Energy Proceedings
Vol 33, 2023
ISSN 2004-2965

Challenges, Countermeasures and Development Direction of CCUS Industry Chain Construction under the background of Dual Carbon Strategy

Yu Jing[1]*, Fang Pingliang[1], Zhou Bo[1], Zhao Yang[2], Zhang Hongyuan[1], Li Bing[1], Huang Hongchun[1], Chen Changchang[1], Yu Jinchen[1]
1 CNPC Engineering Technology R&D Company Limited,Beijing, China
2 College of Petroleum Engineering, China University of Petroleum (Beijing)
(*Corresponding Author:yujingdr@cnpc.com.cn)

ABSTRACT

The CCUS/CCS process is an important means to achieve carbon neutrality goals. From the current scale of the industry, a complete industry chain covering carbon capture, transportation, utilisation, and storage has been established, led by state-owned enterprises. However, the development of the industry chain faces high barriers to cross-industry cooperation among upstream, midstream, and downstream enterprises as well as difficulties in matching cross-regional sources and sinks, making the coordination of the entire industry chain more difficult. In addition, there is a lack of large-scale industrial demonstration of the process in China; at the same time, the business model is not mature. This paper proposes policy-making suggestions to promote the construction of the CCUS industry chain from four aspects: ① providing special incentive policies for high-cost links such as carbon capture and carbon storage; ② creating marketing and benefit-sharing mechanisms among upstream, midstream, and downstream enterprises in the industry chain; ③ formulating special laws, regulations, and standard system for each link of CCUS/CCS project construction and operation; ④ setting up programs for leading enterprises to integrate various links of the industry chain. To systematically organize the development characteristics of China's CCUS industry, this paper recommends three policies to promote the construction of the CCUS industry chain: ① strengthening the construction of basic databases and collaborative sharing platforms, and accelerating the construction of CCUS infrastructure; ②accelerating the construction of industrial clusters by utilizing mechanisms such as division of labor and collaboration between upstream, midstream, and downstream enterprises in the industrial chain, and using business models that create mutual benefit, complementarity, and synergy; ③ issuing special incentive policies for carbon capture and sequestration, formulating marketization and benefit distribution mechanisms for upstream, midstream, and downstream enterprises in the industrial chain, and formulating special laws, regulations, and standards for CCUS/CCS systems.

Keywords: CCUS, industrial chain， business status， challenges, countermeasures

1. INTRODUCTION

Carbon capture, utilization, and storage (CCUS/CCS) refers to the process of separating carbon dioxide from industrial processes, energy use, or the atmosphere, and directly utilizing it or injecting it into geological formations to achieve permanent carbon dioxide emissions reduction(DOI:10.16606/j.cnki.issn0253-4320.2022.09.003, Zhang Fan, 2022,Modern Chemical Industry). The CCUS/CCS industry chain is a complete chain that relies on CCUS/CCS technology to achieve carbon dioxide emissions reduction, consisting of carbon capture, transportation, utilization, and storage. The CCUS/CCS industry chain covers multiple fields including production, processing, and logistics, and has the characteristics of a long industrial chain, high technological integration, high dependence on geological conditions and geographical location, and great development potential(Fu Di, 2022,Oil and Gas and New Energy).

2. THE IMPORTANCE OF CCUS/CCS INDUSTRY CHAIN

2.1 Background of "Dual Carbon" Theme

This is a paper for International CCUS Conference 2023 (ICCUSC2023), April 14-15, 2023, Beijing, China.

2.1.1 Internation

The global energy sector is facing significant changes in terms of development stage, international landscape, and energy transition. A variety of factors, including the COVID-19 pandemic and unexpected geopolitical events, are pushing the global energy sector into a new stage of development. Addressing climate change has become an important task for global energy development, and the trend towards clean and low-carbon energy transition is becoming increasingly pronounced. Countries committed to carbon neutrality now cover 74% of global greenhouse gas emissions(CNKI:SUN:HJGC.0.2015-S1-260,Su Hao, 2015,Environmental Engineering), and more countries are implementing clearer emissions reduction roadmaps. However, addressing climate change remains a long and difficult journey that requires the collective wisdom and strength of all humanity. It is essential to design the optimal overall emissions reduction path and plan, implement more effective and consistent policy measures, and maximize the synergistic effects of various forces and factors, while fully optimizing and developing various emissions reduction technologies(CNKI:SUN:DTSJ.0.2013-01-012,Chen Xin, 2013,Low Carbon World).

