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CO_2 emission reduction path and cost analysis for a chemical industry company in East China based on CCUS

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ABSTRACT

CO_2 emission reduction has become the consensus of various industries in China. CO_2 capture, utilization and storage, as an important means for CO_2 emission reduction, is one of the necessary paths to achieve carbon neutrality. Combined with the CO_2 emission of a chemical industry company in the region of East China, this paper introduces the recovery methods, processes and costs of different CO_2 emission sources, and analyzes the CO_2 emission reduction path for the company. Results showed that the process complexity and unit cost of CO_2 capture decreased with the increase of concentration of CO_2 emission sources, the carbon recovery cost per ton of high concentration CO_2 emission source is only about 1/3 of that of low concentration CO_2 emission source, which has significant economic benefits on the premise of downstream absorption pathway. Therefore, priority should be given to the recovery of high concentration CO_2 emission sources. The carbon recovery economy of low concentration CO_2 emission sources is poor, so priority should be given to using new energy to reduce their emissions, and coupling new energy technologies in the recovery process to reduce the recovery cost.

Keywords: CO_2, CCUS, carbon emission, cost, analysis

1. INTRODUCTION

As the most important greenhouse gas, carbon dioxide is the main factor leading to global climate change[1]. As a result, governments around the world have made relevant plans to reduce carbon dioxide emissions. On September 22, 2020, at the General Debate of the United Nations General Assembly, China has promised to achieve carbon peak and carbon neutrality by 2030 and 2060[2]. In July 2021, the national carbon trading market was launched. Carbon emission reduction is not only an environmental issue, but also an economic and development issue[3].

According to different specific measures, carbon emission reduction can be divided into: carbon free technology for source treatment, carbon reduction technology for process treatment, and carbon removal technology for terminal treatment[4]. Among them, carbon dioxide capture, utilization and storage (CCUS), as a kind of carbon removal technology for terminal treatment, is taken for one of the necessary paths to achieve carbon neutrality[5]. As the first step of CCUS, carbon capture is of great significance to the analysis of carbon emission reduction path by analyzing carbon emission sources from the perspective of carbon capture process and cost.

The chemical industry is one of the significant sources of carbon emissions in China[6], accounting for about 4.8% of the total carbon emissions of all industries in China in 2019. Carbon emissions from the chemical industry include direct emissions from production processes and indirect emissions from external energy consumption (such as fuel combustion and power supply, etc.)[7]. The process gas in the chemical industry usually needs to be decarbonized, leading to the discharge of a large amount of high concentration CO_2 gas from some devices, such as low-temperature methanol washing device.

Although some literates have reported the process flow and operation status of different CO_2 gas source recovery, due to the significant difference in the types of gas source and the cost of public works, it is impossible to conduct a unified comparison. Or due to the lack of thinking from the perspective of industrial application, the proposed process flow and scheme is

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unreasonable which resulting in inaccurate results. The research institute where the researchers of the project work have been engaged in the technical development and application promotion in the field of CCUS for a long time, and has multiple sets of industrial application achievements of carbon capture for different CO_2 gas sources. Consequently, combined with the situation of CO_2 emission sources of a chemical industry company in East China, this project aims at propose appropriate CO_2 recovery methods for different CO_2 emission sources from an industrial perspective, establish CO_2 recovery processes for different CO_2 emission sources, and calculate CO_2 recovery costs of different emission sources under the same benchmark, so as to put forward appropriate CO_2 emission reduction paths to achieve cost-efficient carbon emission reduction.

2. THE SITUATION OF CO_2 EMISSION OF A CHEMICAL INDUSTRY COMPANY

The main products of the chemical industry company are synthetic ammonia, hydrogen, etc and its own power plant is used to provide steam and electricity. The main carbon dioxide emission sources are shown in Tab. 1.

Tab. 1 Main carbon dioxide emission sources of the chemical industry company

NO.	*Carbon emission device*	*CO_2 emissions tons/year*	*CO_2 concentration*
1	Low temperature methanol washing section of synthetic ammonia unit	560,000	98.5%
2	Low temperature methanol washing section of synthetic ammonia unit	431,000	80%
3	Low temperature methanol washing section of hydrogen production unit	455,000	98.5%
4	Low temperature methanol washing section of hydrogen production unit	1,019,000	80%
5	Power boiler unit	828,000	13%

It can be seen from the table that as a chemical industry company focusing on the products of inorganic chemical raw materials, the CO_2 emission sources of the company can be divided into two categories. First, flue gas containing low concentration of carbon dioxide from the power boiler unit, whose CO_2 concentration is about 13%, and the annual total emission is about 830,000 tons. Second, tail gas of decarbonization process containing high concentration of carbon dioxide, whose CO_2 concentration is above 80%, or even above 99%, mainly from the low-temperature methanol washing section of synthetic ammonia and hydrogen production unit, and the annual total emission is about 2.46 million tons.

