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# Analysis of Carbon Capture and Storage Technology in China

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***Abstract:*** The global warming caused by the greenhouse effect is a hot topic of concern for society as a whole, and carbon dioxide emissions are the main reason for this issue. Based on the fact that China has the highest carbon footprint worldwide, different scholars have discovered that carbon capture and storage technology plays an enormous part in efficient emission reduction and in delaying climate change. Therefore, this paper collected data through literature review to analyze the current status of CCS technology in our country, summarizes its application in the oil and gas industry, and identifies the problems and challenges faced based on this analysis. This paper has found that our country still has weaknesses and shortcomings in certain aspects of CCS technology, with ample room for improvement in terms of costs, research and development, and policies. In addition, CCS (Carbon Capture and Storage) technology that makes use of increased oil recovery from carbon dioxide is the most effective option for raising oil production in the oil and gas sector while also having the potential to significantly lower emissions. Green and sustainable development is a national aim that we are able to strongly promote by expanding investment in research and project execution, as well as through enhancing cooperation and learning with the worldwide community.

## 1. Introduction

In recent years, the global economy and level of industrialization have continuously increased, leading to the ongoing production of greenhouse gases. Significant negative effects include extreme weather, climate change, global warming, and biodiversity loss as a result of this. It is widely believed that the massive $CO_2$ emissions during the accelerated process of industrialization advancement is the main culprit behind the greenhouse effect [1-2]. Compared to other greenhouse gases such as water vapor and methane, carbon dioxide has the greatest impact on temperature, with the highest emissions, and a considerably longer lifetime than other gases. Against this backdrop, Carbon Capture and Storage (CCS) technology has come into the public vision and carried out intensive research and application. Currently, CCS projects have demonstrated that they are economically viable and can reduce $CO_2$ emissions if certain conditions are furnished [3].

The technology for capturing and storing carbon dioxide pertains to industrial construction such as coal-fired power plants, and it is stored in geological reservoirs (depleted oil fields, saline-alkali layers, coal seams), or further applied for production [4]. The fundamental operation process of CCS technology is divided into three phases: capturing carbon dioxide from exhaust gases, then compressing it, subsequently, transporting it to subterranean storage sites for storage. Depending on the crafts or the application of the power plant, there are three primary means to capture $CO_2$, respectively are pre-combustion capture technology, post-combustion capture technology, and oxy-fuel combustion technology. The transportation procedure may require carrying the captured carbon dioxide to a location some distance away from the $CO_2$ source for more straightforward transport and storage, and typically, trapped $CO_2$ gas is condensed to high density in captured apparatus. As for storage process, geological storage technology and ocean sequestration technology is the main method that is employed extensively. Currently, researchers across various fields worldwide are making continuous efforts to reduce carbon emissions and create a low-carbon environment. They are actively engaged in related technological research and have published a substantial amount of literature, laying an important foundation for further studies. For instance, in order to minimize costs and reduce stationary $CO_2$ emissions in the United States, Hasan et al. proposed a multi-scale framework for the optimization design of the $CO_2$ capture and storage (CCS) supply chain network [5]. Seigo et al. analyzed 42 existing studies on public perceptions of and attitudes towards CCS technology and concluded that additional case studies are needed to examine the likelihood of CCS technology being implemented at the project level [6]. A simulated examination of the efficiency of $CO_2$ reduction methods in the worldwide power industry was carried out by Wise et al., assuming that international climate policies will become more rigorous [7]. Fl ø et al. simulated the model developed for the $CO_2$ capture pilot plant in Brindisi, Italy, four flexible operating modes—exhaust emission, variable solvent regeneration, solvent storage, and load tracking—were tested on the dynamic performance of the $CO_2$ capture process [8]. In addition, some scholars have also used the Production Theory Decomposition Analysis (PDA) method to analyze the impact of carbon emission factors, energy intensity, output scale, carbon efficiency, energy efficiency, technological efficiency, and technology catch-up effects on carbon emissions [9]. As of now, there are more than 70 large-scale CCS projects planned worldwide, of which 8 are under construction and 53 are included in investment plans [10].

In recent years, scholars both domestically and internationally have made significant progress in the research of CCS technology. Nevertheless, despite important experimental results and real-world applications, there are still certain gaps in the theoretical framework on this subject because of the speed at which technology and information are developing. To this end, it is necessary to promptly organize and update technical information, as well as the connections between them, to facilitate comprehensive application in the future.