2.1.2 Nation

Peak carbon emissions and carbon neutrality are major strategic decisions made by the Central Committee of the Communist Party of China to coordinate both domestic and international situations.

In September 2020, the 75th United Nations General Assembly announced China's goal of achieving carbon peaking and carbon neutrality. In October 2021, China released the "Opinions on Fully, Accurately, and Comprehensively Implementing the New Development Concept and Achieving Carbon Peaking and Carbon Neutrality" and the "Action Plan for Carbon Peaking Before 2030". On January 24, 2022, China proposed that the "dual carbon" goal would be a hard constraint and will accelerate the low-carbon transformation of traditional industries, promote industrial restructuring and upgrading, reduce energy consumption and carbon emissions of the industrial sector, and gradually achieve the decoupling of economic growth and carbon emissions(Group W, 2021,Worldwide Refining Business Digest). The low-carbon and clean utilization of fossil energy is the key to promoting energy transformation and ensuring energy security.

CCUS/CCS can support the retention of coal-fired power generation capacity: currently, coal-fired power generation accounts for more than 40% of the total carbon emissions from energy-related activities in China, making it the largest emitting industry. In the future, CCUS/CCS can capture more than 90% of carbon dioxide produced during coal-fired power generation (Cheng Liang, 2022,China Petroleum), making it the most economical, reasonable, and scalable carbon reduction method for coal-fired power generation.

CCUS/CCS has opened up a green development model of "carbon sequestration for enhanced oil recovery": in the near to medium term, CCUS/CCS mainly focuses on carbon sequestration and utilization for enhanced oil recovery, and carbon dioxide flooding can increase the oil and gas recovery rate by an average of 10%-20%(Ye Y, 2018, Chinese Engineering Science). According to incomplete statistics, the use of this technology can increase China's oil production by nearly 2 billion tons, equivalent to "recreating" a Daqing oilfield, providing strong support for ensuring China's energy security.

2.2 The Strategic Position of CCS/CCUS

Developing the CCS/CCUS industry chain is a major measure to achieve the national "dual carbon" goal. According to data from the Chinese Academy of Engineering, China's total carbon dioxide emissions reached 11.6 billion tons in 2020, accounting for nearly 30% of the world's total carbon dioxide emissions(ISBN : 9781315691176, Endres D,2016,Performances of an international professional community). It will take 30 years to complete the process of "carbon peaking to carbon neutrality" that developed countries took 50-70 years to achieve. The International Energy Agency (IEA) believes that to achieve the goal of controlling global temperature rise within 1.5°C by the end of this century, 32% of carbon emission reduction tasks need to rely on CCS/CCUS technology. It is expected that by 2060, China will still have 2.6 billion tons of carbon dioxide emissions, of which nearly 2 billion tons of carbon dioxide will be stored through CCS/CCUS, accounting for more than 3/4 of the total carbon reduction, playing a decisive role in achieving the carbon neutrality goal(DOI:10.1016/j.egypro.2013.06.702,Hao S, 2015,Environmental Engineering).

Developing the CCS/CCUS industry chain is an important means to promote new infrastructure and regional coordinated development. The CCS/CCUS industry has the characteristics of a long industrial chain and a large investment-driven effect. It is estimated that building a CCS/CCUS with a scale of 1 billion tons will

require a total investment of over one trillion yuan and can drive related industries to achieve a output value of over 10 trillion yuan(Xu Zixin, 2016,North China Electric Power University (Beijing)), becoming an important area of new infrastructure and economic growth.

The CCS/CCUS industry can promote regional coordinated development. Based on the characteristics of resource distribution, the future CCS/CCUS industry will be mainly located in the northeast, northwest, north, and southern offshore regions of China, which is highly consistent with major regional strategic initiatives such as the revitalization of the northeast, the development of the western region, the coordinated development of the Beijing-Tianjin-Hebei region, and the construction of the Guangdong-Hong Kong-Macao Greater Bay Area, having good synergies and driving effects.

3. CURRENT SITUATION AND MAIN ISSUES OF INDUSTRIAL CHAIN DEVELOPMENT

3.1 Global Industrial Layout

The global CCS/CCUS industry is still in the early stage of commercialization, with developed countries such as the United States and Europe leading in terms of industry scale and technology. There are currently 27 large-scale CCS/CCUS demonstration projects in operation (20 of which are for EOR and 7 are for dedicated geological storage), which can capture and store about 40 million tons of carbon dioxide per year. Among them, the United States has 12 large-scale CCS/CCUS demonstration projects, with a carbon capture and storage scale of about 25 million tons per year, accounting for 60% of the global total(DOI:10.3969/j.issn.1009-1742.2010.08.006,Jin Yong, 2010, Chinese Engineering Science.DOI:10.2139/ssrn.3366199, Walker J, 2019, SSRN Electronic Journal). Globally, the CCS/CCUS industry chain is mainly dominated by oil companies. International oil companies such as ExxonMobil, Chevron, and BP are leading in the forefront technologies of carbon capture, enhanced oil recovery, carbon storage, and other areas, making them the leaders of the CCS/CCUS industry.