3. ANALYSIS OF REDUCTION OF PATHS FOR DIFFERENT CO_2 EMISSION SOURCES

3.1 Recovery methods of different CO_2 emission sources

3.1.1 Common CO_2 recovery technologies

The recovery of medium and low concentration carbon dioxide mainly includes two steps. Firstly, the medium and low concentration carbon dioxide is concentrated to obtain high concentration carbon dioxide, and then compressed and cooled to make it liquid, so as to facilitate storage and transportation[8]. At present, chemical solvent absorption is the main treatment method for medium and low concentration carbon gas in industry[9], among which organic amine solvent is the most widely used[10].

The organic amine solvent absorption method uses the chemical reaction between the organic amine solvent and the carbon dioxide in the feed gas to transfer the carbon dioxide from the gas phase to the liquid phase in the absorption tower, and then send it to the regeneration tower to decompose the reaction products of the organic amine and carbon dioxide by heating up, and the released gas can be cooled to obtain high concentration carbon dioxide gas. At the same time, the regenerated organic amine solvent can be recycled by returning to the absorption tower after cooling[11].

For the liquefaction process of high concentration carbon dioxide, at present, the most widely used method in industry is the low-temperature and low-pressure liquefaction method[12], which realizes the transformation from gaseous carbon dioxide to liquid carbon dioxide by compressing and cooling the carbon dioxide at normal temperature and pressure to 2~2.5MPa and -20~-25 ℃[13]. According to the different impurities in high concentration carbon dioxide feed gas and the quality requirements of liquid carbon dioxide products, the liquefaction of high concentration carbon dioxide may also include drying, refining (such as desulfurization, dehydrocarbon, etc.), rectification and other operations[14].

3.1.2 Recovery methods of different CO_2 emission sources

Based on common CO_2 recovery technologies, corresponding recovery methods are established for different CO_2 emission sources as follows.

For flue gas containing low concentration CO_2, the process flow of CO_2 recovery path is shown in Fig. 1. The raw flue gas shall be pretreated first to ensure the stable operation of the absorption and regeneration operating system. In the absorption tower, the CO_2 in the feed gas is absorbed by the solvent, and the captured flue gas can be vented. In the regeneration tower, the solvent absorbing CO_2 regenerates CO_2 under heating and stripping, and the obtained solvent is returned to the absorption tower for recycling. The gaseous CO_2 is successively compressed, refined, dried and liquefied/rectified to obtain liquid CO_2 products, which is sent to the storage tank for storage.

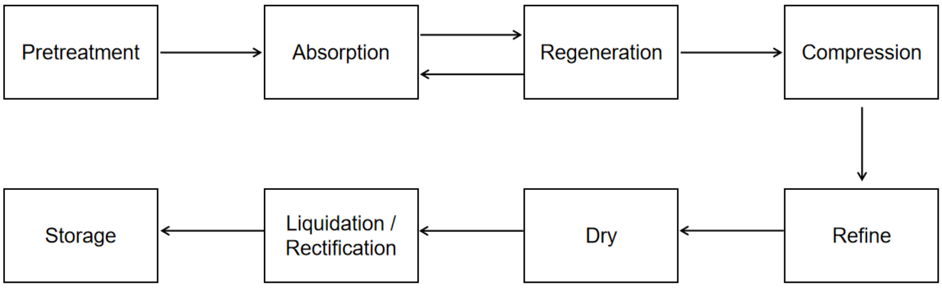

Fig. 1 Recovery path of low concentration carbon dioxide

For high concentration carbon dioxide, the process flow of CO_2 recovery path is shown in Fig. 2. The feed gas is directly compressed, and then refined, dried, liquefied / rectified to obtain liquid CO_2 products, which is sent to the storage tank for storage.

