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Analysis of CCS Technology Applied in Green Building

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Abstract. As the global climate change crisis intensifies, the integration of green building practices with carbon capture and storage (CCS) technology is increasingly emerging as a focal point of research within the architectural domain. Green buildings prioritize resource efficiency, environmental sustainability, and long-term viability, while CCS technology serves as an effective mechanism for mitigating carbon emissions. This paper examined the application of CCS technology in green buildings and identifies its significant potential across various stages of building design, construction, and operation. Firstly, CCS technology can substantially reduce carbon emissions during the production processes of construction materials—particularly in high-emission sectors such as cement and steel manufacturing. Furthermore, by synergizing CCS technology with energy systems utilized in building operations, it becomes feasible to capture carbon emissions generated from routine energy consumption, thereby facilitating a near-zero carbon footprint. Nonetheless, challenges related to integration complexity and elevated costs hinder the deployment of CCS technology within existing structures—especially older buildings where spatial constraints and infrastructural limitations pose considerable obstacles. The lack of clear economic incentives has deterred numerous construction projects from investing in CCS solutions, further constraining its broader adoption within the built environment.

Keywords: Green Building; CCS Technology; Carbon Emissions.

1. Introduction

As the global community's need to address climate change becomes increasingly urgent, the application of innovative technologies in various industries is becoming increasingly important, especially in the construction and energy sectors. The construction industry is one of the major sources of global greenhouse gas emissions, accounting for a significant proportion of global carbon emissions. With the concept of sustainable development, the research of green building technology and related emission reduction technology has become a hot spot, among which carbon capture and storage technology (CCS) is gradually regarded as a key means to cope with the challenge of global climate change. CCS technology plays a vital role in reducing carbon emissions by capturing carbon dioxide (CO_2) and securely storing it underground, preventing it from entering the atmosphere.

In high-carbon industries, CCS technology shows significant emission reduction potential, especially in the traditional energy sector and heavy industries such as coal-fired power plants and steel. In recent years, researchers have begun to explore how CCS technology can be applied to the construction sector, especially in the design and operation of green buildings, to further reduce the carbon footprint of buildings throughout their life cycle. The construction and building operations sector is one of the major contributors to global carbon emissions, and the introduction of CCS technology provides these sectors with new emission reduction solutions, helping to further reduce the global carbon emissions.

In recent years, significant progress has been made in the research of green building technologies, especially in the areas of energy efficiency and sustainable design. Scholars have conducted in-depth research on the combination of green buildings and carbon emission reduction technologies, and gradually explored how to achieve carbon neutrality in the building field through new technological means. Bui et al. studied the use of CCS technology in industry and power generation, noting that despite significant progress in CO_2 capture technology, large-scale commercialization remains challenging. These challenges stem mainly from high costs, infrastructure complexity, and lack of policy support. However, with the continuous development of technology, the application prospect of CCS technology in the field of construction has gradually been recognized and has become an emerging hot spot in the field of construction research [1]. Fontenelle et al. further explored the important role of CCS technology in the Sustainable Development Goals (SDGs). Their research found that CCS technology could not only help mitigate climate change, but also support the achievement of multiple SDGs goals, particularly in reducing carbon emissions from the industrial sector. Through improved governance structures and technological innovation, CCS technology is expected to achieve wider application [2]. The report of the International Energy Agency also highlights the key role of CCS technology in the global progress towards carbon neutrality. The report points out that despite the gradual adoption of green energy technologies, deep emissions reductions in industry and buildings still need to rely on negative emission technologies such as CCS. The IEA called on governments to increase policy support for CCS, particularly in developing countries, through funding and technology transfer to help them deploy CCS projects to meet global climate targets [3]. In the construction sector, the design concept of green buildings emphasizes sustainability and energy efficiency, and the integration of CCS technology into the building system can effectively reduce carbon emissions in the urban environment. Using carbon capture technology during construction, carbon dioxide can be safely stored underground, thereby reducing carbon emissions during the building's life cycle. This will not only help the construction industry achieve carbon neutrality, but also provide new ideas for the global response to climate change. Hanifa et al. explored the application of accelerated mineral carbonization technology (AMC) in building materials, pointing out that this technology has significant emission reduction potential, especially in building materials such as cement and concrete. Through AMC technology, carbon dioxide can be captured and converted into stable carbonates that are permanently stored in building materials, thereby reducing the amount of carbon in the atmosphere [4]. In their research, Shu et al. conducted an in-depth analysis of the application of CCS technology in energy systems, exploring its key role in achieving net zero emissions. Modeling the German energy system, Shu et al. found that CCS technology plays an integral role in reducing greenhouse gas emissions, especially in sectors where deep reductions are difficult to achieve through conventional means, such as the steel and cement industries. The study also notes that increasing carbon storage not only significantly reduces overall emissions, but also reduces the operating costs of the entire system [5].

