WEP Warwick Evans Publishing

Transactions on Engineering and Technology Research
ISSN: 2960-1797, eISSN: 2960-2246 | Volume 4
ACEGE 2024

Carbon Dioxide Seabed Storage Technology and Development

Biyuan Wang

School of Municipal and Environmental Engineering, College of Hebei University of Architecture, Zhang Jiakou, China

yy8angle@ldy.edu.rs

Abstract. With the acceleration of global industrialization, the massive use of fossil fuels led to a sharp rise in atmospheric CO_2 concentrations, triggering a series of environmental problems such as global warming and sea level rise. As an important component of carbon capture, utilization, and storage (CCUS) technology, offshore carbon sequestration held significant importance for achieving global emission reduction targets. This study focused on CO_2 seafloor storage technology and its development, describing four methods of CO_2 ocean storage: ocean water column storage, ocean sediment storage, CO_2 replacement gas hydrate storage, and ocean fertilization. The feasibility of seabed sequestration technology was discussed from three perspectives: policy background, economic costs and benefits, and technological application conditions. Additionally, the study analyzed the bottlenecks in applying this technology and proposed coping strategies. As an indispensable part of the CCUS strategy, offshore carbon sequestration played a crucial role in achieving global greenhouse gas (GHG) emission reduction targets.

Keywords: CCUS; CO_2 Ocean Sequestration; Ocean Water Column.

1. Introduction

In recent years, global climate has undergone significant changes due to the impact of human activities. Global warming has become a major challenge to the survival and development of mankind, and carbon peaking and carbon neutrality have become a global consensus, which is an inevitable choice for achieving sustainable development of the global economy and society. Carbon Capture and Storage (CCS) technology is the process of separating carbon dioxide from industrial or related emission sources, transporting it to a storage site, and isolating it from the atmosphere for a long period of time [1]. This technology is considered to be the most economical and feasible way to reduce greenhouse gas emissions on a large scale and slow down global warming in the future. As an important part of the carbon dioxide capture, utilisation and storage (CCS) strategy, offshore geological storage of carbon dioxide is a key initiative to combat global climate change [2]. It is a carbon capture and storage (CCS) technology in which carbon dioxide captured from multiple sources is pressurised, transported to a dedicated offshore storage platform, and subsequently injected into suitable formations on the seafloor, with the aim of permanently isolating the carbon dioxide from the atmosphere and seawater, whilst seeking to create added value in the process. Oceanic CO_2 storage is not only one of the most promising approaches to achieve CO_2 reduction in CCS technology, but also a valuable reference for further research on CO_2 storage technology with a deeper understanding of its current development.

The concept of ocean CO_2 storage can be traced back to the 1970s, when it was first proposed by C. Marchetti, who conceived the idea of injecting CO_2 directly into the Mediterranean Sea and transferring it to the deep Atlantic Ocean using submarine currents to achieve natural storage. 1996 saw the world's first commercialised CO_2 storage project, Sleipner, in Norway. Sleipner, the world's first commercial CO_2 ocean storage project, was successfully launched in the Norwegian North Sea, and so far more than 2 million tonnes of CO_2 have been injected into the water layer without any leakage for more than 20 years, which is a strong proof of the technical feasibility of long-term CO_2 ocean storage. 2.58 trillion tonnes, highlighting the huge potential of geological storage of CO_2 in the sea [3]. It is particularly worth mentioning that in August 2021, China National Offshore Oil

Corporation (CNOOC) successfully launched China's first offshore CO_2 storage demonstration project (Sea Carbon Sequestration) in the Enping 15-1 oilfield cluster in the Pearl River Estuary Basin, and independently developed a full chain of technology and equipment systems covering CO_2 capture, treatment, injection, storage and monitoring on offshore platforms. This pioneering move marks that offshore CO_2 geological storage has become an important strategy to address the challenge of greenhouse gas emissions in developed coastal regions of China, and is also an indispensable key technological support for the achievement of the national goal of 'carbon peaking and carbon neutrality'. In addition, Hirai .revealed the close relationship between the dissolution rate of CO_2 in the deep ocean and the flow rate, pressure and temperature of the surrounding seawater through experimental studies, and pointed out that the complete dissolution of CO_2 can be achieved by optimising the injection rate and radius, while Brewer. et al. observed the process of hydrate formation from liquid CO_2 in the deep ocean through direct experiments, which further verified the technological feasibility of oceanic storage of CO_2 [4]. In the annual report of China CO_2 Capture, Utilisation and Storage (CCUS), Cai Bofeng et al. comprehensively sorted out the current status and level of development of domestic and international CO_2 capture, transport, utilisation and storage technologies, providing valuable reference information for the industry [5].