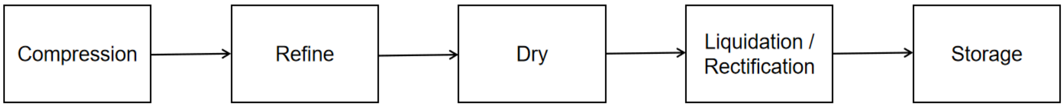

Fig. 2 Recovery path of high concentration carbon dioxide

3.2 Recovery process of different CO_2 emission sources

Combined with the carbon emission sources of the company and the economic value of carbon capture recovery rate of various processes, 700,000 t/a, 1 million t/a and 1.3 million t/a CO_2 recovery units are built respectively for the flue gas of power boiler, 98.5% and 80% CO_2 gas of low-temperature methanol washing section of synthetic ammonia and hydrogen production. The unit processes are shown in Fig. 3, Fig. 4 and Fig. 5 respectively.

For the flue gas of the power boiler, the CO_2 recovery process flow is as follows: the feed gas first enters the washing tower for impurity removal and cooling, and then is sent to the absorption tower by the fan. Part of the CO_2 is absorbed by the solvent, and the tail gas is vented into the atmosphere from the top of the tower after being washed by the washing section at the upper part of the absorption tower. The rich liquid absorbing CO_2 flows out from the bottom of the absorption tower, and then sent to the upper part of the regeneration tower after the heat is recycled by the rich and lean liquid heat exchanger. CO_2 is desorbed partially by stripping, and then enters the reboiler for further desorption. The lean liquid after CO_2 desorption flows out from the bottom of the regeneration tower, then is pumped into the water cooler after heat exchange by the rich and lean liquid heat exchanger, and enters the absorption tower after cooling. The solvent circulation forms a process of continuous absorption and desorption of CO_2. The desorbed CO_2 and water vapor are separated to remove water after cooling, and the gas CO_2 with purity of 99% is obtained, which is sent to the compressor for pressure boosting. The compressed CO_2 gas enters the drying tower and uses the adsorption of molecular sieve to remove water from the gas. The dried CO_2 gas enters the aftercooling reclaimer to reclaim the cooling capacity of non condensable gas, and then enters the liquefier to indirectly cool the compressed CO_2 gas with refrigerant to condense and liquefy the CO_2 gas into liquid CO_2. After the condensed CO_2 entering the separator, the non condensable gas is obtained at the top of the separator which is sent to the aftercooling reclaimer to reclaim the cooling capacity, and the liquid CO_2 product is obtained at the bottom of the separator which is sent to the storage tank for storage.

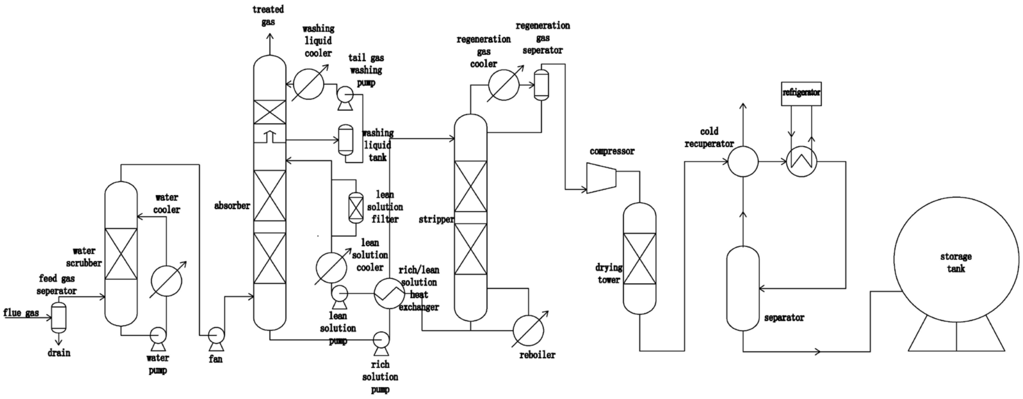

Fig. 3 Process flow of CO_2 recovery from flue gas of power boiler

For the 98.5% CO_2 gas from the low-temperature methanol washing of synthetic ammonia and hydrogen production, the CO_2 recovery process flow is as follows: the 98.5% CO_2 gas from the low-temperature methanol washing of synthetic ammonia and hydrogen production is directly sent to the compressor for pressure boosting, and the compressed CO_2 gas enters the aftercooling reclaimer to reclaim the cooling capacity of non condensable gas, and then enters the liquefier. The compressed CO_2 gas is indirectly cooled by refrigerant to condense and liquefy the CO_2 gas into liquid CO_2. After the condensed CO_2 entering the separator, the non condensable gas is obtained at the top of the separator which is sent to the aftercooling reclaimer to reclaim the cooling capacity, and the liquid CO_2 product is obtained at the bottom of the separator which is sent to the storage tank for storage.