Although the application of CCS technology in industrial and power generation has been extensively studied, the application research in the field of green buildings is still relatively limited. There are few studies on how to effectively integrate CCS technology into building design, construction, and operation, and the feasibility, economics, and combined environmental impact of the technology have not been fully explored. Therefore, this paper focused on the application prospects of CCS technology in green buildings, and analyzed its feasibility, technical challenges, and potential impacted on carbon emissions during building operations. This paper aimed to provide theoretical basis for the future application of CCS technology in green building design and putted forward relevant policy recommendations.

2. Current Status of CCS Technology

Carbon capture and storage (CCS) is a key technology for tackling climate change that involves three main steps. The first is the capture of carbon dioxide, usually by chemical absorption, physical adsorption, or membrane separation techniques. Among them, chemical absorption technologies use amine solvents to capture carbon dioxide in flue gas and are particularly suitable for post-combustion processes in coal and natural gas power plants. The second step is the compression and transport of carbon dioxide. Captured CO2 is usually transported by pipeline or ship to safe storage sites, such as depleted oil and gas fields or deep saline aquifers. The final step is the injection and geological storage of carbon dioxide. In this process, carbon dioxide is injected into deep geological structures, ensuring its long-term storage without leakage. Through this process, carbon dioxide is permanently sequestered, avoiding its entry into the atmosphere, and reducing its impact on the climate.

CCS technology has been successfully applied in many industries around the world, especially in high-emission industries. The most typical applications are in heavy industries such as fossil fuel power generation, cement production, and steel manufacturing. In these areas, CCS can achieve significant emissions reductions by capturing CO_2 produced during production and storing it safely. For example, Canada's Boundary Dam power plant, the world's first large-scale commercial CCS project, has captured more than one million tonnes of CO_2 per year since it became operational in 2014. The Petra Nova project in the US is also one of the largest CCS applications in the world, demonstrating the feasibility of the technology in large-scale power generation facilities [6]. In addition, in the cement and steel industries, Hanifa et al. noted that CO_2 emissions in these industries could be reduced by up to 90% by integrating CCS technology into the production process.

Although CCS technology shows significant potential in several areas, there are still challenges to its widespread adoption. The first is the high cost. The construction and operation costs of CCS projects are very high, and every step of capturing, transporting, and storing CO_2 requires significant financial support [7]. Bui et al. point out that current CCS costs range from $40 to $80 per ton of CO_2 capture, making many projects economically unviable, especially in the absence of a carbon pricing mechanism. In addition, the deployment of CCS technology also faces complex technical issues, especially safety in geological storage. The long-term storage of CO_2 involves the complexity of the geological structure and the possible risk of leakage. If carbon dioxide leaks from storage facilities, it could contaminate nearby groundwater resources. For example, CO_2 makes water more acidic when it encounters groundwater, leading to the dissolution of metals and other harmful substances, thus affecting water quality. Such potential environmental risks have attracted widespread attention from the public and policy makers [8]. Nevertheless, the study by Shu et al. suggests that further reductions in CCS costs are expected through technological advances, especially with large-scale implementation and technology optimization . Some countries have promoted the commercial adoption of CCS through policy incentives, such as carbon taxes and subsidies. For example, the United States has promoted the development of carbon capture projects through the "45Q tax credit" policy, allowing large facilities such as the Petra Nova project to operate. In addition to cost and technical challenges, social acceptance and policy support are another obstacle to CCS adoption. Fontenelle et al. point out that there are public concerns about the safety of CO_2 geologic storage, particularly concerns about potential seismic risks and groundwater contamination. Therefore, policymakers need to increase awareness and education about CCS technology, enhance public trust, and strengthen regulation to ensure the safety of the storage process.

3. Examples of Application of CCS Technology in Green Buildings

3.1. Green Buildings

Green building is mainly to reduce the negative impact of buildings on the environment through energy efficiency and resource conservation. It emphasizes not only reduced energy consumption in the building in the whole life cycle and pay attention to the sustainable use of materials, and buildings to the ascension of the health and comfort of [9]. Green building design often involves multiple dimensions, including efficient energy use systems, the integration of renewable energy sources, the use of sustainable building materials, and effective water management. In addition, green buildings employ strategies such as natural ventilation and passive design to minimize reliance on mechanical cooling and heating systems, thereby reducing energy consumption and carbon emissions.

To promote the global development of green buildings, several international green building assessment standards came into being. The most representative standards include LEED (Leadership in Energy and Environmental Design) and BREEAM (Building Research Establishment Environmental) Assessment Method), these standards for green building design, construction and operation provides clear guidelines and evaluation system. Green building is not only a technical concept, but also an important part of a global sustainable development strategy. By driving an environmentally friendly transformation in the construction sector, green buildings make a significant contribution to meeting global climate goals and play an integral role in future urban development planning.

