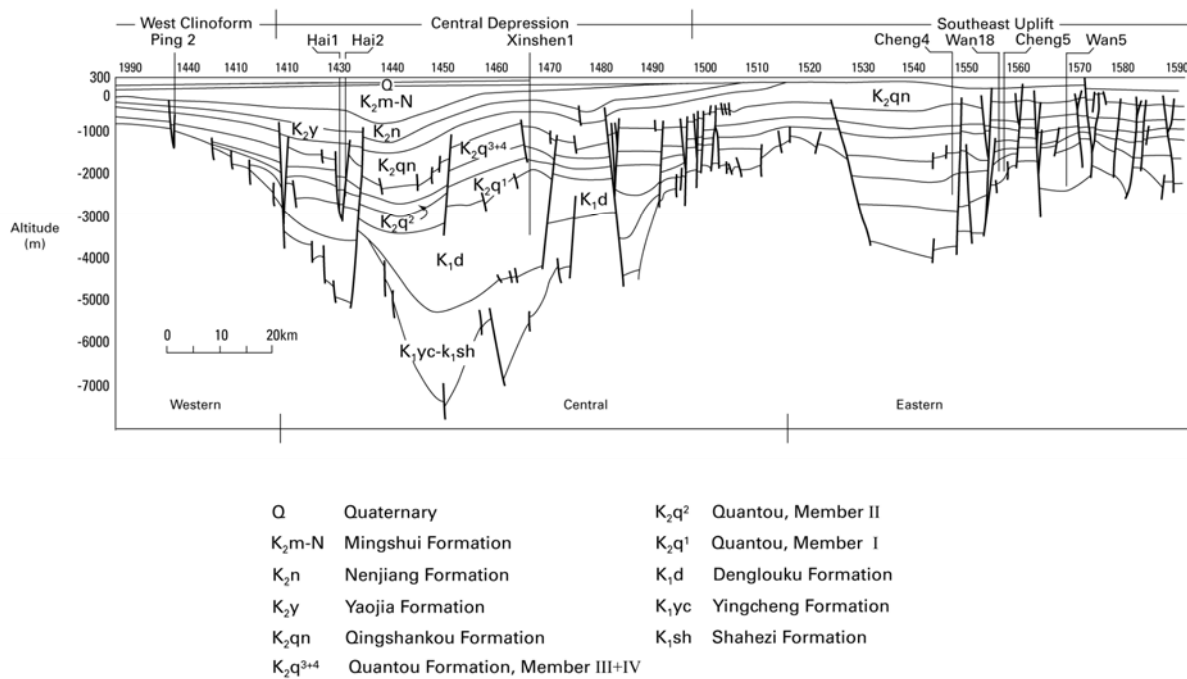


Figure 3 Stratigraphic section of Songliao Basin

4 Faulting in the Songliao Basin

The Songliao Basin is a large basin with complex geological condition. In general, faults and the fractures near the faults are usually quite heterogeneous and anisotropic. In many cases, the hydraulic transmissibility along the direction of fault strike is larger than that in cross section. Many of the oilfields in the Jilin and Daqing Oilfield complexes are trapped in anticlinal structures, and some show many small faults, similar structures may also be present in the aquifer regions.

However, sufficient detailed data about the faults in the aquifers of the Songliao Basin are not available. In comparison with some major faults in the other regions of China, the faults in the Songliao Basin are not highly active. For this report, it was inferred that the influence of the faults on CO₂ storage in deep aquifers in the Songliao Basin is not significant, though much more data and research would be needed to consider faulting in this region in detail.

5 Saline aquifers and seals in the Songliao Basin

The geological characteristics of deep aquifers (Qingshankou Formation K₂qn and Quantou Formation K₂q) in the Songliao Basin are favourable to CO₂ storage, though more detailed assessment is needed to evaluate individual sites. The aquifers consist of sandstones with fair permeability and porosity. They are extensively distributed across the Songliao Basin at depths suitable for CO₂ storage with overlying impermeable seals comprising stable mudstones.

The deep saline aquifers suitable for storage of CO₂ are mainly within the Qingshankou Formation. It also has extensive intra-formational lacustrine seals. Shale formations above the seal could provide a succession of barriers to vertical migration of CO₂ and potentially prevent any leakage of CO₂ if it penetrates through the main caprock.

The average combined thickness of the saline aquifer formations (Qingshankou, Quantou and others) in the Songliao Basin is about 380m.

5.1 Formation temperature and pressure

It is difficult to predict the regional temperature and pressure for the Qingshankou Formation as data are concentrated in restricted areas around the oilfields. Figure 4 and Figure 5 show the actual temperature and pressure gradients for the Qingshankou Formation in selected sites from the Jilin Oilfield (unpublished). The average temperature gradient is 3.76 °C/100 m. The average pressure gradient is about 1.16 MP/100 m.