This paper reviewed the representative research work and demonstration project cases of marine CO_2 geological storage at home and abroad, comprehensively analyse its development history, and based on the current research status, point out the urgent problems to be solved in the future development, and then put forward corresponding countermeasures.Issues with the Tianjin Binhai Wetland Ecosystem.

2. Status of Seabed Carbon Dioxide Storage Technologies

Tianjin is located in the eastern part of the North China Plain, adjacent to the Bohai Sea. Current approaches focus on ocean water column storage, ocean sediment storage, CO_2 displacement gas hydrate storage and ocean fertilization.

(1) Ocean Water Column Storage: The first step in the implementation of ocean water column storage technology involves the injection of captured carbon dioxide (CO_2) into deep-sea water at a carefully regulated rate using pipeline systems and ship facilities. The core concept of the sequestration approach is to utilise the diverse group of ions and molecules present in the natural environment of the ocean, mainly bicarbonate ions (HCO_3^-), carbonate ions (CO_3^{2-}), carbonic acid (H_2CO_3), and carbon dioxide (CO_2) in its dissolved state, which together form a highly stable buffer system. By triggering a series of complex physical and chemical reactions, this system can effectively promote the dissolution and absorption of CO_2, thus successfully achieving the goal of long-term storage.

(2) Marine Sediment Storage: Through a well-designed pipeline system, we inject CO_2 into the thick and stable sediment layer of the seabed. Since the density of CO_2 is higher than that of the pore water in the sediment layer, this unique physical property enables CO_2 to be stably sealed under the pore water of the sediment layer, thus achieving effective carbon sequestration. As early as 1997, Koide.et al [5] pioneered the idea of using deep-sea sediments to store CO_2, and explored the possibility of three different depths of sediments as potential storage sites: the shallow seafloor (depths of less than 300 metres), the deep seafloor (depths of 300 to 3,700 metres), and the ultra-deep seafloor (depths of more than 3,700 metres). Under the extreme high-pressure, low-temperature conditions of the deep ocean, CO_2 is able to form an ice-crystal-like hydrate in seabed sediments. This crystalline hydrate dissolves at a very low rate in seawater, thus greatly reducing the potential threat of CO_2 to all types of organisms in marine ecosystems. It is also worth mentioning that the formation of CO_2 hydrate can significantly reduce the porosity of the sedimentary layer, and may even completely block the pore space, leading to a decrease in permeability. This change not only enhances the confinement of the storage system, but also further improves the CO_2 storage effect [6-7]. This innovative storage strategy provides a powerful technical support for us to cope with global climate change.

(3) CO_2 replacement for gas hydrate storage: At the end of the 20th century, Ohgaki.et al. [8] creatively put forward an idea: using CO_2 to replace CH_4 (methane) in the hydrate deposits on the seabed. This idea was then formally recognised and defined by the US Department of Energy, who explicitly proposed the concept of 'EGHR' (Enhanced Gas Hydrate Recovery by CO_2 Replacement) in the relevant scientific report, aiming to enhance the efficiency of gas hydrate recovery by CO_2 replacement. The concept of 'EGHR' (Enhanced Gas Hydrate Recovery by CO_2 Replacement) was clearly proposed in the report. Under certain temperature conditions, the pressure required to stabilise CO_2 hydrate is significantly lower than that of combustible ice (gas hydrate). Based on this physical property, the injection of CO_2 gas into the gas hydrate layer on the seabed can effectively induce the decomposition of combustible ice. During the decomposition process, the water released combines with the injected CO_2 gas to form a more stable CO_2 hydrate. Especially important is that the heat released during this chemical reaction can also continue to provide the energy needed for the decomposition of combustible ice, thus forming a self-sustaining virtuous cycle.

(4) Ocean Fertilisation: By adding micronutrients (e.g. Fe) and macronutrients (e.g. N and P) to the oceans, enhancing the photosynthesis of phytoplankton, accelerating phytoplankton reproduction and production, and increasing the conversion rate of CO_2 from inorganic molecules to organic carbon with the help of the biological chain within the oceans, thus increasing the uptake and storage of atmospheric CO_2 by the oceans, and ultimately achieving carbon sequestration [9].