3.2. Combination of Carbon Capture Technology and Green Building

CCS (Carbon capture and Storage) technology was initially used mainly in traditional high-carbon emitting industries, such as fossil fuel power plants and heavy industry. However, as global action on climate change accelerates, researchers and practitioners are beginning to explore the potential of bringing CCS technology to the construction industry, particularly in green buildings. Green buildings emphasize resource conservation, energy efficiency and sustainable development, and CCS technology fits in with these goals, providing a new solution for carbon reduction throughout the building life cycle.

During the production of building materials, especially energy-intensive materials such as cement and steel, large amounts of carbon dioxide are usually emitted. Cement industry itself is one of the main sources of global carbon dioxide emissions, per 1 ton cement production will be about 0.7 to 1 ton of carbon dioxide emissions. Applying CCS technology to these production processes can capture and store a high percentage of carbon emissions, thereby reducing the negative environmental impact of material manufacturing. Studies have shown that by incorporating carbon capture technology into the cement production process, 90% of the CO_2 emissions generated during production can be effectively captured. This not only helps green buildings reduce their carbon footprint during construction, but also contributes to carbon reduction throughout the building supply chain.

In addition, in operation stage of the construction, building energy consumption, especially in heating, cooling, lighting and other daily energy demand, also can produce large amounts of carbon dioxide emissions. Combined with CCS technology, power plants can capture the carbon dioxide produced by their operations during energy consumption, storing it in geological structures underground. At the same time, waste heat recovery is also widely used to drive carbon capture devices, for example, in the Petra Nova project, a coal-fired power plant uses part of the waste heat to drive the capture equipment, thereby reducing the need for additional energy. In this way, green buildings can achieve near-zero carbon emissions during operation.

Canada's Boundary Dam power plant, for example, is the world's first large-scale commercial carbon capture and storage project, capturing and storing 1 million tonnes of CO_2 per year. Although the project is mainly used in the power generation sector, its technology and implementation experience can also be borrowed from the construction sector, especially in energy-intensive buildings, whereby integrating similar CCS technology, buildings can achieve full process control from energy consumption to carbon sequestration.

The Porthos project in Europe provides another success story for the use of CCS technology in buildings. The project through the industrial park and capture the carbon dioxide in the construction site, through pipes in offshore storage facilities, storage in the underground saline aquifers. This project demonstrates the possibility of using a centralized CCS system to serve multiple construction projects and industrial facilities, and effectively reduce CO_2 emissions in a local area [10]. This way, especially suitable for high density urban area, many buildings and industrial facilities can share a CCS system, further improve the carbon capture efficiency, and reduce costs. At the same time, the project plans to power its CCS equipment with renewable energy sources such as wind and solar. This model can reduce the operational energy consumption of CCS systems, making them more environmentally friendly and economically viable. While the project is currently in the planning and pilot stages, it provides a strong argument for using renewable energy to power CCS equipment in buildings and industrial facilities in the future.

However, the application of CCS technology in green buildings is not limited to large-scale commercial projects. The residential buildings of the future can also achieve carbon reduction with CCS technology, especially in the emerging low carbon and net zero emission housing sector. By combining renewable energy with carbon capture technologies, residential buildings will be able to capture and store carbon emissions during daily use, moving towards a more sustainable model of building operations . In general, the application of CCS technology in green buildings has broad prospects. Although at present is still in the early stage of development, but with the progress of technology and cost down, the future of green building design and operation will be more and more dependent on CCS technology integration, to contribute to global carbon neutral targets.

4. CCS Technology in The Application of Green Building Barriers and Coping Strategies

4.1. Technical Challenges of CCS Technology in Building Applications

The application of CCS technology in buildings faces many technical challenges. The first is the complexity of integration. Buildings, especially existing old buildings, which are older and not designed in accordance with current energy standards, have not considered later technological upgrades. In the process of building retrofitting, the integration of energy systems with CCS equipment is extremely difficult due to space, structural and infrastructure constraints [11]. Second, the high cost of CCS technology also poses a significant obstacle. The cost of installing and maintaining CCS systems is high, and it is often difficult for building developers and owners to bear this additional financial burden. Many projects have reservations about investing in CCS technology due to the lack of clear economic returns in the short term. These technical challenges not only increase the difficulty of CCS technology in building applications, but also limit its wider adoption.