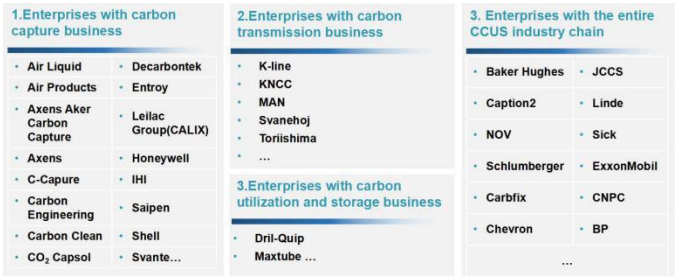

Fig. 1. Leading companies in the global CCUS/CCS industry chain

Table. 1. Frontier Technologies in the Global CCUS/CCS Industry Chain

Domain	The name of the technology
Carbon capture	Low concentration carbon dioxide capture
	Carbon capture technology before combustion
	Direct air capture technology
Carbon transport	Long distance pipeline transportation technology of supercritical carbon dioxide
	Low cost pipeline construction
	Anticorrosive Technology for Long Distance Sour Gas Pipeline Transportatio
	Injection/circulation compressor
	LNG technology, LPG technology carbon dioxide transport ship
Carbon utilization & Carbon sequestration	Steam Methane Reforming SMR Technology
	New generation carbon dioxide- EOR technology
	carbon dioxide underground escape and detection evaluation system

The international development of the CCS/CCUS industry has three main characteristics:

First, there is a high degree of match between carbon sources and sinks: carbon sources are concentrated, and the distance between the carbon source area and the carbon storage area is close, with a well-developed regional pipeline network and low carbon transportation costs.

Second, enterprises with strong carbon storage capabilities dominate the industry: "carbon storage" resources are a necessary condition for the development of the CCS/CCUS industry. Enterprises with rich "carbon storage" resources lead the construction of the CCS/CCUS industry chain. Excellent geological conditions, superior geographical location, and mature injection technology help ensure the safety and stability of the industry chain.

Third, mature market mechanisms and policies: carbon source companies in the United States pay for carbon storage based on market prices, and carbon

storage companies can also receive relevant government support policies, thereby promoting the development of industry clusters and infrastructure sharing.

Table 2. Carbon dioxide subsidy price for 45Q tax credit policy in the United States (USD/ton of carbon dioxide)

Year	2018	2019	2020	2021	2022	2023	2024	2025	2026
Geological storage	25.70	28.74	31.77	34.81	37.85	40.89	43.92	46.96	50.00
EOR/CCU	15.29	17.76	20.22	22.68	25.15	27.61	30.07	32.54	35.00

3.2 Industrial Development in China

China's CCUS/CCS industry is currently in the industrial demonstration stage. There are about 40 CCUS/CCS demonstration projects in operation or under construction, mainly in the petroleum, coal chemical, and power industries with small-scale capture and EOR demonstrations. The carbon capture capacity is about 3 million tons per year, and the storage capacity is about 1.8 million tons per year. From the current industrial scale, there is still a gap compared to Europe and the United States, but a relatively complete industrial chain has been formed, and there is enormous potential for future development(DOI:10.7666/d.Y2538084, Liu Jiajia, 2014, Jiangsu University).

Two major advantages are as follows:

Complete industrial chain: A relatively complete industrial chain covering carbon capture, transportation, utilization, and storage has been formed.

Enormous development potential: Under the goal of carbon neutrality by 2060, China will still have 2.6 billion tons of carbon dioxide emissions, of which nearly 2 billion tons of carbon dioxide will be stored through CCUS/CCS (including storage in depleted gas reservoirs and deep saline aquifers)(DOI:10.2139/ssrn.3366199, Walker J,2019, SSRN Electronic Journal).