This paper mainly discussed the technological methods of carbon capture and storage, analyzes the current status of CCS technology in the country and the challenges it faces. Additionally, it provided an overview of the cutting-edge applications, principles, and prospects of CCS technology in the oil and gas industry. Although after continuous research breakthroughs, CCS, as a primary focus of low-carbon technology, still faces challenges. It holds significant importance for our country's clean production, sustainable development, and achieving dual carbon goals.

## 2. Current Status of Carbon Capture and Storage Technology

### 2.1. Technology Research and Development

In terms of technological research and development, our country has published the highest number of public patents related to CCS technology, and the trend is increasing year by year. At the same time, our country has a favorable environment for renewable energy generation technologies, and CCS technology has also overcome many technical challenges. Carbon capture and storage technology first captures and separates the carbon dioxide it produces, then compresses it before transporting it to a suitable storage location, where it is sealed away from the atmosphere. The carbon capture stage can be divided into pre-combustion carbon capture, post-combustion carbon capture, and oxy-fuel combustion capture technologies, on the basis of the location of $CO_2$ capture. The section headings are in boldface capital and lowercase letters. The process flow chart of the capture system in CCS technology is depicted in Figure 1.

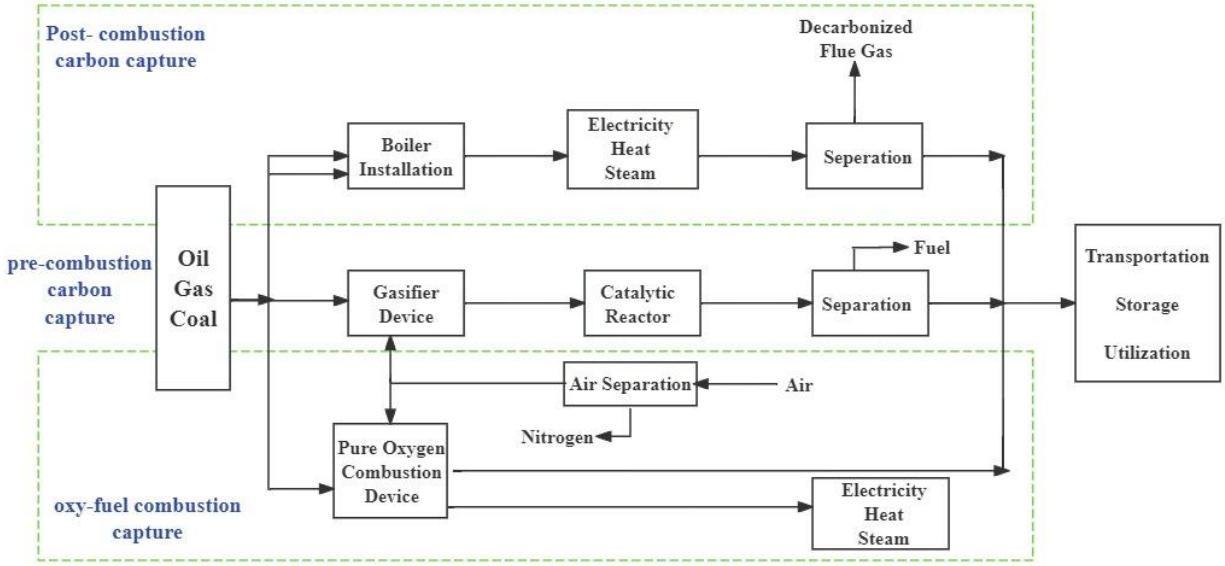


Figure 1: Process Flow Chart of Capture System in CCS Technology

At present, CCS technology is mainly applied in power plants and large industrial processes such as oil and gas, by blocking the captured $CO_2$ through storage techniques. These include four processes primarily focused on geological storage and ocean storage, while the other two are ore carbonation and industrial utilization. Geological storage involves injecting captured carbon into underground geological formations, where $CO_2$-EOR and $CO_2$-ECMB technologies can enhance the recovery rates of oil and gas reservoirs and increase methane production. Currently, marine technology refers to the injection of $CO_2$ into sediments or the water column, with the most widely used method being the storage technology that replaces it with natural gas hydrates.

