RESEARCH PROJECT 1

AN INTEGRATED MONITORING SYSTEM FOR THE CO_2-EOR DEMONSTRATION PROJECT AT THE YANCHANG OILFIELD

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1. GENERAL

China is a country highly dependent on fossil fuels. Coal, oil, natural gas and other fossil fuels have accounted for over 90% of primary energy consumption over a long period of time, with coal alone accounting for around 70%. Since the start of the 21st century, China's CO_2 emissions have increased rapidly. According to International Energy Agency (IEA) statistics: in 1990, China's CO_2 emissions related to fossil fuel use were only 2.4 billion tons, in 2000 they were approximately 3.1 billion tons, and by 2007 they reached 6.083 billion tons, accounting for 20.75% of the total global emissions, approximately the same proportion as China's population. Carbon Capture, Utilisation and Storage (CCUS) is one of the most high-potential and effective methods for tackling the greenhouse effect in the coming decades. CCUS has an immense development potential, due to its long-term low cost and relatively high compatibility with China's conditions, making it a potential breakthrough in the field of emissions reduction technology for China.

Xinjiang is China's most important energy industry base, with coal petrochemical industries being its pillar industry. Along with advancement in development in the west of China and the development of Xinjiang aid work by all provinces and cities, major industrial parks have opened one after another in Xinjiang, and Xinjiang will face new, more serious tests in terms of energy consumption intensity and energy and industry structure. There are a large number of coal-to-chemical plants, coal-fired power plants, cement plants, chemical fertiliser plants and steel mills with large capacity. These plants concentrated in Xinjiang, while population density throughout the region is relatively low. The large amount of combustion material consumed is primarily coal, and in the process a large volume of CO_2 gas is discharged. The intense greenhouse gas emissions contributed to a certain degree of environmental pollution. Due to the Xinjiang region being rich in coal resources, a large number of coal-fired power plants with huge capacities have been built or are under construction. Because of this, Xinjiang's CO_2 emissions continue to grow.

This research project aimed at Xinjiang Guanghui New Energy Company's Fuyun Coal to Gas 100,000 tons/year CCUS Pilot Project. Using Xinjiang East Junggar (Zhundong) oilfield region geological data and coal-to-gas industry design information as the base, and through analysis of the carbon dioxide sequestration, capture and transportation conditions of the region surrounding the discharge source, a suitable technical path and implementation plan was proposed, and the technical feasibility and risks of the implementation plan were evaluated. In combination with the current status and development trends of Xinjiang industries, the advantages and obstacles for developing CCUS in Xinjiang were analysed. An industrialisation development roadmap with policy recommendations was submitted to the local government authorities to strengthen CCUS capability in the Xinjiang region and to promote early implementation of larger-scale demonstration projects.

2. NECESSITY FOR THE PROJECT

2.1 PROJECT BACKGROUND

Xinjiang's energy resources have always occupied a pivotal position in the context of the whole country's energy resources. As a remote energy-rich province in the west, Xinjiang's energy has its own unique characteristics, with the energy industry structure being relatively simplistic in the development and utilisation of its energy. With extensive development and utilisation, problems such as resource wastage, environmental pollution and inappropriate development have appeared. After the introduction of the Western Development Strategy in 2000, and especially since the 2008 National Aid Program for Xinjiang, Xinjiang has entered a period of rapid economic development but carbon emissions have also headed higher, exceeding the national level. In 2004, Xinjiang's carbon emissions were close to 5.4 billion tons of standard coal, and rapidly increasing.

Xinjiang's average annual growth of carbon emissions from 1978 to 2014 was 19%, far higher than the national average level of 13%. Its carbon emissions per 10,000 yuan of GDP is also significantly higher. In 2009, carbon emissions per 10,000 yuan of GDP was 1.7 tons of standard coal, more than three times the national average. With rapid economic growth and rising energy consumption, from a sectoral perspective manufacturing industry and electricity, gas and water production and supply industries are the major sectors that consume fossil fuels and produce carbon emissions.

The continuous population expansion in Xinjiang, partly due to double-digit birth rates, has led to an increase in carbon emissions in the daily lives of its citizens. Per capita energy intensity has played an important role in the changes in carbon emissions, as a change in the structure of people's energy consumption has failed to have an effect on reducing emissions, so CO_2 emissions continue to grow in Xinjiang, and reducing emissions has become an important issue.

Xinjiang's coal resources are mainly distributed in the Junggar Basin to the north of the Tian Shan Mountains and in the Yili Basin/northern Tarim Basin region. The resources area has a "north rich, south poor" layout, and coal resources in northern Xinjiang account for more than 90% of Xinjiang's coal. The rich coal resources in the Junggar Basin have not only brought huge economic benefits, but also caused serious pollution to the environment. Surrounding the Junggar Basin, there are many industrial plants that use a large amount of coal to produce electricity, chemical, steel and other products, emitting a large volume CO_2 in the process.

For carbon dioxide geological storage and oil displacement projects, the most important considerations are: 1) a stable CO_2 supply source, 2) a relatively mature technology and a reasonably cost in capturing CO_2, and 3) a reasonable distance and cost for transporting CO_2. An analysis of the CO_2 sources, including in the East Junggar (Zhundong), Huoshaoshan, Beisantai, Shanan, Shabei, Ganhe and Cainan oilfields and in the Changji Autonomous Prefecture, concluded that the large coal consumers and carbon dioxide emitters surrounding Junggar Basin provide a reliable source for CO_2 for CO_2 geological storage and oil displacement technology (CO_2-EOR) to be adopted in the oilfields in the region.

2.2 CURRENT STATUS OF RESEARCH IN CHINA AND OVERSEAS

2.2.1 RESEARCH SITUATION OVERSEAS

The predecessor of CO_2 geological storage and oil displacement technology (CO_2-EOR) is carbon dioxide capture and storage (CCS), which has a singular purpose of reducing carbon dioxide emissions in the atmosphere. One of the issues facing CCS is its high cost. This could be addressed by CO_2-EOR, as in the process of sequestration, the use of CO_2 itself enhances oil recovery and increases economic benefits.

Atlantic Refining Company in the United States was the first company to prove that CO_2 could improve the flow of crude oil. After extensive research and experiment, Whorton obtained the patent for CO_2 oil displacement in 1952. Initially, only CO_2 was used as a solvent for crude oil or carbonated water. At the time, the technology did not allow CO_2 to be mixed with crude oil, and could only be used as an extractant to extract light components from crude oil. After more than ten years of development, CO_2 was able to be used as a miscible displacement fluid. However, the relatively harsh conditions of CO_2 miscible flooding resulted in a research bottleneck, leading researchers to focus on CO_2 immiscible flooding.

By the 1970s, CO_2 flooding technology had developed extensively. A large number of CO_2 flooding tests were carried out by researchers in the United States, the former Soviet Union and other developed countries, and the findings demonstrated a clear economic benefit as the results showed CO_2-EOR increased oil production by 15%–25%. With the rising price of petroleum energy and the discovery of natural CO_2 gas reservoirs, the United States achieved rapid development in the 1980s and 1990s. During this period CO_2 flooding technology had matured and become the most recognised technology to enhance oil recovery, e.g. recognised by countries such as the United States and Canada.

CO_2 flooding has been adopted in countries such as the United States, Canada, Russia, Australia, and Germany. This currently includes 292 oilfields in the United States using CO_2 flooding technology, and their average recovery rate has increased by 7%–15%. The daily output of crude oil in the U.S. has increased six times in the last ten years. Because of the vast natural CO_2 resources in the United States., CO_2 flooding technology has become a mainstream technology. At present, the total amount of CO_2 injected into oil reservoirs in the United States is approximately $2{,}000 \times 10^4$ –$3{,}000 \times 10^4$ t/a. As of 2004, the United States had carried out 71 CO_2 flooding projects, and the daily oil production reached 32,731.8 m^3/d. The United States has become the country with the most CO_2 flooding projects and the most mature technology.

At the Marrakech Climate Change Conference in 2016, the Global Carbon Capture and Storage Institute (GCCSI) released the Global Status of CCS 2016 Report. The Report stated that CCUS technology had developed steadily worldwide and made significant progress on a global scale.

Table 2-1 Progress of key CCUS technology projects worldwide

Project	Scale	Country	Progress
KuXiaoMu CCS Demonstration Project	Capture: 10×10^4t/a	Japan	In operation
Petra Nova Carbon Capture Project	Capture: 1.4×10^4t/a	USA	Near operation
Air Product Steam Methane Reformer to Enhance Oil Recovery Project	Capture and utilisation (CO_2-EOR): 300×10^4t	USA	In operation
Quest	Storage: 100×104t	Canada	In operation
Boundary Dam CCS Project	Capture and utilisation (CO_2-EOR):100×10^4t	Canada	In operation

Petrobras Santos Basin Pre-Salt Oilfield CCS Project	Capture and utilisation (CO_2-EOR): 300×10^4t	Brazil	In operation
Sleipner CO_2 Storage Project	Quasi-sequestration:1600×10^4t (operating 20 years)	Norway	In operation
Jilin Oilfield EOR Project	Capture and utilisation (CO_2-EOR): More than 100×10^4t	China	In operation

2.2.2 RESEARCH STATUS IN CHINA

The first CO_2 flooding research in China was conducted in Daqing oilfield. In the 1970s natural CO_2 resources were used to carry out small-scale CO_2-EOR pilot tests, and the results showed the oil recovery rate increased by around 10%. However, due to the limitations of China's natural CO_2 resources and infrastructure, only preliminary testing was performed before the project ended. Later, with the discovery of small-scale natural CO_2 gas sources, the stagnant CO_2-EOR work in China was able to be continued:

In the late 1990s, Daqing oilfield opened a CO_2 test area in southern Sartu and carried out testing. This is the first time such experiments were conducted in collaboration with foreign companies. The CO_2 was sourced from refinery by-products and reached a purity of 96%. The pilot testing was carried out on Pu 1 and Sa II_{10-14} reservoirs. The two tests adopted early stage water flooding, while later a water-CO_2 alternating method was used. The total CO_2 gas injection amount was approximately 0.20 PV (PV: ratio of the volume of polymer solution injected underground to total pore volume), and the testing period was five years (1990–1995). The two tests showed an increased rate of 6% using CO_2-EWR, and for each additional ton of crude oil, it would require 2,200 m^3 of CO_2 to be injected. This testing was the precedent for oil displacement by domestic industry CO_2 tail gas.

In 1995, Jilin oilfield also began the study of CO_2-EOR in the Xinli oilfield block. The CO_2 gas used in the testing was sourced from a natural CO_2 gas reservoirs and a fertiliser plant with CO_2 annual emissions of 4,000 m^3/h. The testing confirmed immiscible flooding with good results. In 1996, Jiangsu oilfield conducted CO_2 flooding tests at the Fu 14 fault block. The recovery rate increased by 4% and the CO_2 utilisation rate was 1,240m^3/t, confirming the feasibility of restoring small fault block reservoirs, maintaining reservoir pressure and realising CO_2 miscible flooding. In 1998, both Shengli oilfield and Liaohe oilfield carried out CO_2 flooding testing. Shengli oilfield achieved an average single well increase of more than 200t. Liaohe oilfield also achieved good results in heavy oil reservoir testing. In 2011, the Karamay oilfield in Xinjiang also began to study CO_2-EOR technology, conducting pilot testing in the J1021 well in the Ji 7 well area, with an increase of 216t. Having completed statistics on the main CO_2 emission sources in the Junggar Basin, a preliminary evaluation of the storage potential was made. The CO_2-EOR technology application carried out the oilfield block on the northwest edge of the Junggar Basin also showed good results. The continuous development and spreading of CO_2-EOR technology led Chinese government owned and private enterprises to conduct their own research on CO_2-EOR. The main focuses of their research are on their capacity to service oilfields by providing CO_2 capture technology and equipment, and their ability to form a complete chain operation model in combination with oilfield storage sites.

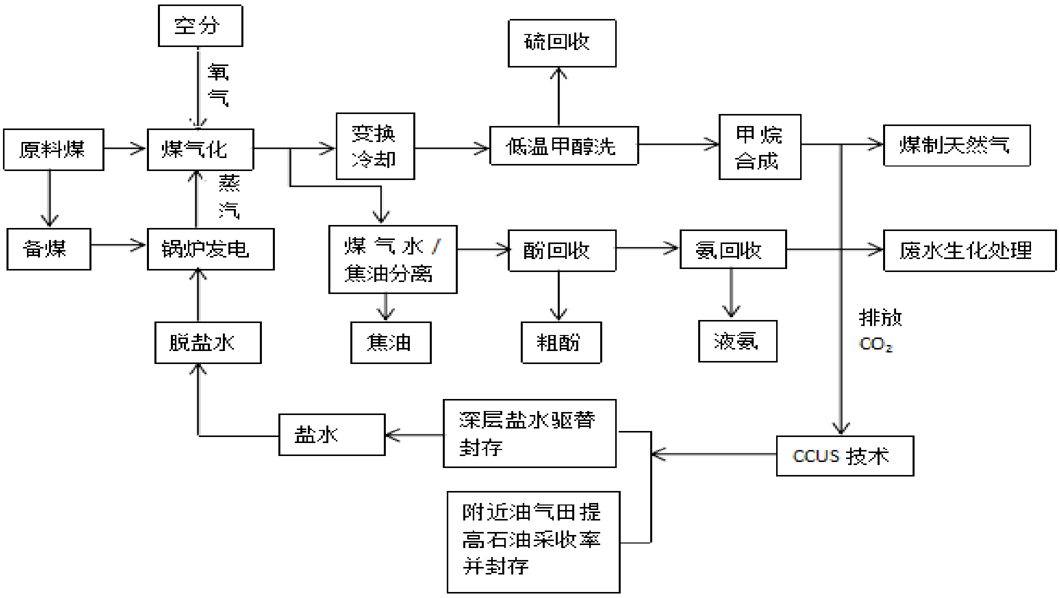
CO_2-EOR technology research has been carried at each major oilfield in China. Although the technology has matured after nearly 40 years, the overall technical strength in China lags behind Europe and America, and the technology in the western region of China remains behind the eastern region.

2.3 PROJECT IMPLEMENTATION PROCESS FLOW

CO_2 causes global warming with temperature range fluctuations already exceeding the natural range posing a serious threat to human survival and social and economic development. The most effective method for the geological management of CO_2 is to inject it into oil and gas fields, because it not only stores the CO_2, but also improves oil and gas field recovery rates.

For the Xinjiang Guanghui East Junggar Kamusite 4 billion m^3 Coal to Gas Green/Low Carbon CCUS Project, the main source of CO_2 is captured from the Xinjiang Guanghui New Energy Company'ss Coal to Gas Project. The CO_2 is compressed, enriched, pressure-boosted, liquefied, and ultimately stored or transported as a liquid product to the East Junggar oilfield for displacement. The specific project process flow is set out in the following:

Figure 2-1 Project implementation flow chart



3. SCREENING OF THE STORAGE TEST SITE FOR THE GUANGHUI CCUS PILOT PROJECT

3.1 STORAGE TEST SITE SCREENING DETAILS

A suitability assessment of CO_2-EOR technology for the Junggar Basin region was carried out and a composite evaluation from the perspectives of CO_2-EOR geological sequestration indicators, CO_2-EOR reservoir suitability indicators and gas source and environmental indicators was undertaken, which assessed CO_2-EOR technology as quite suitable for the Junggar Basin. Then, on the basis of already collected East Junggar oilfield data, geographical information relating to each of the relevant oilfields and an analysis of the main factors impacting CO_2 geological storage in the East Junggar oilfield, the primary CO_2 geological sequestration and flooding indicators were screened.

3.2 PURPOSE AND SIGNIFICANCE OF STORAGE TEST SITE SCREENING

Firstly, the CO_2-EOR potential for the whole of the Junggar Basin was obtained. Then, based on carbon source conditions, suitable blocks in the East Junggar region were selected for evaluation. Ultimately, three oilfields were found to be suitable for the application of CO_2-EOR technology—Beisantai, Shabei and Cainan oilfields. Of these, Cainan oilfield's evaluation score was the highest, with the best implementation outcomes.

3.3 CO2-EOR GEOLOGICAL STORAGE EVALUATION INDICATORS

3.3.1 RESERVOIR RESERVES

Oilfield reservoir reserves are an important indicator of oilfield exploitation prospects, can reflect the degree of potential of CO_2-EOR technology implementation, and can also reflect whether the reservoir has good trapping capability and sedimentation effect. Reservoir oil reserves are also an important indicator for measuring CO_2-EOR technology storage and flooding potential.

Table 3-1 Reservoir storage indicators evaluation table

Oil reserves（10^6t）	＞100	30-100	30	0-30	0
Evaluation standard	Good	Relatively good	Average	Relatively poor	Poor

3.3.2 RESERVOIR DEPTH

According to theory, the reservoir depth must be at least 800 m to reach the supercritical state of miscible pressure and CO_2 sequestration required by CO_2 miscible flooding. In the case of CO_2-EOR storage and flooding technology, the greater the depth, the more difficult and expensive construction becomes, with gas injection results also being impacted. Due to this, reservoir depth evaluation indicators are proposed.

Table 3-2 Reservoir depth indicators evaluation table

Reservoir depth（m）	1500-2000	2000-2500	2500-3000	3000-3500	＞=3500
		1200-1500	1000-1200	800-1000	＜800

Evaluation standard	Good	Relatively good	Average	Relatively poor	Poor

3.3.3 CRUDE OIL DENSITY

Differences in oil density can make a difference to oil displacement efficiency—the higher the density of crude oil, the higher its viscosity and content of its heavy components, resulting in poor displacement. According to the research and data from Bachu et al., the crude oil density that is suitable for CO_2 injection is in the range of 0.7950-0.9600 g/cm^3, from which a crude oil density indicators evaluation table is obtained.

Table 3-3 Crude oil density indicators evaluation table

Crude oil density（g/cm^3）	＜0.82	0.82-0.86	0.86-0.88	0.88-0.9	＞=0.9
Evaluation standard	Good	Relatively good	Average	Relatively poor	Poor

3.3.4 CAPROCK CONDITION

The reservoir caprock is a prerequisite for determining whether the CO_2 can be stored. The continuity and thickness of the caprock, and the extent to which the caprock is destroyed during oil reservoir extraction, will determine the storage quality for the CO_2. The caprock indicators evaluation table is as follows:

Table 3-4 Caprock characteristic indicators evaluation table

Caprock evaluation table	Caprock in place	Great many	Many	Some	Some	None
	Continuity of caprock distribution	Continuous, stable	Relatively continuous and relatively stable	Medium and stable	Relatively poor continuity and stability	Poor continuity and stability
	Caprock thickness（m）	＞=300	150-300	100-150	50-100	＜50
	Extent of damage	＞=300	150-300	100-150	50-100	＜50
Evaluation standard		Good	Relatively good	Average	Relatively poor	Poor

3.3.5 RESERVOIR CHARACTERISTICS

The thickness, permeability and porosity of the reservoir are important indicators for determining the efficacy of CO_2 storage and flooding. Based on existing CO_2-EOR geological storage projects, the properties of the reservoir are generally assessed in terms of clastic rock and carbonate rock. Reservoir thickness directly determines the reservoir's CO_2 sequestration capability. In the case of CO_2-EOR, the flow of solvent will exceed the flow of crude oil and water due to density and viscosity differences between the injectant and crude oil during the reservoir injection process. In the case of gas injection development, the larger the porosity of the rock is, the less capability for sufficient miscibility conditions to be provided, and the flooding agent is more prone to overlap and fingering. Successful CO_2 injection projects generally select reservoirs with a porosity range from 5% to 30%. Reservoir heterogeneity is one of the main factors that directly influence the effect of gas flooding, and the choice of permeability also plays an important role, although the permeability is within a certain range. The permeability selected in the current CO_2-EOR projects is generally 0.1×10^{-3} um^2-500×10^{-3} um^2. Based on the above, the basin reservoir characteristic indicators evaluation table is obtained.

Table 3-5 Reservoir characteristic indicators evaluation table

Reservoir lithology	Clastic rock, layered distribution	Hybrid, layered distribution	Carbonate rock, layered distribution	Non-sedimentary rock	No salt rock
Reservoir thickness (m)	＜10	10-20	20-30	30-40	＞40
Porosity (%)	10-15	15-20	20-25	25-30	＞=30
		8-10	6-8	4-6	＜4
Permeability (10-3um2)	0.1-10	10-50	50-200	200-500	＞=500
Evaluation standard	Good	Relatively good	Average	Relatively poor	Poor

3.3.6 FRACTURE CONDITION

Faults and fissures in reservoir caprock are the main factors affecting the risk of leakage in CO_2 geological storage. CO_2 can leak to the surface through faults or cracks and cause harm. Therefore, the smaller the development of faults and fissures are in the reservoir, the lower the risk of CO_2 leakage and the greater the sealing capacity of the fault. The fracture condition indicator evaluation table is as follows:

Table 3-6 Fracture activity indicator evaluation table

Fracture activity type	Geological characteristics	Limited faults and fractures and large mudstones	Limited faults	Medium faults	Limited large faults	Large faults
			Limited fissures	Medium fissures	Limited large fissures	Large fissures
	Sealing capacity	Good	Good	Medium	Poor	Poor
Evaluation standard		Good	Relatively good	Average	Poor	Poor

3.4 GAS SOURCE AND SURROUNDING ENVIRONMENT EVALUATION INDICATORS

The entire process flow of CO_2-EOR geological storage and flooding technology includes capture, transport, storage and flooding, and safety monitoring. Therefore, we conducted a preliminary evaluation CO_2 sources in Easter Junggar, considering transportation conditions, CO_2 volume, and distance. A gas source and surrounding environment indicator evaluation table and a cost indicator evaluation table were derived from corresponding analysis.

Table 3-7 Gas source and surrounding environment indicator evaluation table

Infrastructure	Complete	Relatively complete	Medium	Incomplete	None
Transportation conditions	Good	Relatively good	Average	Relatively poor	Poor
Gas supply distance（km）	＜50	50-100	100-200	200-300	＞300
Gas supply scale（$10^6 t \cdot a^{-1}$）	＞55	25-55	10-25	5-10	＜5
Evaluation standard	Good	Relatively good	Average	Relatively poor	Poor

Table 3-8 Earnings indicator evaluation table

Earnings	Far greater than costs	Greater than costs	Equal	Lower than costs	Far lower than costs
Evaluation standard	Good	Relatively good	Average	Relatively poor	Poor

3.5 JUNGGAR BASIN CO2-EOR TECHNOLOGY SUITABILITY ASSESSMENT

Separate assessments on the Junggar Basin oil and gas field CO_2 geological storage suitability and CO_2-EOR suitability were performed, in accordance with the National Carbon Dioxide Geological Storage Potential Evaluation and Demonstration Project Implementation Technical Requirements. The Junggar Basin oil and gas field CO_2-EOR technology suitability assessment results are set out in Table 3-9.

Table 3-9 Junggar Basin oil and gas field CO_2-EOR technology suitability evaluation results table

Indicator level	Indicator evaluation level	Weight	Indicator sublayer	Weight	Score	Specific indicator	Weight	Score	Suitability				
									Suitable	Relatively suitable	Average suitability	Relatively unsuitable	Unsuitable
CO_2～EOR geological storage indicators	Regional evaluation	0.25	Basin character indicators	0.3	8.22	Tectonic setting	0.1	9	Craton foreland	Inland rift	Diffuse passive basin	Mountain aggregation	Ocean torsional active trench
						Basin area（km^2）	0.3	9	≥.3in a	50000～100000	10000～50000	1000～10000	<1000
						Basin natural conditions	0.1	3	Deep sea and temperate zone	Deep sea and tropical zone	Shallow sea and desert	Land and subarctic region	Land and polar region
						Basin depth（m）	0.2	10	≥02in	4000～5000	2500～4000	1000～2500	<1000
						Surface temperature（℃）	0.05	5	<～2	～2～3	3～10	10～25	≥50
						Geothermal flow value（MW/m2）	0.1	9	＜54.5	54.5～65	65～75	75～85	＞85
						Geothermal gradient G（℃/100m）	0.15	7.8	<2.0	2.0～3.0	3.0～4.0	4.0～5.0	≥.
									Cold basin	Sub-cold basin	Medium	Sub-thermal basin	Thermal basin

		Safety indicators	0.4	6	Fracture characteristics	0.2	8	Limited faults and fissures, large mudstone	Limited faults and limited fissures	Medium faults and medium fissures	Relatively large faults and large fissures	Large faults and large fissures
					Fracture closure	0.3	7	Good	Relatively good	Medium	Relatively poor	Poor
					Ground motion peak acceleration（g）	0.2	2	＜=0.05	0.05～0.1	0.1～0.15	0.2～0.3	＞=0.4
					Earthquake	0.2	5	Occurs rarely, long distance	Small occurrence rate, relatively long distance	Common occurrence rate, medium distance	Occurs frequently, close distance	High occurrence rate, close distance
					Volcano	0.1	9	Occurs rarely, long distance	Small occurrence rate, relatively long distance	Common occurrence rate, medium distance	Occurs frequently, close distance	High occurrence rate, close distance
		Potential indicators	0.3	9.5	Exploitable coefficient	0.5	9	>0.80	0.80～0.65	0.65～0.50	0.50～0.35	<0.35
					CO_2 storage capacity（10^4t）	0.5	10	≥05r	700～900	500～700	300～500	<300
Trap evaluation	0.25	Caprock indicators	0.4	8.65	Caprock lithology	0.3	9	Gypsum, mudstone and calcareous mudstone	Sandy mudstone and silty mudstone	Silty mudstone and sandy mudstone	Argillaceous siltstone and shaly sandstone	Shale and dense limestone
					Caprock thickness（m）	0.35	8	≥.35	150～300	100～150	50～100	<50

						Caprock distribution continuity	0.35	9	Continuous, stable	Relatively continuous and stable	Medium and relatively stable	Poor continuity and relatively unstable	Poor continuity and unstable
			Storage layer indicators	0.6	5.7	Burial depth（m）	0.25	9	1500～2000	2000～2500	2500～3000	3000～3500	⩾500a
										1200～1500	1000～1200	800～1000	<800
						Thickness（m）	0.2	3	⩾.2	60～80	30～60	10～30	<10
						Porosity（%）	0.3	7	Sandstonepth	15～20	10～15	5～10	<5
									Carbonate rocks ⩾16	12～16	8～12	4～8	<4
						Permeability （10^{-3} um^2）	0.25	3	Sandstoneity k	500～1000	50～500	1～50	<1
									Carbonate rocks ⩾200	100～200	10～100	1～10	<1
CO_2～EOR reservoir		0.3	Fluid indicator	0.3	7	Crude oil density（g/cm^3）	1	7	<0.82	0.82～0.86	0.86～0.88	0.88～0.90	⩾.902
			Oil and gas reserve physical	0.4	8.2	Permeability（10^{-3} um^2）	0.2	9	0.1～10	10～50	50～200	200～500	⩾00m
						Oil and gas reserve depth（m）	0.3	9	1500～2000	2000～2500	2500～3000	3000～3500	⩾500a
										1200～1500	1000～1200	800～1000	<800
						Storage layer thickness （m）	0.3	7	<10	10～20	20～30	30～40	⩾00

suitability indicators	Reservoir evaluation		property indicators			Porosity（%）	0.2	8	10～15	15～20	20～25	25～30	⩾02
										8～10	6～8	4～6	<4
			Oil and gas reserve conditions	0.3	6.75	Oil and gas reserve temperature（℃）	0.3	1.5	80～90	90～100	100～110	110～120	⩾20
										70～80	60～70	50～60	<50
						Oil and gas reserve pressure（M Pa）	0.3	9	15～20	20～25	25～30	30～35	⩾53
										12～15	10～12	8～10	<8
						Exploitable coefficient	0.4	9	>0.80	0.80～0.65	0.65～0.50	0.50～0.35	<0.35
	Gas source evaluation	0.1	Gas source indicator	1	8	Gas source scale（$10^6 t\cdot a^{-1}$）	0.6	10	⩾06	25～55	10～25	5～10	<5
						Gas source distance（km）	0.4	5	<50	50～100	100～200	200～300	⩾00
	Environment and facility cost indicator	0.1	Transportation indicator	0.4	7	Transportation situation	1	7	Good	Relatively good	Average	Relatively poor	Poor
			Environment	0.6	6.8	Social environment	0.1	5	High public acceptance and complete laws and regulations	Relatively high public acceptance and relatively	Average public acceptance and laws and	Poor public acceptance and laws and regulations need	Public rejection

Gas source and environment indicators			indicators							complete laws and regulations	regulations need to be revised	to be established	
						Infrastructure	0.4	7	Complete	Relatively complete	Medium	Not complete	None
						Earnings	0.5	7	Far greater than costs	Greater than costs	Equal	Lower than costs	Far lower than costs
Score				7.3585					9	7	5	3	1

The computed results show that the composite evaluation score with respect to CO_2-EOR geological storage indicators, CO_2-EOR oil reservoir suitability indicators and gas source and environment indicators for the Junggar Basin is 7.3585, which means that CO_2-EOR technology is assessed as relatively suitable for the Junggar Basin. Next, on the basis of the relevant evaluation results, a Junggar Basin CO_2-EOR suitability source matching assessment map was made, as set out in Figure 3-1:

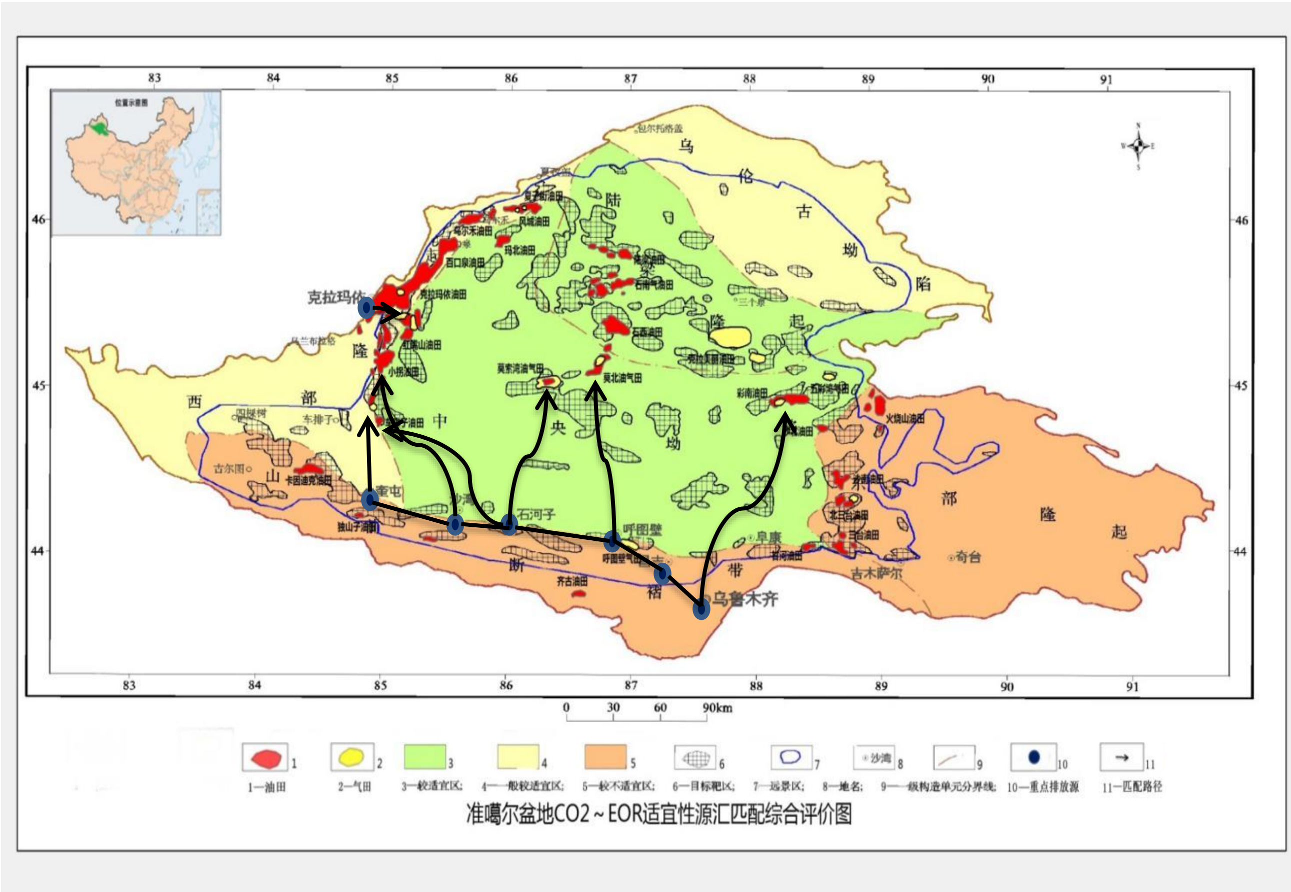


Figure 3-1: Junggar Basin CO_2-EOR suitability map

The Junggar Basin has a wide distribution of suitable carbon dioxide geological storage areas, with good reservoir physical properties and suitable natural conditions. Additionally, the high degree of gas and oil exploration is a benefit for implementing CO_2-EOR technology.