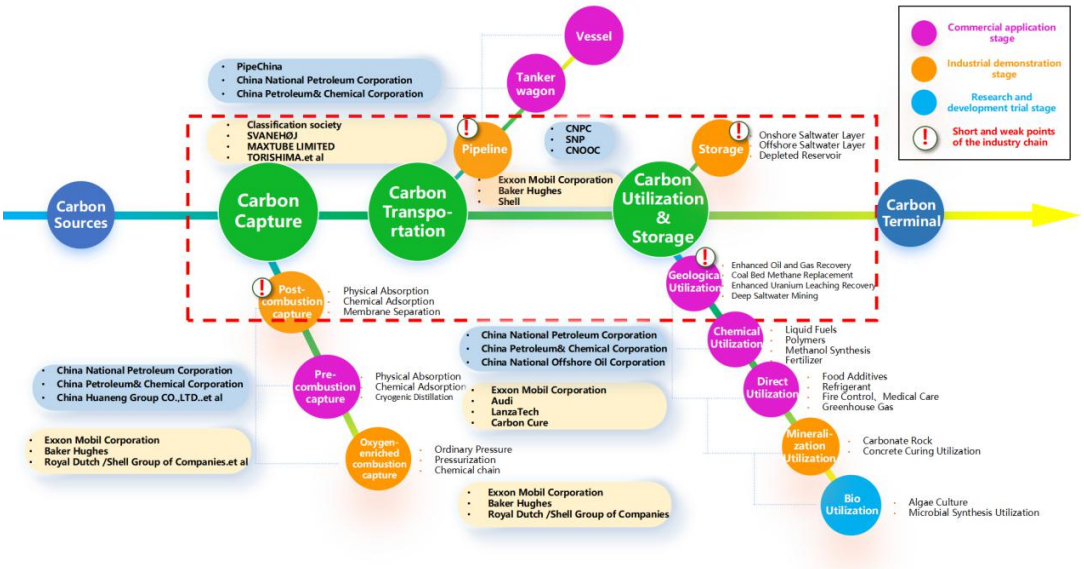

Fig. 2. China's CCUS/CCS industry chain

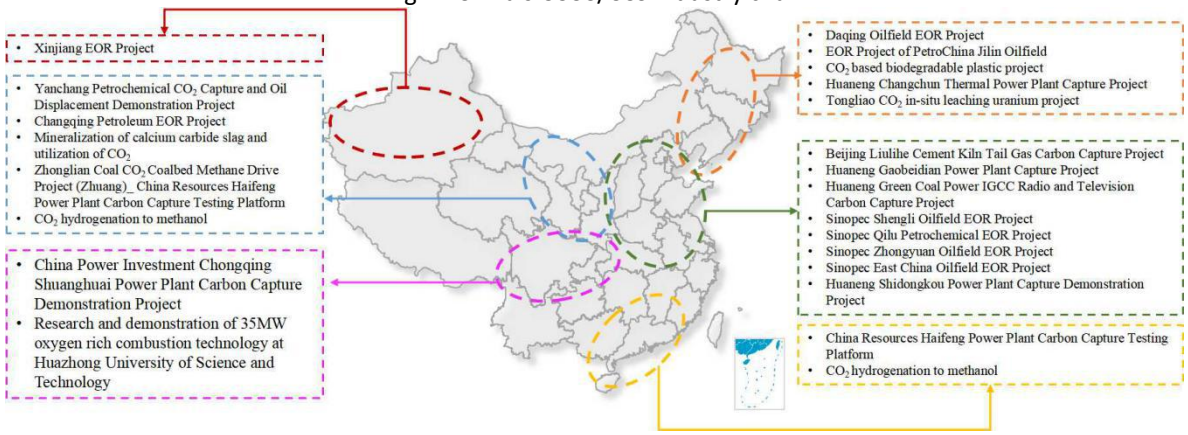

Fig. 3. Major CCUS/CCS projects in China

Central enterprises are taking a leading role in the development of China's CCUS/CCS industry, and the leading companies include China National Petroleum Corporation (CNPC), China Huaneng Group, China Petroleum & Chemical Corporation (Sinopec), China National Energy Administration (CNEA), China National Offshore Oil Corporation (CNOOC), and State Grid. CNPC has a leading advantage in carbon EOR and storage, Huaneng Group has an advantage in carbon capture, and State Grid is leading in pipeline construction and operation(DOI:10.7122/438081-MS,Meng, 2015,the Carbon Management Technology Conference .Group W , 2016,Process Safety & Environmental Protection).