## 2.2. CCS Demonstration Projects in China

The research and development of CCS technology in our country started relatively late, but due to the high level of attention from the government, it is now advancing rapidly.China has become a leading country in the world in terms of utilization technologies such as $CO_2$ mineralization utilization and microalgae utilization, and China has already established several demonstration projects. As of 2022, the scale of projects put into operation in our country has significantly increased, with the number reaching over a hundred, including more than 1 ×104 t/a and superior projects, and more than 50 ×1044 t/a and superior projects [11]. In 2010, China's first full-process CCS project was launched in Ordos City, Inner Mongolia Autonomous Region. Whereafter, the number of excellent projects in our country has been increasing year by year, with the Huaneng Group's Tianjin Green Coal Power IGCC Technology focusing on the food-grade utilization of carbon dioxide captured before combustion, the 10,000 t/a capture demonstration at the China Power Investment Corporation Chongqing Shuanghuai Power Plant, the Shenhua Group's Ordos CCS demonstration project focused primarily on pre-combustion capture and the utilization of saline aquifers for storage in 2021. A summary of typical CCUS demonstration projects in our country can be found in Table 1.

Table 1: Typical CCS Demonstration Projects in China

| Project | Implementing Unit | Scale/ ×104(t/a) | Key Technology or Feature |
|---|---|---|---|
| Shengli Oilfield CCUS Full Process Demonstration Project | Qilu Petrochemical, Shengli oilfield | 100 | Low temperature distillation capture, oil storage |
| Jilin Oilfield CCUS-EOR Full Process Demonstration Project | Jilin oilfield | 35 | Capture and storage of oil after the combustion of composite amine absorbents. |
| Huaneng Gaobeidian Power Plant Capture Project | Huaneng Group | 0.3 | Possible to achieve the resource utilization of food-grade carbon dioxide. |
| Huaneng Changchun Thermal Power Plant Capture Project | Huaneng Group | 1 | Phase change capture technology |
| Huaneng Green Coal IGCC Power Plant Carbon Capture Project | Huaneng Group | 10 | IGCC-based capture technology |
| Zhongyin Petrochemical Qilu petrochemical EOR Project | Qilu Petrochemical, Shengli oilfield | 100 | Coal gas tail gas capture and oil recovery storage |
| Sinopec East China Oilfield EOR Project | East China Oil Field, Nanhua Company | 10 | Can improve oil recovery |
| Huaneng Shitongkou Power Plant Capture Demonstration Project | Huaneng Group | 12 | Total quantity control can be achieved |
| Cnooc West South China Sea Oil Field CCUS Project | Western oil field | 10 | Can improve oil recovery |
| Sinopec Shengli Oilfield CCUS Project | Shengli Oilfield | 30 | Can improve oil recovery |

In addition, the $CO_2$ capture, utilization, and storage project of Qilu Petrochemical-Shengli Oilfield is the largest operational project, mastering integrated application of enhanced oil recovery technology, achieving an annual capture capacity of one million tons of $CO_2$.

## 3. The Main Applications of CCS Technology In the Oil and Gas Industry

CCS technology is applied in various industries such as coal power, steel, and oil and gas. According to statistics, the oil and gas industry is one of the sectors with high carbon emissions, while the effective application of CCS technology can reduce emissions during oil and gas extraction, extend the lifespan of oil fields, and increase crude oil production. In addition, based on the dual-carbon policy, China attaches great importance to its development, and some oil and gas companies have already invested significant amounts of money in this technological field. The most mature method for capturing $CO_2$ in the application of CCS technology is primarily the solvent absorption method. And when transported through pipelines to abandoned oil fields or geological formations, it is combined with CCS-EOR, which is the most effective carbon dioxide enhanced oil recovery technology.

The research on enhanced oil recovery (EOR) using carbon dioxide injection technology is at the core of oil and gas field development. Oil and gas reservoirs are an excellent choice for storing carbon dioxide. Our country's oil and gas reservoirs have sufficient storage suitability, and oil and gas wells have diverse advantages and access channel, and can form a relatively complete CCS-EOR technology and standard system, making them suitable geological sites for $CO_2$ storage.

The principle is to inject carbon dioxide into depleted oil and gas reservoirs, where $CO_2$ will be permanently stored after injection. In oil and gas reservoirs, it is necessary to utilize the internal flow of reservoir fluids to inject water and other substances into the reservoir to maintain pressure in exchange for oil. Then, by fully dissolving the injected $CO_2$ with the residual oil, the miscible drive formed by their infinite solubility can enhance oil production and achieve the maximum recovery rate of oil and gas [12].

Recently, China's acceleration of the mass application of CCS technology in the oil and gas industry has also achieved very high results. For instance, the industrial application of CCS by China National Petroleum Corporation are multiple stages of CCS technology applied in the Changling gas field of Jilin Oilfield, whose increase in recovery rate and the excellent effect of $CO_2$ injection have made it the largest CCS-EOR full-process demonstration project in Asia; China National Offshore Oil Corporation has promoted CCS technology research in the Daya Bay area and has launched the first offshore project, led by the Enping 15-1 carbon dioxide injection and storage demonstration project. Under the guidance of policies, our country will continuously increase $CO_2$ injection volumes and plans to establish a CCS industrial base with a capacity of tens of millions of tons by 2050. The prospects for its technology in the oil and gas industry are very promising.