The method for calculating the carbon dioxide theoretical storage quantity of the oil reservoirs is mainly based on a material balance equation. It is assumed that the space left from gas and oil extraction can all be used to store carbon dioxide. When using carbon dioxide to improve the gas and oil production rate, the carbon dioxide theoretical storage quantity in the oil reservoir can be calculated according to the following two formulas:

Before carbon dioxide breakthrough:

$$M_{co_2to} = \rho_{co_2r} \times (E_{RBT} \times N \times B_o)$$

After carbon dioxide breakthrough:

$$M_{co_2to} = \rho_{co_2r} \times [(E_{RBT} + 0.6(E_{RHCPV} - E_{RBT})]N \times B_o$$

In the formula:

M_{CO_2to} —The carbon dioxide theoretical storage quantity in the oil reservoir, 106t；

ρ_{CO_2r} —The carbon dioxide density under the oil reservoir conditions, kg/m3；

N—Crude oil storage quantity，109m3；7395*106m3

BO—Crude oil volume factor，m3/m3；

ERBT—The original extraction rate before carbon dioxide breakthrough，%；

ERHCPV—The original extraction rate when injecting carbon dioxide of a certain hydrocarbon pore volume (HCPV), %.

Without considering the injection and water recovery issues, the parameter selection is based on average values of a large amount of data.

Table 3-10: Junggar Basin oilfield storage calculation parameters and results

CO_2 density under oil storage conditions, kg/m^3	Crude oil storage quantity/10^6 t	Crude oil storage density kg/m^3	Crude oil volume factor	Original extraction rate before carbon dioxide breakthrough /%	Original extraction rate when injecting CO_2 of a certain hydrocarbon pore volume, %	CO_2 theoretical storage quantity in the oil reservoir /10^{6}t
860	8700.0	840	1.1665	24.6	32.24%	3897.22

3.6 EAST JUNGGAR REGION CO2-EOR TECHNOLOGY SUITABILITY ASSESSMENT

Based on the National Carbon Dioxide Geological Storage Potential and Suitability Evaluation issued by the Institute of Hydrogeology and Environmental Geology, China Geological Survey and data collected from the Junggar oilfields, relevant geographical information was obtained (as shown in Figure 3-2), combined with an analysis of the main factors that impact CO_2 geological storage in the East Junggar oilfield, and then the main indicators for CO_2 geological storage and flooding were selected. Accurate values for the indicators were then confirmed by consulting experts attending the CCUS meeting via interviews and written questionnaires. An assessment system for CO_2-EOR potential in the East Junggar oilfield was thereby established. A score for each evaluation indicator was derived by assigning the values 9, 7, 5, 3 and 1 to the corresponding assessment sets (suitable, relatively suitable, average suitability, relatively unsuitable and unsuitable).The weighting of the indicators was determined analytically by taking the safety of the injected CO_2 as the main reference point. Finally, the CO_2 geological storage suitability and the CO_2-EOR suitability composite value were calculated according to the weighted average method. An East Junggar CO_2-EOR technology geological storage and flooding suitability assessment table was drawn up, as shown in Table 3-11:

Table 3-11 East Junggar CO_2-EOR technology geological storage and flooding suitability assessment table

	Criterion layer	Assessment indicator	Weight	Huoshaoshan oilfield	Beisantai oilfield	Shabei oilfield	Shanan oilfield	Cainan oilfield
				Score	Score	Score	Score	Score
East Junggar CO_2-EOR suitability composite assessment system	Oil storage	Oil storage amount	10%	87,490,000 tons	18,430,000 tons	4,264,700 tons	16,630,000 tons	19,000,000 tons
				7	7	3	3	7
		Oil storage depth	10%	2,470m	2,273m	1,400m	2,700m	2,300m
				7	7	7	5	7
		Crude oil density	5%	0.8432g/cm^3	0.8278g/cm^3	0.8040g/cm^3	0.7480g/cm^3	0.8273g/cm^3
				7	7	9	7	7
	Geology	Caprock condition	25%	411m	100m	95m	15m	25m
				4.3	4.3	4.3	4.3	5
		Porosity	5%	7%-12%	17%-26%	5.33%-25.33%	6.4%-20.9%	20%
				9	3	3	5	7
		Permeability	5%	3.75×10^{-3}μm^2	59×10^{-3}μm^2	0.13-55(10^{-3}μm^2)	0.01-416(10^{-3}μm^2)	165×10^{-3}μm^2
				9	3	3	3	5

East Junggar CO_2-EOR suitability composite assessment system		Oil reservoir fracture condition	25%	Oil reservoir fractures are complicated, CO_2 geological storage cannot be implemented	3 reverse fractures from east to west. 1 fracture from northeast to southwest, 1 fracture from northwest to southeast	There are small-scale traps in oil reservoir fractures	The oil reservoir is cut off by fractures and is not complete	The oil reservoir has fractures and traps
				0	5	7	3	7
	Economy	Transportation situation	5%	Convenient transportation, 206 national highway	Convenient transportation, Fucai Road, Xingfu Road	Convenient transportation, Fucai Road and Xingfu Road separately go through the area from east to west	Convenient transportation, Fucai Road and Xingfu Road separately go through the area from east to west	Convenient transportation, Gurbantunggut Desert Highway passes through this area
				9	9	9	9	9
		Gas source distance	10%	Zhundong Industrial Park, 160km Wucaiwan Industrial Park, 20km Kamusite Industrial Park, 76km	Zhundong Industrial Park, 90km Wucaiwan Industrial Park, 56km Kamusite Industrial Park, 150km	Zhundong Industrial Park, 140km Wucaiwan Industrial Park, 12km Kamusite Industrial Park, 105km	Zhundong Industrial Park, 114km Wucaiwan Industrial Park, 45km Kamusite Industrial Park, 138km	Zhundong Industrial Park, 200km Wucaiwan Industrial Park, 78km Kamusite Industrial Park, 100km
				7	6.33	7	6.33	5
		Overall score：		4.875	5.458	5.725	4.458	6.3

Figure 3-2 Map of East Junggar oilfield

（喀木斯特工业园区—Kamiste Industrial Park，滴 2 井区—No. 2 well area，彩南作业区——Cainan operation area，火烧山油田—Huoshaoshan Oilfield，沙北油田—Shabei Oilfield，五彩湾工业园区— Wucaiwan Industrial Park，沙南油田—Shanan Oilfield，北三台油田—Beisantai Oilfield，准东工业园区—Zhundong Industrial Park）

In summary, there are three oilfields suitable for the application of CO_2-EOR technology—Beisantai, Shabei and Cainan oilfields. Of these, the evaluation score for Cainan oilfield was the highest, with the best implementation outcomes.

4. FEASIBILITY ANALYSIS ON THE CAPTURE TECHNOLOGY FOR THE GUANGHUI CCUS PILOT PROJECT

4.1 THE PURPOSE AND SIGNIFICANCE OF THE CAPTURE TECHNOLOGY ANALYSIS

Prior to the launch of the CCUS Pilot Project, there was a comprehensive analysis done on the development of carbon source capture technology, and a judgement was made as to whether, from the many mature technologies worldwide, the capture technology adopted by the Xinjiang Guanghui Coal to Gas Project was scientific and rational, and whether it was conducive to the pilot test and the smooth progress of the Project. Further, an evaluation of issues such as the relative location and distance of carbon sources, the surrounding industries, carbon sink points, CO_2 transportation routes and costs was performed, so as to create a scientific and rational prefeasibility study.

4.2 CARBON SOURCE OVERVIEW

Xinjiang Fuyun Guanghui New Energy Company has signed Memorandums of Cooperation separately with Central Asia Petroleum Company and Wuhuan Xinrui Chemical Company to use Wuhuan Xinrui's food grade liquid carbon dioxide technology to capture CO_2 produced by the Xinjiang Fuyun Guanghui Kamusite Coal to Gas Project and provide compliant liquid carbon dioxide to Central Asia Petroleum for oil displacement. With rich experience and mature technology, Guanghui Company has become the first choice for CCUS projects in Xinjiang.

4.2.1 SOURCE AND SPECIFICATIONS OF RAW MATERIALS

1) Raw material sources

The main carbon source supply points for this Project are numerous large-scale coal-fired power plants, coal-to-chemical plants and steelworks from the following places (ordered furthest to nearest): Kuitun, Dushanzi area, Shawan, Shihezi City, Manasi, Hutubi, Changji, Miquan, Fukang, Wujiaqu and Urumqi.

2) Raw material specifications

Table 4-1 Main raw materials specifications and quantities table

No.	Raw material name	Specification	Unit	Quantity	General properties	Remarks
1	PSA purge gas		Nm^3/h	15,000		
	Total		Nm^3/h	15,000		

3) Auxiliary materials supply

Table 4-2 Main auxiliary materials specifications and quantities table

No.	Raw material name	Specification	Unit	Quantity	Source	Remarks
1	AEA		t/a	10	China	
	Total					

4.2.2 SITE CONDITIONS

Xinjiang Guanghui's Coal to Gas Project site is located in the Kamusite Industrial Park in Fuyun County, Xinjiang Autonomous Region. The site is located about 160 kilometres south of the county seat, on the west side of National Highway 216. Topography and geomorphology: the landform of the proposed site is classified as Gobi and an alluvial-proluvial platform. Its elevation is approximately 960 meters, and the terrain is flat and simple. The land is classified as state-owned unused desert.

The Project's mode of water supply is mainly pipeline transportation from Qiakuertu Township to the production area with a distance of about 80 kilometres. The Caiwan - Kamusite 220 kV power transmission project has been fully completed, and a 220kV transmission line with wire diameter of LGJ - 2 x 240 has been built to the Kamusite substation. Two 180MVA transformer units are planned for construction at the substation. Currently, the construction of one 180MVA transformer unit has been completed. The output voltage level is 110kV and 35KV. Rainwater is to be piped out of the plant. Because the terrain of the site is very flat, the main flood control issue is to solve waterlogging in the plant.

The reference environmental conditions for performance evaluation are as follows:

Average temperature: 4.3 °C
Pressure: 925hPa
Average annual precipitation: 208mm
Average annual total evaporation: 1,445.5mmMaximum wind speed: 20.0m / s
Prevailing wind direction: WNW
Maximum snow depth: 71cm
Soil freezing depth: 141cm

4.2.3 CARBON CAPTURE TECHNOLOGY OVERVIEW

The IPCC Fifth Assessment Report released in 2014 pointed out that CO_2 is still the most significant greenhouse gas. In terms of CO_2 emissions from human activities in 2010, electricity and heating accounted for 25%, agriculture, forestry and land use 24%, industry 21%, transportation 14%, construction 6.4% and others 9.6%. Most scenarios estimated that non-renewable energy supply would continue to be dominated by fossil fuels over the coming decades, with the proportion of CO_2 emitted from burning of fossil fuels becoming greater, but also the most controllable. CCS technology refers to CO_2 captured and separated from relevant combustion emission sources and transported to oil and gas fields, oceans and other places for long-term storage, thereby preventing or significantly reducing greenhouse gas emissions, so as to reduce the impact on the Earth's climate. CCS is considered to be the most effective measure for this purpose. The cost of carbon capture accounts for about 2/3 of the total system, so the research and development of carbon capture technology is crucial for the development of CCS technology. At present, coal-fired power plant carbon capture technology is mainly divided into three kinds: the first is pre-combustion capture, the second is oxy-fuel capture and the third is post-combustion capture. The choice of carbon capture technology depends on the type of fuel, the method of combustion, the temperature of combustion, the CO_2 concentration and partial pressure in the gas, as well as the existing technology and costs.

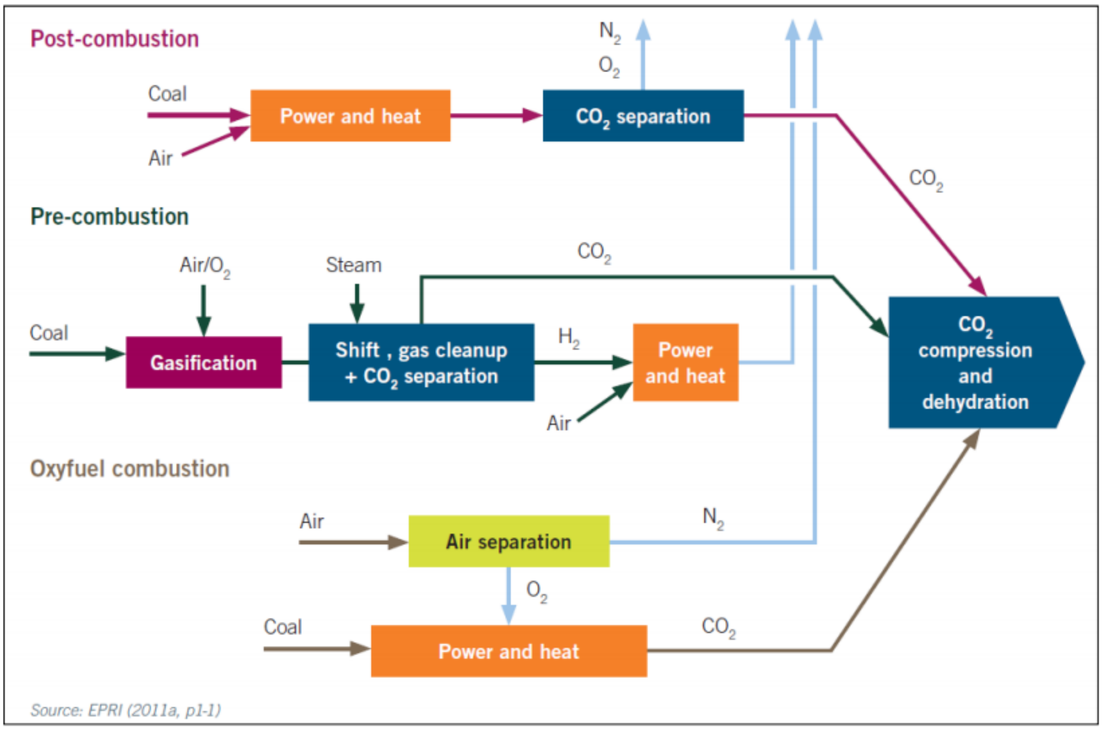


Figure 4-1 Main separation processes of CO_2 in coal-fired power plants

4.2.3.1 PRE-COMBUSTION CAPTURE TECHNOLOGY

Removing carbon from the fuel prior to combustion will inevitably convert the carbon in the fuel to a readily separable material. Taking a coal-fired thermal power plant as an example as shown in Figure 4-2, partial oxidation reaction of coal with water vapour or oxygen occurs at high temperature and pressure to produce a certain amount of CO and H_2, so-called "syngas". After purification of the syngas via particle removal, the syngas CO reacts with water vapour to form CO_2. Then, CO_2 is removed by absorption and adsorption technology (for example, the Seloxol method that has been widely applied in industry), and then almost clean H_2 fuel gas is obtained. Although fuel gasification is more complex and costly than traditional direct combustion, in the CO_2 separation process, separation is simpler and lower cost under high pressure and high CO_2 concentration conditions. Unlike post-combustion capture of CO_2 through chemical reaction between CO_2 and an absorbent, a more suitable method of CO_2 capture prior to combustion is the physical absorption and adsorption of CO_2 under high pressure and high concentration followed by desorption.

However, the energy consumption of pre-combustion capture is relatively large. In particular, in the fuel gas recombination and CO_2/H_2 mixture gas separation process, the initial fuel conversion step is more complicated, and compared with the post-combustion system the cost is higher. However, the high concentrations of CO_2 produced by the shift reactor (typically 15% to 60% by volume on a dry basis) and the high pressure conditions used in these applications are more conducive to CO_2 separation. The pre-combustion system can be used in power plants with integrated gasification combined cycle (IGCC) technology.

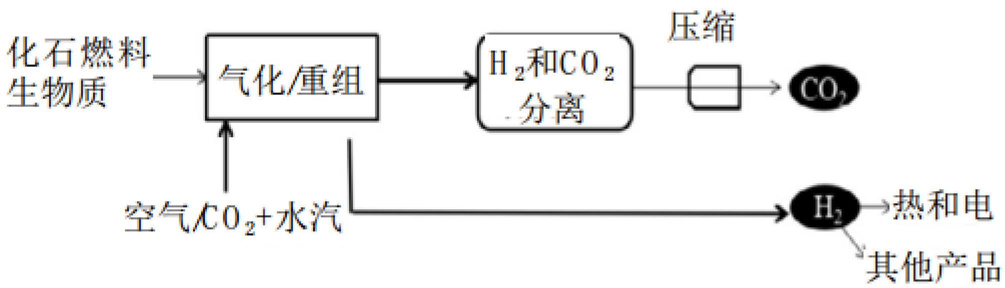


Figure 4-2 Pre-combustion CO_2 capture system schematic

4.2.3.2 OXY-FUEL COMBUSTION CAPTURE TECHNOLOGY

Oxy-fuel combustion technology refers to the introduction of pure oxygen without nitrogen in the combustion process, resulting in a flue gas with a high CO_2 concentration of up to 85% or more, which facilitates subsequent storage. Oxy-fuel combustion capture has very significant development prospects. Since no nitrogen is involved in the combustion process, the combustion temperature is higher and only a trace amount of NOx is generated. Therefore, the energy consumption of the whole carbon capture process is comparatively low.

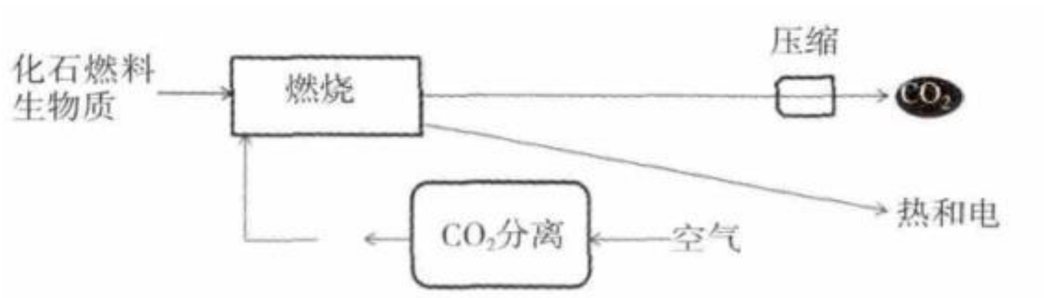


Figure 4-3 Oxy-fuel combustion CO_2 capture system schematic

However, the core of oxy-fuel combustion capture is the oxygen production process. Low temperature separation and membrane separation technology is often used, and the cost of the oxygen production process is very high. Due to the high temperature of the oxy-fuel combustion process, the material tolerance of the burner and the structural design and modification of the burner become relevant. In light of the oxygen production cost and the burner structure issues, at the moment this process is mainly limited to laboratory and pilot studies. Argonne National Laboratory is currently looking into modification of the oxy-fuel burner, so that the burner can integrate CO_2 transfer, utilisation and storage.

4.2.3.3 POST-COMBUSTION CAPTURE TECHNOLOGY

Post-combustion capture of CO_2 from thermal power plants is feasible under certain economic conditions, and has been industrialised. Conventional thermal power plants generate heat and electricity through the combustion of coal with air, with pollutants such as SO_2, NOx and particulates being generated during the combustion process. Since the CO_2 capture process needs to maintain the relative cleanliness of the mixed gas, the general process occurs after dust removal, desulphurisation and denitrification. There are many branches of post-combustion capture technology, which are mainly divided into membrane separation, low temperature distillation, physical adsorption and chemical absorption. Currently, the most widely used and efficient CO_2 capture method is alcohol amine absorption. The alcohol amine method can capture 85%~95% of CO_2, absorb the CO_2 solvent and then heat and desorb, to obtain high concentration CO_2 gas for transportation and sequestration.

Although commercial CO_2 capture systems have not yet been fully established, hundreds of alcohol amine method capture projects have been set up over the past 20 years and mainly used to capture CO_2 in feedstock in industries such as the food and beverage industry, as well as a small number of thermal power plants. The concentration of the alcohol amine absorption solution is generally about 20%. Increasing the concentration of the absorption solution can improve the capture efficiency and reduce energy consumption, but a higher absorption liquid concentration can also increase corrosion of equipment. Therefore, with differently designed capture systems and equipment, the technological process and parameters vary widely.

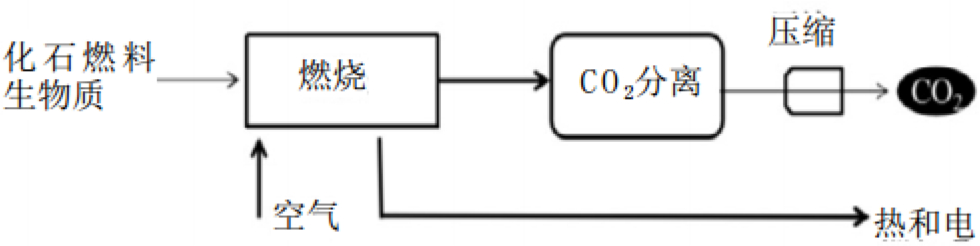


Figure 4-4 Post-combustion CO_2 capture system schematic

(1) Membrane separation

Membrane separation is a separation method that uses pressure as the driving force, and is divided into the membrane separation method and the membrane absorption method. The membrane separation method has the advantages of simple structure, convenient operation, less investment, compact equipment, small area and low energy consumption. The membrane method is not very suitable for CO_2 flue gas separation in thermal power plants. On the one hand, the selectivity of membrane materials is low, and the separation purity is not high. On the other hand, CO_2 in power plant flue gas has low partial pressure and poor economic performance. At present, the membrane separation method is still in the pilot test stage, with the Membrane Technology and Research, Inc. (MTR) being a typical example.

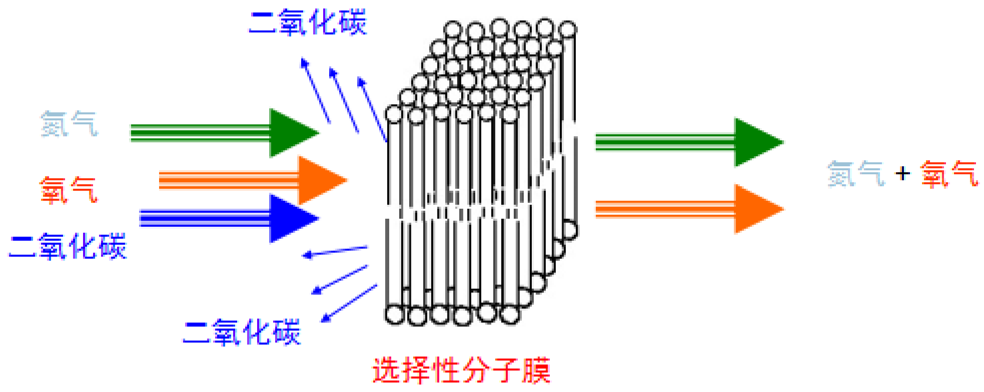


Figure 4-5 Membrane separation method schematic

(2) Low temperature distillation

CO_2 exists in a gaseous state at normal temperature and pressure. When the pressure is high enough and the temperature is lower than a certain value, gaseous CO_2 can be transformed into a liquid state. By this principle, the CO_2 in a gas mixture can be separated out. To make it more economically reasonable to use this method for a mixture with a higher CO_2 content, liquid CO_2 products can be obtained directly by using compression, condensation and purification. Gas mixtures with low CO_2 content need to be compressed and cooled many times to concentrate and separate the CO_2 from the mixed gas.

A typical low temperature distillation process is the N_2/CO_2 cryogenic distillation separation method of Davy McKee Corp. in the United States.

Figure 4-6 Low temperature distillation method schematic

(3) Physical adsorption method

The adsorption method can be divided into pressure swing adsorption (PSA), temperature swing adsorption (TSA) and pressure-temperature swing adsorption (PTSA), according to adsorption principles. PSA is a method based on the selective adsorption of CO_2 in feed gas by a solid adsorbent, with adsorption at high pressure and desorption at low pressure. TSA involves adsorption and desorption by changing the temperature of the adsorbent, with absorption at lower temperature and desorption at higher temperature. Due to the large energy consumption of the TSA method, pressure swing adsorption is used more in industry at present. The adsorbents commonly used in the adsorption method include zeolite, activated carbon, molecular sieves and aluminum gel.

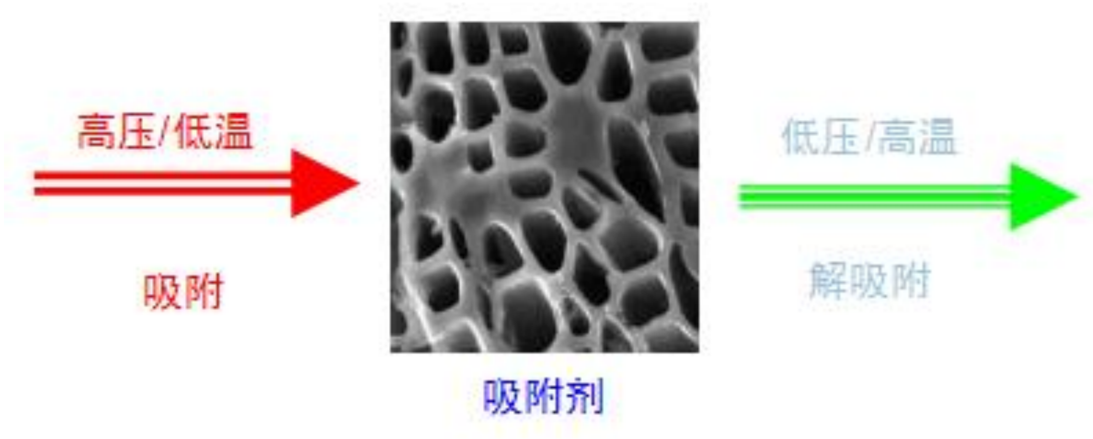


Figure 4-7 Physical adsorption method schematic

Currently PSA and TSA have been successfully commercialised in the ammonia and natural gas industries, but they are not suitable for flue gas discharge with low CO_2 concentrations and high adsorption selectability, so adsorption technologies are not currently used for CO_2 capture in coal-fired power plants.

(4) Chemical absorption method

Chemical absorption is the use of CO_2 and absorbent in the absorption tower to form a weakly bonded intermediate compound via chemical reaction. The intermediate compound solution is then heated in the regeneration tower to desorb the CO_2, while the absorbent can be regenerated.

This technology is relatively mature and widely used in the petroleum and chemical industries. It has also been used in coal-fired power plants.

4.2.4 COMPARISON OF CO_2 CAPTURE TECHNOLOGIES

Table 4-3 Capture method comparison table

Classification	Applicability	General characteristics
Physical absorption method	For CO_2 partial pressure and higher total pressure feed gas decarbonisation	Mostly large absorption capacity. The solvent regeneration only needs decompression and gas extraction, and the energy consumption is low. Low corrosiveness. Low CO_2 recovery rate.

Physicochemical absorption method	For decarbonisation of feed gas with high total pressure of CO_2 partial pressure	Larger absorption capacity. The solvent regeneration needs decompression and thermal regeneration, the energy consumption is lower than that of chemical absorption, and the physical absorption method is high. High CO_2 recovery rate.
Chemical absorption method	Absorption is easily affected by the CO_2 partial pressure and the total pressure of the feed gas	Fast absorption rate. High degree of purification. The regeneration of the solvent should be heated and the energy consumption of regeneration is high. Strong corrosiveness. High CO_2 recovery rate.
PSA	The adsorption pressure needs to be greater than 0.7MPa	Low energy consumption. No pollutant discharge. The process is simple. The adsorbent is used for long periods, with small loss and high purification. Effective gas CO and CH_4 loss is higher. High investment and occupies a large area.
Membrane separation method	Requires higher CO_2 partial pressure	Low energy consumption. The operation is simple. High investment at present. Industrialisation is not mature.
Low temperature separation method	Requires higher CO_2 concentration	The energy consumption is related to the concentration. The separation process is economical only when the concentration of CO_2 is greater than 90%, otherwise the energy consumption is high. Mainly used for the separation and purification of high concentration CO_2 gas at present.

