frontiers in Energy Research

OPINION
published: 11 March 2022
doi: 10.3389/fenrg.2022.860665

CCUS Industry Under Target of Carbon-Peak and Carbon-Neutrality: Progress and Challenges

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Keywords: carbon-peak and carbon-neutral, CO2 capture, CO2 utilization, CO2 storage, CO2 reduction

OPEN ACCESS

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Specialty section:
This article was submitted to Carbon Capture, Utilization and Storage, a section of the journal Frontiers in Energy Research

Received: *23 January 2022*
Accepted: *10 February 2022*
Published: *11 March 2022*

Citation:
Cao L, Lei S, Guan Y, Wang Y, Zhang Y, Tian J, Wang T, Luo B and Ren T (2022) CCUS Industry Under Target of Carbon-Peak and Carbon-Neutrality: Progress and Challenges. Front. Energy Res. 10:860665. doi: 10.3389/fenrg.2022.860665

INTRODUCTION

Since the industrial revolution, carbon emissions in the atmosphere have increased by about 25–30% due to the increasing frequency of human activities. As human society progresses, the increase in greenhouse gases in the atmosphere caused by human activities has led to global warming and other climate problems have gradually become apparent. In the past decade, climate anomalies and natural disasters have occurred around the world, and the culprit is CO_2 emissions.

On September 22, 2020, Xi Jinping announced at the 75th General Debate of the United Nations General Assembly that "China will increase its independent national contribution, adopt stronger policies and measures, and strive to peak CO_2 emissions by 2030 and work towards achieving carbon neutrality by 2060." The introduction of the dual carbon targets has sparked strong interest in the domestic and international communities. Carbon dioxide capture, utilization and burial (CCUS) technology is gradually being taken seriously by society as an emerging technology and important means that is expected to achieve large-scale low-carbon utilization of fossil fuels, reduce CO_2 emissions, guarantee energy security and achieve sustainable development.

History of CCUS Technology Development

The development of CCUS technology has gone through the process of technology birth, development, and future commercial application (Li, 2022). In general, the development of CCUS technology is relatively early, as early as 1952, Wharton et al. achieved CO_2 enhanced recovery and obtained the patent (Stalkup, 1978). The first CO_2 injection project was implemented in the United States in 1964 (Stalkup, 1978). In 1972, the U.S. began to apply carbon dioxide flooding commercially (Stalkup, 1978). In 1989, MIT initiated the first carbon capture and burial project (Chai, 2013). Since then, CCUS technology has started to receive widespread attention and research work worldwide.

Compared with developed countries in Europe and the United States, China's CCUS technology has developed late, but in recent years it has developed rapidly. Early on, China focused more on CCS, and under the guidance of relevant national policies, domestic universities and researchers institutions have carried out many researches and demonstration work around this technology, and the carbon policy has gradually changed from CCS to CCUS. It can be said that CCUS technology is the new development trend of CCS technology, compared with CCS Compared with CCS, CCUS can resource CO_2, reduce emissions and output at the same time, which has both environmental, economic and social benefits, and is highly feasible.

Current Status of CCUS Technology Development

Currently, globally, CCUS technology is developing rapidly, with more than 130 CCUS-related facilities under construction and in operation worldwide as of September 2021, a significant increase

TABLE 1 | Completed CCUS demonstration projects in China (Duan et al., 2018).

Project name	Location	Capture capacity	Year of operation
CNPC Jilin Oilfield CO_2-EOR Research and Demonstration	Jilin	35	2007
Huaneng Group Shanghai Shidongkou Capture Demonstration Project	Shidongkou	12	2009
CCU Demonstration Project in Shengli Oilfield	Shandong	40	2010
Guodian Investment Chongqing Hechuan Double Carry Power Plant Carbon Capture Demonstration Project	Chongqing	1	2010
Erdos Coal to Oil CO_2 Capture and Storage Project	Ordos	10	2011
Lianyungang Clean Coal Energy Power System Research Facility	Jiangsu	3	2011
Tianjin Beitang Power Plant CCUS Project	Tianjin	2	2012
Carbon Capture Project of Yanchang Petroleum Yulin Coal Chemical Company	Jingbian	5	2012
Huaneng Green Coal Power IGCC Plant Capture Utilization and Storage Demonstration	Tianjin	6–10	2016
Xinjiang Dunhua Li Carbon Dioxide Capture Project	Karamay	10	2016
Huazhong University of Science and Technology 35 MW Oxyfuel Project	Hubei	10	Suspension of operations
China Resources Haifeng Power Plant Carbon Capture Test Platform Project	Guangdong	2	2019