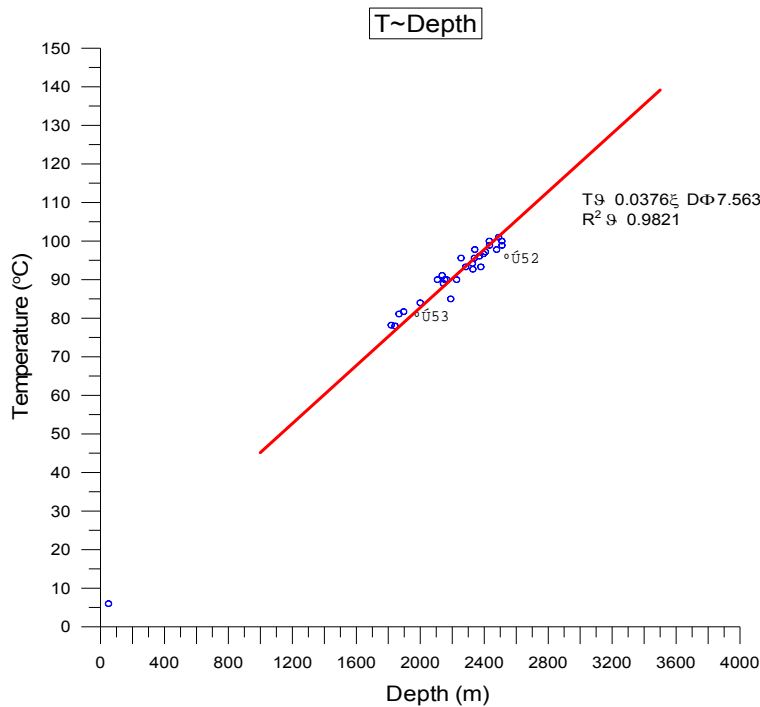


Figure 4: Temperature gradient of the Qingshankou Formation in the Songliao Basin

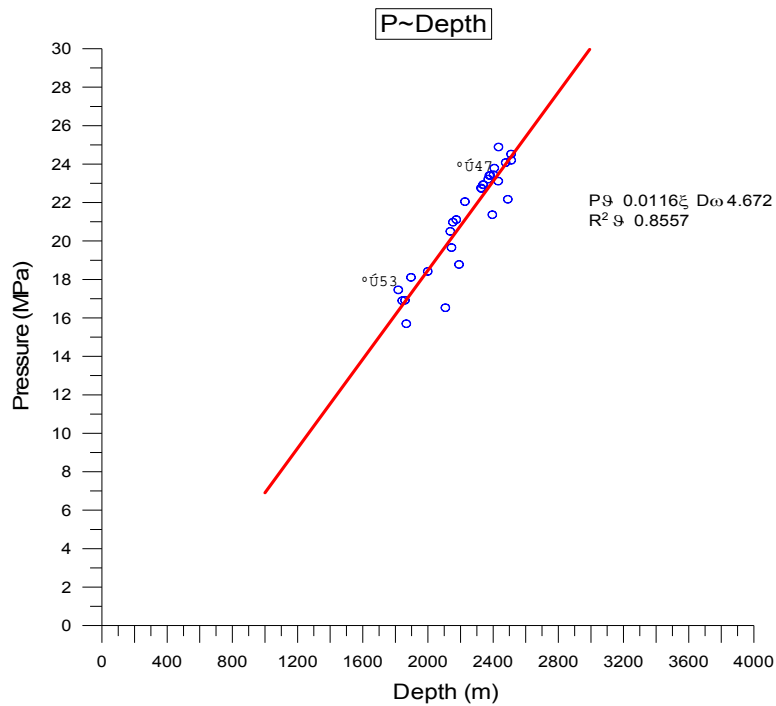


Figure 5: Pressure gradient of the Qingshankou Formation in the Songliao Basin

5.1.1 Aquifer permeability

Reservoir rocks of the aquifer formations (Qingshankou, Quantou and others) deposited in fluvial-deltaic systems have fair to good permeability.

Borehole log core analysis reports suggest that porosity in the Qingshankou Formation ranges from 10% to 20%. Data from permeability analysis reports are too inconsistent to reach a firm conclusion as to the values to be used to assess storage potential. For calculation purposes, a permeability with modal value of 20-30mD (milliDarcies) was selected as the majority of reported data falls within this range.

5.1.2 Formation water chemistry

The main hydrochemical components of the Qingshankou Formation pore water are Cl^- , HCO_3^- and Na^+ . The main pore water type is $\text{NaHCO}_3\text{-NaCl}$ (Figure 6) (Zhai 1987).