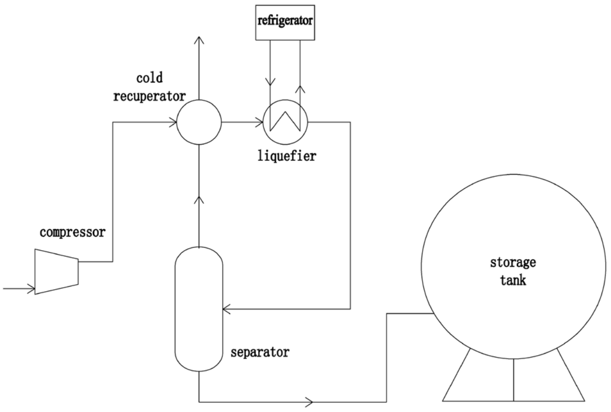

Fig. 4 Process flow of 98.5% CO_2 recovery

For the 80% CO_2 gas from the low-temperature methanol washing of synthetic ammonia and hydrogen production, the CO_2 recovery process is as follows: the 80% CO_2 gas from the low-temperature methanol washing of synthetic ammonia and hydrogen production is directly sent to the compressor for pressure boosting, and the compressed CO_2 gas enters the aftercooling reclaimer to reclaim the cooling capacity of non-condensable gas, and then enters the liquefier. The compressed CO_2 gas is indirectly cooled by refrigerant to condense and liquefy the CO_2 gas into liquid CO_2. After the condensed CO_2 entering the distillation tower, the non-condensable gas is obtained at the top of the separator which is sent to the aftercooling reclaimer to reclaim the cooling capacity, and the liquid CO_2 product is obtained at the bottom of the distillation tower which is sent to the storage tank for storage after subcooling.

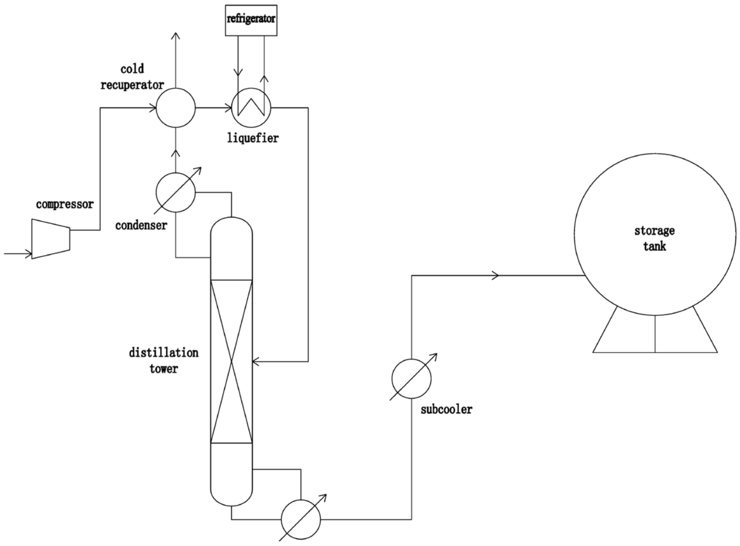

Fig. 5 Process flow of 80% CO_2 recovery

3.3 Recovery cost of different CO_2 emission sources

3.3.1 CO_2 recovery benchmark regulations

Due to the obvious difference of utility cost between different companies, and different liquid CO_2 products also have a notable impact on the recovery process and cost[15], the utility cost benchmark and product benchmark of CO_2 recovery process are first specified here, as shown in Tab. 2 and 3 respectively.