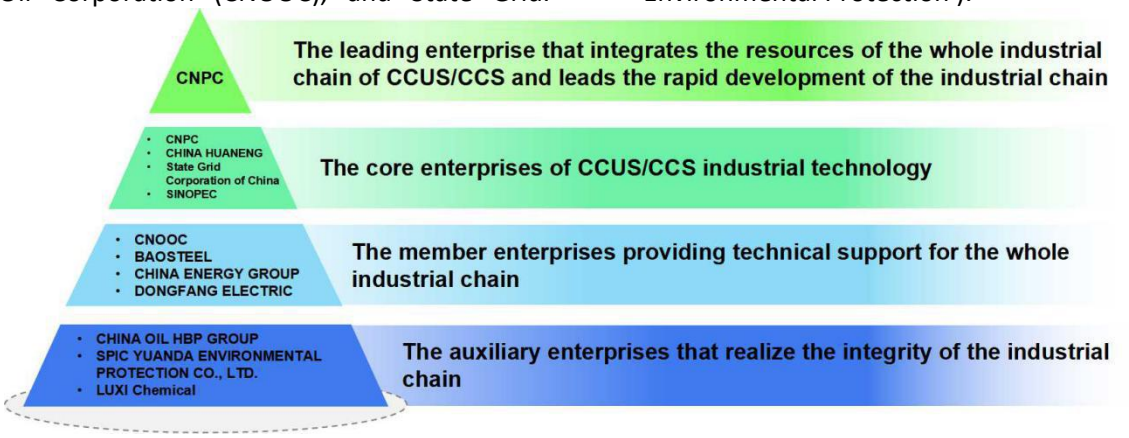

Fig. 4. Composition of Chinese CCUS/CCS Industry System Enterprises

3.3 Core Risks and Challenges Facing the Industry

Compared with developed countries in Europe and the United States, China's CCUS/CCS technology and industry development are still in the industrial demonstration stage, and there are weak links in the industrial chain. The coordination and overall planning of the entire industry chain is challenging, requiring a leading enterprise to effectively integrate the various links of the industry chain and promote rapid development.

3.3.1 Weak Industry Foundation, Shortcomings, and Low Comprehensive Competitiveness

Weak industry foundation and lack of shared facilities: The basic database, collaborative sharing platform, and other facilities are still not perfect. There is a lack of carbon dioxide transportation pipelines (the total length of carbon dioxide pipelines in North America is 8,000 km, while in China, it is only 70 km)(ISBN:9781119593324,Hao M , 2020).

Shortcomings and weaknesses: High-end carbon capture materials and processes, as well as core components of high-end compression units, still rely on imports. It is urgently needed to deploy strong basic research projects to promote localization and application, enhance the supply chain's guarantee capability.

High comprehensive cost: Taking carbon capture as an example, this link accounts for 70% to 80% of the total cost of the industry chain. The capture cost in China is as high as 400-600 yuan/ton(Zhong Ping, 2011, China Population, Resources and Environment), about twice that of foreign countries. To achieve the economic benefits of carbon dioxide utilization, the cost of carbon capture needs to be reduced to below 200 yuan/ton(DOI:10.3969/j.issn.1674-8069.2013.05.010,Han Guifen, 2013, Electric Power Technology and Environmental Protection). It is imperative to reduce costs through technological innovation, scaling, and commercialization.

3.3.2 Lack of a Large-Scale Industrial Cluster and an Effective Business Model

Difficulty in overall coordination and planning of the entire industry chain: The CCUS/CCS industry involves many links, and the characteristics of cross-industry, cross-domain, cross-enterprise, and cross-region (referred to as "four cross") are obvious(CNKI:SUN:DTSJ.0.2014-13-005, Li Qi, 2014, Low Carbon World). The development of the industry chain faces high barriers to cross-industry cooperation between upstream, midstream, and downstream enterprises and difficulties in matching sources and sinks across regions. It is necessary to rely on industrial clusters and mature business models to achieve large-scale development.

Immature business model: Currently, there is a lack of large-scale industrialized demonstrations of the entire process in China, and the business model is

immature. From the operation of some small-scale CCUS/CCS demonstration projects in China, the division of labor and cooperation mechanism and mutually beneficial and complementary, symbiotic business models among upstream, midstream, and downstream enterprises in the industry chain have not yet formed(CNKI:SUN:DTSJ.0.2013-01-012,Chen Xin, 2013, Low Carbon World). These are all critical factors restricting the development of industrial clusters, and the scale effect is difficult to achieve. It is urgent to accelerate the construction of industrial clusters,establish an effective coordination mechanism, and establish a long-term, fair cooperation model to effectively address issues such as gas supply, pipeline transportation, and relationships between local enterprises(DOI:10.4172/2090-4541.1000164, Huaman R, 2015,Journal of Fundamentals of Renewable Energy and Applications).

