Status and Strategies for Advancing Carbon Capture and Storage Technology

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Abstract. As global climate change becomes more and more severe, carbon capture and storage (CCS) technology is widely regarded as one of the key pathways to achieve carbon neutrality. However, despite the theoretical potential of CCS technology to reduce emissions, its widespread deployment progresses slower than expected. This review deeply discusses the current situation, challenges, and future development countermeasures of each link of the CCS technology chain. The analysis indicates that there is a significant gap in the maturity of each link in the CCS technology chain. For example, the carbon capture technology is relatively advanced, while the verification of the storage link is relatively lagging, which seriously restricts the widespread deployment of CCS technology. To solve the above problems, this review proposes to establish a CCS deployment framework guided by the technology-scenario matching decision model. At the same time, a phased implementation path is proposed: in the near term (2025-2035), cluster-based deployment reduces unit costs, and in the long term, the synergy of the technology chain will be optimized with the help of artificial intelligence. In addition, the paper highlights the importance of strengthening technology research and development, policy support, and increasing public participation.

Keywords: carbon capture and storage, technology maturity, economic analysis

1. Introduction

In the context of intensifying global climate change, carbon neutrality has become the core goal of the sustainable development of all countries. Carbon capture and storage (CCS) technology is an important means of reducing emissions, separating carbon dioxide from industrial sources, and safely storing it in geological formations, thereby reducing greenhouse gas concentrations in the atmosphere. CCS technology includes a range of different stages, including capture, sequestration, and transportation. Carbon capture and storage technology has been listed by the International Energy Agency (IEA) and the United Nations Intergovernmental Panel on Climate Change (IPCC) as a "key pillar technology" to achieve carbon neutrality due to its irreplaceable role in the emission reduction pathway. According to the Global Carbon Capture and Storage Institute (GCCSI), as of 2023, only about 135 large-scale commercial CCS projects have been completed in the world, with less than 40 million tons of CO_2 stored annually, accounting for only 0.1% of the current global annual carbon emissions [1]. Despite the great potential of CCS technology, its deployment rate is much slower than expected, and its scale lags significantly behind.

The core restricting the development of CCS lies in the significant imbalance in the technology maturity of each link in the whole industry chain. On the one hand, the technology of carbon capture is relatively mature. According to the 2022 report of the International Energy Agency, the cost of capture has dropped to US$40-80/ton CO_2 [2]. On the other hand, progress in transportation and storage has been slow. This is mainly limited by insufficient geological validation, questionable long-term safety, and a lack of regulations. The Petra Nova project in the United States was suspended in 2020 due to deviations in the assessment of the capacity of the storage site, highlighting the shortcomings of the back-end of the industrial chain. This kind of technology chain fault of "advanced capture and lagging storage" makes it difficult to guarantee the overall economy and reliability of the project, and further inhibits the willingness to invest. Based on the above situation, this review focuses on the systematic comparison of CCS full-chain technologies, aiming to accurately identify the key bottlenecks restricting its large-scale development and formulate phased and operational promotion strategies accordingly. The review results are expected to provide theoretical support and practical guidance for promoting the wide application of CCS technology and helping to achieve the global carbon neutrality goal.

2. Overview of carbon dioxide capture technologies

In the context of tackling greenhouse gas emissions, carbon dioxide capture technology, as an important means to reduce carbon emissions, has become the focus of global research and industrial application. The capture technology is mainly divided into three main methods: post-combustion capture, pre-combustion capture, and oxy-fuel combustion capture. Different capture technologies have different technical paths and economic advantages, and are suitable for various industrial processes and coal-fired power plants.

2.1. Post-Combustion Capture

Post-Combustion Capture captures the carbon dioxide produced in the flue gas after the fuel has been completely combusted. This technology has been used in several areas, especially in conventional coal and natural gas power plants. The main process is to extract carbon dioxide from the emitted flue gas by chemisorption, physical adsorption, membrane separation, or low-temperature separation. At present, amine absorption is one of the most widely used methods in post-combustion capture technology. It uses absorbents such as alcohol amine to chemically react with carbon dioxide, thereby achieving the separation of carbon dioxide. This technology has a high carbon dioxide capture efficiency, generally reaching more than 90%, and has strong adaptability to the combustion process, and can be applied to various types of combustion equipment [3].