4.2. Coping Strategies and Policy Support for CCS Technology

To cope with the above challenges, we must adopt various strategies and policy support. First, through technological innovation and large-scale production, the cost of CCS equipment can be effectively reduced, making it more economically viable in construction applications. In addition, the integration needs of CCS technology should be considered in the design of buildings, and sufficient space and infrastructure should be reserved in new projects to install and operate carbon capture systems in the future. Policy support is also crucial in promoting the adoption of CCS technology. The government can provide financial subsidies, tax breaks and cheap loans, reduce the economic pressure of developers and owners. In addition, the development of mandatory carbon emission regulations requiring high-emission buildings to implement CCS technology is also an effective means to promote the widespread use of this technology. Through international cooperation and technology sharing, countries can also jointly address the challenges of CCS technology in construction applications and accelerate the introduction of this technology on a global scale.

5. Conclusion

This study revealed that CCS (carbon capture and storage) technology has significant application potential in the field of green building, especially in the production of building materials and building operation process, CCS technology can effectively reduce carbon emissions. Studies have shown that in high-carbon emitting industries such as cement and steel, combined with CCS technology can capture and store more than 90 percent of carbon dioxide, significantly reducing the negative environmental impact of the material manufacturing process. In addition, CCS technology can be integrated with the energy system in the operational phase of the building, effectively capturing the carbon dioxide produced during the daily energy consumption of heating, cooling, and lighting. This combination can drive green buildings to achieve near-zero carbon emissions, further advancing the global carbon neutrality process. Despite the promising applications of CCS technology, its implementation in buildings faces many challenges, such as integration complexity, space constraints, and high costs. At present, the application of CCS technology in the field of industry and power generation is relatively more research, but its application in green buildings is still relatively limited. This paper filled this gap and further enriches the field of green building research by analyzing in detail the feasibility of CCS technology in building design, construction and operation and its impact on carbon emissions. However, the adoption of CCS in buildings faces some important challenges.

First, integration complexity is a major barrier, especially in existing, older buildings, where the spatial and structural limitations of installing and maintaining CCS systems significantly increase the technical difficulty. Secondly, the high cost of CCS system makes many construction projects can't afford the extra financial burden, especially in the absence of clear economic returns in the short term. Future research should focus more on how to reduce the cost of CCS technology and improve its economic viability. In addition, policy support is also crucial, and governments should encourage developers and owners to invest in CCS technology through subsidies, tax incentives and other means.

This study provided a theoretical basis for the future application of CCS technology in green buildings, and puts forward policy recommendations to address technical challenges, aiming to promote the wider application of CCS technology in the construction sector and contribute to the realization of global carbon neutrality.

References

[1] M. Bui, C. S. Adjiman, A. Bardow, Carbon capture and storage (CCS): The way forward, Energy Environ. Sci. 11 (2018) 1062-1176.

[2] A. L. Fontenele, D. L. Peyerl, L. G. L. Zacharias, M. Ciotta, E. M. Moretto, The role of the sustainable development goals for better governance of carbon capture and storage (CCS), Desenvolv. Meio. Ambiente. 62 (2023) 478-498.

[3] Information on: https://www.iea.org/reports/ccus-in-clean-energy-transitions.

[4] M. Hanifa, R. Agarwal, U. Sharma, P. C. Thapliyal, L. P. Singh, A review on CO2 capture and sequestration in the construction industry: emerging approaches and commercialized technologies, J. CO2 Util. 67 (2023) 102292.

[5] D. Y. Shu, S. Deutz, B. A. Baumgärtner, N. Leenders, A. Bardow, The role of carbon capture and storage to achieve net-zero energy systems: trade-offs between economics and the environment, Renew. Sustain. Energy Rev. 178 (2023) 113246.

[6] H. Eldardiry, E. Habib, Carbon capture and sequestration in power generation: Review of impacts and opportunities for water sustainability, Energy Sustain. Soc. 8 (2018) 1-16.

[7] A. L. Fontenele, D. L. Peyerl, L. G. L. Zacharias, M. Ciotta, E. M. Moretto, The role of the Sustainable Development Goals for better governance of Carbon Capture and Storage (CCS), Desenvolv. Meio. Ambiente. 62 (2023) 478-498.

[8] M. Shen, F. Kong, L. Tong, Carbon Capture and Storage (CCS): Development Path Based on Carbon Neutrality and Economic Policy, Carbon Neutrality. 1 (2022) 37.

[9] Y. Li, Y. Rong, U. M. Ahmad, X. Wang, J. Zuo, G. Mao, A comprehensive review on green buildings research: bibliometric analysis during 1998–2018, Environ. Sci. Pollut. Res. 28 (2021) 46196-46214.

[10] J. Fan, J. Zhang, L. Yuan, N. He, Y. Zhao, W. Xin, Deep Low-Carbon Economic Optimization Using CCUS and Two-Stage P2G with Multiple Hydrogen Utilizations for an Integrated Energy System with a High Penetration Level of Renewables, Sustainability 16 (2024) 5722.

[11] A. Saari, S. Junnila, J. Vimpari, Blockchain's grand promise for the real estate sector: a systematic review. Appl. Sci., 12 (2022): 11940.