Tab. 2 CO_2 recovery utility cost benchmark

Item	*Cost*
Circulating water	0.2 CNY/t
Electricity	0.5 CNY/kWh
Steam（0.4MPa）	80 CNY/t

Tab. 3 CO_2 recovery product benchmark

Item	*Value*
CO_2 content	≥99%

Free water	None
Smell	No odor

3.3.2 Recovery process and cost of different CO_2 emission sources

Based on the above unit scale and recovery process, the main equipment of the three units can be obtained, as shown in Tab. 4-6. It can be seen from the table that due to the low CO_2 concentration in the flue gas, it is essential to use the absorption method to concentrate the CO_2 in the feed gas, so that the number of equipment of 700,000 t/a flue gas CO_2 recovery unit is far more than that of 1 million t/a 98.5% CO_2 recovery unit and 1.3 million t/a 80% CO_2 recovery unit.

Tab. 4 Equipment of 700,000 t/a flue gas CO_2 recovery unit

No.	*Name of equipment*	*Quantity*	*No.*	*Name of equipment*	*Quantity*
1	Water scrubber	1	14	Fan	2
2	Absorber	1	15	Water pump	2
3	Stripper	1	16	Tail gas washing pump	2
4	Washing liquid cooler	1	17	Lean solution pump	2
5	Lean solution cooler	2	18	Rich soluiton pump	2
6	Rich/lean solution heat exchanger	4	19	Compressor	1
7	Reboiler	2	20	Drying tower	2
8	Regeneration gas cooler	1	21	Cold recuperator	1
9	Feed gas separator	1	22	Liquefier	1
10	Regeneration gas separator	1	23	Refrigerator	2
11	Water cooler	1	24	Separator	1
12	Washing liquid tank	1	25	Storage tank	2
13	Lean solution filter	1			

Tab. 5 Equipment of 1 million t/a 98.5% CO_2 recovery unit

No.	*Name of equipment*	*Quantity*	*No.*	*Name of equipment*	*Quantity*
1	Compressor	2	4	Refrigerator	2
2	Cold recuperator	1	5	Separator	1
3	Liquefier	1	6	Storage tank	2

Tab. 6 Equipment of 1.3 million t/a 80% CO_2 recovery unit

No.	*Name of equipment*	*Quantity*	*No.*	*Name of equipment*	*Quantity*
1	Compressor	2	6	Reboiler	1
2	Cold recuperator	1	7	Condenser	1
3	Liquefier	2	8	Subcooler	1
4	Distillation tower	1	9	Storage tank	2
5	Refrigerator	2			

Further, the consumption of the three CO_2 recovery units can be obtained, as shown in Tab. 7-9. It can be seen from the table that the regeneration tower needs thermal regeneration in the process of flue gas CO_2

recovery, which consumes a lot of steam, so the consumption cost per ton of CO_2 is significantly higher than that of CO_2 recovery from tail gas of low-temperature methanol washing, about 2~3 times of the latter.

Tab. 7 Consumption of 700,000 t/a flue gas CO_2 recovery unit

No.	*Item*	*Annual consumption*	*consumption /t CO_2*	*Annual consumption cost million CNY*	*Consumption cost /t CO_2 CNY*
1	Circulating water	91 million tons	130 t	18.2	26
2	Electricity	175 GWh	250 KWh	87.5	125
3	Steam	980,000 t	14,000 t	78.4	112
4	Other	-	-	29.4	42
Total				213.5	305

Note: 1. The solvent absorption section of the unit adopts the new high-efficiency and low-energy flue gas carbon capture solvent and process of Sinopec Nanjing Chemical Research Institute Co., Ltd.

2. Other consumption is mainly CO_2 recovery solvent, molecular sieve for drying, etc.

Tab. 8 Consumption of 1 million t/a 98.5% CO_2 recovery unit

No.	*Item*	*Annual consumption*	*consumption /t CO_2*	*Consumption cost million CNY/a*	*Consumption cost /t CO_2 CNY*
1	Circulating water	20 million tons	20 t	4	4
2	Electricity	180 GWh	180 KWh	90	90
3	Steam	0	0	0	0
4	Other	-	-	0	0
Total				94	94

Tab. 9 Consumption of 1.3 million t/a 80% CO_2 recovery unit

No.	*Item*	*Annual consumption*	*consumption /t CO_2*	*Consumption cost million CNY/a*	*Consumption cost /t CO_2 CNY*
1	Circulating water	39 million tons	30 t	7.8	6
2	Electricity	325 GWh	250 KWh	162.5	125
3	Steam	0	0	0	0
4	Other		-	0	0
Total				170.3	131

Based on the above main equipment and consumption of the units, the total cost of CO_2 recovery of the three units can be obtained, as shown in Tab. 10. It can be seen from the table that the total cost of 700,000 t/a flue gas CO_2 recovery unit is three times that of 1 million t/a 98.5% CO_2 recovery unit; For the tail gas of low-temperature methanol washing, although the CO_2 concentration decreased by less than 20%, the total cost per ton of CO_2 increased by 35%.