However, the main disadvantage of post-combustion capture is the high energy consumption, especially in the CO_2 adsorption and desorption process, which often requires a large amount of thermal energy. For example, solvent absorption, as a common method of post-combustion capture, involves the consumption of a large amount of steam to drive the desorption of carbon dioxide, which greatly increases its cost and energy consumption [4]. In addition, the corrosiveness of solvents during the capture process and the control of carbon dioxide purity pose several technical challenges. Despite this, post-combustion capture is still the main technological path to achieve significant emissions reductions from existing large-scale stationary sources, mainly power stations and large industrial plants.

2.2. Pre-Combustion Capture

Pre-Combustion Capture is a process that reacts with oxygen and air to produce "syngas" or "fuel gas" composed of carbon monoxide and hydrogen before the fuel enters the combustion system. Carbon monoxide reacts with steam in a catalytic reactor to produce carbon dioxide and more hydrogen. This technology is mainly used in carbon dioxide capture in the gasification process, and its basic principle is to use the water gas reaction to generate syngas after coal or natural gas gasification, and separate carbon dioxide through physical adsorption or chemical adsorption. Due to the maturity and similarity of the technologies, pre-combustion capture technology can be applied to industries with high CO_2 emissions, such as chemicals (natural gas and coal-based) and steel [5].

The Integrated Coal Gasification Combined Cycle (IGCC) power generation system is a typical application scenario of pre-combustion capture technology. In this system, the coal is gasified to produce syngas, part of which is used to generate electricity, and part of which is separated from carbon dioxide through a physical or chemical absorption process. The IGCC plant is a highly integrated and complex system, and China Huaneng Group's GreenGen project, the first pilot project of IGCC technology in China, is designed to capture more than 80% of CO_2. As of September 23, 2018, the GreenGen IGCC unit has been in continuous operation for 3,917 hours, setting a new world record for continuous operation of an IGCC unit. And the actual operating efficiency of the first phase of IGCC units can reach about 41%. The GreenGen project serves as an important demonstration of IGCC technology in China, demonstrating the potential of the technology in terms of efficiency, continuous operation capacity, and environmental performance, with emission indicators outperforming some natural gas power plants [6]. Although the pre-combustion capture technology has achieved high capture efficiency in IGCC power generation systems, the high investment cost and reliability of IGCC power generation technology have limited its development. On the one hand, complex equipment (e.g., gasification, purification, and combined circulation systems) drives up costs; On the other hand, reliability issues such as coal type adaptability and equipment stability still need to be solved. To a certain extent, these factors limit the large-scale popularization and application of pre-combustion capture technology.

2.3. Oxy-fuel combustion technology

Oxy-fuel combustion technology provides a high concentration of oxygen to the combustion system, so that the fuel can be burned in an oxygen-rich environment, to improve the combustion efficiency and reduce carbon dioxide concentration. Oxy-fuel combustion can be achieved in different ways, such as an air separation unit (ASU) to provide pure or oxygen-enriched air, or to obtain high concentrations of oxygen through membrane separation technology. The advantage of this technology is that it can significantly improve the combustion efficiency, reduce the emission of pollutants such as nitrogen oxides, and at the same time greatly increase the concentration of carbon dioxide in the flue gas, which is convenient for subsequent capture and separation. However, there are also some significant drawbacks to oxy-fuel technology. The air separation plant is one of the key equipment for oxy-fuel combustion, and its investment cost and operating energy consumption are high, which increases the overall cost of oxy-fuel combustion technology. The energy requirements of current ASU technology increase as oxygen purity levels increase. For a typical flame-fired power plant design with 95% oxygen purity, the energy loss from oxygen production is approximately 60% [7]. Therefore, to make oxy-fuel carbon capture more economical, air separation methods that consume less energy than current cryogenic systems are required. In addition, oxygen-rich combustion will lead to an increase in combustion temperature, which puts forward higher requirements for the materials and structure of combustion equipment, and requires the use of high-temperature and corrosion-resistant materials, which further increases the investment cost of equipment. In addition, there are certain limitations on the adaptability of oxy-fuel combustion technology, and the combustion process may be affected for some fuels with low calorific value or fuels with more impurities [8].