It is proposed that Chengdu Wuhuan Xinrui food-grade liquid carbon dioxide technology be used for CO_2 produced by Xinjiang Guanghui New Energy Co. Ltd.'s Kamusite Coal to Gas Project. The CO_2 from Xinjiang Guanghui would be compressed, enriched, pressure-boosted, liquefied, and ultimately stored or transported as a liquid product for oilfield displacement. Through the above technical means, carbon dioxide can be enriched to 99.8%, and its quality is adequate to be applied in Central Asia Petroleum carbon dioxide flooding technology. At the present stage, a 100kt/a liquid CO_2 project with investment of 34 million yuan will be temporarily constructed, and later the CO_2 capture project capacity will be expanded according to Central Asia Petroleum's requirements. The Figure below sets out a flow chart of the Xinjiang Guanghui CO_2 capture technology:

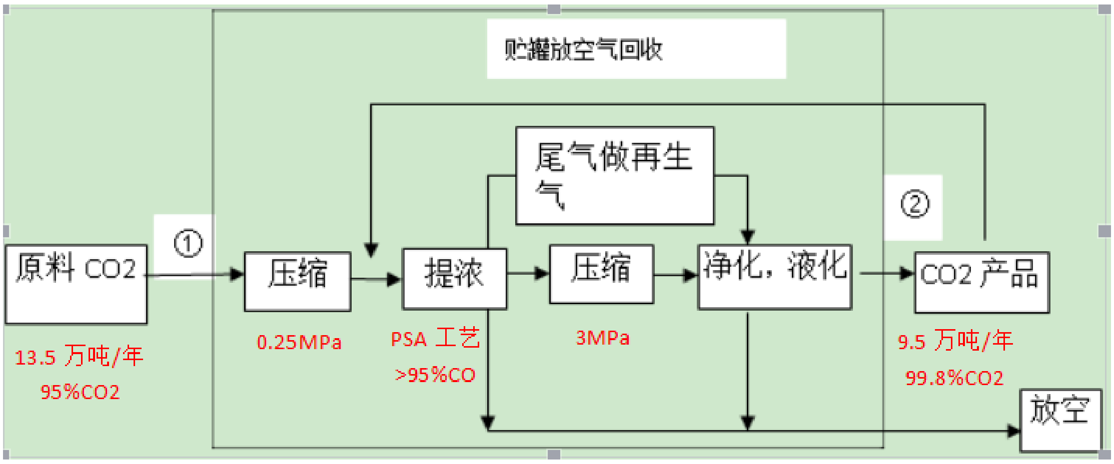


Figure 4-8 Xinjiang Guanghui food grade liquid carbon dioxide technology diagram

4.2.5 TECHNICAL PROCESS AND KEY EQUIPMENT

4.2.5.1 ABSORPTION AND DESORPTION PROCESS FLOW

The purge gas (150kPa, 40 ℃) from the PSA hydrogen production unit enters the absorption tower from its base (11-T01), and is countercurrently in contact with the lean amine liquid coming in from the upper part of the absorption tower. The CO_2 in the gas is absorbed by the solution and flows out from the bottom of the tower. Purified purge gas is sent to the reformer for combustion.

The CO_2-enriched rich amine stream from the bottom of the absorption tower (11-T01) is sent to the lean/rich amine heat exchanger (11-E01) via the rich amine feed pump (11-P01A/B) to carry out heat exchange with the hot lean amine liquid from the bottom of the desorption tower (11-T02). When the temperature rises to a predetermined value, it is sent to the desorption tower (11-T02). The rich amine liquid is regenerated in the desorption tower (11-T02), while the CO_2 is separated from the amine liquid. The top stream of the desorption tower (11-T02) is cooled to a set temperature through the desorption tower top air cooler (11-EA01) and desorption tower top cooling unit (11-E04), and then flows into the return tank (11-V03) after being cooled to a set temperature. The liquid at the bottom of the return tank returns to the desorption tower through the desorption tower top return pump (11-P03A / B). Some of the gas in the return tank is sent to a compression device for compression, while the remainder is vented as tail gas.

The lean amine liquid regenerated at the bottom of the desorption tower (11-T02) is sent to the lean/rich amine heat exchanger (11-E01) via the desorption tower bottom pump (11-P02A/B), to carry out heat exchange with the hot lean amine liquid from the bottom of the absorption tower (11-T01). When the temperature drops to a predetermined value, it flows to the lean amine air cooler (11-EA02) and lean amine cooling unit (11-E02) for cooling. After it cools to a set temperature it enters the top of the absorption tower (11-T01) for absorption. The supplementary water is sent to the lean amine liquid pipeline after the lean amine liquid air cooler (11-EA02) via the demineralized water pump (11-P04A/B), to supplement the loss of moisture and maintain the balance of amine liquid concentration in the system.

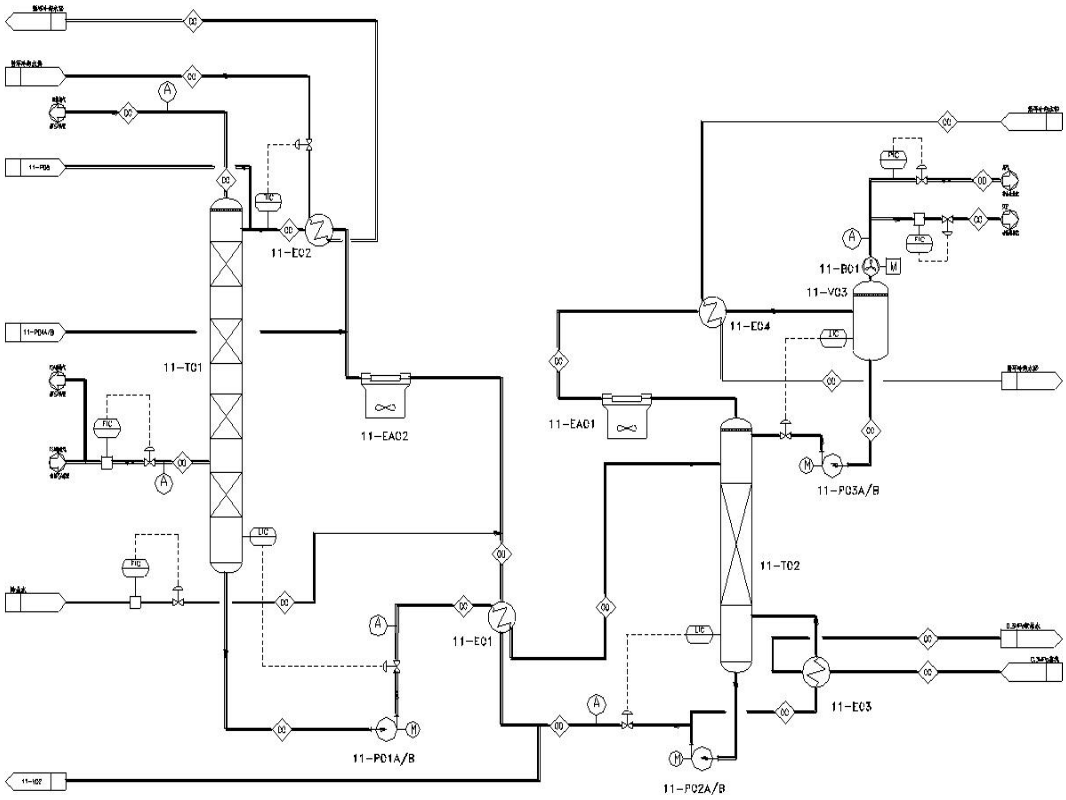


Figure 4-9 Absorption and desorption process flow chart

4.2.5.2 COMPRESSION LIQUEFACTION PROCESS FLOW

This Project uses a carbon dioxide low temperature liquefaction scheme to produce carbon dioxide. Carbon dioxide is compressed to 2.1MPa (G), and water and other impurities are removed through adsorption drying, following which the carbon dioxide enters a low-temperature refrigerating machine to cool and liquefy. The liquid is then sent to storage tanks for storage. The CO_2 from the adsorption and purification stage put into an oil-free piston CO_2 compressor with a small amount of self-evaporating gas from the liquid storage tank, compressed to 2.1MPa (G), and the liquid precipitated during the compression process is separated. It then enters the compression heat regeneration adsorption dryer, for further drying and water removal which, on the one hand, improves product purity and, on the other hand, prevents freezing and blocking in the refrigerating unit. The dry CO_2 enters the refrigerator and is liquefied at a saturation temperature of -18°C. It is designed to be super-cooled by 7°C, that is, the CO_2 exits the refrigerating unit at a temperature of -25°C and then enters the liquid storage tanks. Two sets of compressors, dryers and refrigerators are selected, one for use and the other for standby.

4.2.5.3 TANK AREA PROCESS FLOW

Liquid CO_2 from the compression liquefaction unit is sent to the tank farm via pipeline, stored in double-layer vacuum insulated vertical pressure storage tanks, and then sent out to users via tank car.

4.3 EQUIPMENT OVERVIEW

4.3.1 ABSORPTION EQUIPMENT OVERVIEW

All the equipment comprising the absorption and desorption device were purchased within China. General equipment such as pumps, etc need to be high quality, high efficiency and energy saving. The design and manufacture of non-standard equipment must strictly follow the relevant standard specifications. In the main components of the absorption and desorption device, 7 non-standard units, 9 pumps and 2 other sets of equipment are shared. For the absorption and desorption equipment classification summary, see Table 4-4; for the absorption and desorption device pump classification summary, see Table 4-5; for the absorption and desorption device non-standard equipment classification summary, see Table 4-6.

Table 4-4 Desorption device main equipment table

No.	Equipment name	Specifications	Unit	Number	Weight	Material	Price	Equipment source	Remarks
1	Tower		Set	2				China	
2	Non-standard		Set	7				China	
3	Pump		Set	9				China	
4	Other		Set	2				China	Air cooler

Table 4-5 Absorption and desorption pump classification summary

No.	type	Domestic order		Domestic order		Total		Remarks
		Number	Weight (t)	Number	Weight (t)	Number	Weight (t)	
1	Centrifugal pump	9				9		

	Total	9				9		

Table 4-6 Absorption and Desorption Device Non-Standard Equipment Summary Table

No.	Type	Domestic order				Overseas order				Remarks
		Number	Metal weight			Number	Metal weight			
			Weight (t)	Alloy steel			Weight	Alloy steel		
				Material	Weight			Material	Weight	
1	Heat exchanger	4								

4.3.2 COMPRESSOR

For model selection of the refrigerator unit for the compression and liquefaction devices, see Table 4-7.

Table 4-7 Refrigerator unit model selection table

No.	Type	Unit	
1	Model		Screw refrigeration system
2	Single unit cooling capacity	kW	500
3	Refrigerant		R134a
4	Evaporation temperature	℃	-30
5	Liquid carbon dioxide outlet temperature	℃	-25
6	Voltage	V	10k
7	Single unit power	kW	360
8	Cooling water inlet / outlet temperature	℃	33/38

9	Single unit cooling water circulation	m^3/h	150
10	Units in set	Unit	2
11	Remarks		One in use, one in standby

4.3.3 TANK FARM EQUIPMENT

There are 4 vertical double-layer vacuum insulation tanks in the tank farm, with a single tank capacity of $100m^3$ and a total tank capacity of $400m^3$.

4.3.4 KEY EQUIPMENT SCHEME

The absorption tower adopts a plate tower, while the desorption tower adopts a packed tower. The circulating pump adopts a centrifugal pump. Domestic equipment is used for compressors, refrigerators, etc as well as for the double-layer vacuum insulated storage tanks.

4.3.5 LARGE EQUIPMENT OVERVIEW

Large equipment is shown in Table 4-8.

Table 4-8 Large equipment table

No.	Name	Specification	Solution	Remarks
1	Absorption tower	Φ3000×20000	Large object transportation	
2	Desorption tower	Φ3500×20000	Large object transportation	

4.4 SOCIAL FEASIBILITY

The "13th Five-Year Plan for National Scientific and Technological Innovation" released by the State Council in August 2016 states that developing clean and efficient energy technologies is one of China’s key scientific and technological development pathways during the 13th Five-Year Plan period. We should focus on strengthening the research and development of technologies such as coal-fired carbon dioxide capture, utilisation and storage, and promoting a special technology: implementing a large-scale one million tons/year coal-fired carbon dioxide capture demonstration project. The demonstration project is located in Kamusite Industrial Park, Fuyun County, Xinjiang. The production of the project has achieved all the conditions for carrying out the carbon dioxide capture and compression project, and has a definite demonstration effect.

4.5 TECHNICAL FEASIBILITY

China's CO_2 emissions mainly come from energy consumption. The sources of CO_2 emissions from China's energy activities include stationary sources, mobile sources, and emissions from energy extraction, processing and transportation. From the perspective of fuel type, coal is the main source of CO_2 emissions from China's fossil fuels. From the perspective of emissions source type, stationary sources are the main source of CO_2 emissions in China. As for the break-down of stationary sources, the industrial sector is the largest source of CO_2 emissions; power generation boilers and industrial boilers are the two major types of emission-generating equipment. Xinjiang is no exception. With a large number of high volume and high CO_2 concentration emission sources, Xinjiang is cost-advantaged with respect to CO_2 capture. In addition, a survey of the main industrial sources of CO_2 in Xinjiang was performed, providing basic data support for carrying out strategic and basic research on the main methods, storage capacities, target areas and early implementation opportunities for CO_2 geological storage in the region. As shown in Figure 4-10 and Table 4-9, the sources of CO_2 emissions in Xinjiang are mainly concentrated in such industries as thermal power, cement, steel, chemical and coal-to-gas, with the largest concentration of emission sources being in the coal power industry, reaching 273.4528 million tons of CO_2 emissions, followed by thermal power, steel, chemical and coal chemical industries.

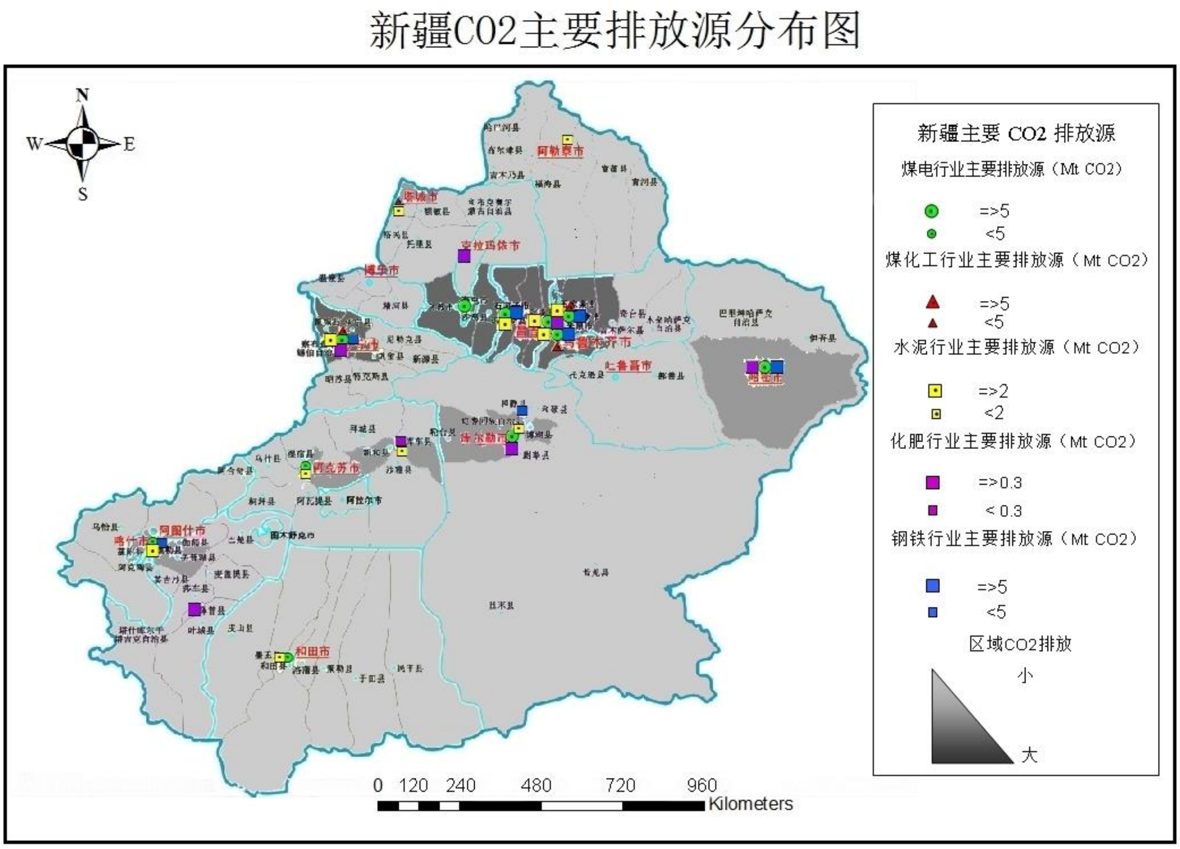


Figure 4-10 Distribution of main CO_2 sources in Xinjiang

Table 4-9 CO2 emissions from various industries in Xinjiang

No.	Capture industry	CO_2 emissions converted (million tons)
1	Coal power industry	273.4528
2	Cement industry	40.5095
3	Steel industry	86.46
4	Fertiliser industry	3.115
5	Coal chemical industry	149.745
6	Petrochemical industry	62.7137
7	Coking industry	6.7971

4.6 ENVIRONMENT AND HEALTH RISKS

4.6.1 POLLUTION SOURCES

1. Waste water: see Table 4-11.

Table 4-11 Waste water conditions table

No.	Name	Emission site	Emissions (m^3/h)	Contaminant / concentration （wt%）	Emission method	Direction	Remarks
1	Waste water treatment	Absorption and desorption device	2		Direct	Waste water treatment plant	Intermittent

2. Waste gas: see Table 4-11.

Table 4-11 Waste gas conditions table

No.	Name	Emission spot	Emissions (m³/h)	Contaminant / concentration （wt%）	Emission method	Direction	Remarks
1	Desorbed tail gas	Desorbing tower	5803.7	-	High altitude emission		CO_2

3. Waste liquid (residue): see Table 4-13.

Table 4-13 Waste liquid (residue) table

No.	Name	Emissions volume (m³/h)	Emission frequency	Concentration of pollutant（wt%）		Treatment measures and removal rate（%）	Direction
				Name of pollutant	Production concentration		
1	Waste amine liquid	100	Once/year	AEA	25%		Centralised processing

4. Noise: for noise conditions, see Table 4-14.

Table 4-14 Noise conditions table

No.	1
Name of equipment	Compressor
Sound source location	Compressor room
Type and specification of equipment	Oil free piston type

Number	2
Technical parameters	550KW
Sound level dB（A）	85
Treatment measures	Concrete wall; exhaust muffling
Noise level db(A)	＜80
Operating characteristics	Continuing

4.6.2 GOVERNANCE MEASURES

5. Waste water treatment: the discharged waste water is cleaning waste water, which is directly discharged to the plant waste water pipe and sent to the waste water treatment plant for treatment.
6. Waste gas treatment: the waste gas contains CO_2, but contains no other toxic and harmful substances, and so is discharged into the air.
7. Waste liquid (sediment) treatment: the amine liquid is used as absorption liquid and recycled in the absorption and desorption device. When its performance cannot meet production needs, it is partially replaced. The displaced waste amine liquid is transported outside via tank car for treatment.
8. Noise management: athe compressor room adopts concrete walls, and the compressor exhaust pipe adopts noise reduction measures, following which the compressor noise is <80dB (A).

Risk emergency measures: of all the raw materials, auxiliary materials and products, only a large-scale leak of the AEA amine liquid that acts as absorption liquid would impact the environment. AEA is not allowed to enter sewers or watercourses. Leaks should be controlled with inert material and absorbed in dry sand or soil.

4.6 SUMMARY

Xinjiang Fuyun Guanghui New Energy Company has signed a Memorandums of Cooperation separately with Central Asia Petroleum Company and Wuhuan Xinrui Chemical Company, to use food grade liquid carbon dioxide capture technology of Wuhuan Xinrui Chemical Company to capture CO_2 from the Xinjiang Guanghui Fuyun New Energy Company Kamusite Coal to Gas Project and provide compliant liquid carbon dioxide to Central Asia Petroleum for oil displacement. With rich experience and mature technology, Guanghui Company has become the first choice for CCUS projects in Xinjiang.

5. FEASIBILITY ANALYSIS OF THE CO_2 TRANSPORTATION METHOD AND ROUTE

5.1 CO_2 TRANSPORTATION MODE AND ROUTE ANALYSIS

For the feasibility of the transportation phase, 3-years and 20-years of pipe transportation were considered and 3-years of tanker truck transportation was considered, for each of the three candidate sites.

Carbon source: Kamusite Industrial Park Coal to Gas Project, captured carbon dioxide of 100,000 tons/year, density of 99.8%.

Carbon sink: The Di-2, Di-12 and Di-20 well area of the Cainan oilfield.

Conditions along the pipeline: The terrain is relatively flat. There are no rivers, roads, railways or other obstacles along the pipeline. The main terrain is the Gobi Desert, with topographic relief of less than 200m. The construction conditions are favourable.

Possible CO_2 transportation methods: pipeline and tanker truck.

5.2 THE PURPOSE AND SIGNIFICANCE OF CO_2 TRANSPORTATION MODE AND ROUTE ANALYSIS

The choice of CO_2 transportation route and mode is determined by the distance between the carbon source and carbon sink, environment along the route, the economic cost, and policies, laws and regulations. In order to ensure that, on the one hand high-quality, safe and stable carbon sources can be chosen and, on the other hand, the needs of the carbon sink point are considered, it is necessary to undertake an analysis. The results of the analysis will help us understand and analyse the whole process of CCUS technology better and more intuitively, so that our final decisions will be more consistent with the needs of production and research, and play an exemplary role for the development and promotion of CCUS technology in Xinjiang.

5.3 SCREENING OF TRANSPORTATION ROUTES

Picture 3-1 The possible tanker truck transportation route

Table 5-1 The relative distance and different transportation modes between carbon source and sink point

	Emission source-Di-2 well	Emission source-Di-12 well	Emission source-D-20 well
Emission source (km)	63.6	73.3	75.8

	Emission source-D-2 well	Emission source-Di-12 well	Emission source-Di-20 well
Tanker truck transportation distance (km)	76	73.3	86
Straight-line pipeline transportation distance (km)	63.6	73.3	75.8

The different transportation modes have different transportation limitations:

Tanker Truck transportation conditions:

1. The CO_2 tank must be a semi-refrigerated cylindrical steel tank.
2. The transportation pressure must be 2MPa， and the transportation temperature -30℃.
3. The CO_2 tank must have a storage capacity of 50t based on the transportation scale. Currently, the lump sum price of highway tanker truck transportation is 1.1yuan/t.km.

Pipeline transportation restrictions:

1. The pipeline operational temperature cannot be higher than that of the compressor.
2. The temperature tolerance limit of the pipeline and pipeline outer coating.
3. The pipeline inlet pressure must be much higher than the CO_2 critical pressure of 7.38Mpa.
4. The aim of setting the upper pressure limit is mainly to decrease the cost, and also related to the pressure loading limit of the flange. In addition, a shut off valve must be installed along the CO_2 pipeline.
5. The pipeline transportation cost: fixed cost (pipe material cost, line installation fee, land acquisition fee, telecommunications evaluation, survey and design, and pipeline station investment), operation and management cost (power costs, monitoring costs, maintenance costs, and salary and allowances costs).

5.4 TECHNICAL SCHEME

5.4.1 CURRENT STATUS OF TECHNOLOGY

1. The current status of CO_2 pipeline transportation technology

There have been CO_2 pipelines since the early 1970s, and the current technology is mature, with the majority in the United States. Today, there is about 7,000km of CO_2 pipelines in the world, most of which are used for enhanced oil recovery (EOR). In the United States, EOR has nearly 40 years' history of use in industry. At present, the volume of CO_2 used for EOR that is transported via pipeline has exceeded 65 million tons per year, accumulating rich engineering experience. Looking at the current CO_2 pipeline technology, we realise that there are no truly insurmountable difficulties in the transportation of CO_2 via pipeline.

The safety risk of transporting CO_2 gas mainly comes from the high concentration state and potential leakage of the gas during transportation. Compressed CO2 is heavier than air, which makes it easy to gather in low-lying areas, and push out the oxygen near the ground.

When CO_2 is transported in a supercritical or liquid state, it is necessary to cool the CO_2 to -78°C (after decompression). Long time operation may lead to brittle and ductile fractures, and it is necessary to use proper material/wall thickness or anti-fracture devices for protection.

Because of the high vapour pressure, the toughness of the steel of a CO_2 pipeline must be much higher than that of a natural gas pipeline. This is one of the major difficulties in converting existing natural gas pipelines into CO_2 pipelines.

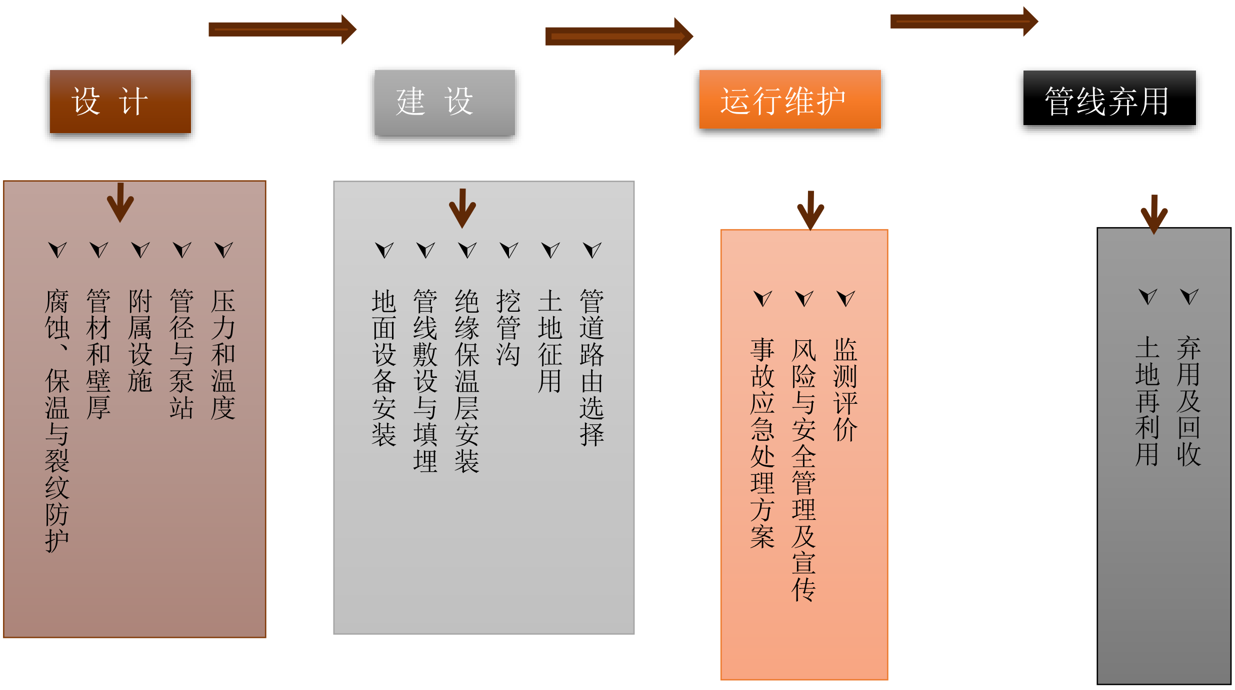
For the CO_2 pump and compressor, the two phase flow zone between the suction section and the compression/pumping section should be avoided during CO_2 transportation.

2. The current status of highway tanker transportation technology

The application of CO_2 transportation technology with respect to highway tankers is mature, being commonly used in the field of food processing and some small-scale CO_2 flooding tests. For tanker truck transportation, the most important thing is storage tank technology. In the present case, only steel tank storage technology is used for CO_2 storage. The capacity of tank cars varies from 2t to 30t according to user needs. Generally, the pressure and temperature parameters of highway tanker transport CO_2 are (1.7MPa, -30 C) or (2.08MPa, -18 C).

Due to the influence of air tightness and other conditions during transportation, CO_2 will inevitably generate leakage. The leakage rate can reach 10%, depending on the transportation time and distance.

5.4.2 CO_2 Pipeline Implementation Process Flow



5.4.3 SELECTION OF PIPELINE TRANSPORTATION TECHNOLOGY

Selection of technology: Kamusite Industrial Park is located in Fuyun County, Altay Prefecture, Xinjiang Province, which has a large temperature difference between day and night. Transportation in a supercritical state can easily result in CO_2 two-phase flow, blockage, leakage and even explosion during transportation. A better method is to use dense phase liquid transportation (the pressure exceeds the critical pressure and the temperature is lower than the critical temperature). Pipeline design is pressure 12MPa, steel X65, epoxy resin anticorrosion layer + polyurethane foam insulation layer + polyethylene jacket waterproof layer and 3PE anticorrosion layer. The pressure of the capture outlet is 1.7MPa-2.2MPa, and it needs to be pressure-boosted to 12MPa. A compressor is used for three-stage compression. There is no need for pressurisation along the line, and a valve chamber is installed 15km away from the inlet. Spacing between line block valve chambers is set at 15km. A receiving device is installed at the end of the line.

Table 5-2 Basic design parameters for CO2 pipeline

Name	**Unit**	**Dense phase**
Inlet pressure	Pin[MPa]	12
Outlet pressure	Pout[MPa]	9.2
Transport temperature	T [K]	>20℃
Transport scale	M[t/a]	0.1
Transport distance	L [km]	80
CO_2 compression factor	ZCO_2	0.32
CO_2 density	ρCO_2 [kg/m^3]	625-1025
Steel density	P Steel [g/cm^3]	7.85
Electrovalency	pc [RMB/KW.h]	0.066
Equipment capacity factor	CF	0.8
Period of depreciation	N[years]	20

5.4.4 OPERATION AND MANAGEMENT

1. CO_2 pipeline operation and management

Pipeline operation is divided into three aspects: daily operation, routine operation and maintenance, and also includes health, safety and the environment. Generally speaking, the whole operation needs to consider training, inspection, safety integration, pipeline identification marking, public education/publicity, injury prevention program, communication, facility safety and leak detection. Normally, the pipe control centre directs the daily operation of the pipe. Routine operations include: CO_2 receiving conditions (pressure, temperature, components and flow); maintaining stable operation; maintaining minimal operation pressure under demand; avoiding a transient state as far as possible; doing daily work (hydraulics calculations and equipment performance evaluations); and equipment performance inspections.

2. Operation and management of highway tankers

The operation and management of highway tankers mainly includes storage tank maintenance, truck maintenance management, loading/ unloading personnel management and fuel (diesel) supply.

5.5 SOCIAL FEASIBILITY

Social feasibility includes site accessibility, policy compliance, regulatory compliance, resource overloading, public approval, etc. Here the focus is on site accessibility and policy compliance.

5.5.1 POLICY AND REGULATORY COMPLIANCE

The worldwide CO_2 experience provides standards and specifications for the design, construction and operation of CO_2 pipelines. In addition, the CO_2 pipeline facilities designed in North America today conform to the current specifications and standards for oil and gas pipeline systems. In China, the construction and operation of CO_2 pipelines should also conform with the relevant policies and regulations of China's oil and gas pipeline systems. Refer to the Table below for international application standards and regulations for the design, construction and operation of pipelines:

Table 5-3 International and Chinese standards for CO_2 pipes

Standards code	**Region**	**Specification name**
SH*****	China	Specification for design of carbon dioxide pipeline (Draft for comment)
ISO 13623 (related to DINEN14161)	International Standard	Petroleum and natural gas industry - Pipeline Transportation Systems
ASME B31.4	International Standard	Pipeline Transportation System for Liquid Hydrocarbons and Other Liquids
ASME B31.8	International Standard	Gas Transmission and Distribution Piping Systems
U.S health and safety directives		U.S health and safety directives

ASME B31	USA	Process pipe
API 1104		Pipe welding
API 5L		Specification for pipeline steel pipe
CSA Z662	Canada	Oil and Gas Pipeline Systems
CSA Z276-94		Liquefied Natural Gas - Production, Storage and Treatment
AS2885\AS2885-1\AS2885-2\AS 2885-3\AS 1978\AS 2018\AS 1697\AS 4041	Australia	Pipeline - gas and liquid petroleum
BS 8010	United Nations	Pipeline Code of Practice
BS 4515\CP 2010 Part 5\IP Codes	United Nations	Specification for welding of steel pipelines on land and offshore
AS 1978	United Nations	
DNV-RP-J202	Norway	Design and operation of CO_2 pipeline
DNV-OS-F101		Ocean pipeline system
IP6	Britain	Pipeline specification
BS PD 8010 2004		Regulations for the use of pipelines - Submarine Pipelines
BS EN 14161		Oil and gas industry - Pipeline Transportation Systems
NEN 3650\3651 NEN EN 10208\10285	Netherlands	Pipeline system

5.5.2 SITE ACCESSIBILITY

The majority of CO_2 pipeline sites are located on requisitioned land. Except for ground facilities such as the pumping stations and monitoring stations that are on permanently requisitioned land, it usually only requires temporary requisitions of land during the pipeline laying process to if the pipelines were buried below the surface. After the pipeline has been fully laid, the excavated soil can be refilled, and the land restored to its original function. Therefore, these areas of land are classified as temporary land. Land acquisition rights are different for different types of land, and therefore need to be treated differently. In China, infrastructure projects such as energy, roads, railways and telecommunications are all classified as national infrastructure projects supported by the State, and are given priority in the annual land use plan and in land supply when land use rights are approved.