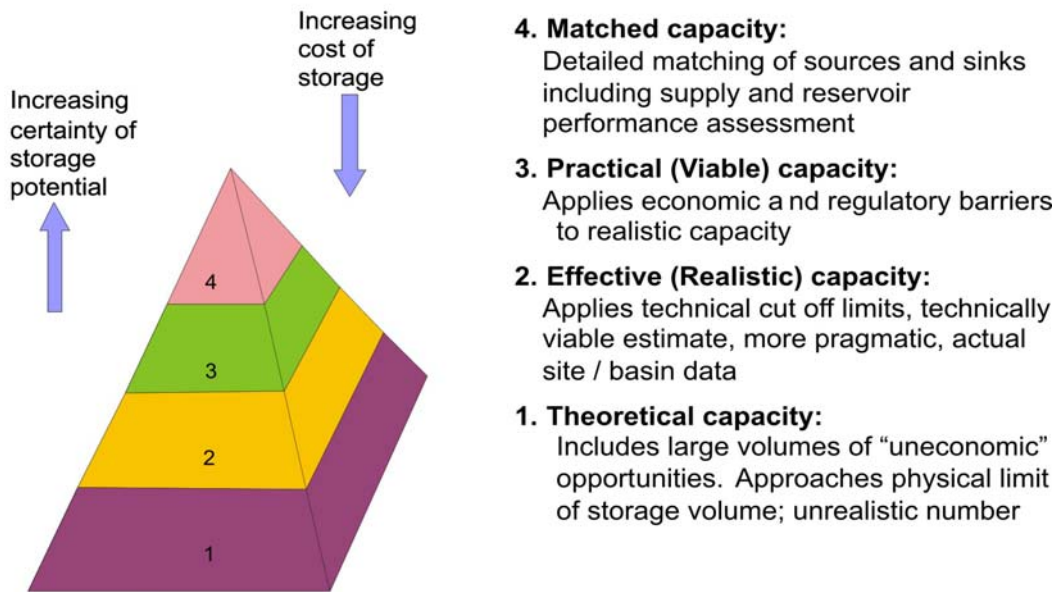
Group	Formation	Member	Thickness(m)	Oil Layer	Geologic Cross Section		Average VAlue (g/l)
Q						HCO ₃ ⁻ Na ⁺	
R						HCO ₃ ⁻ Na ⁺	6.0
K ₂	Ming Shui Si Fang Tai			M		HCO ₃ ⁻ Cl ⁻ Na ⁺	1.1~1.8
						Na ⁺	1.1
	Nen Jiang	5	0 250			Cl ⁻ HCO ₃ ⁻ Na ⁺	1.0~6.9
		4	210 260			Cl ⁻ HCO ₃ ⁻ Na ⁺	1.5~12.3
		3	60 80	H		Cl ⁻ HCO ₃ ⁻ Na ⁺ Cl ⁻ Na ⁺	8.1~10.0
		2	70 150				
		1	60	S		Cl ⁻ HCO ₃ ⁻ Na ⁺	0.8~12.8
K ₁	Yao Jia	2	40 100			Cl ⁻ HCO ₃ ⁻ Na ⁺	9.7~17.6
		3				Na ⁺	13.8
		1		P		Cl ⁻ HCO ₃ ⁻ Na ⁺	8.8~32.3
						17.6	
	Qing Shan Kou	2	200 500			Cl ⁻ HCO ₃ ⁻ Na ⁺	9.6~43.7
		3		G		Na ⁺	29.2
		1	50 80				
	Quan Tou	4	70 125	F		Cl ⁻ HCO ₃ ⁻ Na ⁺	5.5~9.9
							7.2
		3	360 450	Y		Cl ⁻ Na ⁺ Cl ⁻ HCO ₃ ⁻ Na ⁺	3.7~9.0
							6.7
		2	450 480	N		Cl ⁻ Na ⁺	1.90~8.1
						12.8	
		1	70 300	N		Cl ⁻ Na ⁺ Cl ⁻ HCO ₃ ⁻ Na ⁺	5.3~10.2
						8.1	
J	Deng Lou Ku		0 1500			Cl ⁻ Na ⁺	1.8~5.5
							5.1
			0 3000			Cl ⁻ HCO ₃ ⁻ Na ⁺	2.7~9.5
						6.2	
P ₂						Cl ⁻ Na ⁺	5.0

Figure 6: Geochemistry of the formation waters (Q – Quaternary, R – Tertiary, K – Cretaceous, J – Jurassic; Pz – Palaeozoic)

6 Methodology for assessment of CO₂ storage potential

The following method has been used to estimate the CO₂ storage potential in deep saline aquifers in the Songliao Basin (Figure 7):

CO₂ Storage Potential Pyramid



The above pyramid can be simplified as follows:

