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Current Status and Challenges of CCUS Technology Development from a Global Perspective

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Abstract: As climate change intensifies, achieving carbon neutrality has become a global focal point. Carbon Capture, Utilization, and Storage (CCUS) technology, as a crucial tool, offer hope for achieving climate goals by capturing CO_2 emissions, utilizing captured CO_2, and permanently storing it. This paper analyzes the definition and role of CCUS technology, focusing on the development status in the United States, Europe, and Asia. It delves into challenges related to technological innovation, economic cooperation and investment, social and political factors, and international collaboration. The development of new capture technologies and efficient storage and transportation systems is key to improving the feasibility and economy of CCUS technology. Economic cooperation and investment require close cooperation between the public and private sectors, as well as support from international institutions, to jointly promote the CCUS project. In terms of social and political factors, the improvement of social acceptance and policy regulations is a key bottleneck in the development of CCUS technology, which requires the joint efforts of the government, enterprises, and all sectors of society. The research results indicate that through comprehensive considerations such as technological innovation and global cooperation, CCUS technology is expected to achieve greater breakthroughs on a global scale and become a powerful tool for addressing climate change.

Keywords: CCUS; Climate Change; Carbon Neutrality; Technological Innovation; Economic Cooperation and Investment

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1 Introduction

The global processes of industrialization and urbanization have brought about an undeniable energy demand, concurrently exacerbating greenhouse gas emissions, leading to an increasingly significant impact of climate change [1-3]. Climate change not only has profound effects on ecosystems and biodiversity but also poses a potential threat to the global economy and social structure [4, 5]. Traditional patterns of energy production and usage result in the substantial release of greenhouse gases, such as CO_2, into the atmosphere, intensifying the greenhouse effect and leading to a rise in global temperatures [6-8]. Scientists have unequivocally pointed out that urgent and profound actions must be taken to reduce greenhouse gas emissions in order to prevent temperatures from rising beyond the perilous threshold of 1.5 degrees Celsius. In this challenging moment, Carbon Capture, Utilization, and Storage (CCUS) have emerged as a crucial tool in mitigating the process of climate change [9-12]. CCUS technology captures CO_2 generated in industrial and energy production processes and securely stores it underground, offering the potential to significantly reduce the concentration of greenhouse gases in the atmosphere. The

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principles of CCUS technology involve three main steps: Capture, Utilization, and Storage [13-15].

Capture is the core of CCUS technology, involving the extraction of greenhouse gases from various emission sources to prevent their direct release into the atmosphere. Capture can be categorized into the following methods: (a), capturing CO_2 before the combustion process, which can be achieved through techniques such as gas separation or chemical absorption. (b), capturing CO_2 after combustion, is primarily applicable to emissions from power plants and industrial processes. This includes adsorption, and membrane separation technologies. (c), capturing CO_2 directly from the atmosphere, aims to reduce the carbon footprint of industrial processes. This may involve chemical absorption, or other technologies. The captured CO_2 can be safely and efficiently transported to storage sites through pipelines or other means of transportation [16, 17].

The captured CO_2 can be utilized in various ways, including: (a), Carbonation: Reacting CO_2 with alkaline substances to form carbonate, applicable in the production of construction materials, and more. (b), Synthetic Fuels: Utilizing CO_2 and hydrogen to produce synthetic fuels, such as synthetic natural gas or synthetic petroleum. (c), Ecosystem Restoration: Using CO_2 to stimulate plant growth, for example, through reforestation efforts.

In terms of CO_2 storage, several methods can be employed: (a), Underground Storage: Injecting captured CO_2 into underground reservoirs, such as oil fields, natural gas fields, or deep rock formations, for permanent storage. (b), Hydrate Storage: Forming stable compounds by combining CO_2 with hydrates and storing them at the deep seabed. (c), Mineralization Storage: Reacting CO_2 with minerals to form stable carbonate, which is then stored underground. Through these three steps, CCUS technology can effectively manage CO_2, reduce greenhouse gas emissions, thereby contributing to addressing climate change and promoting sustainable energy development. Furthermore, the widespread adoption of CCUS technology is expected to steer industries, energy production, and societal development towards a low-carbon trajectory, creating a more sustainable path for the future.

This paper examines the current status and challenges of CCUS technology from a global perspective, analyzing the issues and future directions of the technology across multiple dimensions, including technical, economic, social and political, and international cooperation.