2.4. Summary

Table 1 shows the comparative and summary analysis of the characteristics of the three capture technologies of post-combustion, pre-combustion, and oxy-fuel combustion. The analysis shows that although different capture technologies have their advantages, they face challenges in terms of technical maturity, economics and facility adaptability: the renovation of old plants is often forced to choose high-cost post-combustion capture technology; Pre-combustion capture is more suitable for new projects than retrofits due to the high initial investment in gasifiers and other equipment. Oxy-fuel combustion is limited by the economics of the air separation unit, and it is difficult to achieve large-scale independent promotion. With the continuous advancement of technology and the gradual reduction of costs, these trapping technologies are expected to be more widely used in the future.

Table 1. Comparison of key characteristics of major CO_2 capture technologies

Technical dimension	Capture after burning	Capture before burning	Oxy-fuel combustion
Energy consumption characteristics	High The constraints are significant	Lower Some conditions need to be optimized	Higher It is necessary to break through the technical bottleneck
Maturity level	Highest Some of the technologies have been commercialized	Some of the technologies are mature	Developing
Economical	Retrofit costs are medium Operational energy consumption drives up long-term costs	The initial investment is extremely high Suitable for new projects	ASUs account for more than 40% of the cost Poor economy
Capture efficiency	High	Lower	Higher Affected by combustion stability

3. Technical and economic analysis of CO_2 transportation

In the chain of carbon capture and storage technology, transportation plays a key role in connecting the upper and lower levels. It not only determines the efficiency of CO_2 transfer from the capture point to the storage point or utilization point, but also directly affects the economy and operability of the entire project. At present, pipeline transportation and ship transportation are two mainstream methods, but each is suitable for different scenarios. There are significant differences between the two in terms of technology maturity, cost structure, and applicable scenarios. A reasonable selection of transportation modes is crucial to improve the efficiency of the CCS system and reduce costs.

3.1. Pipeline transportation

Pipeline transportation is the most commonly used and mature mode of CO_2 transportation in current CCS projects, especially for industrial clusters with continuous land and large emissions. It works by compressing CO_2 to a supercritical (typically 7.38 MPa, above 31.1°C) or liquid state and transporting it to a storage or utilization site via a high-pressure pipeline. CO_2 pipeline transportation technology was first applied to secondary oil recovery (EOR) projects in the United States, and has decades of engineering experience.

As of 2022, more than 8,000 kilometers of CO_2-specific pipelines have been built worldwide, with the United States alone accounting for more than 75% of the total length [1]. Pipeline transportation has significant economies of scale, and the larger the transportation volume, the lower the cost per ton.

According to statistics, a 500 MW baseload power plant with an annual operating load factor of 90% and an 85% carbon capture rate can capture about 1.5 million tons of CO_2 per year, and the cost of capturing and compressing CO_2 is about US$1.1/kWh [9]. In terms of transportation costs, the cost of 300 km of overland transportation via pipeline is about $6/ton of CO_2 (about $0.2/kWh of power generation); Maritime transport over the same distance is more expensive, around US$15/ton (US$0.5/kWh) [9]. Pipeline transportation has become an ideal way to transport carbon dioxide due to its high efficiency, safety, and stability, and its suitability for long-term large-scale deployment.

However, there are also several constraints to pipeline transportation. First of all, the upfront investment cost is high, and the construction period is long, especially in land acquisition, environmental assessment, cross-regional coordination, etc. Second, when deployed in areas with complex terrain (such as mountainous areas and dense urban areas) or across borders, pipeline route planning is difficult and costly. It is estimated that the cost of hilly terrain is about 50% higher than that of flat terrain, such as grasslands [10]. In addition, the economics of building pipelines are highly dependent on the geographical proximity between capture and storage sites, which can lead to a spike in project costs if the distance is too far or the emissions are insufficient.