5.6 TRANSPORTATION COST BUDGET

An economic evaluation based on the relevant international and domestic codes and regulations for design, construction and operation of pipelines, and the economic parameters of the Altay pipeline project, was carried out. Then, the resultant CO_2 pipeline transportation costs were evaluated with the Di-2 well as the storage site, as shown below.

Costs: mainly includes: fixed costs: construction cost (material cost, line installation cost, land requisition cost, telecommunications evaluation, survey and design, and pipeline station investment); operation and management costs (power cost, monitoring cost, maintenance and protection cost, salary and benefits, etc).

A one-time investment in transportation requires 212,500,000 yuan, the annual operating cost of the demonstration for 3 years is 6,700,000 yuan and, with pressurisation costs, the total investment over 3 years is 241,500,000 yuan, with an average cost of 115.2 yuan/t CO_2 and levelised cost of 1.44 yuan/t.km. If the pipeline costs are calculated according to a depreciation period of 20 years, the annual operating cost is 5,230,000 yuan. With pressurisation costs, the total investment over 20 years is 380,700,000 yuan, with an average cost of 38 yuan/t CO_2 and levelised cost of 0.48 yuan/t.km.

Table 5-2 Xinjiang Guanghui CO_2 pipeline cost

Cost	Amount (3 years)	Amount (20 years)
Pressurisation cost	8,934,000	59,560,000
Pipeline transportation total fixed cost	212,500,000	212,500,000
Pipeline operating cost	6,708,600 yuan/year	5,433,800 yuan/year
Pipeline transportation total cost	241,500,000	380,700,000
Average cost	115.20 yuan/t CO_2	38.00 yuan/t CO_2
Levelised cost	1.44 yuan/t. km	0.48yuan/t. km

Finally the cost of these two transportation methods was compared by analysing the total transportation costs of the Xinjiang Guanghui demonstration project, as detailed in Table 5-4:

Table 5-4 Comparison of the cost between the two transportation methods

Emission source-block Di-2	3 years	20 years	Distance

Total cost of tanker truck transportation	105,300,000 million	702,000,000 million	76km
Total cost of pipeline transportation	241,500,000 million	380,700,000 million	63.6km

According to the above table, within the three year demonstration period, the tanker truck transportation cost is lower. However, if large scale transportation is undertaken at a later stage, the average cost of the CO_2 pipeline transportation is lower.

5.7 SUMMARY

From a technical and economic point of view, tanker truck transportation is cheaper in the three year demonstration period. But if large-scale transportation is carried out later, it is advisable to build a pipeline for CO_2 transportation, as the average cost is lower. Under the assumption of full use of own funds, the transportation operating cost for 3 years is 241 million Chinese yuan, and the transportation operating cost for 20 years is 3801 million Chinese yuan.

Pipeline transportation technology in China is very mature, especially for long-distance transportation. Although there is no existing pipeline specifically for transporting CO_2, we can undertake technology implementation by combining long-distance oil and gas pipeline experience at home with relevant overseas CO_2 pipeline transportation standards. It is concluded that this project is technically and economically feasible.

In addition, carbon dioxide is a common compound in the air. At normal temperature, it is a colourless and odourless gas, which has a slightly larger density than air and can dissolve in water. Carbon dioxide is a non-flammable, non-toxic, and asphyxiant gas. For humans, low concentrations of carbon dioxide excite the respiratory centre and cause breathing to be deeper and faster. High concentrations of carbon dioxide can inhibit and paralyse the respiratory centre. Therefore, risk analysis of the pipeline transportation project is also of critical importance.

The risk of pipeline transportation can be divided into three categories: risk in the engineering process, risk during operation, and social harm. The main risk and accident prevention measures are shown in Table 5-5.

Table 5-5 Main risks and protective measures for pipeline transportation

Risk classification	**Source of risk**	**Event**	**Target**	**Consequences**	**Accident prevention measures**	**Emergency measures**

Engineering process	Construction of equipment, laying of pipe and construction of valve chamber	Improper operation and quality of equipment	Construction personnel	Mechanical damage: slag burn, electric shock and noise caused by construction	1) Set up carbon dioxide gas detectors in process equipment area and valve chamber, to detect and alert CO_2 leakage, so as to ensure the safety and reliability of persons, equipment and production process. 2) Install a sonic detection system along the pipeline, to detect and alert CO_2 leakage. 3) Set up corresponding grounding devices for power supply and distribution, automatic control and telecommunications equipment and buildings.	1) Set up a safety relief system for accident conditions. 2) Establish corresponding safety management organisations, carry out hierarchical management, and implement safety supervision, inspection and rewards and penalties in the scope of their respective responsibilities.
Project operation period	Pipe, process equipment, valves	Equipment failure, leakage, corrosion, communication failure, operation error	Pipeline equipment	Pipe corrosion perforation, rupture, leakage		
			Workers and passers-by	Health issues, a large leak can cause fainting and suffocation		
			Environment			
Social harm factors	Third party destruction	Unintentional destruction: road repairs, construction, mining, pipelines illegal tie-in	Pipeline equipment	Pipeline destruction, subsidence and overload, causing pipeline deformation and damage.		
		Intentional destruction: acts of lawbreake		Economic losses, human casualties		

		rs and terrorists				

It is necessary to formulate emergency measures for the pipeline transportation project:

1. Set up a safety relief system for accident conditions. In order to protect the safety of equipment, pipelines and CO_2 long-distance pipelines in the process area, install safety valves in the pressure vessel and the ball receiving cylinder in the pipeline station, with the safety valve to be automatically released when the pressure is too high. In the event of an accident or leakage in the CO_2 pipeline, the station valve should be shut down urgently to isolate the station and pipe section (Ministry of Industry and Information Technology announcement, 2016).
2. Establish corresponding safety management organisations, carry out hierarchical management, and implement safety supervision, inspection and rewards and penalties within the scope of their respective responsibilities.

6 FEASIBILITY ANALYSIS OF THE XINJIANG CCUS PILOT PROJECT TARGET SITE

6.1 TARGET TEST SITE ANALYSIS DETAILS

Data collection and analysis of the current status of the main well area of East Junggar Cainan oilfield was undertaken, and the Di-12, Di-2, Di-20 well blocks in the Badaowan oil reservoir of Cainan and Dishuiquan oilfields were screened. Ultimately, it was confirmed that the Di-2 well area is more suitable for CO_2-EOR technology than the Di-12 well area.

6.2 THE PURPOSE AND SIGNIFICANCE OF THE TARGET TEST SITE ANALYSIS

Through the screening of the three blocks in the Badaowan Formation oil reservoir of Cainan and Dishuiquan oilfields, the true details of each well area can be seen more intuitively and clearly. In combination with the transportation needs and the needs of the well area itself, as well as economic factors, the details help us in subsequent test site selection, and make it more scientific.

6.3 ANALYSIS OF THE CHARACTERISTICS OF THE MAIN WELL AREA OF CAINAN OILFIELD

The estimated geological reserves of the Badaowan Formation oil reservoir are 19 million tons, and the recoverable reserves are 4.6 million tons. Strata crude oil density is 14-108 m.pas, and the density of crude oil is 0.88-0.91 mg/cm^3.

The Badaowan Formation oil reservoir of Cainan and Dishuiquan oilfields comprises the Di-12, Di-2 and Di-20 well blocks. Due to production pressure during the early stage of well exploitation, production of most wells at that time exceeded design capacity, and injection and extraction intensity was high, resulting in a short period of stable production. After production capability was established, the three blocks quickly entered into decline one by one, and comprehensive treatment was undertaken to reverse the situation. Centering on the recovery of stratum pressure, the production and absorption intensity, injection separation and profile control were gradually adjusted, and research into early reservoir description and mining technology and policy boundaries was launched. The results were transformed into production, and after 2009 the reservoir decline gradually slowed down. Currently, the water flooding control and water flooding utilisation in the Di-12 and D-2 wells is relatively high. Due to the strong heterogeneity of the reservoir, the water flooding control and water flooding utilisation of the Badaowan Formation reservoir remains at a high level, through measures such as injection separation and profile control. But compared with the early years it is still in decline. However, in the Di-20 well area the swept volume of water has reduced due to strict water injection channeling, and the degree of water flooding utilisation of the reservoir has decreased. After injection separation, profile control and water injection optimisation, it recovered to 76.7% in 2015. At present, the traditional water flooding method has been unable to achieve the oilfield's calibrated recovery rate, and the oilfield urgently needs to change its extraction method.

The main oil producing blocks in the Cainan oilfield are Di-12, Di-2 and Di-20. The three blocks are located in the Dinan Uplift in the eastern part of Junggar Basin. To the north is the Dishuiquan Sag, and to the south is the Dongdaohaizi Sag and the Wucaiwan Sag, as shown in Figure 6-1. The three blocks are 14.4 km apart.

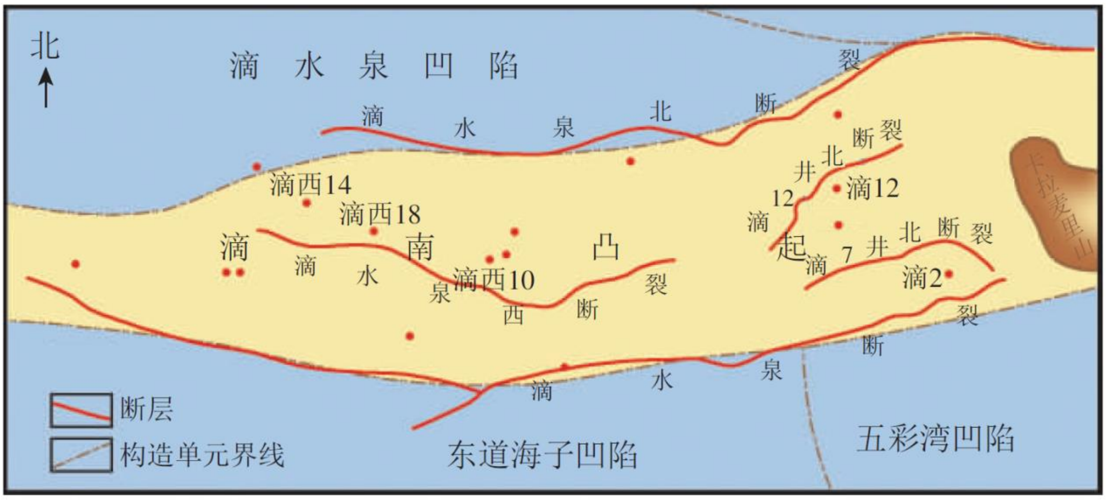


Figure 6-1 Cainan oilfield faults

The Dinan Uplift was formed in the Middle and Late Carboniferous Period, and the Indosinian movement at the end of the Late Jurassic led to its uplift and erosion, resulting in the unconformity between the Carboniferous and Jurassic systems. The Lower Jurassic Badaowan Formation in the Dinan Uplift is one of the three main reservoirs in the Cainan oilfield, with the others being the Sangonghe Formation and Xishanyao Formation.

The Badaowan Formation is in regional unconformity contact with the underlying Carboniferous system, and in conformity contact with the overlying Sangonghe Formation. It is divided into three sections, J_1b_1, J_1b_2 and J_1b_3, from bottom to top. J_1b_1 is light grey sandy conglomerate with a thickness of 0-70 m. J_1b_2 is dark grey mudstone mixed with a small amount of grey fine sandstone or siltstone with a thickness of 80-100m. J_1b_3 is light grey sand conglomerate with a thickness of 100-120m. J_1b_1 is the main oil bearing layer.

Mainly three types of sedimentary facies have developed in the Badaowan Formation, from bottom to top: braided river, lake and braided river delta, which can be further subdivided into five subfacies: braided river channel, flood plain, braided river delta plain, braided river delta front and shore-shallow lake, together with nine types of microfacies: channel, heart beach, wetland, distributary channel, subaqueous distributary channel, intertributary bay, estuary dam, distant sand bar and shore-shallow lake mud. The deposits of the Badaowan Formation reservoir are mainly fan delta front deposits, with rapidly changing sedimentary microfacies, overlapping multi-stage river channels, strong heterogeneity and developed interbeds.

The Badaowan Formation is the main reservoir of the Di-12, Di-2 and Di-20 wells.

6.3.2 STATUS OF EXTRACTION IN THE DI-2 WELL AREA

The Di-2 reservoir is a lithologic reservoir with edge water controlled by faults. The reservoir height is 135 m, the oil area is 1.43+0.8=2.24 km^2, and the geological reserves are 58.6+34.17=92.77 x 10^4t. It was developed in 2007 with a 280 m inverse 7-spot injection pattern. Under the pressure of production, production of most wells in the early stage exceeded design capacity, and injection and extraction intensity was high, resulting in a short period of stable production. After production capability was established, it quickly entered into decline. In 2009, the absolute oil volume of the reservoir decreased by 29.2%. Comprehensive treatment was undertaken to reverse the situation. Centering on the recovery of stratum pressure, the production and absorption intensity, separate injection and profile control were gradually adjusted, the reservoir decline gradually slowed down to 14.1% in 2010. At present, the reservoir is in a mid to high water cut and mid extraction stage. The viscosity of crude oil in the Di-2 well area is high, the viscosity at 50°C is 23.9 ~ 151 mPa, with an average of 110.1 mPa. S. The water flooding effect is poor. Despite a combination of re-injection with adjustment of production and absorption intensity, together with small layer fine water injection and profile control, water flooding is poor and not effective in most wells. Some wells still have strong injection and production, which leads to water breakthrough and rapid water cut increase in the high permeability channels. The current reservoir extraction situation in the Di-2 well area is shown in Figure 6-3 and Table 6-2.

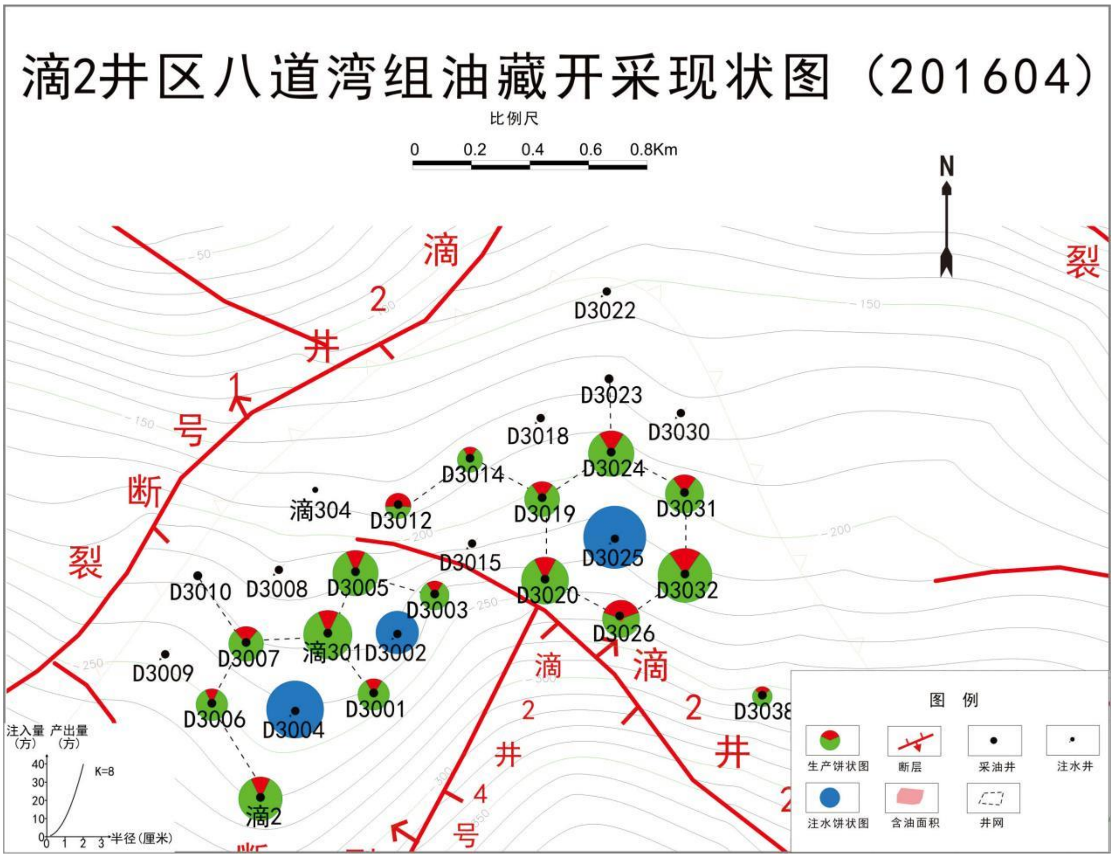


Figure 6-3 Current status of reservoir extraction in the Di-2 well area

Table 6-2 Di-2 well area reservoir details

Total number of oil wells	23	Number of open wells	17	Cumulative amount of gas (10^4m^3)	144
Total number of water injection wells	9	Number of open wells with water injection	4	Gas extraction degree (%)	4.97
Daily liquid volume (t)	115	Daily oil yield (t)	23	Production schedule (%)	4.53
Daily water injection (m^3)	41	Composite water content (%)	79.6	Oil production schedule (%)	0.92
Cumulative water production (10^4m^3)	18.3	Cumulative water injection (10^4m^3)	31.1	Degree of extraction (%)	15.2
Cumulative oil production (10^4t)	14.1	Water cut increase rate (%)	-13.4	Monthly injection production ratio	0.35

Table 6-5 Di-12, Di-2 well area data sheet

Region	**Di-12**	**Di-2**
Reservoir description	Grey medium - thin, medium coarse, conglomerate sandstone, area 5.57 km^2, thickness 6.6 m	Grey medium - thin, medium coarse, conglomerate sandstone, area 1.43 km^2, thickness 5 m
Buried depth of reservoir	Middle depth 1115 m	Middle depth 970 m
Ground temperature	44.6℃	40.3℃
Reservoir inclination	5-8°	5-8°
Formation pressure	Central pressure 8.678 MPa	Central pressure 7.043 MPa
Oil area of reservoir	5.57 km^2	1.43 km^2
Initial oil saturation	55.8%	54.4%
Porosity	19.20%	17.80%
Effective thickness	6.6 m	5.0 m
Viscosity of crude oil mPas	39.8（ground）	110.1（ground）
Density of crude oil g/cm^3	0.87-0.883	0.9-0.909
Middle depth of reservoir	1115 m	970 m
Central pressure	8.678 MPa	7.043 MPa
Saturation pressure	5.773 MPa	5.92 MPa

Temperature in the middle of the oil layer	44.6℃	40.3℃
Pressure coefficient	0.778	0.726
Ground saturation pressure difference	2.905 MPa	1.123 MPa
Saturation degree	66.5%	84.1%
Injection well	20	9
Producing well	45	23
Well spacing	＜280 m	＜280 m
Daily single well injection	＜18 m^3	＜18 m^3
Time and degree of reservoir extraction	Developed in 2005 The extraction degree is less than 15%	Developed in 2007 The extraction degree is greater than 15%
Reserves（comparing the two）	Slightly larger	Minimal
Ground transportation conditions	The surface is covered by Quaternary system Gobi Desert, the terrain is undulating, the local level is flat, there is a small amount of vegetation coverage, the ground level is 599-804m, and there is no surface water system or residential areas.	
Other	Cold in winter, with a minimum temperature of -40°C, hot summer drought conditions, with a maximum temperature of 45°C. The annual average precipitation in the area is less than 50 mm, and the annual evaporation exceeds 2000 mm. Highway can be reached directly from the Cainan oilfield, and transportation is convenient.	

Through comparison and screening, it is confirmed that the Di-2 well area is more suitable for CO_2-EOR technology than the Di-12 well area.

1. The reserves of the Di-2 well area are small, the degree of extraction is high, and there is a potential demand to improve output through CO_2-EOR technology.
2. The viscosity of Di-2 crude oil is higher than that of the D-12 well area, and the sand layer has a monoclinic structure, which is more suitable for CO_2 flooding;
3. The Di-2 well area .in the candidate site is closer to the highway or service roads. Either tanker truck or pipeline could be used as the transportation mode.

6.4 EAST JUNGGAR CAINAN OILFIELD DI-2 WELL AREA CO_2-EOR SUITABILITY ANALYSIS

6.4.1 PHYSICAL GEOGRAPHY

The Di-2 well block is located in the Dinan Uplift in the East Junggar Basin, and from a tectonic perspective is classified as a secondary tectonic unit of Luliang Uplift (Qin Xusheng et al, 2008). To its north is the Dishuiquan Sag, and to the south are the Dongdaohaizi Sag and Wucaiwan Sag. The surface is desert, covered with a small amount of vegetation, with an average altitude of 740 m. There is no surface water nor residential areas. It is cold in winter, with a minimum temperature of -40°C, and it is dry in summer, with a maximum temperature of 45°C. The average annual precipitation in the area is 50 mm, and the annual evaporation exceeds 2000 mm.

6.4.2 STRATIGRAPHIC LITHOLOGY

The Dinan Uplift was formed in the Middle and Late Carboniferous Period, and the Indosinian movement at the end of the Late Jurassic led to its uplift and erosion, resulting in the unconformity between the Carboniferous and Jurassic systems. The strata in this region from top to bottom are Cretaceous Tugulu Group, Jurassic Xishanyao Formation, Sangonghe Formation, Badaowan Formation and Carboniferous Bashan Formation. The main lithology of each group is:

Tugulu Group (K1tg): about 800 m thick. The upper part is interbedded layers of large light brown mudstone and grey-brown silty mudstone. The middle part is interbedded with grey mudstone and sandy mudstone. The lower part is grey siltstone and gravelly anisomerous sandstone, and the bottom is grey gravel.

Xishanyao Formation (J2x): generally about 60-80 m thick, it is a large set of grey and dark grey mudstone with fine sandstone at the bottom.

Sangonghe Formation (J1s) generally about 70-100 m thick. The middle and upper part is grey-brown mudstone grey-brown fine sandstone and medium sandstone interbedded with unequal thickness. The lower part is light grey gravel, medium sandstone and gravelly anisomerous sandstone.

Badaowan Formation (J1b) generally about 120-150 m thick. The middle and upper part is interbedded layers of grey-brown mudstone and grey gravelly anisomerous sandstone, and the lower part is grey fine sandstone, medium sandstone and anisomerous sandstone.

Carboniferous Bashan Formation (C2b): generally dark grey and grey sandstone, and tuff, andesite and dacite interbeds.

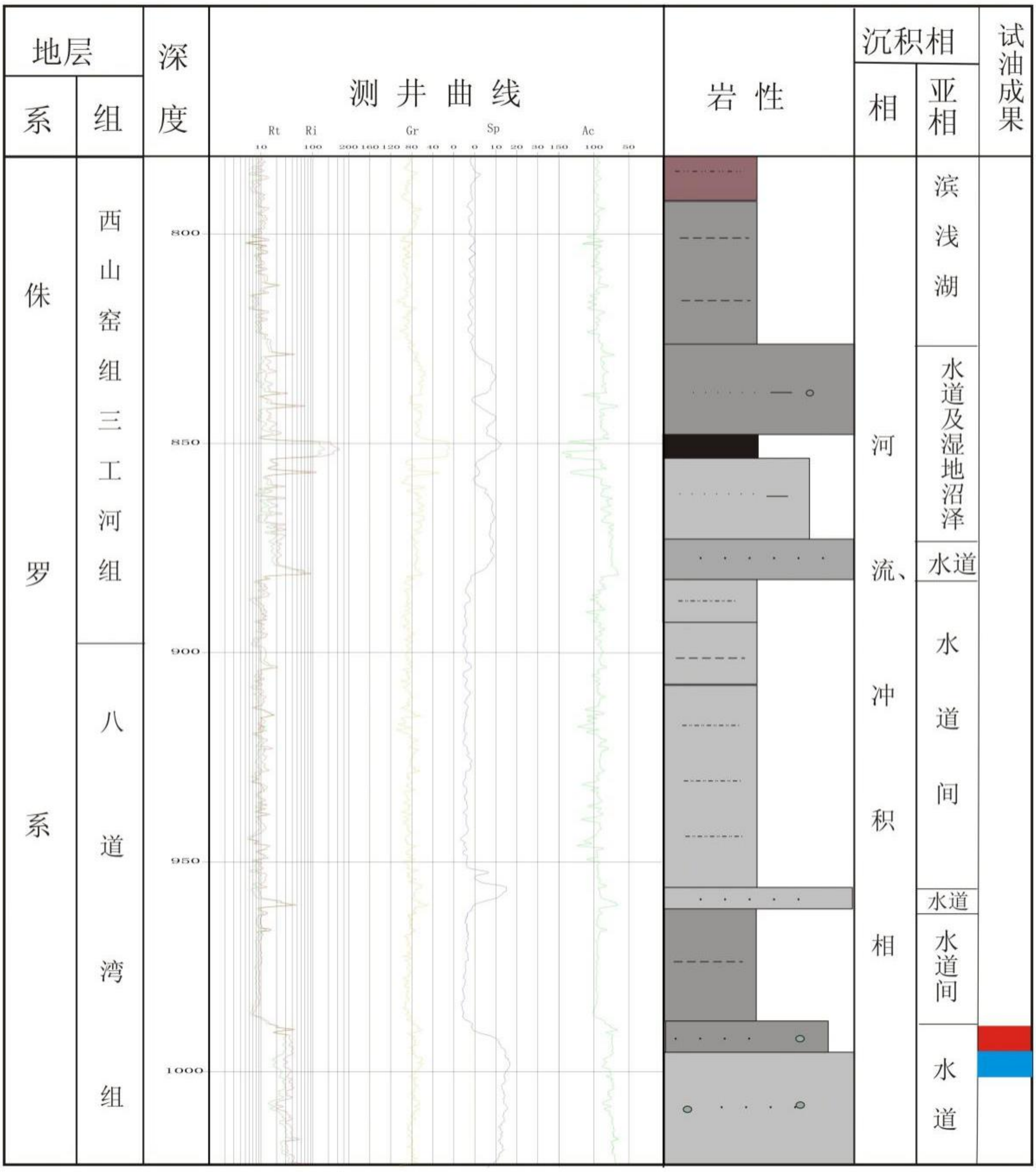


Figure 6-5 Sedimentary facies histogram of Jurassic Badaowan Formation in the Di-2 well area

6.4.3 GEOLOGICAL STRUCTURE

The structure of the top surface of the sand layer at the bottom of the Badaowan Formation is monoclonal, with no structural traps that consistently tilts south. The larger faults are the No. 1, 2, 3 and 4 faults. See Figure 6-6 below.

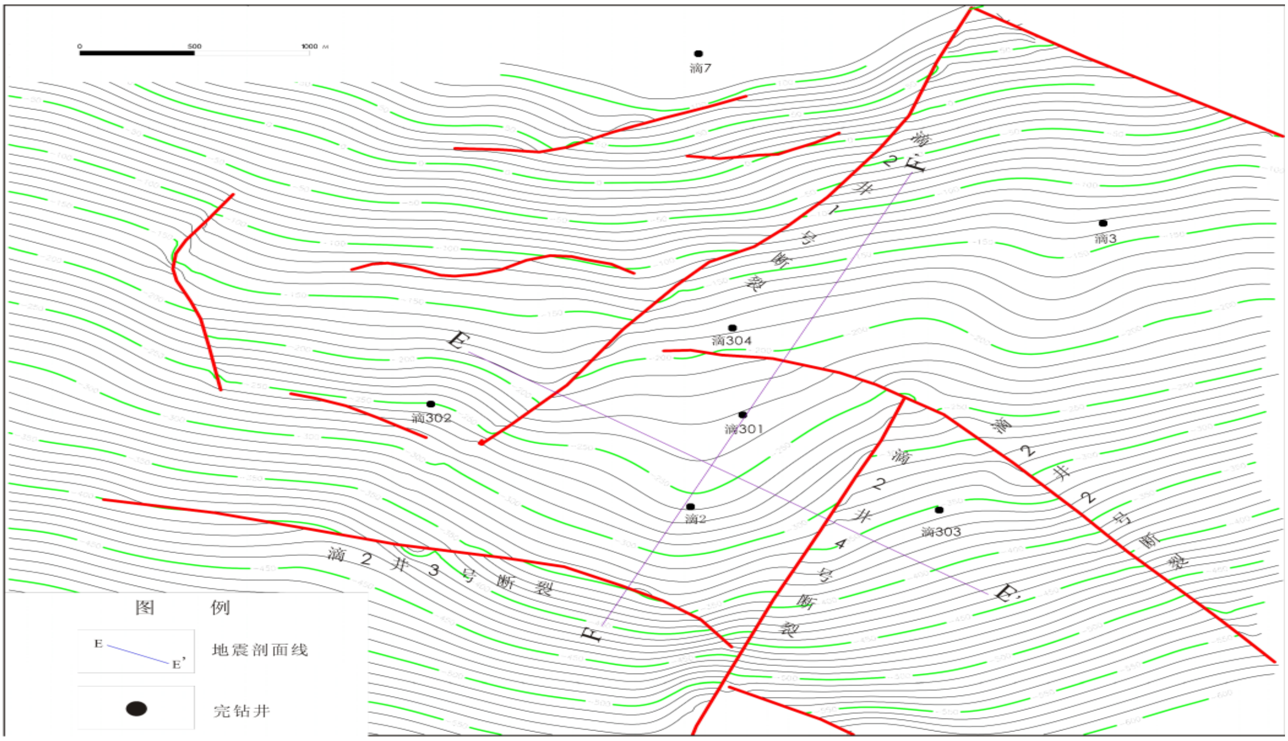


Figure 6-6 The fracture map of the Badaowan Formation in the Di-2 well area

The oil-bearing sand layer at the bottom of Badaowan Formation in the Di-2 well block is classified as the first member of the Badaowan Formation (J_1b_1). The lithology of the oil reservoir is grey fine sandstone, medium sandstone and gravelly anisomerous sandstone, sandy small conglomerate and near-shore facies. The thickness of the oil reservoir is generally 10-20 m within the reservoir range, and the thickness of glutenite in Di-302 well in the west and Di-3 well in the north-east is zero. From Di-304 well it thins to the north-east.

According to public data, the density of stratum oil in the Di-2 well block is 0.8648 g/cm3, the stratum oil viscosity is 107.7 mPa s, the compression coefficient is 0.143 E-3/MPa, the gas oil ratio is 27.7 m3/m3, the wax content is 1.26%-5.56%, the average is 2.89%, and the solidification point is -6--26 C.