2 Global Development Status of CCUS Technology

2.1 CCUS Projects in the United States

The United States has consistently been at the forefront of CCUS technology, actively promoting the implementation of related projects to address greenhouse gas emissions and climate change issues. The implementation of CCUS projects involves various dimensions, including government support, industry participation, and collaboration with research institutions.

The U.S. government supports the development of CCUS projects through a series of regulations and policies. Federal government funding and tax incentives provide enterprises with the impetus to innovate and implement projects in the CCUS field. In addition, various state governments have introduced relevant policies to support and encourage local CCUS projects. This comprehensive government support lays a solid foundation for the development of CCUS technology in the United States.

In terms of implementation, the United States is not only focused on improving the efficiency of existing power plants but also actively promoting the application of CCUS technology in the industrial sector. For instance, the Petra Nova project in Texas is the first large-scale commercial carbon capture power plant in the United States, operational since 2017. The project captures CO_2 from a post-combustion coal-fired power plant and injects it into an oil field to enhance oil and gas recovery. The successful operation of Petra Nova provides robust practical experience for similar projects, demonstrating the feasibility of CCUS technology in the power industry.

The United States is also advancing the implementation of CCUS technology in the industrial and manufacturing sectors. Several large industrial enterprises are actively investing and collaborating on CCUS projects to reduce carbon emissions in their production processes. These initiatives not only contribute to companies fulfilling their social responsibilities but also provide practical examples for the continuous improvement of related technologies. CCUS projects in the United States have achieved significant accomplishments in reducing carbon emissions, improving energy efficiency, and driving economic growth. By implementing CCUS technology, not only has atmospheric greenhouse gas emissions been reduced, but it has also provided a relatively clean way of generating power for the energy industry. Additionally, the application of CCUS technology has created employment opportunities in related industries, promoting sustainable economic growth. The United States has made remarkable progress in the implementation and promotion of CCUS technology. Government support, corporate participation, and research institution efforts have collectively propelled the development of this field.

2.2 CCUS Development in Europe

In Europe, the development of CCUS technology has consistently received strong policy support from the European Union (EU), aiming to address climate change, drive the transition to clean energy, and promote sustainable development. The development of CCUS in Europe involves not only policy guidance but also multi-sectoral cooperation and the implementation of significant projects.

The EU has outlined the position of CCUS technology in the European energy system through a series of strategic documents and regulations. Policy documents such as the "European Green Deal" and the "Climate Law" explicitly state the EU's carbon neutrality goals and identify CCUS as a key means to achieve them. The continuous improvement of the European carbon market provides market mechanism support for CCUS projects, making them more economically attractive. Against the backdrop of policy support, Europe actively promotes several CCUS projects, with one of the most notable being the Norwegian Full-Scale project. This project is a full-sized carbon capture power plant located in Norway, employing advanced capture technologies to inject CO_2 into underground storage layers while generating clean electricity. The implementation of such significant projects not only enhances the feasibility of CCUS technology but also provides experience and reference for future similar projects. The EU also plays an active role in international cooperation. The EU has established cooperation frameworks with countries such as Norway, jointly advancing the global application of CCUS technology. This international collaboration facilitates the sharing of technology, experience, and resources, promoting the global dissemination of CCUS technology.

The development of CCUS in Europe is also evident in the active participation of the industry. Some energy companies and industrial giants invest and collaborate in the European region, collectively committed to driving the innovation and implementation of CCUS technology. This public-private collaboration model provides a more solid foundation for the large-scale application of CCUS technology.

2.3 Progress of CCUS in Asia

In Asia, the development of CCUS is showing a diverse and positive trend, with countries taking measures to mitigate climate change and reduce carbon emissions. Among them, countries such as China, Japan, and South Korea have played important roles in promoting the development of CCUS technology, achieving significant progress in policy formulation and practical implementation.