3.2. Ship transportation

Ship transportation is an alternative to CO_2 transportation that has emerged in Northern Europe, Japan, and other countries in recent years, and is especially suitable for long-distance and cross-sea capture and storage routes. The ship transportation process includes CO_2 liquefaction, cryogenic tank storage, loading, transportation, unloading, and regasification injection, etc., and its technical part is borrowed from the liquefied natural gas (LNG) transportation system, which has a certain degree of maturity and feasibility.

Pipeline systems are preferred when the transport distance is short (less than about 150 km) or the transport volume is very large (well above 5 million tons per year). And for long-distance transportation, ship transportation is more economically advantageous in some cases. For example, when the transport distance is between 500 and 1500 km, the cost per ton of CO_2 transported by ship is 7-62% lower than that of an offshore pipeline [11].

At present, Norway's Northern Lights project is the world's first commercial CO_2 shipping-storage demonstration project, with a planned annual transportation capacity of 1.5 million tons/year, and the injection site is located in the 2,600-meter-deep aquifer on the seabed of the North Sea, using dedicated cryogenic vessels to transport liquefied CO_2 from all over Europe to salt cavern storage sites in the lower North Sea. The successful operation of the project provides a model for the validation of the business model of ship transportation.

Still, there are some challenges associated with ship transportation. For example, the high energy consumption in the CO_2 liquefaction and regasification process places stringent requirements on port infrastructure, requiring dedicated terminals, storage tanks, and loading and unloading equipment. At the same time, it is greatly affected by the external environment, such as weather and sea conditions, and the transportation stability is slightly inferior to that of the pipeline.

3.3. Summary

Comparing pipeline transportation and ship transportation, the two have their advantages and disadvantages in different aspects, and factors such as economic thresholds and infrastructure constraints should be comprehensively considered when choosing transportation modes.

From an economic point of view, the unit cost of ship transportation is slightly higher than that of pipelines, but it offers flexibility and economic advantages in the case of medium transport scales, long distances, or multi-point pooling – single point of storage. The investment intensity of ship transportation is relatively low, and the construction period is short, which is suitable for areas with a start-up period or a lack of onshore continuous pipeline conditions [12]. The high fixed costs of pipeline construction are difficult to amortize in the case of small transportation volumes. If the transportation volume is large, it is necessary to comprehensively consider the pipeline construction cost and the variable cost of ship transportation to determine the optimal plan.

In terms of infrastructure, pipeline transportation relies on a fixed pipeline network, which has a long construction period and high cost, and once completed, it is difficult to change the transportation route, which is suitable for scenarios where the emission source and receiving place are relatively fixed and the transportation demand is stable. Ship transportation has certain requirements for infrastructure, such as ports, and needs to be equipped with complete carbon dioxide loading and unloading and storage facilities, but relatively speaking, its transportation routes are more flexible and suitable for the complex transportation needs of multiple emission sources and receiving places in coastal areas, especially for maritime storage or transnational transportation scenarios.

4. CO_2 sequestration pathways and technical challenges

Sequestration is the final link in the chain of carbon capture and storage (CCS) technologies, and its key task is to stabilize and permanently isolate the captured and transported CO_2 from the atmosphere. Although the CCS system as a whole has gradually matured, the storage process is still the main bottleneck affecting the large-scale deployment of CCS due to strong technical heterogeneity, long long-term verification cycle, and high regulatory requirements. According to different physical and chemical mechanisms, the current storage methods are mainly divided into three categories: geological storage, mineralized storage, and marine storage.

4.1. Geological storage

Geological storage is the most mature and widely used storage method, and its basic principle is to inject compressed CO_2 into deep underground aquifers, depleted oil and gas reservoirs or unexploited coal seams, and use the physical closure of rock formations and a variety of locking mechanisms (such as capillary retention, dissolution, mineralization reaction) to achieve long-term storage. According to the Global CCS Institute, as of 2022, more than 30 geological storage projects have entered the commercial operation stage, with an annual storage capacity of more than 40 million tons [1]. The advantages of geological storage are large capacity, mature technology, and stable operation, which are suitable for coping with large-scale industrial carbon emissions. However, this approach also faces some key challenges, such as the high compatibility of the reservoir-caprock system, the risk of leakage (e.g., through faults, old wells, etc.), the induction of earthquakes, and the destruction of geological CO_2 reservoirs [13]. In addition, there are differences in storage capacity and safety of different geological structures, resulting in a long site selection and implementation cycle, which affects the deployment progress.