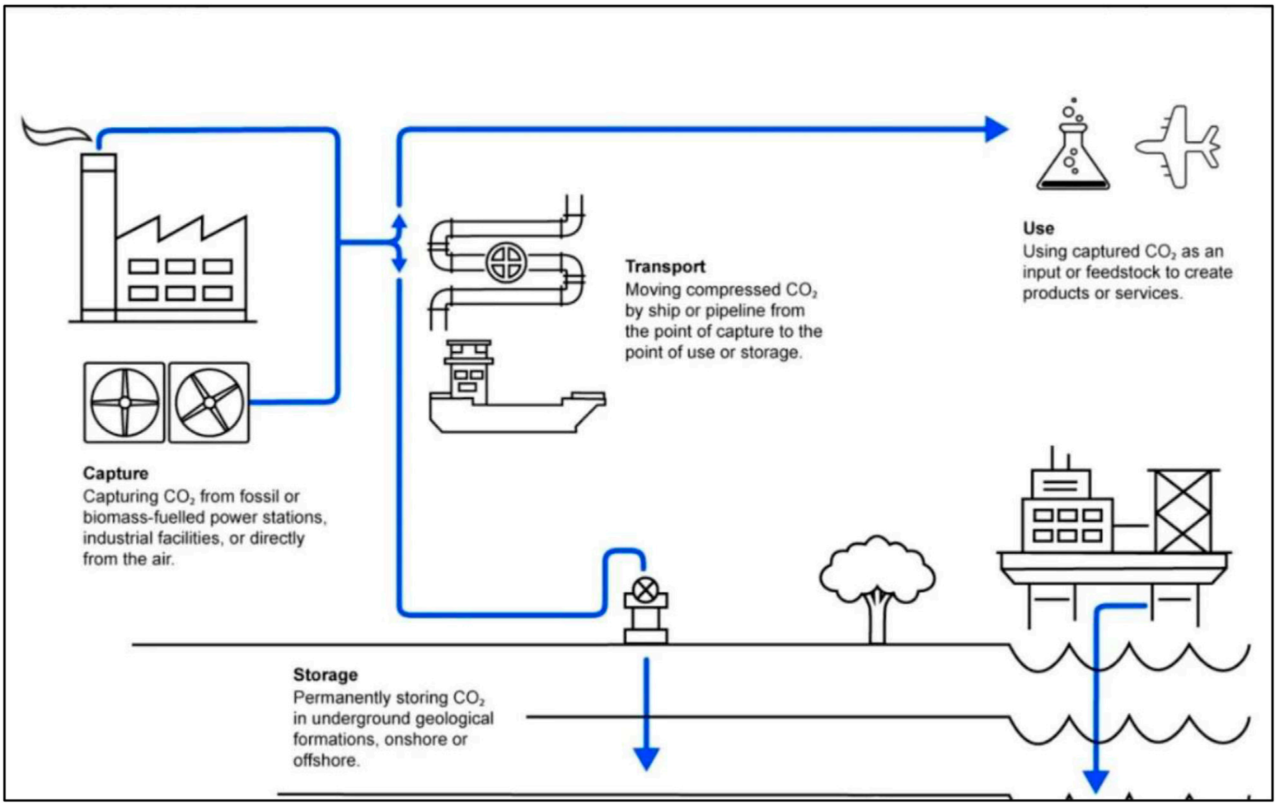

FIGURE 1 | CCUS flow chart.

compared to 2020. Meanwhile, there is an upward trend in the scale of facilities, CO_2 capture volume, and industrial clustering.

Although China's CCUS technology has made great progress in recent years (Chen, 2013), most of the current domestic CCUS projects are dominated by 100,000t level capture capacity (Cheng et al., 2017), and the main project table is shown in **Table 1** (Zhao et al., 2021).

In addition to the above-mentioned completed 10,000t-100,000t-scale projects, compared with the global leading level. There are more than 10 large-scale CCUS projects planned to be completed and put into operation in China (Li et al., 2011), including the 2000000t level like Shanxi International Energy Group CCUS project, Shenhua Ordos coal-to-oil project, Huaneng Green Coal IGCC Project Phase III and many 1000000t level projects, but most of these projects were later or cancelled due to economic benefits, technical support and other issues. To change this situation, we need to further promote the development of basic research work and professional technology research and development to achieve CCUS technology industrialized development (Mi and Ma, 2019).