As one of the world's largest carbon emitters, China actively engages in the field of CCUS, implementing a series of policies and practical measures. The Chinese government has issued the "Action Plan for Peak Carbon and Carbon Neutrality," outlining carbon neutrality goals and paths, and proposing the construction of a batch of exemplary CCUS projects by 2030. Specifically, China promotes the application of CCUS technology in high-carbon-emission industries such as power generation, petrochemicals, and steel to achieve emissions reduction and efficient resource utilization [18, 19]. The National Energy Administration has proposed in the "Action Plan for Accelerating Oil and Gas Exploration and Development and the Integrated Development of New Energy (2023–2025)" that by 2025, through oil and gas to promote the efficient development and utilization of new energy, meet the new electricity demand caused by the increase in electrification rate of oil and gas fields, replace exploration and development of self-use oil and gas, and accumulate clean substitutions. The China Shengli Oilfield CCUS project is the country's first commercial CCUS project, collecting industrial CO_2 emissions and injecting them into oil fields to not only increase oil and gas recovery rates but also effectively reduce emissions. China National Petroleum Corporation (CNPC) has explored the use of CO_2 to enhance oil recovery in the Daqing oilfield and completed the CCUS-EOR project (CO_2 capture and storage for enhanced oil recovery) full industrial chain commercial demonstration, forming a comprehensive technological system. In 2022, CNPC's CCUS special project injected over 100×10^4 tons of CO_2.

Japan has taken proactive measures to achieve carbon neutrality and considers CCUS technology as one of the key tools. The Japanese government has introduced the "Green Growth Strategy," emphasizing the importance of developing CCUS technology and planning to construct multiple CCUS demonstration projects by 2030. Additionally, Japanese companies actively engage in CCUS research and implementation, collaborating with international partners to promote technological innovation and experience sharing. This comprehensive policy support and industrial investment have laid the foundation for Japan's development in the CCUS field.

South Korea has also made significant progress in the fields of carbon neutrality and climate change. The South Korean government has set a clear goal to achieve carbon neutrality by 2050, identifying CCUS technology as a key enabler for this objective. South Korean companies actively invest in CCUS technology research and demonstration projects, including the application of CCUS technology in power plants and industrial production. Additionally, South Korea collaborates with international partners to enhance exchange and cooperation in CCUS technology innovation and application.

The progress of Asian countries in the development of CCUS technology reflects their commitment to addressing climate change and promoting sustainable development. Through policy guidance, the construction of demonstration projects, and international cooperation, these countries actively address carbon emissions issues and promote the large-scale application of CCUS technology. However, challenges such as technical difficulties, economic costs, and social acceptance still need to be addressed. It requires collective efforts to promote the development of CCUS technology and make a greater contribution to achieving global climate goals.

3 Challenges and Difficulties of CCUS Technology

3.1 Technical Challenges

In the development of CCUS, technical challenges have consistently been a crucial issue that urgently needs solutions. This challenge involves innovations in capture technology, feasibility in storage and transportation, requiring collaborative efforts at the global level from the realms of research, industry, and policy.

3.1.1 Innovation in Capture Technology

Capture technology is a critical component in the CCUS technology chain, directly impacting the effective capture and isolation of CO_2. Traditional capture methods include physical adsorption, chemical absorption, and membrane separation, but these methods have challenges such as high energy consumption and complex equipment. Therefore, innovation in capture technology is imperative. In recent years, innovative capture technologies have emerged. One such innovation is the use of advanced materials such as Metal-Organic Frameworks (MOFs) and ionic liquids in physical adsorption techniques. These materials have high selectivity and tunability, improving the efficiency of CO_2 adsorption and reducing energy consumption. On the other hand, chemical absorption technology is also innovating, for example, using renewable energy-driven absorption solvents, reducing reliance on traditional organic amines, thereby enhancing capture efficiency and reducing environmental impact. These new technologies still face challenges in scaling up and economic feasibility. In practical industrial applications, further validation of the stability, sustainability, and cost-effectiveness of these technologies is needed to ensure their significant impact in various factories and power plants.

3.1.2 Feasibility of Storage and Transportation

Storage and transportation are another crucial aspect in the CCUS technology chain, directly involving the long-term isolation and effective utilization of CO_2. Issues such as the selection of geological layers, injection techniques, monitoring, and tracking need to be addressed in the storage process. In terms of storage, underground rock layer injection is considered a viable method but faces challenges in the selection and stability of geological layers. Concerns about underground storage exist at the local level, such as the risk of earthquakes and the potential for underground water contamination. Therefore, it is necessary to ensure the safety of storage through technological means and enhance public acceptance of CCUS technology through effective community engagement and communication mechanisms. In transportation, establishing a reliable and efficient transport network is an urgent issue. Long-distance CO_2 transport requires the development of a comprehensive pipeline system or the use of advanced liquefaction techniques to ensure the safety and economic viability of the transport process. Additionally, monitoring and tracking technologies during transportation need continuous improvement to address potential leakage risks and ensure that CO_2 does not have irreversible effects on the environment during transport.