4.2. Mineralization storage

Mineralization storage is the chemical reaction of CO_2 with calcium, magnesium-rich minerals (such as olivine, serpentine, tailings, etc.) to form stable carbonate minerals, to achieve irreversible permanent storage. Mineralized storage pathways are divided into two types: in-situ mineralization and out-of-situ mineralization [14]. In-situ mineralisation is represented by the CarbFix project in Iceland, which reacts to form carbonates under natural conditions by dissolving CO_2 in water and injecting it into underground basalt formations, resulting in significant sequestration and high stability. Experimental data show that more than 80% of the injected CO_2 completes the mineralization reaction within two years [15]. Ex-situ mineralization is mostly used in alkaline materials such as tailings and industrial waste residues, which are reacted and solidified under surface plant conditions.

Despite the outstanding performance of mineralized sequestration in terms of storage stability and environmental safety, there are three major limitations under current technical conditions. First of all, the reaction efficiency is low. The reaction of carbon dioxide with minerals to form carbonates is naturally very slow, often taking decades or even hundreds of years to complete, and in practice, the reaction must be accelerated utilizing high temperatures, high pressures, or chemical additives, which greatly increases process complexity and energy consumption. Secondly, the cost is on the high side. Compared with traditional geological storage, mineralized storage involves multiple aspects such as ore mining, transportation, grinding, and reaction control, resulting in an overall cost of typically between US$50 and US$210/t CO_2, which is much higher than the current carbon market's ability to pay [16]. Finally, there is strong resource dependence. The magnesium or calcium-rich minerals required for mineralization reactions are not uniformly distributed across the globe, and the suitable geological conditions are mainly concentrated in regions such as Iceland, India, Australia, etc., and other regions often face the problems of difficult access to minerals and high transportation costs if the technology needs to be deployed. Therefore, mineralized storage, although it has potential, is currently more suitable as a complementary path to CCS systems, rather than a workhorse.

4.3. Marine sequestration

Ocean storage is one of the most promising and controversial forms of storage. The technical paths include direct injection of CO_2 into the deep sea, depositing liquid CO_2 on the seabed to form a "CO_2 lake", or injecting it into the seabed sedimentary layer to achieve geological storage. In addition, there is the idea of "biosequestration" by promoting photosynthesis in phytoplankton. The theoretical storage capacity of ocean storage is huge, and it can meet the long-term demand for large-scale carbon removal. However, the environmental risks of this approach cannot be ignored, as deep-sea injection may lead to acidification of seawater, damage to deep-sea ecosystems, and its long-term environmental impact is not yet clear. At present, international conventions such as the London Protocol are cautious or even prohibit CO_2 releases into the oceans. Therefore, although its potential has been widely discussed, the technological maturity and policy feasibility are still in their infancy and are not yet ready for commercialization [17].

4.4. Summary

In summary, the three mainstream storage methods have their advantages and limitations in terms of security, economy, and technical maturity. As the most mature path at present, geological storage has a strong engineering application foundation and storage capacity, but it is still restricted by factors such as difficult site selection, high regulatory costs, and low public acceptance. Mineralized storage has extremely high storage stability and permanence, and has outstanding technical potential, but the scale is limited, the cost is high, and the commercial path has not yet been established. Although marine storage has a theoretically unlimited storage capacity, its environmental impact has not been fully assessed, and the legal and moral risks are high, making it difficult to become a viable option in the short term.

At present, CO_2 capture technology has become more and more mature, and some fields (such as post-combustion capture) have even formed commercial capabilities. Carbon transportation modes have also gradually formed a standard system with flexible deployment capabilities. However, the sealing process lags significantly behind in terms of technical feasibility, safety verification, regulatory system, and social trust mechanism. This lag not only leaves a large amount of captured CO_2 with nowhere to go, but also erodes the confidence of investors and policymakers in the sustainability of the entire CCS system, creating a structural contradiction in which the front end of the chain advances rapidly and the end is blocked.