The above data shows that the Di-2 well area is more suitable for CO_2-EOR technology, because of its small reserves, high degree of extraction, high oil viscosity, sand monoclinal structure and convenient transportation. Furthermore, not only is the Di-2 well area extremely suitable, it is also essential for CO_2-EOR technology to be integrated with Di-2 well's own production.

6.4.4 ANALYSIS OF OUTCROP SAMPLES

Through field investigation and collection of outcrop samples, tests were undertaken on Toutunhe Formation caprock mudstone, Qigu Formation tuff and Kalazha Formation sandstone in the target area using microCT, X-ray diffraction (XRD) and scanning electron microscopy SEM, and the following test results were obtained.

Kalazha Formation:

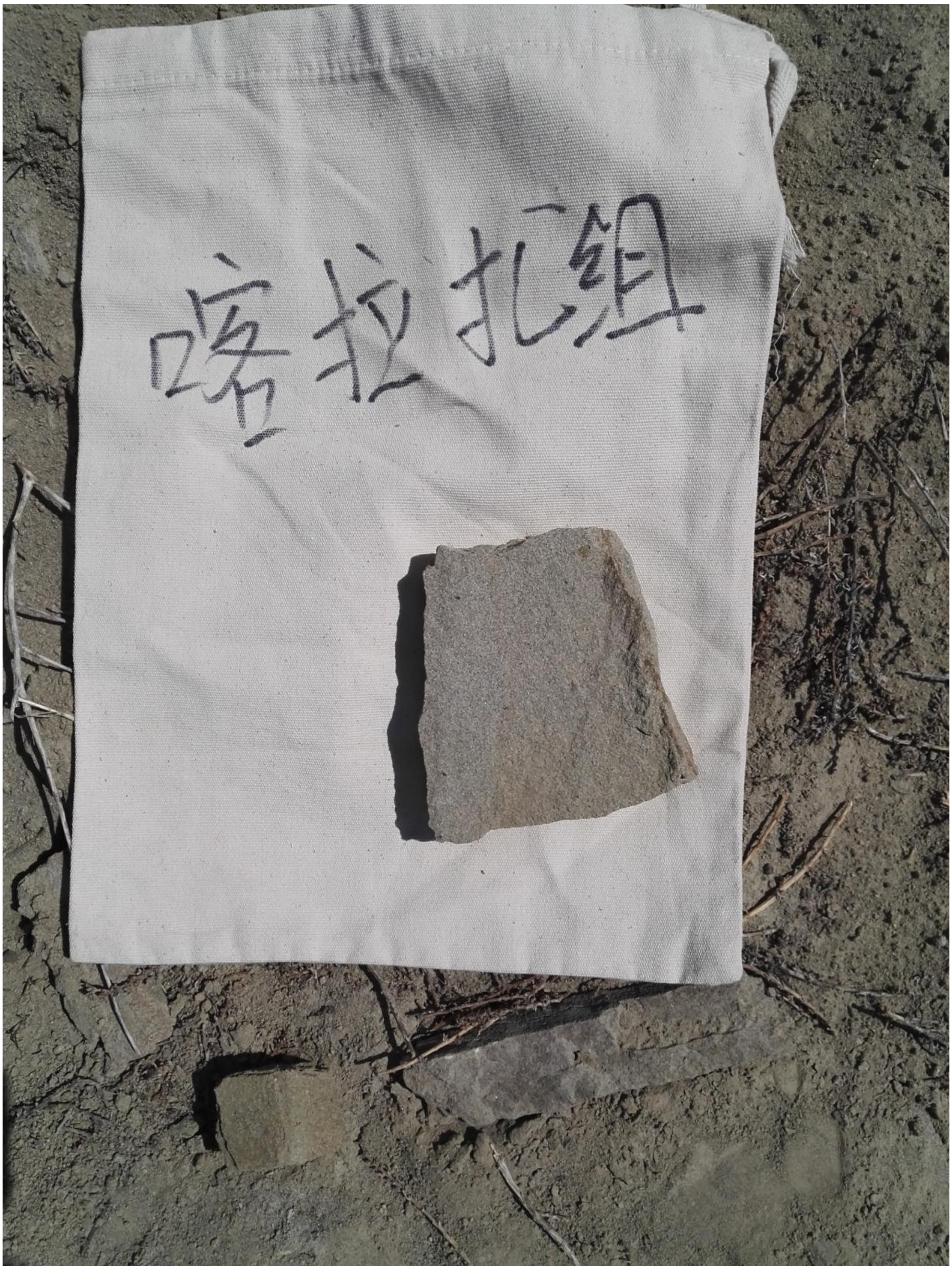


Figure 6-7 Kalazha Formation sandstone sample from the Di-2 well area

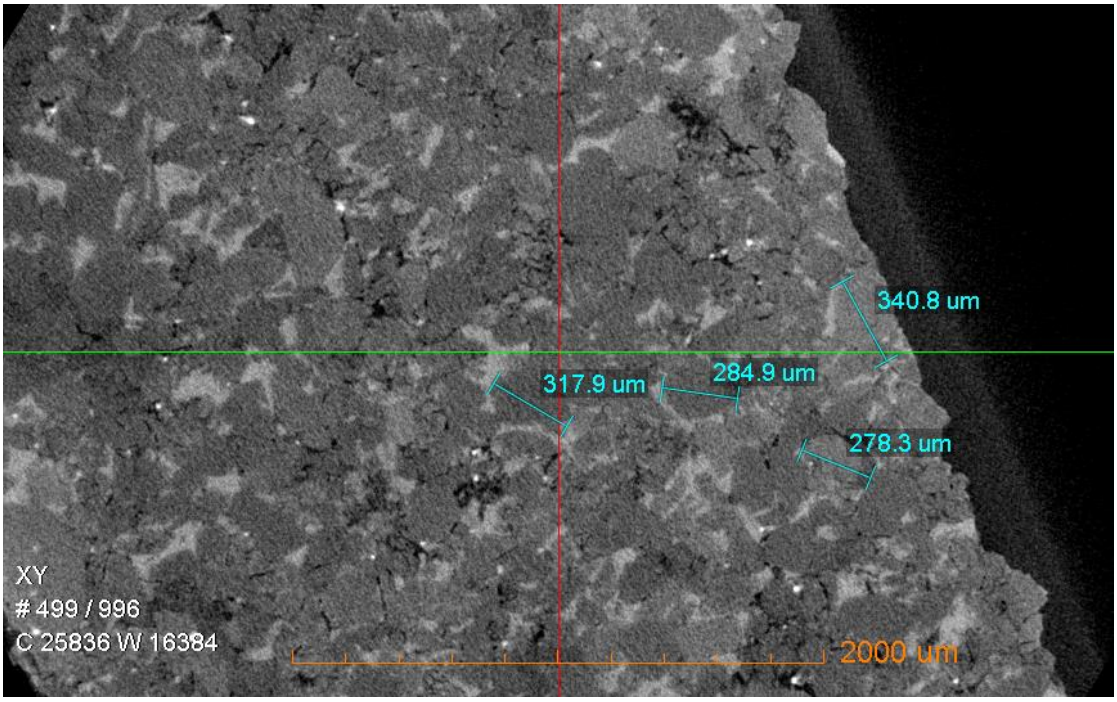


Figure 6-8 microCT scan results of Kalazha Formation sandstone

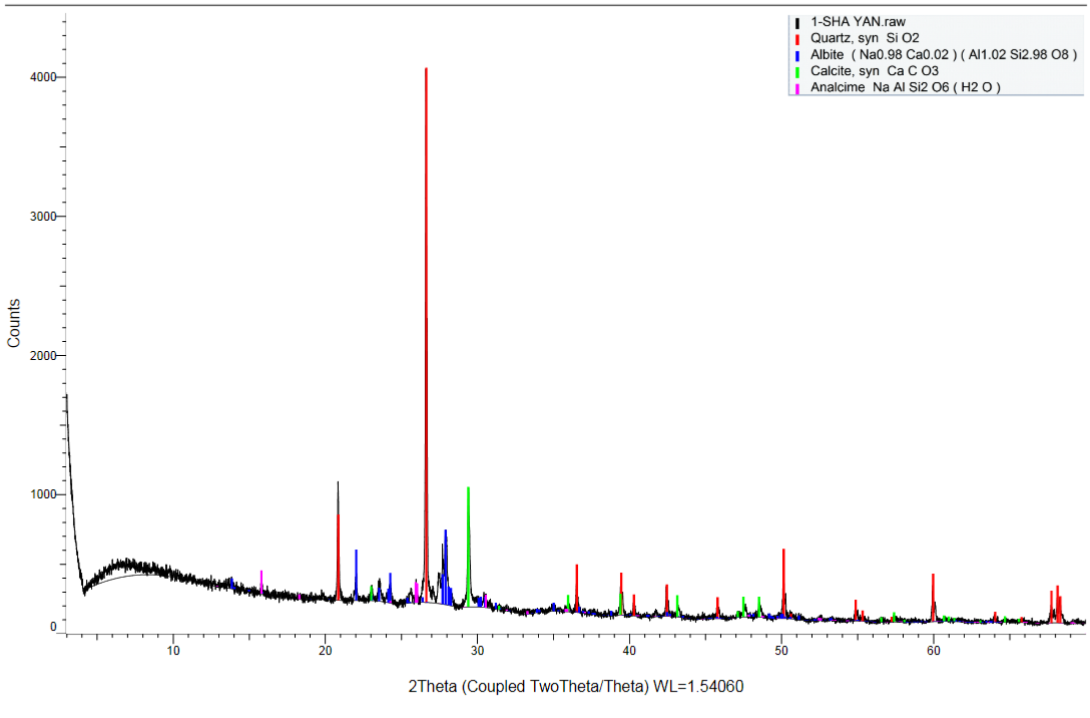


Figure 6-9 X-ray diffraction scan results of Kalazha Formation sandstone

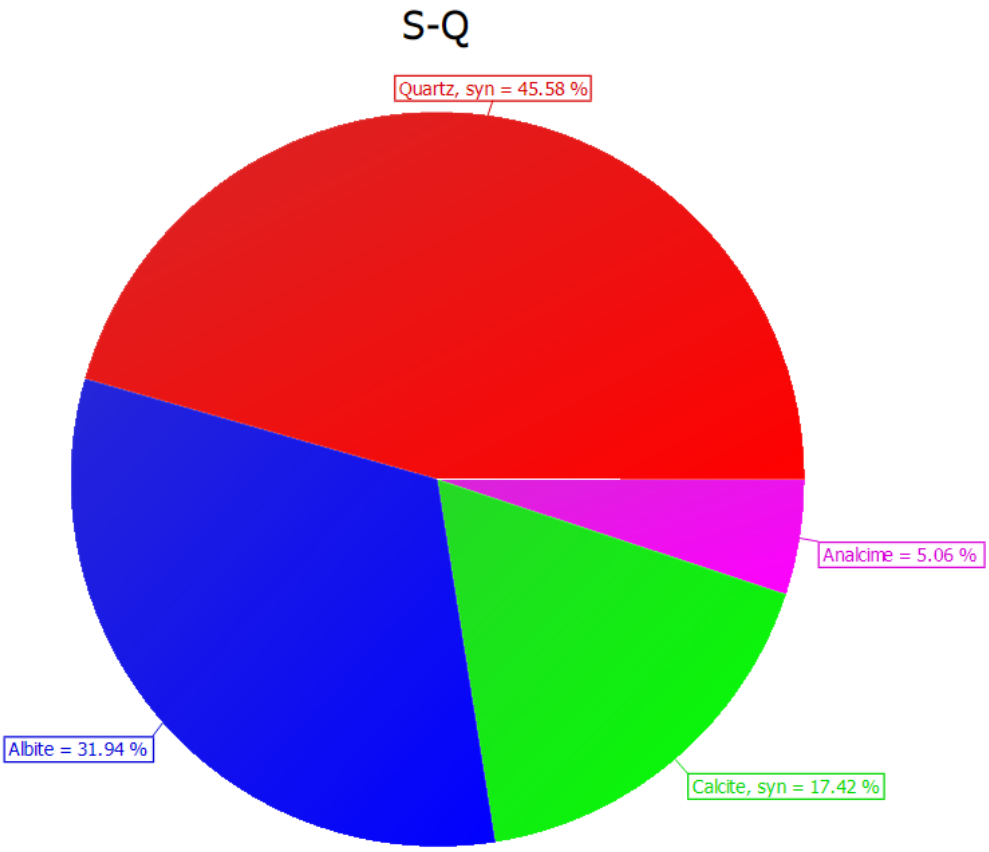


Figure 6-10 Mineral composition of Kalazha Formation sandstone

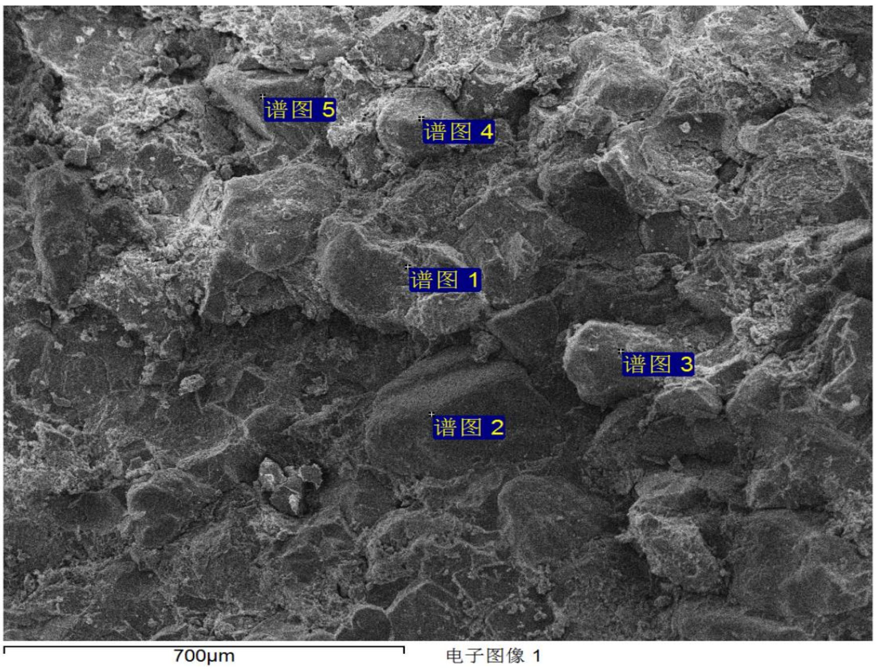


Figure 6-11 SEM image of Kalazha Formation sandstone (magnified 100 times)

Table 6-6 Kalazha Formation sandstone energy spectrum analysis results (mass percentage)

SPECTRUM	STATUS	O	NA	AL	SI	K	CA	FE	TOTAL
NO. 1	YES	49.96	2.65	9.94	28.56	4.45		4.43	100.00
NO. 2	YES	38.26	4.59	13.56	38.96	4.62			100.00
NO. 3	YES	60.96		9.15	23.59	6.30			100.00
NO. 4	YES	56.27	5.85	8.41	23.03		1.11	5.33	100.00
NO. 5	YES	57.99		1.39	40.62				100.00
MAX		60.96	5.85	13.56	40.62	6.30	1.11	5.33	
MIN		38.26	2.65	1.39	23.03	4.45	1.11	4.43	

Toutunhe Formation

Figure 6-12 Toutunhe Formation caprock mudstone sample

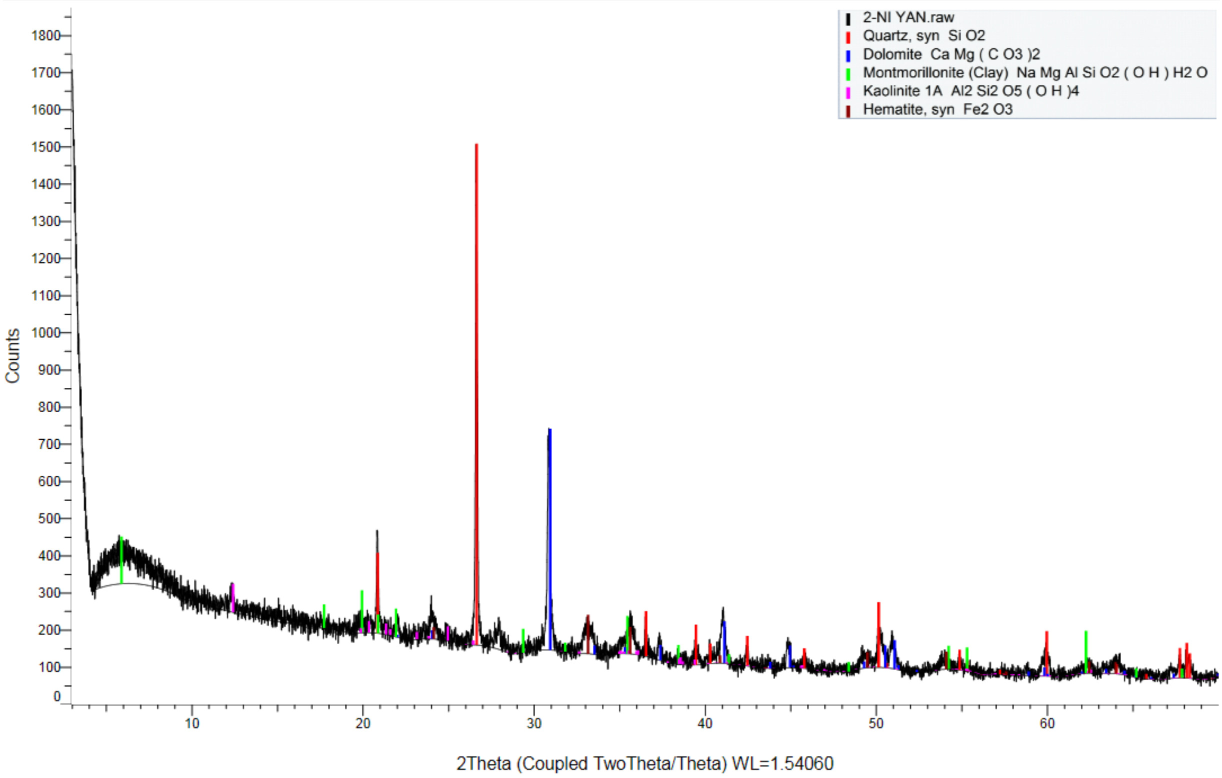


Figure 6-14 X-ray diffraction scan results of Toutunhe Formation mudstone

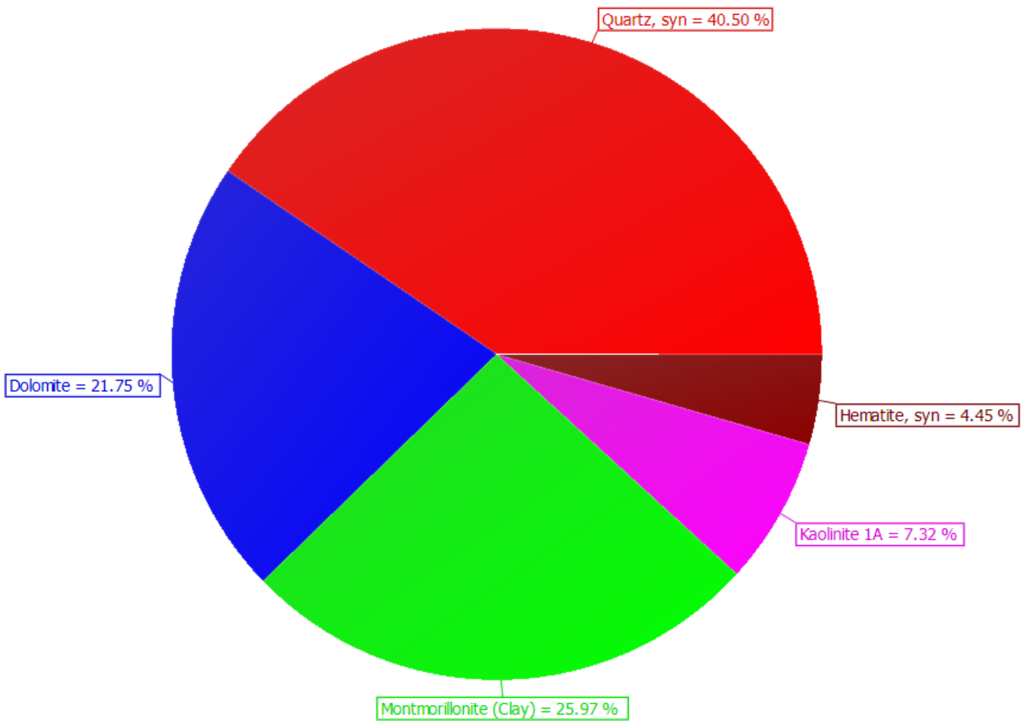


Figure 6-15 Mineral composition of Toutunhe Formation mudstone

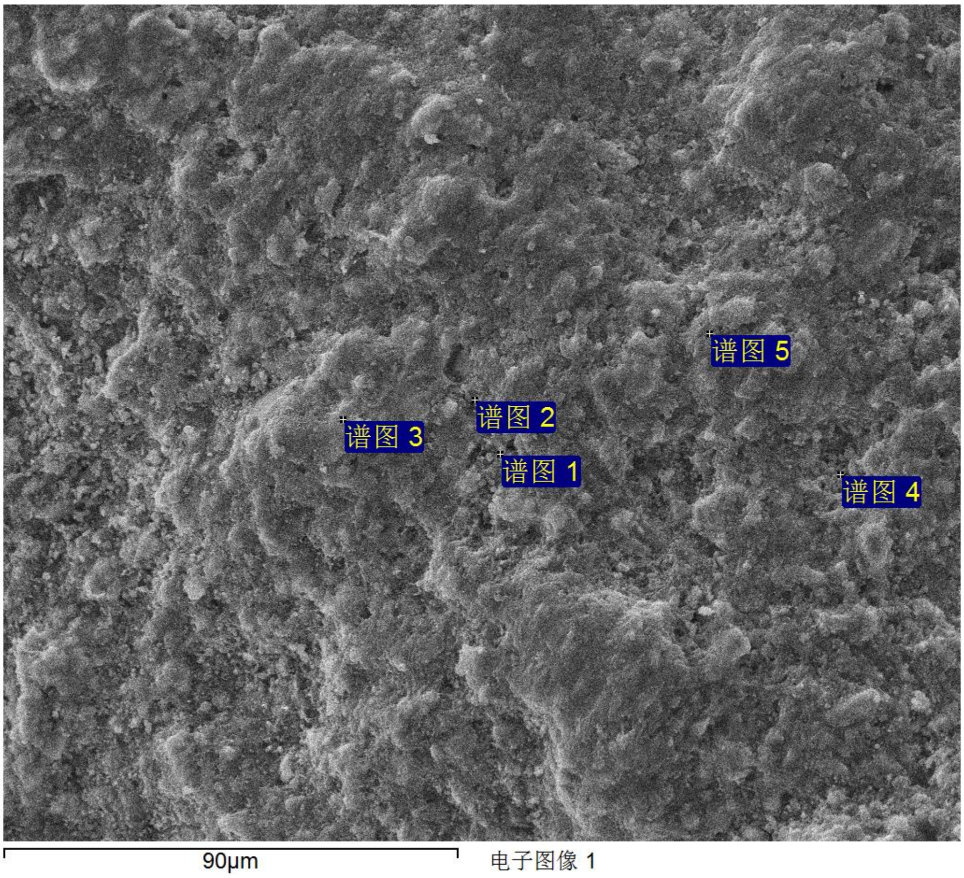


Figure 6-16 SEM image of Toutunhe Formation mudstone (magnified 100 times)

Table 6-7 Toutunhe Formation mudstone energy spectrum analysis results (mass percentage)

Spectrum	Status	C	O	Na	Mg	Al	Si	Ca	Fe	Total
NO.1	yes		50.72			3.01	33.89	2.90	9.49	100.00
NO.2	yes		38.51			8.34	23.57	8.22	21.37	100.00
NO.3	yes		39.14			3.38	6.77		50.71	100.00
NO.4	yes		46.43			6.21	47.36			100.00
NO.5	yes	20.09	46.00	1.74	1.09	5.65	20.26		5.16	100.00
Max		20.09	50.72	1.74	1.09	8.34	47.36	8.22	50.71	
Min		20.09	38.51	1.74	1.09	3.01	6.77	2.90	5.16	

Qigu Formation:

Figure 6-17 Qigu Formation tuff sample from the Di-2 well area

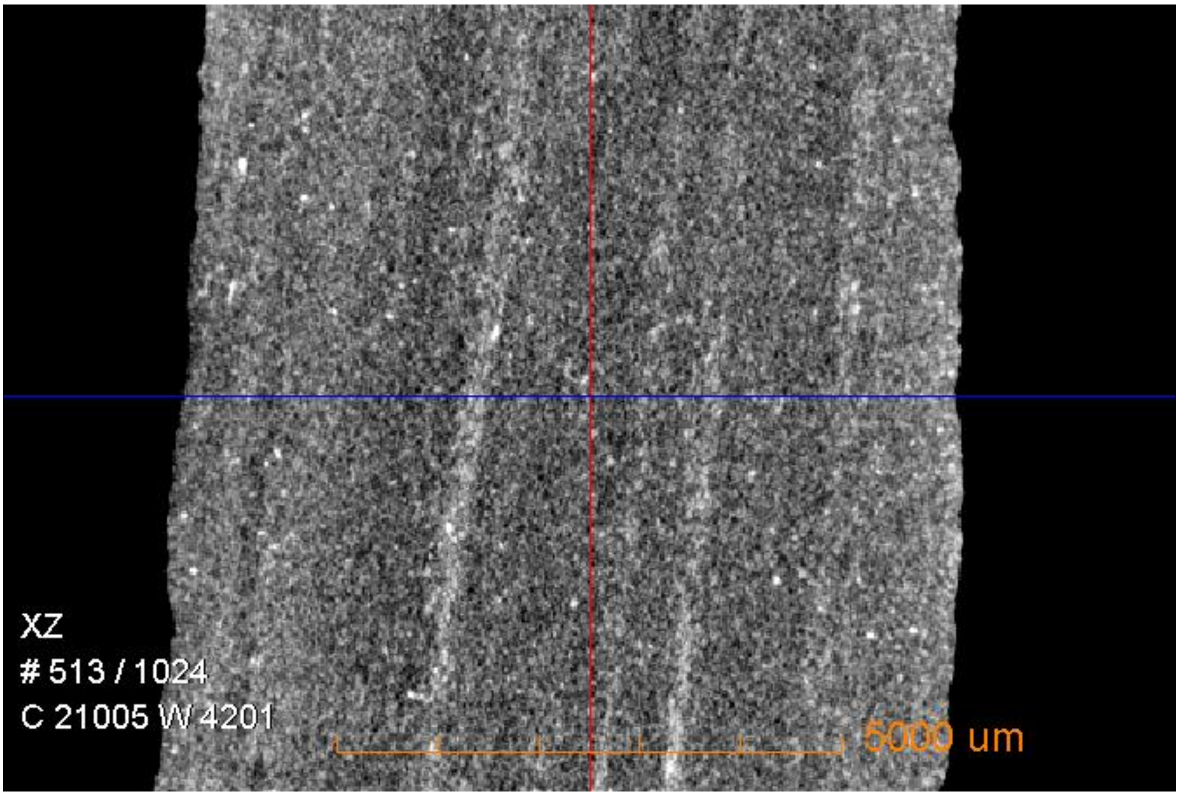


Figure 6-18 microCT scan results of Qigu Formation tuff

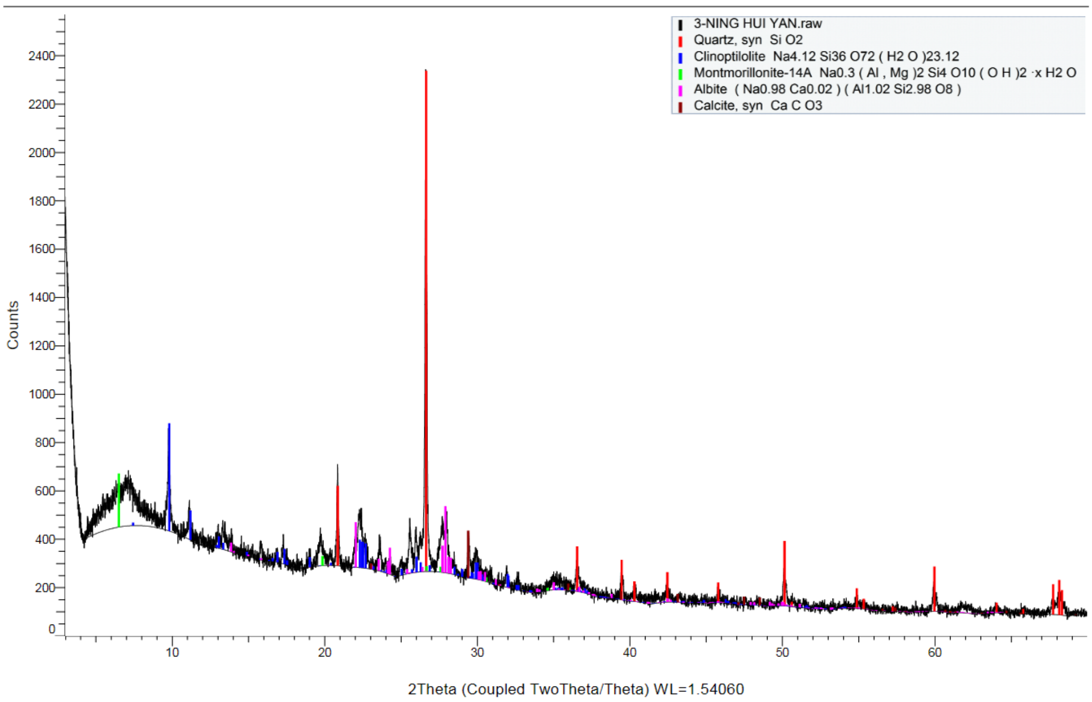


Figure 6-19 X-ray diffraction results of Qigu Formation tuff

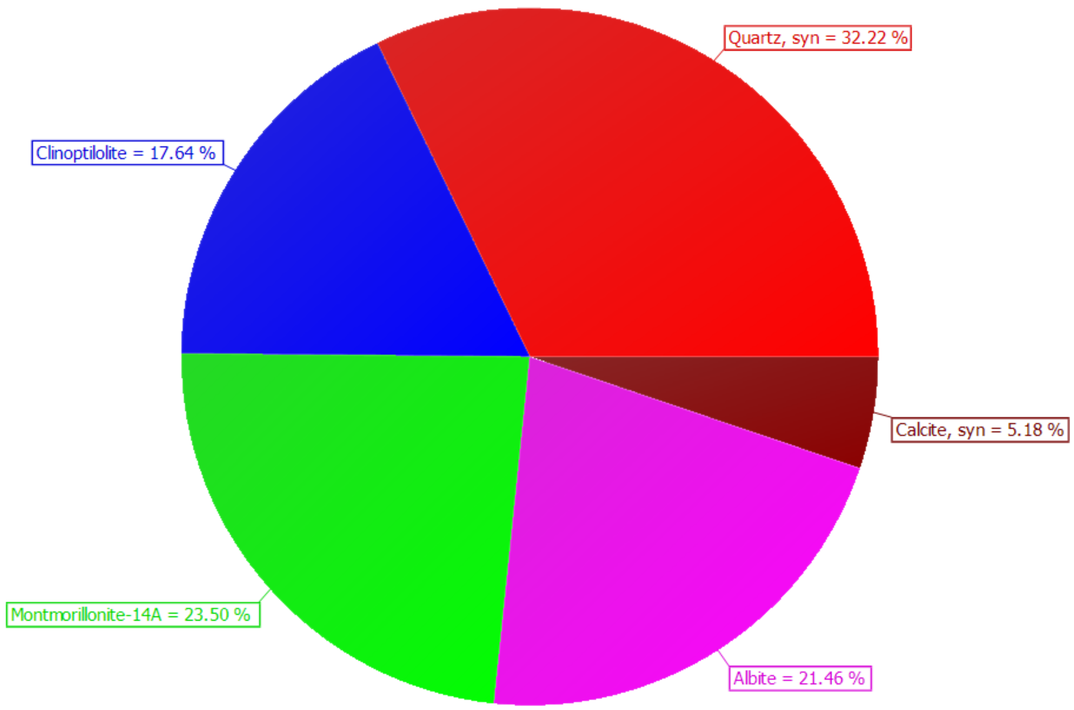


Figure 6-20 Mineral composition of Qigu Formation tuff

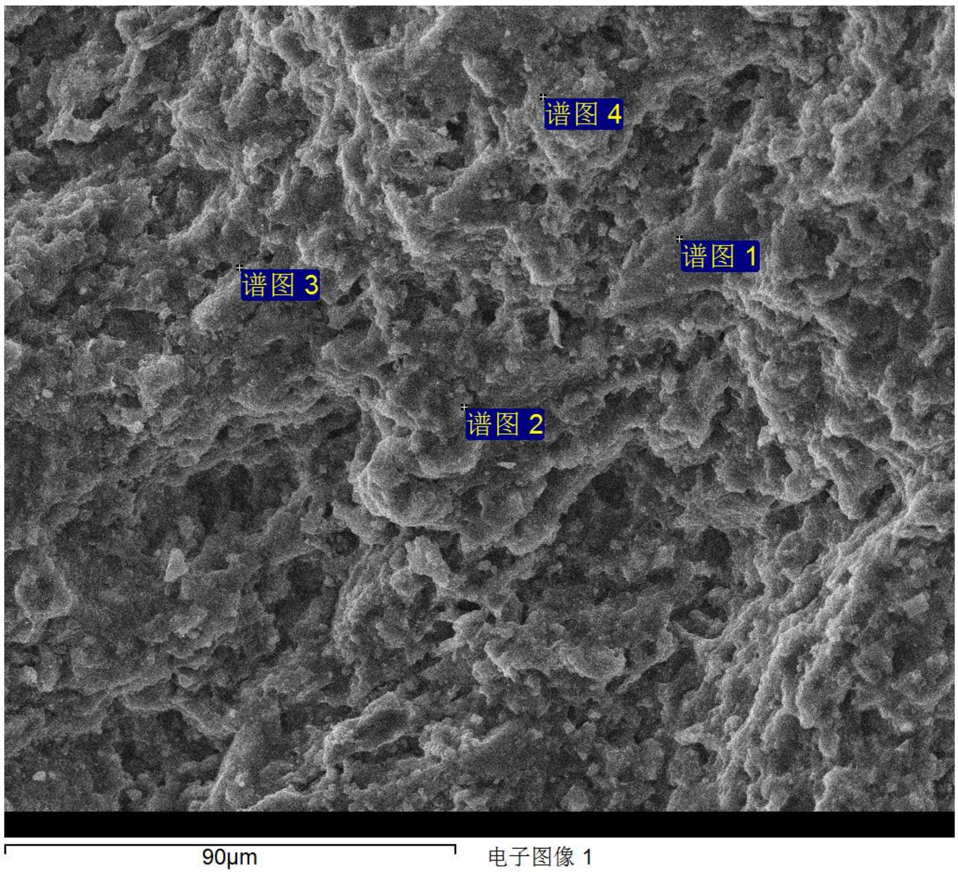


Figure 6-21 SEM image of Qigu Formation tuff (magnified 100 times)