3.2 Economic Challenges

The promotion and application of CCUS technology face a series of economic challenges, including issues related to investment and costs, as well as the establishment of market mechanisms. Addressing these economic challenges is crucial for the large-scale application of CCUS technology and requires comprehensive considerations in terms of policies, funding, and market mechanisms.

3.2.1 Investment and Costs

The implementation of CCUS technology requires a significant amount of capital investment, involving multiple stages such as capture, storage, and transportation, each of which faces considerable cost pressures. The innovation and updates in capture technology bring about substantial research and equipment investments, particularly for the practical application of novel capture technologies that require even greater financial support. Additionally, geological surveys during storage and transportation, injection facility construction, and pipeline system deployment all demand substantial economic support. This presents a practical challenge for many enterprises considering CCUS projects due to the relatively long return on investment periods.

3.2.2 Establishment of Market Mechanisms

The widespread application of CCUS technology also faces the challenge of imperfect market mechanisms. Due to the inadequate pricing of CO_2 emissions and the lack of a clear market value, CCUS projects struggle to compete on a commercial level. Furthermore, the inadequacy of carbon trading markets constrains the development of CCUS technology. In the existing carbon market, CO_2 prices fluctuate significantly, making it difficult to provide stable economic incentives. Governments can guide the stable operation of the carbon market by setting upper and lower limits on carbon prices, and by establishing carbon emission quotas. Simultaneously, CCUS projects can gain carbon emission rights by participating in carbon trading markets, enhancing their economic returns in market competition.

3.3 Social and Political Factors

The promotion and implementation of CCUS technology face constraints not only in terms of technical and economic challenges but also due to social and political factors. Issues such as social acceptance and the refinement of policies and regulations directly impact the development and application of CCUS technology. Achieving a balance in social consensus and political support is crucial for the advancement of CCUS technology.

3.3.1 Social Acceptance

Social acceptance is one of the crucial factors for the promotion of CCUS technology. As CCUS technology involves the capture, transportation, and storage of CO_2, these processes may impact local communities, triggering concerns and opposition from the public. For example, underground storage may raise concerns about induced seismicity, while the construction of transportation pipelines may involve issues of land acquisition and environmental pollution. To enhance social acceptance, extensive and transparent social engagement and communication are essential. Governments and companies should establish effective communication channels with local residents, providing detailed information on the safety and environmental aspects of CCUS technology and seeking input and feedback from residents. Additionally, establishing fair compensation mechanisms and community-sharing mechanisms, allowing local residents to benefit from CCUS projects, can help alleviate public concerns.

3.3.2 The Improvement of Policies and Regulations

The refinement of policies and regulations is crucial for the widespread promotion of CCUS technology. The lack of clear legal regulations increases the uncertainty of CCUS projects, exposing investors to significant risks in decision-making. Government policy orientation directly influences the extent to which businesses adopt CCUS technology. In some countries, the government encourages emission reduction by implementing measures such as carbon emission taxes and establishing carbon markets, providing a better policy environment for the application of CCUS technology. To address this issue, governments worldwide need to establish clear regulations to standardize the application of CCUS technology. These regulations should cover aspects such as the approval process, environmental standards, community participation mechanisms, and more, ensuring the sustainable development of projects. Additionally, governments can provide economic support for CCUS projects through tax policies, fiscal incentives, and other means to enhance investment motivation for businesses.

3.3.3 International Collaboration and Governance

The development of CCUS technology requires international collaboration and governance. Since greenhouse gases transcend national borders, countries should collectively strive to establish unified standards and regulations to promote the global deployment of CCUS technology. Additionally, international cooperation can facilitate the sharing of experiences and technologies, reducing the costs of CCUS projects and enhancing their feasibility.

International organizations and forums play a crucial role in this regard, such as the United Nations Framework Convention on Climate Change (UNFCCC) and the International Energy Agency (IEA). These organizations can promote technological collaboration and policy dialogues among nations, assisting developing countries in enhancing the application level of CCUS technology. Regarding social and political factors, the development of CCUS technology necessitates collaborative efforts from governments, businesses, research institutions, and various societal sectors. By enacting clear policy regulations, enhancing social participation, increasing social acceptance, and fostering international cooperation, a more favorable social and political environment can be created for CCUS technology, propelling it towards a more sustainable and widespread application.