5. Challenges and development strategies of CCS technology

5.1. Challenges faced by CCS technology

Although CCS is widely regarded as an important pillar technology for achieving carbon neutrality, its global deployment is slow and faces multiple challenges. In terms of technology, the technical chain of CCS is composed of three parts: capture, transportation, and storage, but the development maturity of each link is inconsistent, the capture technology is relatively mature, while the storage link lags seriously, which makes it difficult to close the loop of the technology chain.

On the economic side, the average full-chain cost of CCS projects is typically between US$60 and US$150/tonne CO_2, which is much higher than the current carbon price level in most regions, so the market drivers are limited [18]. In terms of policy, there is no unified framework for the division of responsibilities and long-term monitoring obligations after mothballing, which further increases investment uncertainty. Social acceptance is also a potential risk, with a lack of public understanding of the safety of CO_2 storage and the project's vulnerability to public opposition. This misalignment not only weakens the overall efficiency of the system but also exacerbates deployment risk. These multifaceted challenges necessitate tailored strategies for different emission scenarios.

5.2. Development countermeasures of CCS technology

In order to solve these problems, it is necessary to build a decision-making model based on technology-scenario matching, considering different emission source types, scales, geographical locations, cost constraints, and other factors, and match the optimal technology combination in different application scenarios. High-concentration industrial sources (such as natural gas processing) can be preferentially captured before combustion and stored in situ. Combined heat and power facilities around the city should adopt post-combustion capture technology, utilizing short-distance pipeline transportation to store the captured CO_2 in suitable oil and gas reservoirs. The coastal solitary emission sources can be combined with liquid ship transportation and seabed storage clusters to build a cross-border storage system.

In terms of deployment cadence, a phased implementation is recommended that you implement it in phases. Shortly (2025–2035), the regional deployment of CCS should be promoted on the basis of industrial clusters, that is, the construction of shared transportation pipelines and access platforms around multiple carbon sources and one storage point to improve resource utilization efficiency and reduce unit costs. In the medium and long term (2035–2050), with the development of digital technology, AI and big data can be gradually introduced to improve the intelligence level of capture and scheduling, transportation optimization, and injection control, and build a CCS intelligent operation system with dynamic adjustment and real-time response. In addition, the government should speed up the development of mechanisms such as price differential subsidies, carbon sequestration credits, and the transfer of regulatory responsibilities to reduce upfront risks and improve investment attractiveness. At the same time, through the establishment of a transparent information platform and local pilot demonstrations, public awareness and social support will be enhanced, and a sustainable technology-system-society coordinated development path will be formed.

6. Conclusions and outlook

6.1. Conclusion

CCS technology plays a crucial role in achieving global emission reduction targets, particularly in high-emitting industries and negative emission pathways. This paper systematically reviews the current development status of CCS technology, provides a comprehensive comparison and analysis of each stage—from capture and transportation to storage—and highlights that the main barriers to its slow deployment are systemic contradictions such as the fragmentation of the entire industrial chain, the lack of storage infrastructure, and outdated policy mechanisms. In particular, on the storage front, issues like geological adaptability, regulatory frameworks, and social acceptance remain key bottlenecks that hinder commercialization.

In the face of challenges, this review recommends constructing a CCS path selection logic based on the technology-scenario matching decision-making model. At the same time, it advocates a phased deployment strategy, that is, to concentrate resources in the form of clusters shortly to create a regional demonstration effect; In the medium and long term, AI optimization and dynamic management will be introduced to achieve intelligent and efficient operation of the system. At the level of supporting policies, it is necessary to establish a price mechanism, a long-term regulatory framework, and a responsibility division mechanism to provide institutional guarantees for the industrialization of CCS.

6.2. Outlook

Although this s review synthesizes the whole technical chain of CCS and offers recommendations for phased implementation, it provides a theoretical anchor for solving the problem of fragmentation between capture and storage. However, this review is primarily based on the synthesis of existing literature and public project data, and the CCS technology is developing rapidly, and the cost, efficiency, and project deployment data are continuously updated. Future research can continue to track the latest project progress (especially the data of commercial projects from 2024 to 2025) and establish a dynamically updated CCS technical and economic database to provide more timely decision-making support. Deepening the research in the above directions will help build a more complete and operational decision support system for CCS technology evaluation and deployment, and provide a more solid theoretical foundation for accelerating the large-scale and commercial application of CCS technology.