Table 6-8 Qigu Formation tuff energy spectrum analysis results (mass percentage)

Spectrum	Status	O	Al	Si	K	Fe	Au	Total
No.1	yes	46.98	8.11	31.91	13.00			100.00
No.2	yes	57.00	7.73	26.59			8.68	100.00
No.3	yes	57.74	7.13	27.01	3.10	5.02		100.00
No.4	yes	56.44	4.00	39.57				100.00
Max		57.74	8.11	39.57	13.00	5.02	8.68	
Min		46.98	4.00	26.59	3.10	5.02	8.68	

6.5 RESERVOIR MODELING

A structural model can be established to evaluate the storage capacity of CO_2, and validate the accuracy of data verified earlier for the Di-2 well area. Subsequently, the CMG software was used to simulate the injection of CO_2 into the reservoir, so that the effect of sealing and flooding is more intuitive, providing a reference for the subsequent implementation of CO_2-EOR technology.

6.5.1 MODEL ESTABLISHMENT

The structural model is about 4 km in length north to south and about 3.5 km east to west. The maximum thickness of reservoir sandstone is about 40 m, and the elevation depth of the model ranges -550 m-70 m. The establishment of a structural model mainly included the following steps:

1) The elevation depth of the oil-bearing sandstone top boundary was calibrated according to the top boundary depth of the sand layer in the reservoir profile and the contour line of the drilling location in the structural map, comparing the reservoir profile and the sandstone top boundary structural map.

2) The drilling depth of the seismic interpretation profile was calibrated according to the "time - drilling depth" relationship and the seismic profile of the seismological geological well calibration map.

3) The relationship between the drilling depth and the elevation depth was established from the reservoir profile, and the drilling depth of the seismic interpretation profile was converted to the elevation depth.

4) The relative plane coordinates of the seismic interpretation profile were determined according to the seismic profile lines, and the spatial position relationship was established in the PETREL modeling software, as shown in Figure 6-22.

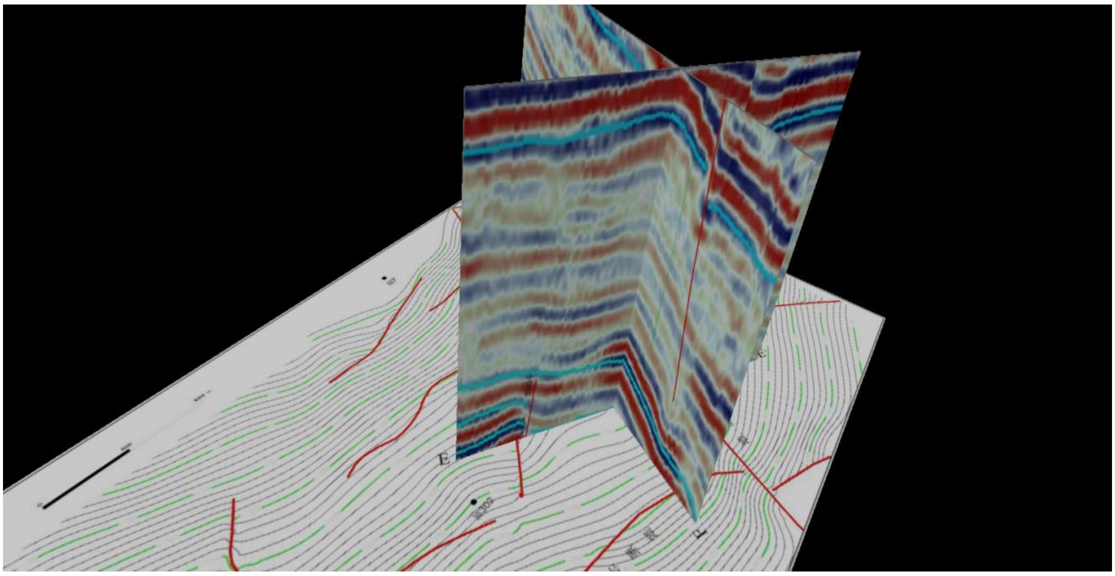


Fig.6-22 Seismic profile lines determine the spatial relationship of the seismic interpretation profiles

The top boundary space surface was constructed according to the contour map of the top boundary, and the contour space surface was constructed according to the contour map of the reservoir sandstone thickness, as shown in Figure 6-22 and Figure 6-23.

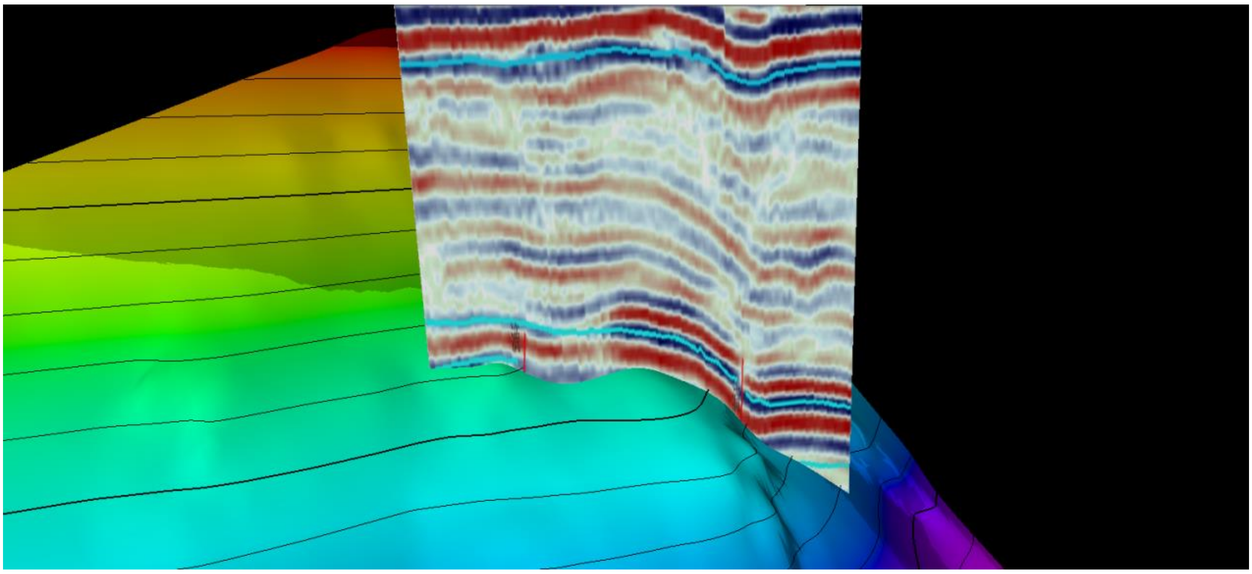


Fig.6-23 Spatial relationship between the top surface of the oil-bearing sandstone and the seismic interpretation profile E-E'

It can be seen that the position of the surface of the top boundary is essentially the same as that of the seismic interpretation profile, and the spatial position of the model is correct.

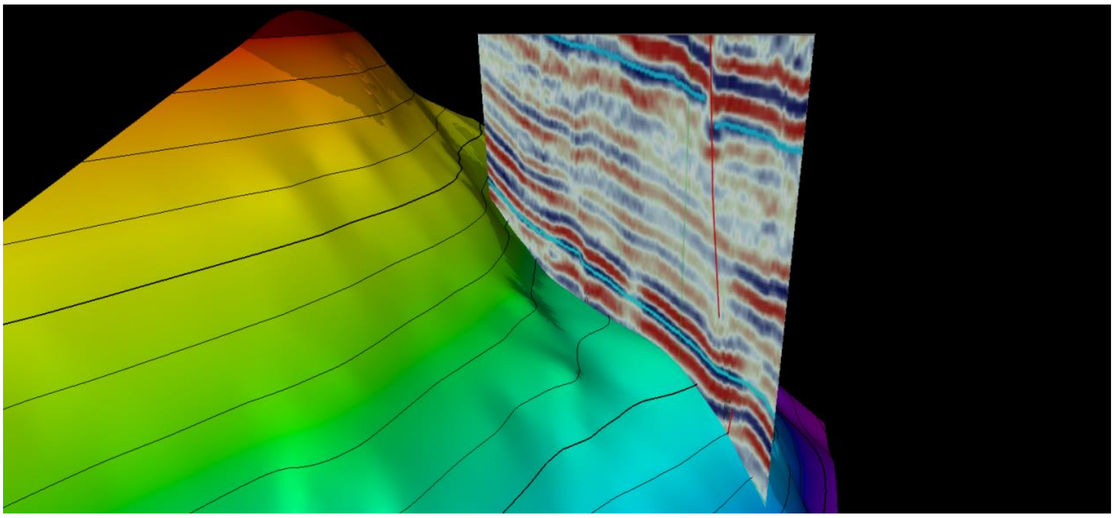


Fig.6-24 Spatial relationship between the top surface of the oil-bearing sandstone and the seismic interpretation profile F-F'

The northwest and southwest directions of the model are bounded by "Di-2 well No. 1 fracture" and "Di-2 well No. 3 fracture", while the other directions are bounded by the map border.

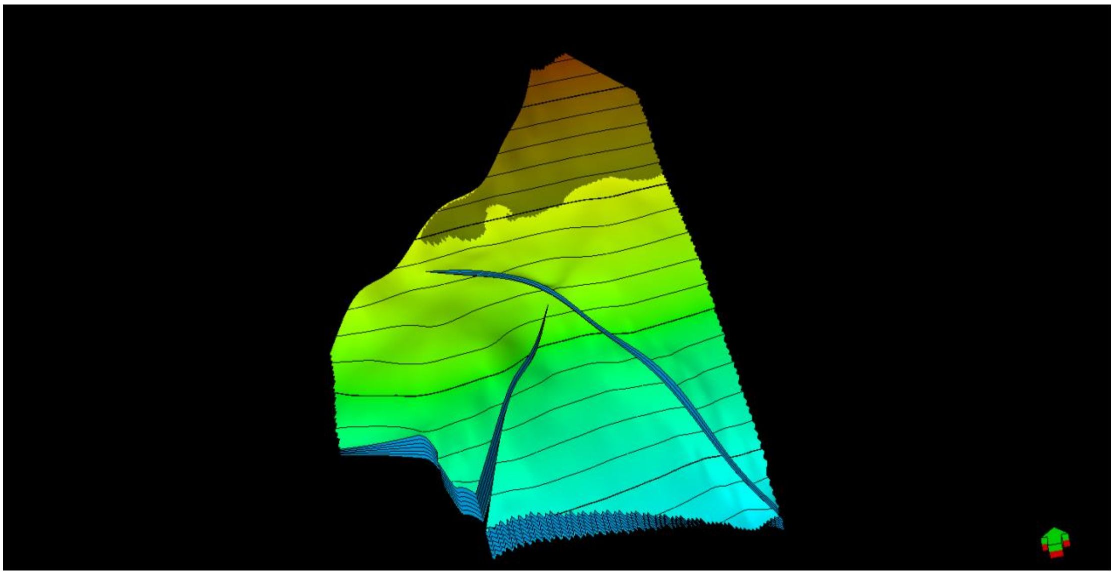


Fig.6-25 Reservoir sandstone tectonic model

The reservoir was cut through by Di-2 well No. 2 and No 4. fractures, and the structural model of the reservoir was obtained, as shown in Figure 6-25. The model generated by the modeling is consistent with the actual Di-2 well reservoir fracture structure. Trap formation occurred in the oil reservoir, which further confirms the feasibility of CO_2 geological storage and flooding.

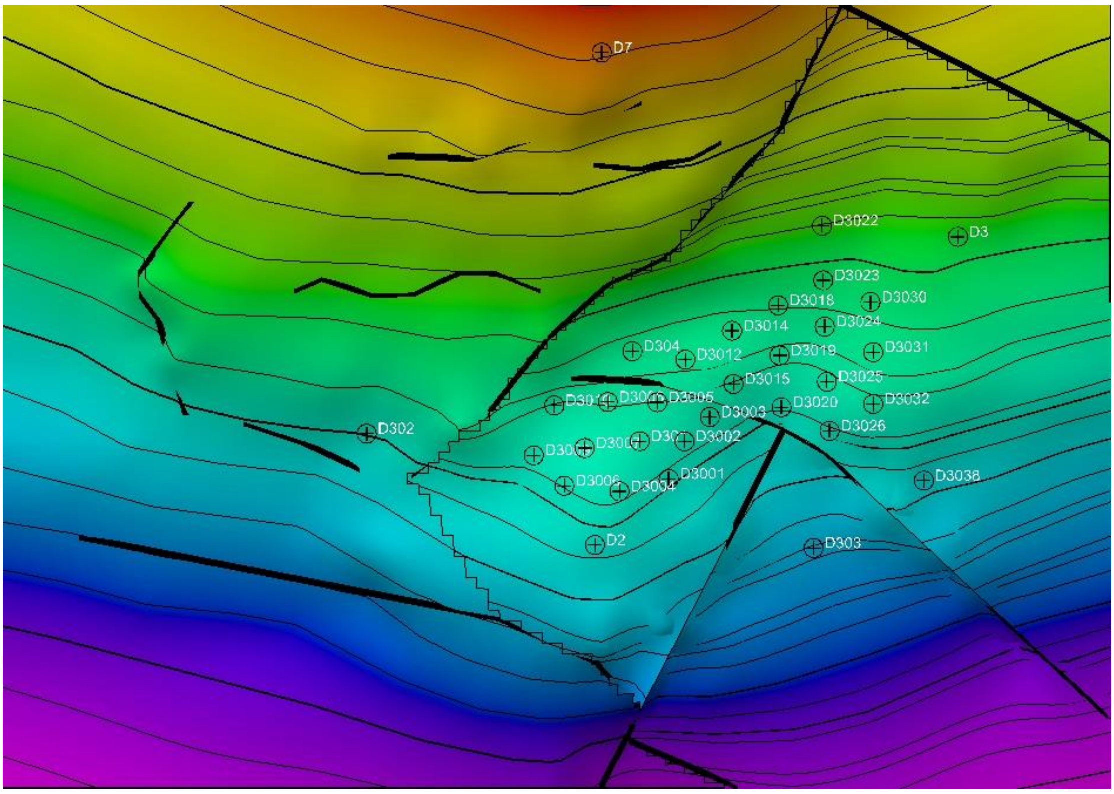


Figure 6-26 Di-2 well area numerical model drilling distribution

The relevant data and parameters when the model was established:

Table 6-9 Reserve parameters table

Block	Layer	Ao	H	ϕ	Soi	Boi	ρo	N		Rsi	Gs
		km^2	m	f	f		g/cm^3	10^4t	10^4tm^3	m^3/m^3	10^8m^3
Di-2	J_1b	1.43	5	0.178	0.544	1.074	0.909	58.6	64.47	28	0.18

Table 6-10 Basic data table of the effective thickness plate of the Di-2 well area

Well No.	NO	SEDP	EDEP	Single layer distance	Single well thickness	RT	DEN	AC	CNL	GR	POR	SO
Di-2	1	992.81	993.19	0.38	1.14	38.94	2.37	74.27	19.21	74.99	17.58	46.59
	2	995.44	996.20	0.76		41.6	2.38	73.15	19.88	76.54	16.8	45.88
Di-301	1	981.06	981.94	0.88	10.76	48.04	2.41	72.2	19	72.53	14.7	42.91
	2	982.69	98919	6.5		45.12	2.3	81.75	23.98	66.69	21.08	58.07

	3	991.94	995.31	3.38		49.43	2.36	80.04	21.44	64.88	17.75	52.77
Di-304	1	926.06	930.44	4.38	4.38	61.62	2.41	74.05	18.88	58.38	15.81	53.05

Table 6-11 Di-2 well block effective thickness data

Well No.	Layer	Tested well	Data extraction well	Resistivity	Density	Porosity	Oil saturation	Oil test result
Di-2	J_1b	991-1000	996-999	30	2.23	26.89	0.611	Oil and water in same layer
D301		991.5-994	992-994	50	2.34	19.6	0.584	Oil layer
D304		927-931	927-931	60	2.42	14.3	0.471	Oil layer

Table 6-12 Di-2 well block crude oil PVT analysis data table

Well No.	Layer	Well section m	Sampling conditions							Analysis results											
			Oil nozzle mm	Gas/oil rate M^3/m^3	Sampling depth m	Pressure M Pa			Temperature ℃	Saturation pressure M Pa	Volume coefficient		Gas/oil rate M3/m3	Compressibility10-3/MPa-1	Contraction rate %	Ground layer crude oil density g/cm^3	Degassed crude oil density g/cm^3	Viscosity m Pa.s			Natural gas relative density g/cm^3
						Oil pressure	Casing pressure	Static pressure			Under saturation pressure	Underground pressure						Under saturation pressure	Underground pressure	Ground condition	
D301	J_1b	981.0 -994.0	62	27.7	Ground	0.15	1.5	7.60	39.7	6.38	1.078	1.074	27.7	0.1416	6.89	0.8648	0.912	104.56	107.66	189.75	0.597

Table 6-13 Di-2 well block water analysis data table

Well No.	Layer	Perforation interval m	Major ion mg/L							OH^-	Mineralisation mg/L	Water type	Hardness	PH	Colour	Odour	Remarks
			CO_3^{2-}	HCO_3^-	CL^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	K^+ and Na^+								
Di-2	J_1b	991-1000	0	2597.98	2258.61	55	0	0	2470.68	0	6083.28	$NaHCO_3$					
		991-1000	25.35	876.34	2580.41	4.94	25.05	5.7	1986.75	0	5066.36	$NaHCO_3$		8.07	Colourless	Oil odour	Sulin classification method

Table 6-14 Di-2 well block surface crude oil analysis data table

Block No.	Layer	Well No.	Well section m	Density g/cm^3	Viscosity m Pa.s				Colloid type	Asphalt	Acid value	Solidification point ℃	Wax %	Sulphate %	Initial boiling point ℃	Distillation %				
					25℃	30℃	40℃	50℃								100 ℃	150 ℃	205 ℃	270 ℃	300 ℃
Di-2	J_1b	Di-2	991-1000	0.9096				151			0.92	-26	2.14	0.026	227				1.5	7.8
			991-1000	0.9043	505.4	389.1	226.4	128.3			1.33	-10	5.56		243				3.3	6.5
			991-1000	0.9014			121.9	70.45			0.0	-6	3.37		162			1.5	6.0	14.0
			990-993.5	0.9135			252.7	147.4			1.016	-20	2.6		220				4.6	11.4
		Di-301	981-994	0.9119			239.2	139.3			0.616	-20	2.39		223				4.1	13.3
			981-994	0.9112			42.35	23.94			1.267	-16	1.26		210.2				6.2	12.8
	Average			0.909				110.1				-16.3	2.89							

6.5.2 SIMULATION RESULTS

After establishing the reservoir model based on the information mentioned above, we simulated the CO_2 injection procedure. Based on the injection scheme, the current water injection wells will all be changed to CO_2 injection wells with an average injection rate of 100,000 tons per year. To verify the oil displacing effect of the CO_2 injection, the oil displacing effects of N_2 injection and water injection were also simulated. A comparison of the three oil displacing schemes with an injection quantity of 100,000 tons per year and simulation period of 3 years for each was performed, and the relevant data was derived.

We established 8 different injection schemes and separately compared them:

1) The displacement effect of water, nitrogen and CO_2 under current injection conditions (9 injection wells: D3022, D3009, D3008, D3015, D3018, D3030, D3004, D3002 and D3025）.

2) The displacement effect of nitrogen and CO_2 using a monocline structure to displace from top to bottom.

3) The displacement efficiency adopting the Water Alternating Gas (WAG) Injection method.

Further, storage capacity under different CO_2 injection schemes was evaluated, and it was hoped that storage and growth capacity could approach close to optimal at the same time.

Table 6-15 Injection schemes (injection quantity of 100,000 t/a for 3 years)

Scheme No.	Injection well	Injection media	Remarks
1	D3022, D3009, D3008, D3015, D3018, D3030, D3004, D3002, D3025	Water	Used current water injection wells only
2		Nitrogen	
3		CO_2	
4	D3022, D3, D3018, D3024, D3031, D304, D3012, D3015, D3020, D3026	Nitrogen	New injection well Injection from top of monoclinic structure
5		CO_2	
6	D3022, D3, D3018, D3024, D3031, D304, D3012, D3015, D3020, D3026, D3009, D3007, D301, D3002, D2	CO_2(30%) H_2O(70%)	New injection well Water Alternating Gas (WAG) Injection
7		CO_2(50%) H_2O(50%)	
8		CO_2(70%) H_2O(30%）	

From the simulation results provided by the CMG reservoir software, it can be seen that in the Di-2 block, the three simulated oil displacing methods (H_2O, N_2, CO_2) were all effective. A simulation of the oil remaining 3 years later is shown in the following Figures:

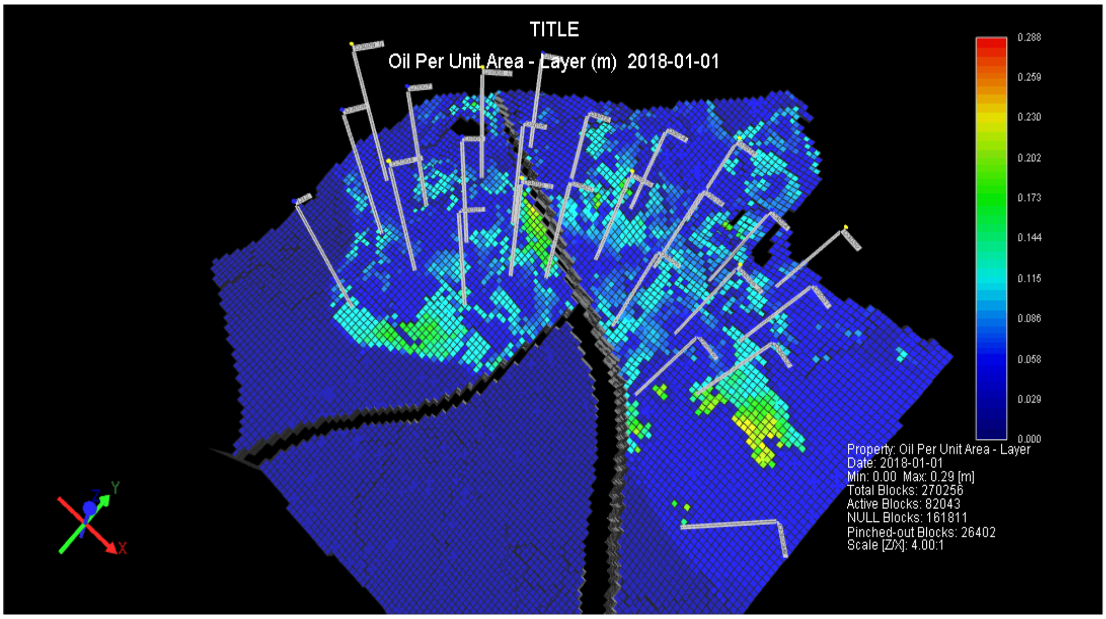


Figure 6-27 Distribution of remaining oil after injecting N_2 for 3 years

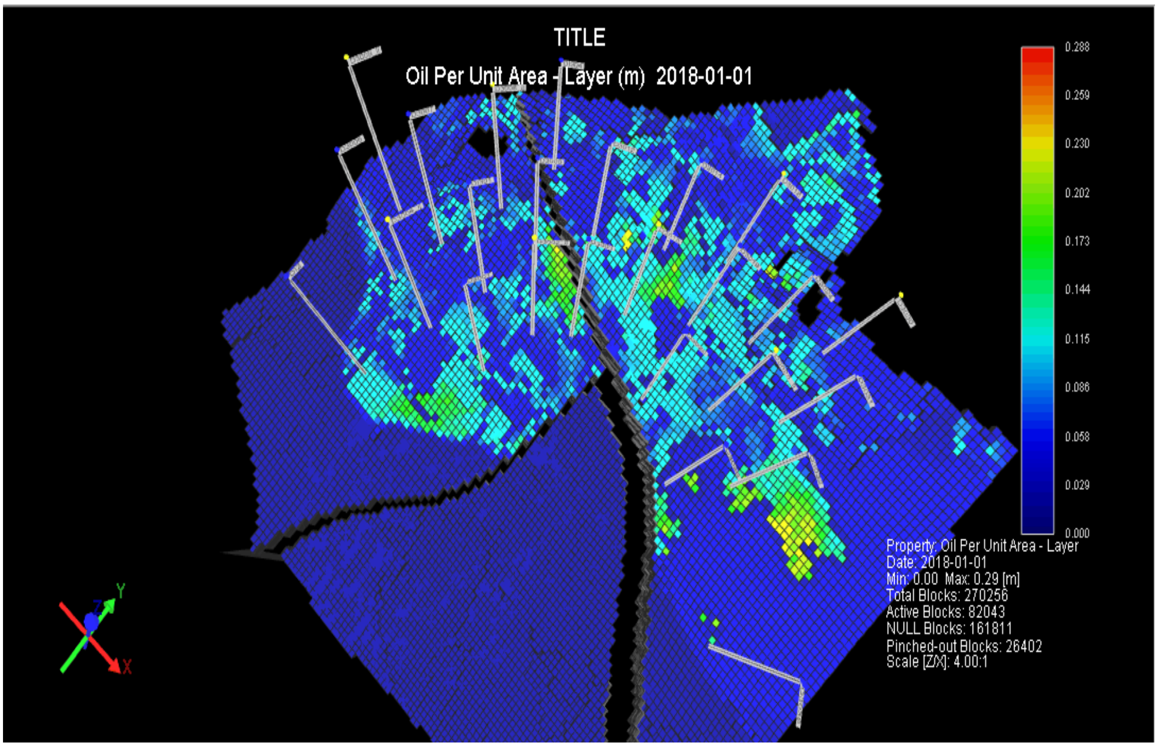


Figure 6-28 Distribution of remaining oil after injecting water for 3 years

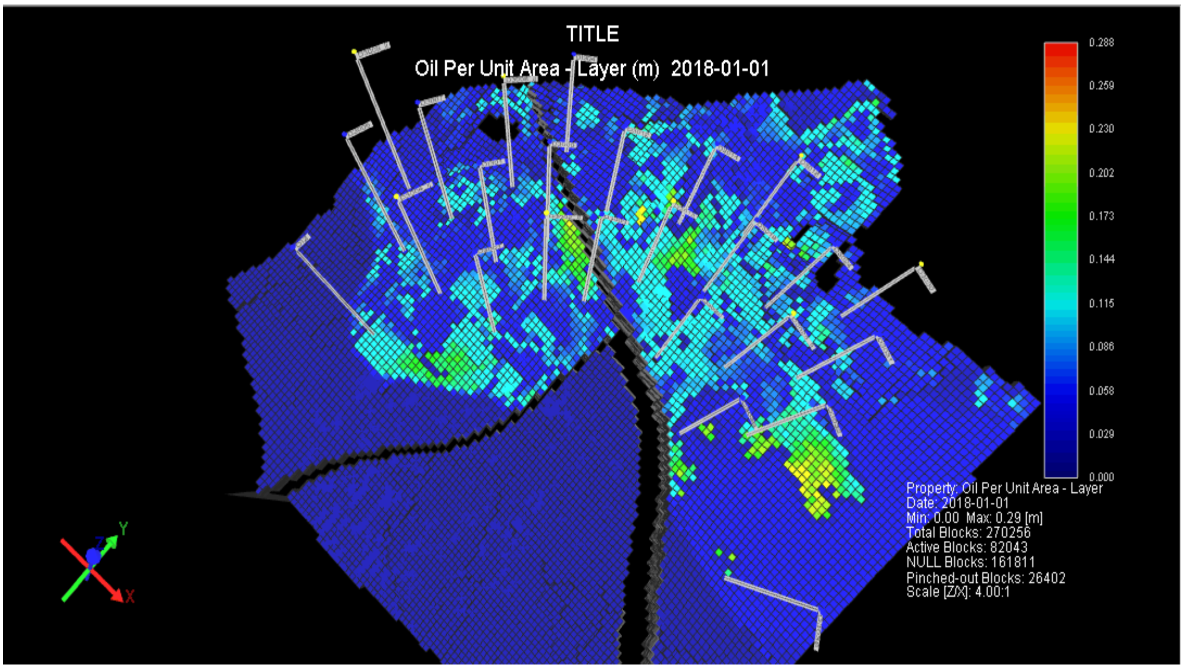


Figure 6-29 Distribution of remaining oil after injecting CO_2 for 3 years

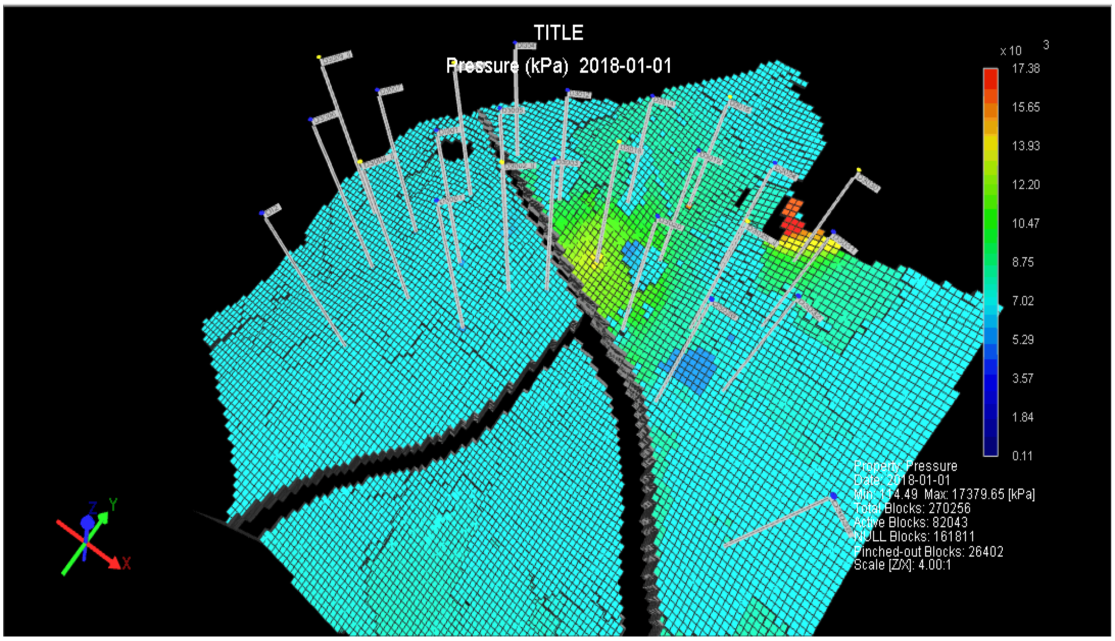


Figure 6-30 Formation pressure map after 3 years

From the formation pressure map after 3 years of simulation, it can be seen that in the case of the existing injection wells, the pressure in some parts is high after average injection of the wells, which may threaten caprock integrity. The number of injection wells would need to be increased or the distribution of the injection volume would need to be adjusted.