## 4. Issues and Challenges of CCS Technology

(1) Challenges arise in managing costs and securing investments. First of all, the research and development investment, equipment purchases, and the exorbitant profits demanded by other countries when exporting technology due to certain limitations in our own technological capabilities during the capture, transportation, and storage processes of CCS technology itself, all of these require a significant investment of costs. Taking the cost of carbon dioxide capture in our country as an example, its price ranges from 800 to 2300 CNY per ton, while the average price of carbon dioxide in China's carbon market during the same period was only about 55 CNY per ton [13]. Moreover, launching it into the market, promoting it, and generating commercial value also require substantial financial support. Whereas coal power continues to be the major application market for CCS technology, newer, more affordable and energy-efficient energy sources are rapidly rendering coal power less attractive to investors. As a result, the market share is facing a decline, the widespread application of CCS technology is restricted, which also affects investment in technological research and development, further exacerbating financial challenges.

(2) Challenges exist in managing the technical level and mitigating risk. Nowadays carbon sequestration technology faces safety challenges. The leakage of $CO_2$ during the sequestration process can affect changes in shallow surface and subsurface stress, leading to environmental disasters such as groundwater pollution, ocean acidification, and geological hazards. For example, in 1986, a severe carbon dioxide leak incident occurred due to the Lake Nyos earthquake, resulting in the deaths of over a thousand people. At the same time, based on the patent publication data related to CCS technology in our country, the quantity of core patents published for carbon sequestration technology and the number of literature citations are both lower than those for carbon capture technology, indicating that it is still in a weak stage. Consequently, at this stage, to break through the bottlenecks in CCS technology research and development, it is essential to prudently utilize underground space and choose appropriate storage location in order to minimize the risk of $CO_2$ leakage.

(3) Challenges stem from navigating policy and regulatory issues. The CCS technology in our

nation is still in the early stages of development, and there have been few pertinent laws and regulations as well as a dearth of focused policies that require immediate attention. CCS technology faces significant environmental risks in aspects such as the selection of transportation routes and storage locations, nonetheless the case, our country has not specifically enacted laws and regulations regarding its safety issues, and the allocation of responsibility for the project is also unclear. Furthermore, take the implementation of CCS injection oil Wells as an example, our country does not have specific supervision and regulation in place, nor has it introduced specific plans or policies regarding economic benefits. Therefore, our country should leverage the driving force of policies, establish unified CCS laws and regulations, and create a comprehensive evaluation and supervision system to enhance confidence in industry development.

## 5. Conclusion

This paper summarized the current state of development of CCS technology, indicating that our country has made certain progress in both technology and the application of demonstration projects. However, due to the ongoing issues and challenges related to cost, research and development, and policy, there is still significant room for development of CCS technology in our country. At this stage, excessive investment in costs and increased competition from other industries have made investment more challenging. Reducing costs requires support from technological upgrades and assistance from national policies, and equal important, the leakage issues faced during the storage process urgently require technological breakthroughs to reduce the potential risks of environmental disasters. Targeted special policies can clearly outline the direction of CCS technology development and influence people's heightened awareness of the issue of excessive carbon emissions. Besides, CCS technology has broad application prospects in the oil and gas industry, which can not only effectively reduce emissions and alleviate environmental problems, but also make a significant contribution to improving oil production rates and economic benefits, so in-depth research on $CO_2$ enhanced oil recovery technology is beneficial for our country to achieve its dual carbon goals.

The main contribution of this paper is to provide a theoretical foundation for future research on CCS technology. The integration of the latest data and information can help identify the current weaknesses in our country and find breakthroughs, conducive to the further development of research. As CCS technology advances, the future study should better comprehend the industry's cutting edge advancements and fortify international collaboration in order to conform to international norms. Simultaneously, the research and analysis of CCS technology is insufficiently thorough, and there are still incomplete shortcomings in key technologies. Our country should strengthen planning and continuously increase investment in technology. Taking into account the underlying causes of the greenhouse effect, we must improve public education and awareness, take greater responsibility of the environment, and essentially raise public understanding of the need to cut back on $CO_2$ emissions. This has a substantial effect on reducing global warming as well.

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