3.3.3 Policy Mechanisms and Standardization Need to be Improved

Lack of policy support: Currently, there is a lack of special incentive policies similar to the US 45Q tax credit for high-cost links such as carbon capture and storage in China.

Market mechanisms need to be improved: Due to factors such as unclear policies for cross-provincial storage, responsibility boundaries, and carbon offset mechanisms, there is no effective market-oriented and benefit-sharing mechanism among upstream, midstream, and downstream enterprises in the industry chain, and they face common problems such as cost sharing, revenue sharing, and responsibility allocation(Li Chenggang, 2022, Oil and Gas Field Surface Engineering).

Lack of a standard system: In the various stages of project construction and operation, there is a lack of specialized laws and regulations and a standard system for CCUS/CCS, which poses significant risks to the healthy development of the industry in terms of project site selection, construction, operation, environmental risk assessment, monitoring, and other aspects.

4. CCUS/CCS INDUSTRIAL CHAIN IMPLEMENTATION PATH AND POLICY SUGGESTIONS

4.1 Strengthen the Top-Level Design of the CCUS/CCS Industry

It is recommended to formulate an overall development plan for CCUS/CCS at the national level, support CCUS/CCS technology as a major national science and technology project, build a systematic policy framework system, and promote the application of CCUS/CCS in the petroleum, chemical, power, steel, and other industries in an orderly manner.

4.2 Promote CCUS/CCS Industrial Demonstration and Commercial Application

① Support the construction of CCUS/CCS industrial parks, accelerate the construction of CCUS/CCS industrial clusters, and gradually incorporate CCUS/CCS technology into the green development technology support system and strategic emerging industries of energy and mining.

② List CCUS projects as public welfare projects, unblock project approval channels, and simplify approval procedures.

4.3 Accelerate the Planning and Layout of the CCUS/CCS Pipeline Network and Cluster Infrastructure Construction

① Increase investment in relevant infrastructure, strengthen the construction of transportation pipelines, establish cooperative sharing mechanisms, and drive the formation of regional CCUS/CCS industry promotion centers based on pipeline facilities and storage sites(Wang Jinnan, 2013, Low Carbon World).

② Improve financing channels, establish government special financial funds, and guide investment institutions to increase investment support.

4.4 Improve Financial and Tax Incentive Policies and Legal System

① Explore the formulation of CCUS/CCS tax incentives and subsidy policies suitable for national conditions and oriented towards carbon neutrality goals, and implement tax reductions or carbon reduction subsidies for carbon utilization and storage projects. For example, tax incentives for new CCUS/CCS technology, preferential interest rates on loans, preferential land policies, preferential policies for project revenue periods, and exemptions for petroleum special income taxes for carbon dioxide-EOR projects(DOI:10.3969/j.issn.1671-7708.2021.09.015, Liu Xiaomin,2021, China Petroleum and Chemical). Eligible equipment and certain infrastructure assets can be accelerated for depreciation.

② Formulate and improve CCUS/CCS industry norms, institutional regulations, and technical specifications, and form a unified industry standard.

4.5 Strengthen CCUS/CCS-related regulatory measures

Resolve jurisdictional responsibilities for sealing carbon dioxide in oil and gas reservoirs, national-local

jurisdictional issues, and jurisdictional issues of competent departments(ISBN:9781119593324, Hao M,2019).