4 Future Development Directions and Collaboration Opportunities

4.1 Technological Innovation and Research and Development

In the development process of CCUS, technological innovation and research and development are the core drivers that promote progress in this field. On one hand, this includes the development of novel capture technologies, and on the other hand, it involves the innovation of efficient storage and transportation systems, both of which are crucial factors in enhancing the feasibility and economic viability of CCUS technology.

4.1.1 Novel Capture Technologies

The development of novel capture technologies is one of the key directions for the advancement of CCUS technology. Traditional capture technologies such as physical adsorption, chemical absorption, and membrane separation have certain limitations in terms of efficiency and economic viability. Therefore, more advanced methods are required to enhance capture efficiency and reduce costs.

A potentially groundbreaking new technology is Direct Air Capture (DAC), which allows for the direct capture of CO_2 from the atmosphere. CO_2 is absorbed from the atmosphere through an adsorbent and then released through thermal processing or other methods. Research on DAC technology aims to improve adsorption efficiency, reduce energy consumption, and explore more environmentally friendly adsorbents. This technology is of significant importance for areas where capturing at the source is challenging. Another innovative direction involves utilizing biological means for capture. Biological capture technology involves the conversion of CO_2 into organic substances by organisms such as plants, algae, or microorganisms, thereby achieving emission reduction. This method holds potential application prospects for specific scenarios, such as ecological restoration near industrial emission sources.

4.1.2 Efficient Storage and Transportation Systems

Efficient storage and transportation systems are crucial links in ensuring the feasibility and long-term stable operation of CCUS technology. Traditional underground storage and pipeline transportation systems face limitations in terms of cost and efficiency, necessitating technological innovation to enhance their performance.

In storage, an emerging technology involves mineralization of CO_2 using rock minerals. This method involves injecting CO_2 into underground rock formations containing alkaline minerals, triggering mineralization reactions and permanently storing CO_2 as carbonate. This not only reduces reliance on traditional underground formations but also offers longer-term storage potential. In the transportation aspect, the emerging technology of liquid CO_2 transportation is gaining prominence. By compressing CO_2 into a liquid state, the volume is reduced during transportation, thereby enhancing transport efficiency. Furthermore, advanced supercritical CO_2 technology is also under research with the aim of increasing transport efficiency while reducing energy consumption.

The government can encourage businesses to innovate through means such as financial investment, research and development incentives, and regulatory frameworks. Businesses, in turn, need to conduct testing and application in actual projects, laying the groundwork for the commercialization of the technology. Research institutions should strengthen fundamental research to drive continuous innovation in CCUS technology. By continuously promoting technological innovation and research and development, CCUS technology is poised to make greater breakthroughs in novel capture technologies and efficient storage and transportation systems, providing more feasible and sustainable solutions for achieving carbon neutrality goals.

4.2 Economic Cooperation and Investment

In the promotion of CCUS, economic cooperation and investment are crucial factors driving the development of this technology. On one hand, this involves collaboration between the public and private sectors, and on the other hand, it entails international institutions supporting CCUS technology, collectively promoting the optimal utilization of economic resources.

4.2.1 Collaboration between Public and Private Sectors

The development of CCUS technology requires close collaboration between the public and private sectors. The public sector plays a crucial role in formulating policies, providing funding, and overseeing regulatory aspects. The government can provide a stable policy environment for CCUS technology through measures such as setting carbon emission standards and implementing carbon trading policies. Government support in initial project investment, tax incentives, and research and development funding can reduce the risks for businesses involved in CCUS projects. At the same time, private sector investment and technological innovation are indispensable components of the development of CCUS technology. Private sector involvement in CCUS projects, including energy companies, industrial giants, and venture capital firms, can not only provide rich experience and resources but also drive technological innovation and commercialization. Establishing a public-private partnership model, jointly shouldering risks, can drive the scaled application of CCUS technology.

4.2.2 Support from International Institutions

International institutions play a crucial role in promoting the global deployment of CCUS technology. For instance, the IEA provides guidance to countries on the development of CCUS technology through the publication of technology roadmaps and policy recommendations. Additionally, international financial institutions such as the World Bank and the Asian Development Bank contribute to the economic foundation of CCUS projects by providing financial support. Various mechanisms under the UNFCCC provide international support for CCUS technology. Mechanisms such as the Clean Development Mechanism (CDM) and carbon market mechanisms under the Paris Agreement provide economic incentives for CCUS projects, encouraging collaboration among countries in carbon emissions reduction.