References

[1] Global CCS. (2024). The 2024 Global Status of CCS. Retrieved from https: //www.globalccsinstitute.com/resources/global-status-report/

[2] IEA, P. (2022). World energy outlook 2022. Paris, France: International Energy Agency (IEA). Retrieved from https: //www.iea.org/reports/world-energy-outlook-2022

[3] Jenkins, J. (2015). A case study of the Petra Nova carbon capture project. The Paulson Institute: Chicago, IL, USA. Retrieved from https: //www.paulsoninstitute.org/wp-content/uploads/2015/10/CS-Petra-Nova-EN.pdf

[4] Raganati, F., Miccio, F. and Ammendola, P. (2021) Adsorption of carbon dioxide for post-combustion capture: a review. Energy & Fuels, 35(16), 12845-12868.

[5] Jansen, D., Gazzani, M., Manzolini, G., Van Dijk, E. and Carbo, M. (2015) Pre-combustion CO_2 capture. International Journal of Greenhouse Gas Control, 40, 167-187.

[6] Xia, C., Ye, B., Jiang, J. and Shu, Y. (2020) Prospect of near-zero-emission IGCC power plants to decarbonize coal-fired power generation in China: Implications from the GreenGen project. Journal of Cleaner Production, 271, 122615.

[7] Rubin, E. S., Mantripragada, H., Marks, A., Versteeg, P. and Kitchin, J. (2012) The outlook for improved carbon capture technology. Progress in energy and combustion science, 38(5), 630-671.

[8] Yadav, S. and Mondal, S. S. (2022) A review on the progress and prospects of oxy-fuel carbon capture and sequestration (CCS) technology. Fuel, 308, 122057.

[9] Gale, J. and Davison, J. (2004) Transmission of CO_2—safety and economic considerations. Energy, 29(9-10), 1319-1328.

[10] Svensson, R., Odenberger, M., Johnsson, F., and Strömberg, L. (2004) Transportation systems for CO_2—application to carbon capture and storage. Energy conversion and management, 45(15-16), 2343-2353.

[11] Vermeulen, T. N. (2011). CO_2 Liquid Logistics Shipping Concept (LLSC) Overall Supply Chain Optimization. Global CCS Institute: Canberra, Australia. Retrieved from https: //globalccsinstitute.com/archive/hub/publications/44046/co2-liquid-logistics-shipping-concept-overall-supply-chain-optimization-simplified-chinese.pdf

[12] Al Baroudi, H., Awoyomi, A., Patchigolla, K., Jonnalagadda, K. and Anthony, E. J. (2021) A review of large-scale CO_2 shipping and marine emissions management for carbon capture, utilisation and storage. Applied Energy, 287, 116510.

[13] Ma, J., Li, L., Wang, H., Du, Y., Ma, J., Zhang, X. and Wang, Z. (2022) Carbon capture and storage: history and the road ahead. Engineering, 14, 33-43.

[14] Kim, K., Kim, D., Na, Y., Song, Y. and Wang, J. (2023) A review of carbon mineralization mechanism during geological CO_2 storage. Heliyon, 9(12), 1-20.

[15] Gíslason, S. R., Sigurdardóttir, H., Aradóttir, E. S. and Oelkers, E. H. (2018) A brief history of CarbFix: Challenges and victories of the project’s pilot phase. Energy Procedia, 146, 103-114.

[16] Sanna, A., Uibu, M., Caramanna, G., Kuusik, R. and Maroto-Valer, M. M. (2014) A review of mineral carbonation technologies to sequester CO_2. Chemical Society Reviews, 43(23), 8049-8080.

[17] Metz, B., Davidson, O., De Coninck, H. C., Loos, M. and Meyer, L. (2005). IPCC special report on carbon dioxide capture and storage. Cambridge: Cambridge University Press. Retrieved from https: //www.ipcc.ch/report/carbon-dioxide-capture-and-storage/

[18] Rubin, E. S., Davison, J. E. and Herzog, H. J. (2015) The cost of CO_2 capture and storage. International Journal of Greenhouse gas control, 40, 378-400.