The displacement effect curve line graph is shown in Figure 6-31. From a comparison of the results, it can be seen that CO_2 displacement has the highest oil recovery rate.

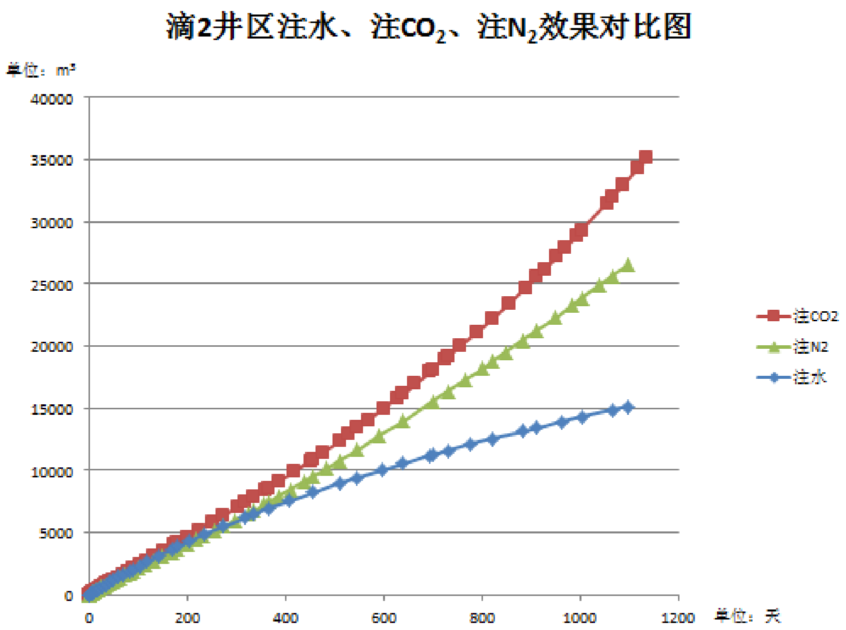


Figure 6-31 Di-2 well block injection results

6.6 SOCIAL FEASIBILITY

The Notice of the State Council on the Issue of a Work Plan for Controlling Greenhouse Gas Emissions during the 13th Five-Year Plan Period, promulgated in October 2016, clearly stated the need to promote “large-scale industrial demonstration of carbon capture, utilisation and storage by the oil and gas industry”. Therefore, the government of Xinjiang Autonomous Region should also actively respond to the call of the Central Committee and take the lead in developing CO_2 storage projects in oil and gas fields, and play a guiding role throughout the whole country.

The storage area is part of PetroChina Xinjiang Oilfield Company’s East Junggar Cainan oilfield. If Xinjiang oilfield can be added to the follow-up oil and gas field CO_2 storage project, then both the abundant geological data on the reservoir cap and the utilisation of the site will greatly promote the project’s start-up.

Xinjiang has carried out decades of oil extraction work in East Junggar Cainan oilfield and has a good relationship with the local community. This Project can provide benefit to the community, as it will reduce the greenhouse effect. As long as the social and environmental benefits are made clear to the local community and they are well informed of the low probability of sudden environmental and safety risks, it is believed that the local community will support this Project.

6.7 TECHNICAL FEASIBILITY

As a major energy province in China, Xinjiang's energy industry has always occupied an important position in the national economy. Overall, the number and production levels of coal chemical plants, coal-fired power plants, cement plants, chemical plants and steelworks in the Xinjiang area are high, and the distribution area is concentrated. While Xinjiang’s population density is relatively low, it consumes a large amount of raw materials (mainly coal) and at the same time emits large volumes of CO_2 intensifying the emissions of greenhouse gases and causing a certain degree of environmental pollution.

Because of the abundant coal resources in the Xinjiang area, there are a large number of coal-fired power plants either already built or under construction, with huge capacity, and there is a great demand for post-combustion capture technology. According to the "Xinjiang 13th Five-Year Development Plan", we should adhere to safe, green, intensive and efficient development principles, promote the clean and efficient use of coal as the main way forward, focus on adjusting industry structures and transforming development modes, and build the 14th national coal base relying on the Junggar, Tuha, Yili and Kubai coalfields.

At the same time, in recent years Xinjiang has vigorously developed clean energy, accelerating the optimisation of energy structures and industry transformation. Based on relevant policies, the manufacture of storage system supporting devices can fully meet the requirements and demands of CO_2 storage, and has brought additional opportunities to the relevant enterprises.

6.8 SUMMARY

A CO_2-EOR test at two single wells in the north of the Di-2 well area was carried out. After 1 week of CO_2 injection, the average daily production of the two wells increased by 3.1 tons in 4 months, the total volume of oil produced increased by 372 tons, and the oil recovery efficiency increased by 12%. A structural model was established using PETREL modeling software, and a CO_2 simulation was undertaken with respect to the Di-2 well area by combining the pilot test data with the reservoir simulation software CMG. In order to verify the oil displacement effect of CO_2, the traditional nitrogen (N_2) displacement and water displacement methods were added to the simulation software. The injection volume was 100,000 tons / year and the simulation period was 3 years for each of the three displacement methods. Ultimately, it was concluded that CO_2 displacement and storage is the best method.

7. GUANGHUI COAL TO GAS CCUS PILOT PROJECT ENVIRONMENTAL RISK ASSESSMENT

7.1 DETAILS OF THE PILOT PROJECT ENVIRONMENTAL RISK ASSESSMENT

According to relevant national regulations, an assessment of the relevant environmental risks was undertaken with respect to the three main phases of the Xinjiang Guanghui Coal to Gas CCUS Pilot Project: capture, transportation and storage. Finally, according to the FPE database, a risk analysis of the entire Project was carried out by matrix analysis. The environmental risk of the Project is medium.

7.2 THE PURPOSE AND SIGNIFICANCE OF THE PILOT PROJECT ENVIRONMENTAL RISK ASSESSMENT

By evaluating the environmental risk of the capture phase, we can prevent fires, explosions, solvent leakage, volatilisation and degradation, as well as carbon dioxide leakage after compression and sequestration, and reduce the pollution and impact caused by emergencies. Through the environmental risk assessment of the transportation phase, we can prevent pipeline leakage and resulting pollution of the underground and surrounding areas from natural causes and human factors in the CO_2 transportation process. The environmental impacts of the storage phase occur mainly in the construction period. Through the environmental risk assessment of the storage phase, we can reduce the likelihood of sudden or slow carbon dioxide leaks that may occur due to improper process selection or storage site selection, and which may trigger a series of environmental issues such as groundwater pollution, soil acidification and ecological damage, and cause adverse effects on human health. Every phase of the Project has targeted emergency measures, thus reducing the corresponding damage and pollution, and improving the safety of the Project.

7.3 RISK ASSESSMENT OF THE CAPTURE PHASE

The source of the carbon dioxide is the Xinjiang Guanghui Energy Kamusite Industrial Park Coal Gasification Plant. It is proposed that Chengdu Wuhuan Xinrui food grade liquid carbon dioxide technology be adopted, using MEA absorbent to capture 100,000 tons / year.

7.3.1 ENVIRONMENTAL IMPACTS

The main environmental impacts of the capture phase are the increase in energy consumption during operation, the change in air pollutant emissions, the production of emission solvents and degradation products, the increase in water consumption and the increase of wastewater and solid waste emissions.

(1) Waste gas

The tail gas of this Project mainly contains CO_2, N_2, H_2O, O_2, etc. According to the current technology level, the emission standard of the "Integrated Emission Standard of Air Pollutants" GB16297-1996 can be achieved.

(2) Waste water

There is no waste water discharged under normal conditions.

(3) Noise

Noise mainly comes from various pumps and pipes, and the noise level is about 85 decibels.

7.3.2 ENVIRONMENTAL RISK ANALYSIS

The environmental risks in the capture phase mainly include fire, explosion, solvent leakage, volatilisation and degradation, as well as CO_2 leakage after compression and sequestration. The risk points are mainly the absorption tower, amine rich flash tank, lean/rich amine heat exchanger, amine regeneration tower, amine regeneration tower reboiler, lean amine buffer tank, lean amine cooler, defoamer tank, steam boiler, various kinds of pumps, as well as flue gas discharge. The risk type is a toxic substance produced by solvent volatilisation and degradation. The consequences of the risk is mainly the pollution and other impacts of the toxic substances produced by the solvent volatilisation and degradation. The analysis of the fire and explosion danger is as follows:

- The CO_2 trapping solution is mainly MEA (monoethanolamine) solution.
- The risk of combustion and explosion of monoethanolamine:
- Combustibility: flammable flash point: 93°C; ignition point: 93.3°C
- Dangerous characteristics: high heat, open fire or contact with oxidising agents causes combustion; severe reaction occurs with sulphuric acid, nitric acid, hydrochloric acid and other strong acids.

Combustion decomposition products: CO, CO_2, H_2O

- Stability: stable
- Polymerisation hazards: cannot appear
- Prohibited materials: acids, acyl chloride, aluminum, copper.
- Fire extinguishing methods: spray water, foam, CO_2, dry powder, sand.

7.4 ENVIRONMENTAL RISK ASSESSMENT OF TRANSPORTATION PHASE

7.4.1ENVIRONMENTAL IMPACT ASSESSMENT OF TRANSPORTATION PHASE

This Project will capture dehydrated and pressurised dry carbon dioxide (concentration 99.5%) from the Xinjiang Guanghui Company Fuyun Coal to Gas Plant, and transport it to the Di-2 well storage at Cainan oilfield. The Project will use pipeline dense-phase liquid transportation (the pressure exceeds the critical pressure and the temperature is lower than the critical temperature). The transportation distance is approximately 75.2km, the design pressure is 12MPa, and it contains a simple polyurethane thermal insulation layer and 3PE anticorrosive coating. With the exception of the metering stations and the pumping stations, most of the pipes are buried underground, at a depth of 1.0-1.2m, with a minimum depth of 0.9m.

The project area is relatively flat, and there are no rivers, roads, railroads or other obstacles along the pipeline. No crossings are required. The main terrain is the Gobi Desert, with topographic relief of less than 200m.

7.4.2 ENVIRONMENTAL IMPACTS

The environmental impacts of the transportation phase of the Project come mainly from the air pollutants and solid waste in the construction period. The main source of air pollution is exhaust fumes and dust from construction vehicles and transport vehicles, with the main pollutants being flue gas, CO_2, NOx, CmHn, SO_2, CO and particulate matter. Solid waste mainly comes from waste materials (such as welding rods, anticorrosive materials, etc) and ordinary rubbish. There is mechanical noise and noise from personnel during the construction process, but these impacts are partial and temporary. With the completion of construction, these impacts will disappear. In the construction process, the content of pollutants in the waste water is very low, and the amount of domestic sewage is small and dispersed, so they can be discharged directly. The main source of pollution during operation is that a small amount of carbon dioxide is discharged from the system when the equipment is subject to maintenance.

7.4.3 ENVIRONMENTAL RISK ANALYSIS AND EVALUATION

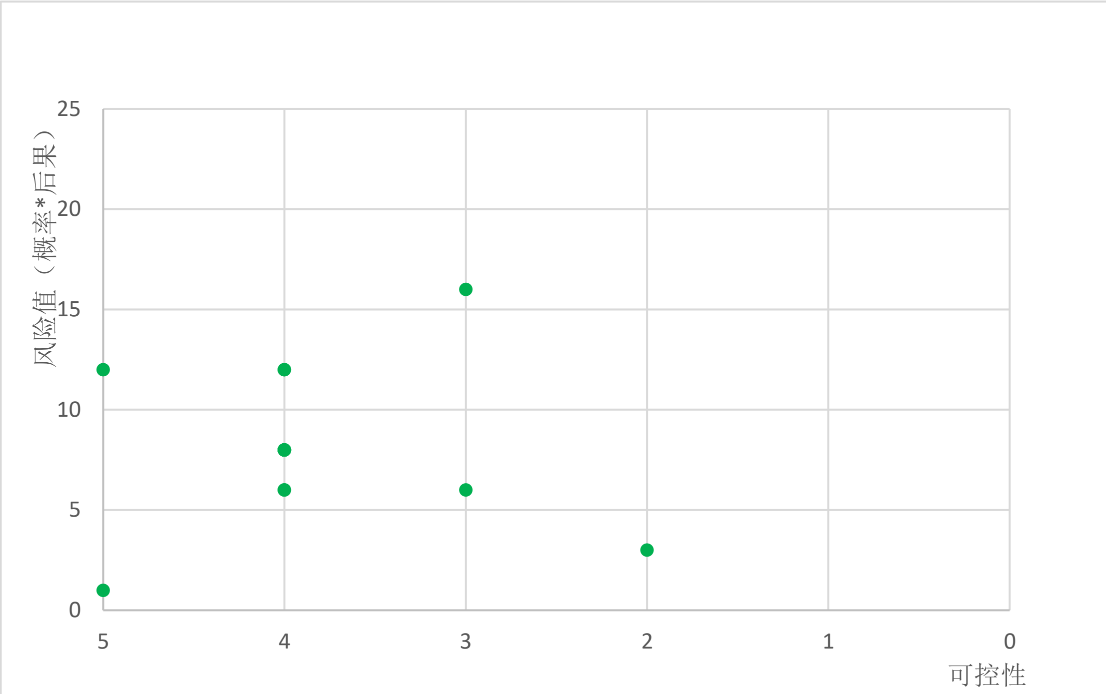
The Project adopts pipeline transportation. There are no rivers, highways, railways or production activities. There is essentially no risk of pipeline leakage caused by agricultural activities, construction activities or third party intentional damage.

The main risks are set out in Table 7-1:

Table 7-1 Main risks of pipeline transportation

No.	Risk	Risk assessment			Explanation
		Consequence（1~5）	Possibility（1~5）	Controllability（1~5）	
1	System design defects	4	2	4	Through strict audit procedures and process management, the design risk can be very low
2	Insufficient material for system design	4	2	4	
3	Improper design in pipeline design process (such as incorrect or inappropriate valve placement)	4	2	4	
4	Improper operation in the process of installation	4	2	4	Strengthening the management of the construction process can greatly improve the controllability of the construction risk
5	Substandard equipment or materials used in installation, pipe laying and valve chamber	4	2	4	
6	Operating at excess pressure	4	2	4	Establish training processes and strengthen
7	Pipeline / equipment / valve malfunction, leakage, corrosion during operation	4	3	4	

8	Operation failure of pipeline, equipment or valve	4	2	4	operation management
9	Human error in operation	4	2	4	
10	Unintentional destruction caused by third party (mining operations)	4	4	3	Strengthen publicity, enhance public awareness and increase the level of identification markings on the pipeline
11	Stratum / soil movement destroys pipeline / equipment / valve chamber	4	2	2	Establish emergency chain mechanism
12	External corrosion (soil type, wall thickness loss, abnormal density, rupture pressure increase, DC/AC interference)	3	1	3	
13	Non fault leakage and corrosion caused by pipe release operation	3	4	5	Rationalise the operation and strengthen the monitoring of the operation process
14	Failure, leakage, corrosion caused by maintenance of pipeline / equipment / valve	3	2	4	
15	Failure, leakage, corrosion in the retesting process	3	2	4	
16	CO_2 gas source interruption	1	1	5	Strengthen communication with the gas suppliers
17	Phase transition caused by temperature change	3	4	4	Select the appropriate thermal insulation material



When the risk value is less than or equal to 4, the risk is considered to be low and acceptable. When the controllability of the risk is greater than or equal to 3, the risk is considered to be controllable. For this Project, due to the temperature difference between day and night in the area where the Project is located, the phase change caused by temperature changes will cause corrosion of the pipeline. Therefore, we must pay attention to pipeline insulation.

7.5 RISK ASSESSMENT OF THE STORAGE PHASE

7.5.1 ENVIRONMENTAL IMPACTS

The environmental impacts of the storage phase occur mainly in the construction period, but sudden or slow carbon dioxide leaks may occur due to improper process selection or storage site selection, causing a series of environmental issues such as groundwater pollution, soil acidification, and ecological damage, as well as adverse effects on human health.

7.5.2 ENVIRONMENTAL RISK ANALYSIS

(1) CO_2 leakage through the caprock

The Di-2 well block is located in the Dinan Uplift in the East Junggar Basin, and from a tectonic perspective is classified as a secondary tectonic unit of Luliang Uplift. To its north is Dishuiquan Sag, and to the south is the Dongdaohaizi Sag and Wucaiwan Sag. The Dinan Uplift was formed in the Middle and Late Carboniferous Period, and the Indosinian movement at the end of the Late Jurassic led to its uplift and erosion, resulting in the unconformity between the Carboniferous and Jurassic systems. The strata in this region from top to bottom are Cretaceous Tugulu Group, Jurassic Xishanyao Formation, Sangonghe Formation, Badaowan Formation and Carboniferous Bashan Formation.

The Project plans to inject carbon dioxide into the first member of the Jurassic Badaowan Formation (J_1b_1). The structure of the top surface of the sand layer at the bottom of the Badaowan Formation is monoclinal with no structural traps, that consistently tilts south. The oil reservoir in the well area is well distributed. The high section of the well block is lithologically sealed, controlling the distribution range of the reservoir. The upper part is mudstone caprock with a thickness of more than 30m, which has good sealing performance. Therefore, the likelihood of leakage through the caprock is small.

(2) CO_2 leakage through a fault

The larger faults in the Di-2 well block are Fault Nos. 1, 2, 3 and 4, all of which are reverse faults. The area has been developed for many years as an oil area and has been subject to 3D seismic interpretation. Therefore, the likelihood of undiscovered faults is very small, and so the likelihood of CO_2 leakage through faults is also small.

(3) CO_2 leakage through a well

There are 9 water injection wells, 23 production wells and no abandoned wells in the Di-2 well block. The Project plans to change the water injection wells to carbon dioxide injection wells. Therefore, there is no leakage through abandoned wells in this Project. The main risk is that the failure of the transformed wells causes carbon dioxide leakage.

(4) Impact of CO_2 leakage on environmental receptors

The leakage of carbon dioxide will impact soil, surface water, groundwater, air and other environmental media, as well as people, animals, plants and microorganisms. For this Project, the Di-2 well block proposed as the injection area is located in the Luliang Uplift and Dinan Uplift in the eastern part of the Junggar Basin. The surface is covered by Quaternary system Gobi Desert. There is a small amount of vegetation coverage, but no surface water system or residential areas. Therefore, the main environmental impact receptors are the atmosphere, soil and groundwater, and the main people affected are the staff of the injection station.

7.5.3 ENVIRONMENTAL RISK ASSESSMENT

The environmental risk sources of the storage link include carbon dioxide and/or other substances that pose an environmental risk, surface capture and transport equipment, existing or new wellbores, and other potential leakage channels. The specific environmental risk factors include: lithospheric factors (focusing on lithosphere engineering geology, hydrogeology and geochemistry, covering reservoirs, caprock and surrounding rock), sealed system external factors (including geological, near surface environmental and human activities; geological environment changes outside the system will directly affect carbon dioxide transport within the system); storage system factors (including the storage system, the interaction between carbon dioxide and other substances, as well as drilling. Of these three elements, the storage system describes the details of the storage concept being considered, including the injection fluid, design parameters, the construction and operation stages, etc.). Based on the above analysis, and in combination with the FEP database, the geological storage environmental risk assessment system for this Project is formed:

Table 7-2 Geological storage environmental risk assessment system

Category			Influencing Factor	Description
Lithosphere （L）	Geology		L1 Geographical position, L2 Natural resources, L3 Reservoir type, L4 Reservoir geometry, L5 Reservoir development, L6 Cover or seal, L7 Extra seal, L8 Lithification or diagenesis, L9 Pore structure, L10 Unconformities, L11 Heterogeneity, L12 Fracture and fault, L13 Undetected fracture, L14 Vertical geothermal gradient, L15 Formation pressure, L16 Pressure and mechanical characteristics, L17 Physical properties of rock	The geological elements of the lithosphere include the reservoir, the overlying rock and the surrounding rock before the injection of carbon dioxide. It is an understanding of the long-term performance and safety assessment of the natural system of carbon dioxide injection.
	Fluid		L18 Fluid characteristics, L19 Hydrogeology, L20 Hydrocarbon	The water and other fluids of the storage system will affect the migration and interaction of the injected carbon dioxide.
External （E）	Geology		E 1 Neotectonic activity, E2 Earthquake	Due to pressure changes and induced hydrogeological changes, tectonic activities and earthquakes have the potential to induce sudden changes in the physical properties of rock.
	Near surface environment	Human behaviour	E3 Demographic characteristics, E4 Life style, E5 Land and water use, E6 Community characteristics, E7 Buildings	Human behaviour will affect the nature and size of the potential human impact.

Category			Influencing Factor	Description
		Land environment	E8 Topographic features, E9 Soil and sediment, E10 Atmosphere and meteorology, E11 Hydrologic state and water balance, E12 Near surface aquifers and surface water, E13 Terrestrial plants and animals, E14 Terrestrial ecosystem	The land environment is the place where most potential impacts will occur.
	Future human activities		E15 Drilling, E16 Mining and other underground activities, E17 Human activities in the surface environment	Human activities will directly interfere with the storage fluid, resulting in an immediate or delayed impact.
Sequestration system（S）	Drill hole	Well completion	S1 Formation damage, S2 Lining and well completion, S3 Workover, S4 Monitoring well	Drilling may provide a "short circuit" for carbon dioxide migration.
		Borehole sealing and abandonment	S5 Hole closing and sealing, S6 Seal failure, S7 Blowout, S8 Old Well, S9 Soil creep around the borehole	The ways in which the holes are closed and sealed are directly related to the possibility that they will be a "short circuit" for carbon dioxide migration.
	Carbon dioxide interaction		S10 Influence of reservoir pressurisation on the cover layer, S11 Effect of reservoir pressurisation on reservoir fluid, S12 Interaction with hydrocarbons, S13 Mechanical processes and conditions, S14 Hydrochemistry, S15 Adsorption of carbon dioxide on desorption, S16 Heavy metal release	The possible interaction of carbon dioxide with solids, liquids, or gases

Category			Influencing Factor	Description
	CO_2 sequestration		S17 Storage concept, S18 Carbon dioxide volume and injection rate, S19 Carbon dioxide component, S20 Scheduling and planning, S21 Pre-closure storage monitoring, S22 Accidents and unplanned events, S23 Pressure overload	

A risk assessment based on the FEP database and the collected data was performed. The evaluation indicators selected included geology, fluid, geological activity, current human activity, the terrestrial environment, future human activity, the drilling situation, CO_2 formation interaction, and CO_2 sequestration and systemic effects. The evaluation indicators and descriptions are shown in the following Table:

Table 7-3 Risk assessment table

No.	FEP Number	FEP Indicator	Explanation
1	4.1.1	Geographical location	East Junggar Basin, Luliang Uplift and Dinan Uplift, under the jurisdiction of the Xinjiang Uygur Autonomous Region, Fuhai County. The surface is desert, a small amount of ground vegetation, average elevation of 740m.
2	4.1.2	Natural resources	Crude oil
3	4.1.3	Reservoir type	Jurassic Badaowan Formation (J1b1), fine, medium sandstone, glutenite
4	4.1.4	Reservoir geometry	The dip angle is 5~8 degrees
5	4.1.5	Reservoir exploitation	According to the early yield forecast, recoverable reserves of $10.49E^4$t, from 2006, 10 years production $6.9E^4$t, 20 years production $10.27E^4$t.
6	4.1.6	Caprock or sealing formation	Mudstone caprock, thickness >30m (oilfield introduction, no data support)
7	4.1.7	Additional seal	None
8	4.1.8.1	Lithification or diagenesis	Sedimentary rock
9	4.1.8.2	Pore architecture	Mainly intergranular pores, intergranular dissolved pores, intragranular dissolved pores, particles mostly point contact, low degree of compaction, particle selection medium ~ poor, large pore throat reservoir. Average permeability of 20.9mD, average porosity of 17.8%.

10	4.1.9	Unconformities	The Dinan Uplift was formed in the Middle and Late Carboniferous, and the Indosinian movement at the end of the Late Jurassic led to its uplift and erosion, resulting in the unconformity between the Carboniferous and Jurassic systems.
11	4.1.10	Heterogeneities	Strong reservoir heterogeneity
12	4.1.11	Fractures and faults	Fractures No. 1, 2, 3, 4 in the Di-2 well block
13	4.1.12	Undetected features	It has been developed for many years, and the likelihood of undetected fractures is low.
14	4.1.13	Vertical geothermal gradient	Temperature gradient relationship T=12.02+0.0292*D, the middle temperature of the reservoir is 40.3°C, the middle depth is 970m, the elevation is -230m.
15	4.1.14	Formation pressure	The reservoir pressure gradient is P=5.054-0.008648*H, the original formation pressure is 7.043MPa, the central depth is 970m, and the elevation is -230m.
16	4.1.15	Stress and mechanical properties	Not yet measured, refer to formation pressure and the nature of outcrop sandstone
17	4.1.16	Petrophysical properties	Not yet measured, refer to formation pressure and the nature of outcrop sandstone
18	4.2.1	Fluid properties	The stratum oil density is 0.8648g/cm^3 107.7mPa, viscosity of stratum compression coefficient is 0.142e-3/mPa-s. The average ground oil density is 0.909g/cm^3, 50°C 23.9~110.1mPa-s, the average wax content is 2.89%, and the freezing point is -6~-26°C.
19	4.2.2	Hydrogeology	
20	4.2.3	Hydrocarbons	Under 50°C conditions, hydrocarbon viscosity of different layers is 70.45~151mPa s.
21	1.1.1	Neotectonics	None

22	1.1.3	Seismicity	According to the "China seismic zoning map", Table C31, Fuhai County earthquake peak acceleration is 0.05g, spectrum characteristic period is 0.45s. According to Table G1, Type II seismic intensity is 6 degrees.
23	6.3.1	Human characteristics	No settlements
24	6.3.3	Lifestyle	No settlements
25	6.3.4	Land and water use	None
26	6.3.5	Community characteristics	None
27	6.3.6	Buildings	Oilfield facilities
28	6.1.1	Topography and morphology	The ground is undulating, and the elevation is 710m~790m
29	6.1.2	Soil and sediment	None, desert area (eastern part of Gurbantunggut Desert)
30	6.1.4	Atmosphere and meteorology	Cold in winter, minimum -40°C, hot drought conditions in summer, maximum 45°C.
31	6.1.5	Hydrological status and water balance	Annual precipitation is less than 50mm, annual evaporation is greater than 2000mm
32	6.1.6	Near-surface aquifers and surface waterbodies	In desert areas, there is no obvious surface water, and spring thaw supplies water. There is a small amount of drinkable spring water in the eastern part of the Dishuiquan region.
33	6.1.7	Terrestrial flora and fauna	According to the distribution map of vegetation in China, the eastern part of Gurbantunggut Desert contains temperate desert plants. Satellite maps show no visible vegetation in the storage area. The storage site in part of the oilfield operation area and there should be no protected plant and animal areas.