At the international cooperation level, governments and businesses of various countries can collectively advocate for the involvement of international institutions. Through the sharing of technology and experiences, this can reduce the global deployment costs of CCUS projects. Additionally, international cooperation helps address legal, policy, and technological challenges faced by CCUS technology on a global scale. Economic cooperation and investment are decisive factors in determining whether CCUS technology can achieve widespread application. Through public-private partnerships and support from international institutions, there will be sufficient economic foundation and resources for the widespread promotion of CCUS technology globally. This collaboration not only contributes to achieving climate goals but also promotes the development of a green economy.

4.3 International Collaboration and Experience Sharing

International collaboration and experience sharing are indispensable components in addressing global climate challenges. By promoting transnational projects, sharing successful experiences, and establishing collaborative mechanisms, the international community can collectively address the challenges of CCUS technology.

4.3.1 Promotion of Transnational Projects

Promoting transnational CCUS projects is an effective approach to enhancing the global application level of CCUS technology. Such projects not only facilitate the sharing of technological experiences but also allow for the sharing of costs and risks, achieving efficient resource utilization. Energy companies, research institutions, and government departments internationally can collaboratively drive transnational CCUS projects through cooperation. The selection of projects can span different countries and regions, covering various industrial sectors to ensure the adaptability of the technology in different environments. Through joint investment, resource integration, and experience sharing, transnational projects are expected to be a significant driving force for the development of CCUS technology.

4.3.2 Establishment of Experience Sharing and Collaboration Mechanisms

Experience sharing is a key driver for the innovation and application of CCUS technology. The experiences accumulated by countries and regions in CCUS projects can offer valuable insights and lessons for other nations. Establishing platforms for experience sharing and collaboration mechanisms is crucial to achieving this goal. International organizations, industry associations, and governments can collaboratively establish mechanisms for sharing CCUS technology experiences. This can be achieved through regular international workshops, technical forums, and training activities to facilitate exchange among experts and professionals from various countries. Simultaneously, establishing an international CCUS technology database to collect and organize information on CCUS projects, technological innovations, and successful experiences worldwide will provide reference and insights for countries.

In terms of cooperation mechanisms, the international community can strengthen collaboration mechanisms under the UNFCCC, encouraging countries to reach clearer consensus on carbon reduction and the development of CCUS technology. Establishing alliances for CCUS technology cooperation can facilitate close collaboration among governments, businesses, and research institutions worldwide, collectively driving the research, development, and promotion of CCUS technology.

4.3.3 Global Governance and Standard Setting

At the global governance level, establishing unified standards for CCUS technology is a crucial element in promoting international cooperation. Unified standards help reduce operational risks in transnational projects and enhance the universality and interoperability of the technology. International organizations such as the IEA can play a leading role in standard setting, encouraging countries to jointly establish global standards for CCUS technology.

Through transnational cooperation, experience sharing, and global governance, the international community can form a more closely-knit collaboration network in the development of CCUS technology. This collaboration can not only drive technological innovation but also provide more choices and support for countries, collectively addressing the challenges of global climate change. In the development of CCUS technology, the international community should collectively strive to build more interconnected and coordinated collaboration mechanisms.

5 Conclusion

Carbon Capture, Utilization, and Storage (CCUS), as a key measure in addressing climate change, is crucial for global sustainability in its development and application. The significance of CCUS technology lies not only in its direct contribution to greenhouse gas emissions reduction but also in providing a transitional solution for high-emission industries, offering flexibility in achieving carbon neutrality goals. By advancing the development of CCUS technology, the energy industry can transition towards a low-carbon direction, slowing down the pace of global climate change. Currently, CCUS technology still faces challenges in aspects such as capture, storage, and transportation. Furthermore, imperfect market mechanisms and operational costs present challenges to CCUS technology. By employing more efficient and cost-effective innovative capture methods, there is hope for achieving a broader application of CCUS technology. Jointly formulating rational policies and market mechanisms globally can provide more stable economic incentives for CCUS technology. Additionally, transnational cooperation and sharing of experiences will provide strong support for the global promotion of CCUS technology. With joint efforts from the global community, CCUS technology has the potential to become a key weapon in achieving carbon neutrality, laying a solid foundation for global sustainable development.

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