CCUS Technology Applications for the Oil and Gas Industry

CCUS means that the carbon dioxide emitted from the production process will be purified and subsequently put into a new production process that can be recycled, rather than simply sequestered. The specific process is shown in **Figure 1**.

It is a mature systemic technology that includes three major components: CO_2 capture, transportation, and utilization and burial, each of which has a separate technical system and theoretical basis.

CO_2 capture technology refers to the separation and collection of CO_2 produced in industrial production, or the separation of oxygen from air for oxygen-enriched combustion to increase the concentration of CO_2 in flue gas, thus reducing the difficulty of capture and energy consumption. At present, domestic and foreign CO_2 capture mainly includes pre-combustion capture, post-combustion capture and oxygen-enriched combustion capture three technical solutions (Fang and Song, 2009), of which post-combustion capture is the more mature and widely used technical route. Pre-combustion capture is mainly used to generate syngas (H_2 and CO) through chemical reactions, convert CO and H_2O into CO_2 and H_2 through further conversion reactions, then separate CO_2. It is mainly used in natural gas boilers and coal-fired power plants, includes several technical methods such as adsorption separation, absorption separation and membrane separation. Oxyfuel combustion method mainly uses pure oxygen or oxygen/carbon dioxide mixture instead of air for combustion, and the removal of nitrogen can produce high purity CO_2 after combustion for direct storage, which has a greater advantage over general combustion air (Xie 2021).

CO_2 transportation technology is relatively mature and can be realized by pipeline transportation, tanker transportation and ship transportation. Pipeline transportation is usually the most inexpensive way to transport CO_2 on land by applying high pressure and transporting it in liquid or supercritical state, and it is mostly used for long-distance transportation, and North America has already realized long-distance pipeline transportation of CO_2 over 8000 km, and the transportation volume is large, which is the most important transportation method. Tanker and ship transportation is similar to LPG and LNG transportation, which is smaller in scale compared to pipelines but more flexible, especially when there are multiple offshore storage facilities that can receive CO_2. The flexibility of ship transport could also facilitate the development of CO_2 capture hubs (regional clusters), which would be able to be connected or converted into a more permanent pipeline network as the volume of CO_2 grows.

CO_2 utilization and storage is to utilize CO_2 geologically or inject it into deep strata by industrial means, to enhance oil, gas, water and other resources extraction and to achieve permanent CO_2 storage. The main storage methods are onshore storage and offshore storage. China has made great development in geological utilization and storage technology in recent years, but there is still an obvious gap compared with the world's advanced level, especially in CO_2 enhanced oil recovery, which is still in the industrial demonstration stage, while some developed countries have formed mature commercial applications.

Prospects and Challenges

From the statistical data, it can be seen that the global goal of carbon reduction and emission reduction has driven the CCUS industry into a fast-growing track, with the world's CCUS industry investment scale approaching USD 3 billion in 2020, showing a significant increase compared to USD 800 million in 2018 and USD 1 billion in 2019, and taking into account China's "coal-rich, oil-poor, and gas-poor" resource storage status and the irreversible trend of global energy low-carbon transition, accelerating the development of CCUS industry has become an inevitable choice to support China's energy security.

A comprehensive analysis of the actual situation shows that there is still a lot of resistance and challenges to achieve large-scale development in the CCUS industry in China: ①Economic aspects. The ultimate goal of CCUS is to achieve emission reduction, but the inability to benefit from emission reduction after spending huge amounts of money will affect the enthusiasm of enterprises to carry out demonstration projects. In addition, the high costs of tankers, ships, and pipeline network deployment during CO_2 transportation also limit to some extent the promotion of CCUS technology. ②Technical aspects. Although some experimental demonstration projects have been carried out in China, they are small in scale, and the whole is in the R&D and experimental stage. Large-scale demonstration projects are delayed or cancelled for various reasons, which seriously hinders the promotion and application of CCUS technology. The environmental and safety aspects of CCUS capture and transportation are mostly liquid CO_2 or supercritical CO_2 at high concentration and pressure, and any accident such as leakage during capture, transportation and storage will have serious impact on the environment and personal safety, especially the environmental impact caused by geological complexity seriously restricts the recognition and acceptance of CCUS. This requires the development of a whole process and stage risk prevention and control program for safety issues throughout the CCUS process.

AUTHOR CONTRIBUTIONS

None.

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Conflict of Interest: YW was employed by the company Changqing Engineering Design Co., Ltd.

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