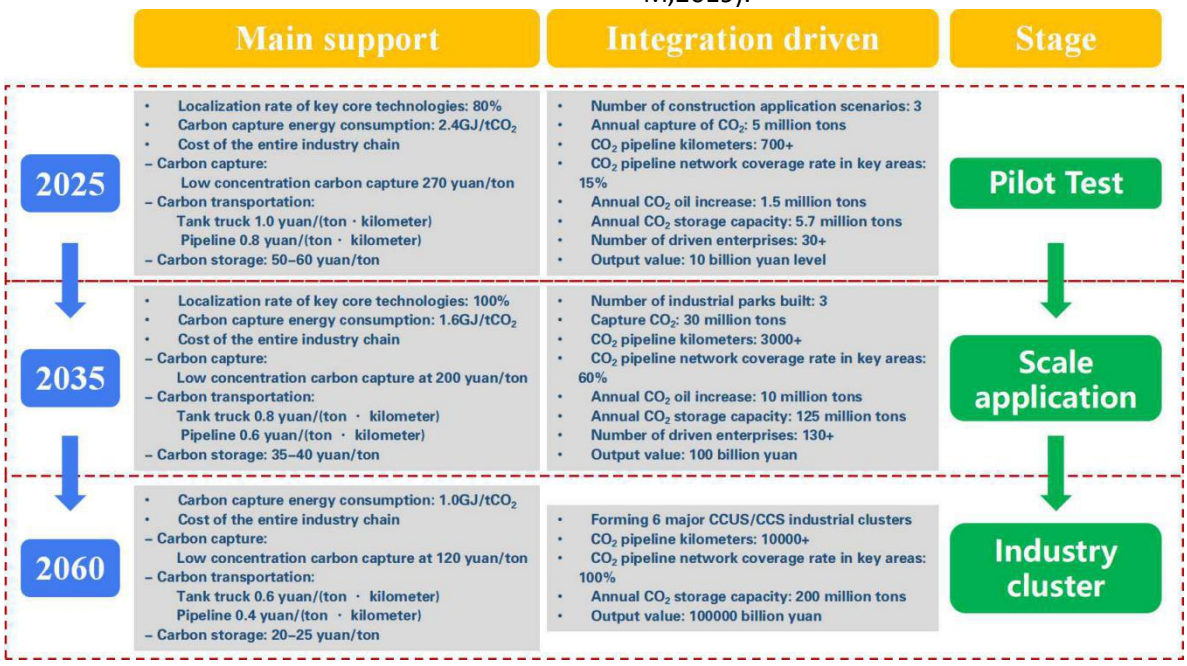

Fig. 5. Phased Objectives of China's CCUS/CCS Industrial Chain

5. CONCLUSIONS

The CCUS/CCS industry chain covers multiple fields such as production, processing, and logistics, and has the characteristics of a long industry chain, high technical integration, high dependence on geological conditions and geographical location, and great development potential. From the current scale of the industry, a complete industry chain covering carbon capture, transport, utilization, and storage has been formed, with central enterprises as the main driving force. However, the development of the industry chain faces challenges such as high cross-industry cooperation barriers among upstream, midstream, and downstream enterprises, and difficulties in matching sources and sinks across regions, making it difficult to coordinate and plan the entire industry chain.

This article proposes decision-making suggestions for promoting the construction of the CCUS industry chain from the aspects of top-level design, industry demonstration and commercial application, planning and layout of CCUS pipeline network and cluster infrastructure construction, financial and tax incentive policies, legal and regulatory framework construction, and industry supervision.

① China should strengthen the top-level design of the CCUS/CCS industry and support CCUS/CCS technology as a major national science and technology project, and establish a systematic policy framework system.

② Accelerate the construction of CCUS/CCS industrial clusters, and gradually incorporate CCUS/CCS technology into the green development technology support system for energy and mining, and the sequence of strategic emerging industries.

③ Strengthen the construction of basic databases and collaborative sharing platforms, and accelerate the construction of CCUS infrastructure. Utilize the mechanism of division of labor and cooperation among upstream, midstream, and downstream enterprises in the industry chain, and use mutually beneficial and complementary business models to accelerate the construction of industrial clusters.

④ Explore the formulation of tax preferences and subsidy policies for CCUS/CCS that are suitable for national conditions and aimed at carbon neutrality goals, and implement tax reductions or carbon emission reduction subsidies for carbon utilization and storage projects. Develop and improve the industry norms, regulatory framework system, and technical specifications for the CCUS/CCS industry, form a unified industry standard, and strengthen relevant CCUS/CCS supervision.

ACKNOWLEDGEMENT

This research was one of the projects financially endorsed by the soft science research project of China National Petroleum Corporation Limited "Research on the countermeasures for engineering technology to create the original technology origin and become the leader of the industrial chain" (CNPCI 20220143-1), "Research on the countermeasures for building the modern engineering technology industrial system of new energy and new business" (20230114-1) ".

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.

REFERENCE

[1]Zhang Fan. Challenges, countermeasures, and development directions of CCUS industrialization under the "dual carbon" target. Modern Chemical Industry, 2022;42(9):13-17.

[2]Fu Di, Tang Guoqiang, Zhao Lianzeng, et al CCUS Whole Process Economic Benefit Analysis . Oil and Gas and New Energy 2022;34 (5): 1044-1047.

[3]Su Hao, Zha Yongjin, Wang Meishan, et al. Analysis of the advantages and disadvantages of CCS and CCUS for carbon emission reduction. Environmental Engineering, 2015; S1:5.