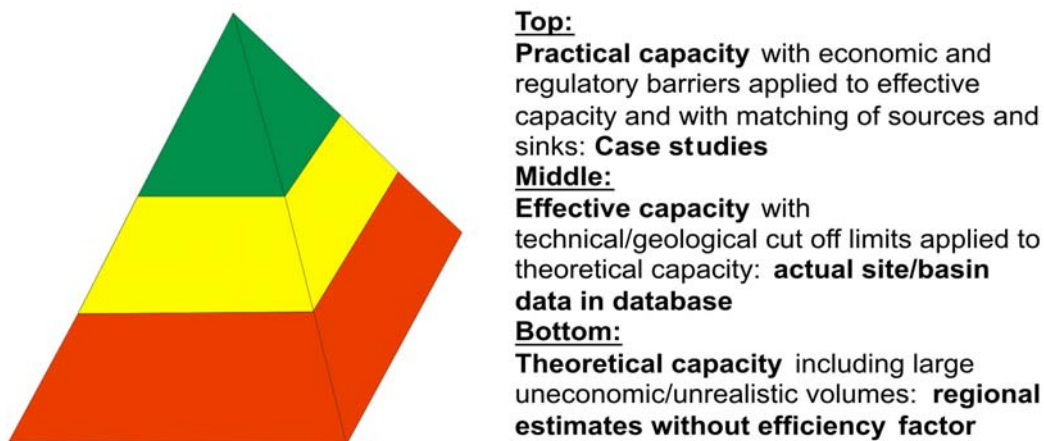


Figure 7: Storage resource - reserve pyramid (from Bachu et al., 2007)

7 Regional assessment of CO₂ storage potential in the saline aquifers of Songliao Basin

7.1 Theoretical storage capacity

The following equation is used to estimate the **theoretical** CO₂ storage capacity (in the bottom of the pyramid, no storage coefficient applied):

$$M_{CO_2t} = A \times h \times \varphi \times \rho_{CO_2r}$$

where

M_{CO_2t} = theoretical storage capacity

A = area of regional aquifer

h = average height of aquifer × average net to gross ratio (net to gross = 50 to 95%)

φ = average reservoir porosity

ρ_{CO_2} = CO₂ density at reservoir conditions

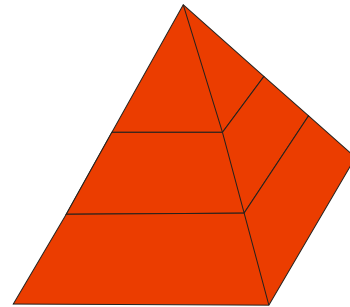


Table 1: CO₂ theoretical storage capacity of saline aquifer in Songliao Basin

Area of regional aquifer (km ²)	260,000
Average height of aquifer (m)	380
Average reservoir porosity (%)	10
CO ₂ density at reservoir conditions(kg/m ³)	700
Theoretical CO ₂ storage capacity(Mt)	69,160

7.2 Effective storage capacity

The effective capacity is estimated by using the following equation (in the middle of the pyramid):

$$M_{CO_2e} = A \times h \times \varphi \times \rho_{CO_2r} \times S_{cff}$$

where

M_{CO_2e} = effective storage capacity

A = area of regional aquifer

h = average height of aquifer × average net to gross ratio

φ = average reservoir porosity

ρ_{CO_2} = CO₂ density at reservoir conditions

S_{cff} = storage coefficient (the S_{cff} in this study of 1–2–10% applied)

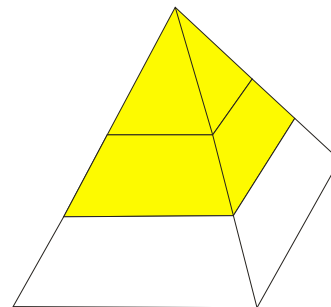


Table 2:CO₂ effective storage capacity of saline aquifer in Songliao basin

Area of regional aquifer (km ²)	260000		
Average height of aquifer (m)	380		
Average reservoir porosity (%)	10		
CO ₂ density at reservoir conditions(kg/m ³)	700		
Storage coefficient	1%	2%	10%
Effective CO ₂ storage capacity(Mt)	691.6	1383.2	6916

8 Conclusion

The Songliao basin has potential for geological storage of CO₂ in deep saline aquifer formations. The Qingshankou Sandstone Formation is a promising saline aquifer unit for long term storage.

The total regional theoretical storage capacity of the saline aquifer in Songliao Basin is about 69,160 Mt CO₂. The effective storage capacity is 691.6, 1,381.2 or 6,916 Mt (million tonnes) depending on the value of storage coefficient applied (1, 2 and 10% respectively).

The aquifers have a large potential storage capacity, however, there are less data available in the public domain, and so this estimate has more uncertainty than the storage estimates for oilfields in the Songliao Basin. Further investigation is needed into saline aquifer storage, in particular at sites close to 'clusters' of large point sources where they could offer large, convenient storage capacity.

9 References

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