Tab. 10 Cost of CO_2 recovery unit with different emission sources

NO.	*Name of unit*	*Investment*	*Utility consumption*	*Total cost*

		million CNY	*million CNY/a*	*/t CO_2 CNY*
1	700,000 t/a flue gas CO_2 recovery unit	440	214	369
2	1 million t/a 98.5% CO_2 recovery unit	260	94	120
3	1.3 million t/a 80% CO_2 recovery unit	410	170	162

3.4 Analysis of carbon emission reduction path

Based on the above process analysis and cost calculation, the following conclusions can be drawn from the analysis of the carbon emission reduction path of the chemical industry company:

（1）In terms of process flow, unit of of low-temperature methanol washing tail gas with 98.5% CO_2 has the simplest process, and industrial grade liquid CO_2 products can be obtained only by compression and cooling; For the unit of low-temperature methanol washing tail gas with 80% CO_2 , due to the insufficient CO_2 content of feed gas, the simple liquefaction operation can not realize the effective recovery of CO_2, and the distillation tower is required to maintain a reasonable CO_2 recovery rate; Since the CO_2 concentration of the feed gas in the flue gas CO_2 recovery unit is only 13%, the feed gas needs to be concentrated by the absorption method first, resulting in a significant increase in the complexity of the process compared with the first two. Moreover, the CO_2 gas raw material obtained by the absorption method contains saturated water, so it needs to be dehydrate before liquefaction.

（2）In terms of cost, the low-temperature methanol washing tail gas recovery unit with 98.5% CO_2 has the lowest cost per ton of CO_2, only 136 CNY, which can meet the economic needs of industrial liquid carbon dioxide market in most regions of China; For the carbon capture unit of low-temperature methanol washing tail gas with 80% CO_2, the CO_2 content of feed gas is not high enough, which not only increases the equipment size and process complexity, but also brings additional operation cost, resulting in the cost per ton of CO_2 rising to 162 CNY. Although it is still lower than the current market sales price of industrial liquid carbon dioxide in most regions of China, the profit space is significantly reduced; The cost of flue gas CO_2 recovery unit is the highest, reaching 363 CNY, which exceeds the market sales price of industrial liquid carbon dioxide in some regions of China, and the economy is insufficient.

（3）Considering the process flows and cost comprehensively, it is suggested that the chemical industry company should give priority to the phased construction of 1 million t/a 98.5% CO_2 recovery unit in the short term on the premise of having market capacity to achieve CO_2 emission reduction at the lowest cost. In the medium term, the phased construction of 1.3 million t/a 80% CO_2 recovery unit can be considered to accelerate the progress of CO_2 emission reduction. In the long term, on the one hand, new energy such as photovoltaic, photothermal and other ways should be introduced to minimize the installed capacity of power boiler, so as to reduce the total amount of boiler flue gas emission. On the other hand, for the remaining power boilers, build matching small-scale flue gas CO_2 recovery units, and consider using biomass energy as boiler raw materials, so as to realize the carbon neutrality of the company.

4. **CONCLUSION**

Carbon emission reduction has become one of the vital missions faced by chemical companies under the background of double carbon era. CCUS is one of the necessary ways to realize carbon neutrality. Combined with the specific carbon emission sources of a chemical industry company in East China, this project researched the method, process and cost of carbon capture, the first step of CCUS, and puts forward an appropriate carbon emission reduction path based on CCUS. The results show that the CO_2 concentration span of carbon emission sources of the chemical industry company is large, and the process complexity and unit cost of CO_2 capture decrease with the increase of CO_2 concentration of carbon emission sources. Therefore, priority should be given to the construction of carbon recovery units for carbon emission sources with high CO_2 concentration. In addition, for the power boiler unit that indirectly emits CO_2, its installed capacity should be reduced by coupling new energy, and biomass energy carbon capture, utilization and storage (BECCUS) should be carried out to finally realize the carbon neutrality of the company.

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DECLARATION OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors read and approved the final manuscript.

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