[4]Chen Xin, Li Xiaochun. Strategic choice of high-carbon energy decarbonization with CCS/CCUS. Low Carbon World, 2013;1:30-33.

[5]Group W . Oil companies should embrace CCS/CCUS. Worldwide Refining Business Digest: The Fast-read Comprehensive Newaletter for Busy Professionals Working in the Refining Industry 2021;Apr..

[6]Cheng Liang, Fan Zhihui, Chen Haixiong, Yang Sixiang. Global CCS/CCUS project practice: gains and losses. China Petroleum, 2022;11:69-72.

[7]Ye Y, Liao H, Wang P, et al. Research on Technology Directions and Roadmap of CCS/CCUS for Coal-Fired Power Generation in China. Chinese Engineering Science, 2018.

[8]Endres D , Cozen B A , O'Byrne M , et al. Performances of an international professional community: CCS/CCUS and its national contexts 2016.

[9]Hao S , Zha Y , Wang M , et al. ANALYSIS OF CCS AND CCUS IN CARBON EMISSION REDUCTION ADVANTAGES AND DISADVANTAGES. Environmental Engineering 2015.

[10]Xu Zixin. Comprehensive economic evaluation and index research on CCS-EOR full process project based on post-combustion capture of coal-fired power plants. North China Electric Power University (Beijing), 2016.

[11]Jin Yong, Zhu Bing, Hu Shanying, et al. Integration of CCS, CCUS, CCRS, and CMC systems. Chinese Engineering Science, 2010.

[12]Walker J . Lessons Learned and Best Practices from Managing CCS/CCUS Projects. SSRN Electronic Journal 2019.

[13]Liu Jiajia. Analysis of the impact of the potential value of China's CCS and CCUS based on physical options on investment decisions. Jiangsu University, 2014.

[14]Walker J . Lessons Learned and Best Practices from Managing CCS/CCUS Projects. SSRN Electronic Journal 2019.

[15]Meng, Xian L . Low-Carbon Development Strategy and CCS/CCUS Practices of Sinopec,the Carbon Management Technology Conference 2015;11:17.

[16]Group W . 45Q tax credit believed to be key for CCS and CCUS projects in the US.[J]. Worldwide Refining Business Digest: The Fast-read Comprehensive Newaletter for Busy Tapia J , Lee J Y , Ooi R , et al. Planning and scheduling of carbon dioxide capture, utilization and storage (CCUS) operations as a strip packing problem. Process Safety & Environmental Protection 2016; 104:358-372.

[17]Hao M , Hu Y , Wang S , et al. The Development Features and Cost Analysis of CCUS Industry in China; 2020, p. 180 – 186.

[18]Zhong Ping, Peng Senzhen, Jia Li, et al. Research and demonstration of carbon capture, utilization, and storage technology in China. China Population, Resources and Environment, 2011;21:5-12.

[19]Han Guifen, Zhang Min, Bao Li. Thoughts on the development and standard construction of CCUS technology. Electric Power Technology and Environmental Protection, 2013;5:4.

[20]Li Qi, Chen Zhenga, Zhang Jiutian, et al. Insights into the future version of China's CCUS technology roadmap: an analysis based on the world CCS roadmap. Low Carbon World, 2014;7:2.

[21]Chen Xin, Li Xiaochun: Strategic choice of high-carbon energy decarbonization with CCS/CCUS. Low Carbon World, 2013;1:4.

[22]Huaman R . A Review on: carbon dioxide Capture Technology on Fossil Fuel Power Plant. Journal of Fundamentals of Renewable Energy and Applications 2015; 05:3-6.

[23]Li Chenggang, Gao Zeji, Chen Zhi. Exploration and thinking on the green transformation and development of Tuha Oilfield under the background of "dual carbon". Oil and Gas Field Surface Engineering, 2022; 41::5-12.
[24]Zou Caineng, Wu Songtao, Yang Zhi, et al. Progress, challenges and significance of building a carbon industry system in the context of carbon neutrality strategy. Petroleum Exploration and Development, 2023;50:16-18.
[25]Wang Jinnan, Liu Lancui. Environmental management considerations for carbon dioxide capture, utilization, and storage (CCUS) projects. Low Carbon World, 2013;01:22-25.
[26]Liu Xiaomin. CCUS safeguards the achievement of the dual carbon target. China Petroleum and Chemical, 2021.
Hao M , Hu Y , Wang S , et al. The Development Features and Cost Analysis of CCUS Industry in China. 2019, p. 65 – 72 .