34	6.1.7	Terrestrial ecological systems	Fragile, low plant distribution, mainly including ammodendron, camel thorn and other arid or desert plants. Kalamaili Nature Reserve is about 3 kilometres from the well area, sporadic surface water, Przewalski's horses, gazelles, wild donkeys and other wild animal species, etc. Squat drought tolerant plants.
35	1.3.5	Drilling activities	Drilling in 1998, and industrial mining began in 2006. There are 32 drilling wells, of which 9 are injection wells.
36	1.3.6	Mining and other underground activities	Oil extraction
37	1.3.7	Surface environment human activities	Oil extraction
38	5.1.1	Formation damage	Slight
39	5.1.2	Well lining and completion	Cased
40	5.1.3	Workover	Regular
41	5.1.4	Monitoring wells	None
42	5.1.5	Well records	Complete
43	5.2.1	Closure and sealing of boreholes	Well sealed
44	5.2.2	Seal failure	None
45	5.2.3	Blowouts	Did not occur during oil production process
46	5.2.4	Orphan wells	Only 10 years of mining, should not exist
47	5.2.5	Soil creep around boreholes	None

48	3.2.1	Effects of reservoir pressurisation on caprock	The water injection has caused the formation pressure to rise from 7.5MPa to 8.7MPa, with no known anomalies. The formation pressure is 7.6MPa at present. The oil field has carried out a 5 day gas mixture flooding experiment, the injection pressure is 9.3MPa, no known anomalies.
49	3.2.2	Effects of reservoir pressurisation on reservoir fluids	
50	3.2.3	Interaction with hydrocarbons	The formation pressure is lower than the minimum miscibility pressure.
51	3.2.5	Mechanical processes and conditions	
52	3.2.9	Hydrochemistry	The formation water type is $NaHCO_3$, the average salinity is 5673.2mg/L, and the chloride ion concentration is 2629.3mg/L. No calcium or magnesium ions. Small amount of sulphate and carbonate ions.
53	3.2.11	Adsorption and desorption of CO_2	Nothing particular relative to other projects. Refer to other engineering data and paper analysis.
54	3.2.12	Heavy metal release	Nothing particular relative to other projects. Refer to other engineering data and paper analysis.
55	2.1.1	Storage concept	Oil displacement and sequestration
56	2.1.2	CO_2 quantities, injection rate	100,000 tons/year, assuming that all 9 injection wells are injected continuously for 365 days a year, the injection rate is 30.44 tons/day. According to public data, the injection rate of CO_2-EOR at Shengli Oilfield and Caihe Oilfield is 20~30 tons/day.
57	2.1.3	CO_2 composition	CO_2 concentration 99.8%

58	2.1.5	Scheduling and planning	No definite arrangements have been made
59	2.1.6	Pre-closure measures	
60	2.1.9	Accidents and unplanned events	Nothing particular relative to other projects. Refer to other engineering data and paper analysis.
61	2.1.10	Overpressuring	Nothing particular relative to other projects. Refer to other engineering data and paper analysis.
62	7.1.1	Loss of containment	Nothing particular relative to other projects. Refer to other engineering data and paper analysis.
63	7.2.3	Release to the atmosphere	Nothing particular relative to other projects. Refer to other engineering data and paper analysis.
64	7.2.2	Impacts on soil and sediment	Nothing particular relative to other projects. Refer to other engineering data and paper analysis.
65	8	Impacts on surface water	Nothing particular relative to other projects. Refer to other engineering data and paper analysis.
66	7.2.1	Groundwater contamination	Nothing particular relative to other projects. Refer to other engineering data and paper analysis.
67	7.2.6	Modified hydrology and hydrogeology	Nothing particular relative to other projects. Refer to other engineering data and paper analysis.
68	7.2.7	Modified geochemistry	Nothing particular relative to other projects. Refer to other engineering data and paper analysis.
69	7.4.1	Health impacts of CO_2	Nothing particular relative to other projects. Refer to other engineering data and paper analysis.
70	7.4.2	Contaminant toxicity	Nothing particular relative to other projects. Refer to other engineering data and paper analysis.
71	7.4.3	Impacts of physical destruction	Nothing particular relative to other projects. Refer to other engineering data and paper analysis.
72	7.4.4	Impacts of ecological modification	Nothing particular relative to other projects. Refer to other engineering data and paper analysis.

73	7.3.1	Impacts of CO_2 on animals	Nothing particular relative to other projects. Refer to other engineering data and paper analysis.
74	7.3.2	Impacts of CO_2 on plants	Nothing particular relative to other projects. Refer to other engineering data and paper analysis.
75	7.3.3	Contaminant physiological toxicology	Nothing particular relative to other projects. Refer to other engineering data and paper analysis.
76	7.3.4	Ecological effects	Nothing particular relative to other projects. Refer to other engineering data and paper analysis.
77	7.3.6	Modification of microorganism systems	Nothing particular relative to other projects. Refer to other engineering data and paper analysis.

Environmental risk receptors mainly include living things such as people, animals and plants, as well as other closely related environmental media, such as groundwater, surface water, atmosphere and soil:

(1) Environmental media. Changes in the environmental quality of the atmosphere, soil, surface water and groundwater within the scope of evaluation;

(2) People. Human health issues such as physiological discomfort and loss of consciousness within the scope of evaluation;

(3) Animals and plants. Changes in the distribution, abundance and ecophysiological behaviour of animals and plants within the scope of evaluation;

(4) Microorganisms. Changes in the number and type of microorganisms within the scope of evaluation.

Table 7-4 Risk receptor classification

<table>
<tr><th></th><th colspan="2">Category</th><th>Indicator characteristics</th></tr>
<tr><td rowspan="8">Impacted receptor</td><td colspan="2">System performance</td><td>Closure performance loss</td></tr>
<tr><td rowspan="4">Environmental medium</td><td>Atmosphere</td><td>Release to the atmosphere</td></tr>
<tr><td>Soil</td><td>Impacts on soil and sediment</td></tr>
<tr><td>Surface Water</td><td>Chemical impacts</td></tr>
<tr><td>Groundwater</td><td>Groundwater pollution
Hydrogeological impacts
Geochemical reaction impacts</td></tr>
<tr><td colspan="2">People</td><td>Health impacts of CO_2
Toxicity of contaminants
Physical destruction impacts
Ecological modification impacts</td></tr>
<tr><td colspan="2">Animal and plant life</td><td>Impacts of CO_2 on animals
Impacts of CO_2 on plants
Contaminant physiological toxicology
Ecological effects</td></tr>
<tr><td colspan="2">Microorganisms</td><td>Modification of microorganism system</td></tr>
</table>

Based on the environmental risk impact and likelihood, the environment risks can be divided into three levels by applying the risk matrix analysis method: low risk, medium risk and high risk.

The possibility of an environmental risk source and an environmental receptor interacting with each other and leading to an environmental risk can be divided into five types: almost impossible, unlikely, possible, likely and almost certain. For the ranking of the consequences and likelihood of each factor, refer to the environmental risks assessment guide of the Ministry of Environmental Protection.

Table 7-5 Likelihood definition table

Type	Description
Almost impossible 1	The likelihood is very low, has never occurred before, but is possible in theory.
Unlikely 2	The likelihood of occurrence during the life of the project is relatively small.
Possible 3	May occur during the life of the project.
Likely 4	May occur more than once during the life of the project.
Almost certain 5	Very likely to occur every year.

Table 7-6 Consequence severity classification table

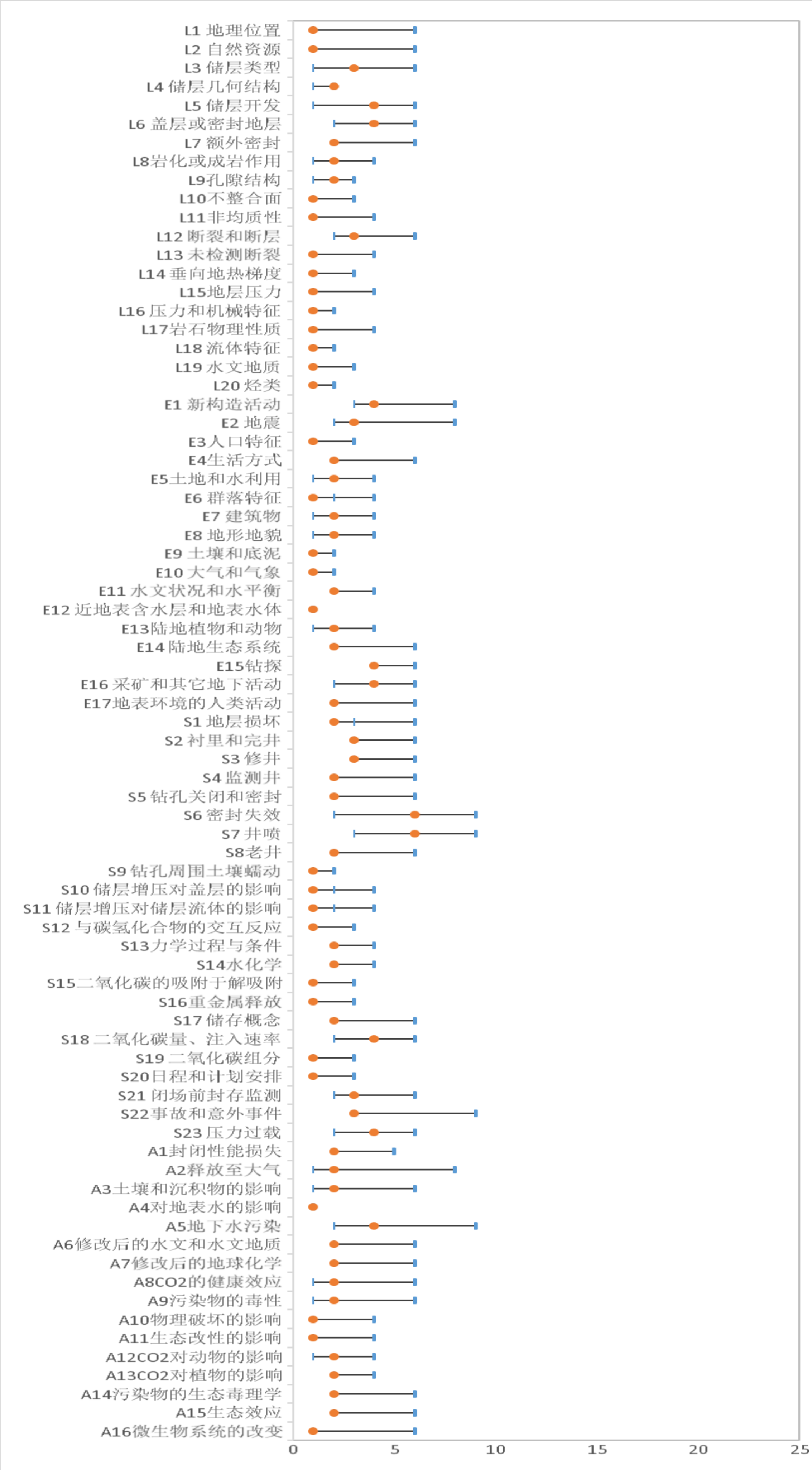
Impact	Grade	Degree of Impact
Insignificant	1	The soil/underground water/surface water/ air environmental indicators do not exceed the environment quality standard/environment background value of the project site, or the carbon dioxide density exceeds the environment background value. Does not have a sustained influence on the environment risk receptors.
Minor	2	The soil/underground water/surface water/ air environmental indicators do not exceed the environment quality standard/environment background value of the project site, or the carbon dioxide density exceeds the environment background value. Some adverse impact on the environment risk receptors, which can be resolved.
Significant	3	Some of the soil/underground water/surface water/ air environmental indicators exceed the environment quality standard/environment background value of the project site, or the carbon dioxide density exceeds the environment background value. Some adverse impact on the environment risk receptors, which can be resolved.
Major	4	Some of the soil/underground water/surface water/air environmental indicators exceed the environment quality standard/environment background value of the project site, or the carbon dioxide density exceeds the environment background value. Some adverse impact on the environment risk receptors, which is difficult to resolve.
Severe	5	Most of the soil/underground water/surface water/air environmental indicators exceed the environment quality standard/environment background value of the project site, or the carbon dioxide density exceeds the environment background value.

		Serious adverse impact on the environment risk receptors, which causes irreversible damage.

The classification criteria in each Table are given a grade 1-5, and the consequence X the likelihood is calculated as shown in the following table. The upper limit, lower limit and best guess values of each FEP are evaluated based on the actual circumstances of the Project, as shown in the following Figure.

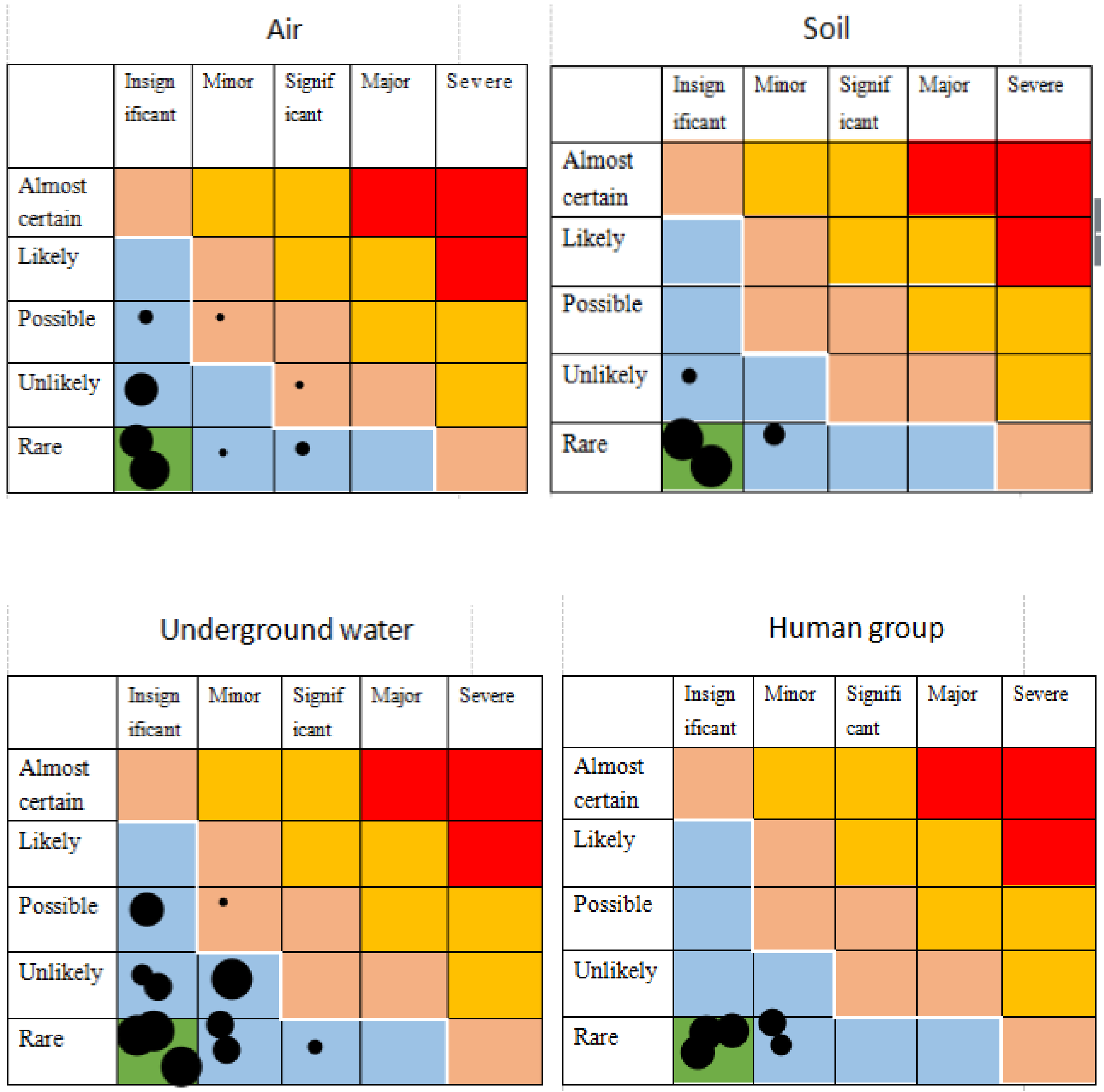
Table 7-7 Consequence matrix

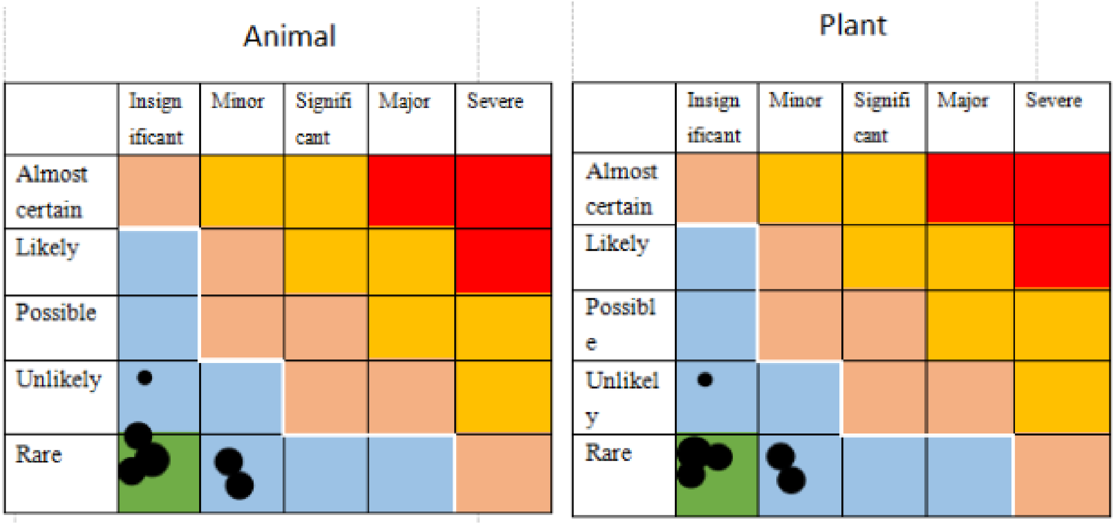
		Impact				
		Insignificant 1	Minor 2	Significant 3	Major 4	Severe 5
Likelihood classification	Almost certain5	5	10	15	20	25
	Likely 4	4	8	12	16	20
	Possible 3	3	6	9	12	15
	Unlikely 2	2	4	6	8	10
	Almost impossible 1	1	2	3	4	5


L1 地理位置
L2 自然资源
L3 储层类型
L4 储层几何结构
L5 储层开发
L6 盖层或密封地层
L7 额外密封
L8岩化或成岩作用
L9孔隙结构
L10不整合面
L11非均质性
L12 断裂和断层
L13 未检测断裂
L14 垂向地热梯度
L15地层压力
L16 压力和机械特征
L17岩石物理性质
L18 流体特征
L19 水文地质
L20 烃类
E1 新构造活动
E2 地震
E3人口特征
E4生活方式
E5土地和水利用
E6 群落特征
E7 建筑物
E8 地形地貌
E9 土壤和底泥
E10 大气和气象
E11 水文状况和水平衡
E12 近地表含水层和地表水体
E13陆地植物和动物
E14 陆地生态系统
E15钻探
E16 采矿和其它地下活动
E17地表环境的人类活动
S1 地层损坏
S2 衬里和完井
S3 修井
S4 监测井
S5 钻孔关闭和密封
S6 密封失效
S7 井喷
S8老井
S9 钻孔周围土壤蠕动
S10 储层增压对盖层的影响
S11 储层增压对储层流体的影响
S12 与碳氢化合物的交互反应
S13力学过程与条件
S14水化学
S15二氧化碳的吸附于解吸附
S16重金属释放
S17 储存概念
S18 二氧化碳量、注入速率
S19 二氧化碳组分
S20日程和计划安排
S21 闭场前封存监测
S22事故和意外事件
S23 压力过载
A1封闭性能损失
A2释放至大气
A3土壤和沉积物的影响
A4对地表水的影响
A5地下水污染
A6修改后的水文和水文地质
A7修改后的地球化学
A8CO2的健康效应
A9污染物的毒性
A10物理破坏的影响
A11生态改性的影响
A12CO2对动物的影响
A13CO2对植物的影响
A14污染物的生态毒理学
A15生态效应
A16微生物系统的改变
0
5
10
15
20
25

As shown in the above Figure, for the evaluation project, the FEPs with high consequence and high probability include mining and other activities, which will impact the safety of the CO_2 injection facilities. Next, the integrity of the wellbore and its devices is also a major factor affecting the environmental risk.

The impact of risk events on environment risk receptors refers to the impact on humans, animals and plants, as well as other closely related environmental media such as groundwater, surface water, air and soil. An evaluation of the consequences and likelihood was performed using the matrix evaluation method, as shown in the following Figure.





Risk level		
Acceptable risk		Super low risk
		Low risk
Unacceptable risk		Medium risk
		High risk
		Super high risk

In the above Figure, a black circle indicates each FEP's consequences and likelihood, and the radius size of the circle indicates that multiple FEPs fall within the same consequence matrix. The larger the radius, the more FEPs are characterised by the same evaluation result. As shown in the above Figure, most of the risk assessment results are located in the bottom left corner of the matrices, which means that the probability of the risk event occurring is very low, and the impact of the risk event on the risk receptors is slight or minor. In addition, by adopting some risk management measures, the risk probability and consequences can be decreased, which can encourage the risks to move to the bottom left corner. Take the highest risk level as the final determination of the environmental risk level assessment, the air and groundwater risk levels are medium, and the soil, animal, plant and human risk levels are all low. The environmental risk of the whole project is medium.

7.6 SUGGESTIONS ON ENVIRONMENTAL RISK MANAGEMENT

At the current stage, several basic principles were formulated based on a consideration of the main environmental risk sources and environmental receptors. Through the control of injection pressure, and strengthening the management of construction, we can lower the risk; through installing monitoring equipment, we can discover risks promptly and control the scope of their impact. Combined with the environmental risk factors analysis table, the following environmental risk control measures are proposed:

1. For sealing of caprock and faults, control the formation pressure so that the caprock breakthrough pressure is not exceeded, and also less than the maximum formation pressure at the time of the oilfield water flooding operation.

2. For the oil wells, first understand the current health status of the wells, and test the corresponding materials for CO_2 corrosion resistance. If the corrosion resistance is insufficient, handle accordingly before injection. Alternatively, formulate a regular maintenance plan in accordance with the corrosion rate and project life.

3. For the atmosphere, soil and surface water, install sampling equipment for the air, soil, deep groundwater and surface water (including U-tubes) and, prior to injection, determine a baseline from one year of monitoring. Thereafter undertake regular monitoring and sampling, and stop injection promptly if any anomalies are discovered.

4. For people, as there are no nearby settlements, ensure the safety and health of construction workers, mainly through strengthening management of the construction process.

5. For animals and plants, the site is part of the Gobi Desert, and animal and plant distribution is scarce. In the injection phase, monitor the plants near the site for any abnormal growth. If any appear, this may be due to CO_2 leakage, in which case injection should be stopped.

6. Finally, use the 3D seismic method to regularly monitor the extent and speed of subsurface fluid flow to see if it has behaved as expected over time.

8. POLICY SUGGESTIONS

CCUS can be adopted in large-scale projects and has the technical characteristics to reduce carbon dioxide emission rapidly. It can also be used to promote fossil fuels (e.g. coal) as a "cleaner" resources. It is an important technology option for ensuring the considerable energy demand can be met over a long term in the future, while minimising CO_2 emissions. CCUS is an important technology option for a large-scale emission reduction in China. However, as CCUS technology in China is still in the initial development stage, large-scale commercial applications have yet to be implemented. The main obstacles for China to embrace CCUS are high costs and technical risks. It is necessary to continue promoting CCUS technology innovation, technology development, and commercial application.

1. Advance the Innovation of CCUS Technology

Technological innovation depends not only on scientists and engineers, but also on social technology systems linked by social, economic and political factors, which directly influence technological progress. We should not only start from the technology itself, but also analyse the innovation system factors outside the technology. China's CCUS innovation system is in the formation stage. In such a stage, large-scale entrepreneurial experiments are needed to promote knowledge. Meanwhile, we also need to strengthen market guidance and resource flow, and encourage new technology investors, to accelerate the process of technology legitimisation. In order to accelerate the CCUS technology innovation system, the following policies should be formulated:

(1) Strengthen government input in the construction of CCUS technology demonstration projects, in order to reduce the uncertainty in the development of new technology and support the spread of technology.

(2) Promote technological innovation cooperation between departments and promote the spread of knowledge and flow of resources.

(3) Through the formulation of comprehensive CCUS policies and technical standards, strengthen the regulation of CCUS technology demonstration activities, so as to improve market guidance and technology legitimisation for CCUS.

(4) Accelerate and encourage the commercialisation of CCUS technology, and pay particular attention to the use of carbon dioxide in industrial application processes, in order to expand the related entrepreneurial activities and cultivation of the market.

2. Strengthen Cooperation between Industry, Scientific Research Institutions and Tertiary Institutions

At present, CCUS in China is still in the stage of technology demonstration. Technological innovation and industrial innovation activities are developing in step. While building an efficient technological innovation system, we need to face the market and promote industrial innovation at the same pace.

We need to build a diversified and open platform for industrial collaborative innovation. Decentralised CCUS innovation chains and resources can effectively accelerate CCUS technology innovation activities, reduce the cost of technological innovation, and promote the spread of technology and skills.

(1) Implementing close cooperation in the development of CCUS industry innovation chains will bring about synergistic innovation within and between industries.

(2) The close integration of enterprises with scientific research institutions and tertiary institutions is a prerequisite for promoting the rapid development of a CCUS technology innovation system.

(3) A collaborative innovation platform should be built to achieve mutual knowledge sharing among different participants, optimise resource allocation and move forward optimally. A basic platform for CCUS technology innovation will overcome the various constraints and obstacles in technology development.

3. Promote Government Research and Development Funding + Energy Enterprises/Non-profit Organisations as the Leading Organisational Model

Government, enterprises and non-profit organisations participating in CCUS technology innovation projects have become a common model for organising and implementing energy technology innovation projects. CCUS innovation projects have high externality and risk characteristics. Enterprises and markets are not enthusiastic in providing CCUS technology. Involvement and intervention by government and public sectors is required, which is also conducive to sharing risks and costs. Clarifying the roles and allocation of tasks amongst the various organisations is the key to successful project implementation. It is then the technological innovation among organisations, rather than the technological innovation of an individual organisation. Suggestions to speed up CCUS technological innovation:

(1) Design clear and step-by-step technical objectives for the project;

(2) Determine the roles and allocation of tasks amongst the various organisations involved in the implementation of the project;

(3) Achieve broad and sustained policy support;

(4) Pay attention to competition and cooperation in the implementation of the project;

(5) Leadership is the core of the resources needed for an integrated project.

4. Tax Incentives for the CCUS Market

It is particularly important to adopt direct policy action to accelerate the application of carbon capture and storage technology. On the one hand, a carbon tax increases the cost of carbon dioxide emissions, indirectly increases the trading price of carbon dioxide in the market, and provides a positive price signal for the broader industry and large carbon emitters to participate in CCUS investment; on the other hand, a carbon tax is a source of revenue for the government to invest in CCUS. Tax incentives for the development of CCUS Technology:

(1) collecting carbon tax

(2) investment tax concessions

(3) accelerating depreciation

(4) production tax incentives

(5) carbon dioxide sequestration tax incentives

5. Establish a Carbon Emissions Trading System

A carbon emissions trading system can be the basis for establishing a market price for carbon dioxide emissions. At present, CCUS technology is facing development obstacles such as high costs and low profits. The main reason for these is that the carbon emissions market price is not sufficient to attract the structural application of CCUS technology. The establishment of a carbon emissions trading system can not only achieve market equilibrium, but also provide enterprises with the corresponding profits from the application of CCUS technology in the carbon trading market. In addition, the limits of carbon dioxide emissions quotas and a higher CO_2 price will encourage fossil fuel energy companies to develop large-scale CCD projects. With the overall carbon emissions and the establishment of a trading market, a price on carbon emissions will increase the revenue of CCUS deployment and promote the commercialised application of CCUS technology.

9. CONCLUSION

CCUS technology has become the focus for worldwide research, with the possible economic benefits from reducing CO_2 in the atmosphere. It is also recognised as the most direct and rapid way to reduce CO_2 emissions. How to reduce costs and increase CO_2 utilisation efficiency rates across the whole CCUS process is the main challenge facing CCUS technology. The abundant reserves of coal, oil and gas is clearly an advantage for adopting CCUS in Xinjiang. Every year, a large quantity of energy resources, such as natural gas and coal, were transported from Xinjiang to the central and eastern regions of China, providing clean energy to downstream production, with production pollution remaining in Xinjiang. Scientific management and sustainable exploitation of resources are seen as the necessary requirements for low carbon development, green development and a low carbon economy.

1. It is proposed that Chengdu Wuhuan Xinrui food-grade carbon dioxide technology be used for part of the CO_2 from the Xinjiang Guanghui CCUS Project. The CO_2 from Xinjiang Guanghui plant will be compressed, enriched, pressure-boosted, liquefied, and stored or transported as a liquid product for oilfield displacement. This process means CO_2 can be purified to 99.8%, meeting the requirement to use Central Asia Petroleum's CO_2 flooding technology.
2. The suitability of CO_2 geological storage and the suitability of CO_2-EOR in the Junggar Basin were separately evaluated, and a CO_2-EOR technology suitability evaluation table for Junggar Basin was obtained. It was concluded that the geological storage area in the Junggar Basin has a wide distribution, good reservoir properties, suitable natural conditions and a relatively high degree of oil and gas exploration, which is all conducive to the development of CO_2-EOR technology.
3 After analysing the main factors affecting the East Junggar oilfield CO_2 geological storage, the main indicators for CO_2 geological storage and flooding were screened to establish an assessment system for CO_2-EOR potential in the East Junggar oilfield. The results showed three oil fields (the Beisantai, Shabei and Cainan oilfields) were found to be suitable for the application of CO_2-EOR technology. Cainan oilfield was regarded as the most suitable, with the best implementation outcomes.
4 In order to verify the accuracy of the CO_2-EOR evaluation system, further comparative analysis of the Cainan oilfield was carried out, and a feasibility analysis was undertaken. The production capacity of Di-12, Di-2 and Di-20 wells blocks of the Cainan oilfield is in a continuous decline. The wells are in a mid-to-high water cut and in a mid-extraction stage. The Di-20 well area has been put into development only recently with a 280 m inverse 7-spot well pattern. The reservoir is in the initial stage of development, with no effects being observed; as a result, CO_2-EOR technology is not being considered for the time being. Compared to the Di-12 well area, the Di-2 well area was found to be more suitable for CO_2-EOR technology because of its small reserves, high degree of extraction, high oil viscosity, sand monoclinal structure and convenient transportation. The accuracy of the CO_2-EOR evaluation system was further confirmed during a field investigation of the Cainan oilfield. Moreover, not only is the Di-2 well area extremely suitable, it is also necessary for CO_2-EOR technology to be integrated with Di-2 well's own production.
5 A CO_2-EOR test at two single wells in the north of the Di-2 well area was carried out. After 1 week of CO_2 injection, the average daily production of the two wells increased by 3.1 tons over 4 months, the total volume of oil produced increased by 372 tons, and the oil recovery efficiency increased by 12%. A structural model was established using PETREL modeling software, and a CO_2 simulation was undertaken with respect to the Di-2 well

area by combining the pilot test data with the reservoir simulation software CMG. In order to verify the oil displacement effect of CO_2, the traditional nitrogen (N_2) displacement and water displacement methods were added to the simulation software. The injection volume was 100,000 tons/year and the simulation period was 3 years for each of the 3 displacement methods. The results showed that CO_2 displacement and storage is the best method.

6. We analysed the environmental risks of CO_2 capture, transportation and storage respectively, and derived corresponding solutions. In the environmental risk assessment of the storage phase, we also developed an environmental evaluation system for the Project's storage component. After considering all the risk factors, the Project is seen as having a medium environmental risk.
7. Due to the of planning regulation change for the Kalamaili Nature Reserve, the original site selected for the Guanghui Pilot CCUS Project has become a protected area; as a result, the Project would not be approved for construction under current conditions.