3. Technical Feasibility of Seafloor Storage

The Qilihai Wetland is located in the southwestern part of Ninghe County, Tianjin, with an area of approximately 344 So far, mankind has been continuously exploring ways to use natural carbon reservoirs to reduce the impact of anthropogenic CO_2 emissions on the atmosphere, and there are currently three known carbon storage layers, with the storage capacity of marine carbon reservoirs being the largest among them. It is even several times higher than the terrestrial carbon reservoir. Therefore, the use of marine carbon reservoirs to implement carbon sequestration has a huge potential. However, before implementing a plan for ocean CO_2 sequestration, we should determine the sequence of tasks to be carried out, so as to ensure the smooth progress of the plan. In the following, we are going to make a preliminary argument and analyze the feasibility of CO_2 seabed storage from the following aspects.

(1) Policy background: A series of policies have been actively formulated both at home and abroad for CO_2 sequestration activities to take place in international waters, and the international marine environmental protection laws include the Law of the Sea, the London Convention and the London Protocol, the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) and other regional treaties. One of the most important of these treaties is the London Convention, and the entry into force of the amendments to Annex I signaled that China, as a party to the Protocol, had 'acquired the right to seabed storage of CO_2'. As a developing country, seabed storage of CO_2 is a right for parties. This marks China's formal entry into the field of seabed carbon storage.

(2) Economic Costs and Benefits: The economic costs of CCS are mainly divided into three parts: CO_2 capture cost, transport cost and storage cost. Among them, the capture cost (including compression) is the highest, and reducing the capture cost can effectively reduce the total cost. In addition to these costs, there are costs for monitoring, and additional costs for remediation and liability. Table 1 shows the costs of CO_2 capture, transport, storage and monitoring costs assessed by the IPCC. It is easy to see from the table that capture costs (including compression) account for the largest share of CCS systems, about 70 per cent. With the development of research technology and economy, the cost of CCS will be gradually reduced.

Table 1. The Cost of Each Part of the CCS System of Evaluation by IPCC

CCS System Composition	Cost range	Remarks
From a coal or gas-fired power plant capture	15~75 USD/tonne CO_2 net capture	Net CO_2 capture cost compared to an equivalent plant without capture
Capture from hydrogen and ammonia production or natural gas processing	5~55 USD/tonne of CO_2 net capture	For high purity tours requiring simple drying and compression.
Capture from other industrial sources	25~115 USD/tonne CO_2 net capture	A number of different technologies and fuels are used
Transport	1~8 USD/tonne CO_2 transport	For mass flow halos of 5~40 MtCOz/yr, cost per 250 km pipeline or shipment
Geological storage	0.5~8 USD/tonne CO_2 injection child	Revenues from enhanced oil recovery not included
Geological Sequestration: monitoring and inspection	0.1~0.3 USD/tonne CO_2 injected	Includes costs for pre-injection, during injection, and post-injection monitoring, and the magnitude of the monitoring side costs will depend on the management requirements.

(3) Conditions for technology application: The Chinese sea area exhibits excellent crustal stability, and its vast distribution of sedimentary basins provides unique natural conditions for geological storage of carbon dioxide (CO_2). These basins are not only vast in area, but also thick in stratigraphic structure and rich in tectonostratigraphic traps, which constitute an extremely favorable geological barrier.F.M. Orr and S. Bachu demonstrated the mechanism of aquifer CO_2 storage, proving the feasibility of this technology [10-11]. In 2008, the former State Oceanic Administration (SOA) initiated the key public welfare project 'China's CO_2 seafloor storage capacity assessment and risk control technology pre-study', which found that there are 11 large sedimentary basins in China's near-shore, with a total storage capacity of 25,000 × 108 t, which are sufficient to carry out the geological storage of CO_2 on the seafloor.

4. Application Bottlenecks and Strategies to Address

With the continuous development of carbon sequestration technology on the seabed, some bottlenecks have been encountered in the process:

(1) Lack of policy support: Since the introduction of CCS (carbon capture and storage) technology, the field has witnessed significant progress and development, however, the core obstacle to its widespread implementation is not the technical challenges, but the lack of a series of clear and powerful policies and regulations at the government level as a solid backing and strong support. As early as the 1990s, BP, as a pioneer in the industry, first began to explore the commercialisation of carbon capture and storage (CCS) technology. Unfortunately, the UK government's attitude towards this technology has always been rather conservative and has not given enthusiastic support, making it difficult to obtain government funding or strong policy support for the promotion of CCS in the U.K. The cost of CCS is huge, and in the absence of clear government support, few companies are willing to invest unilaterally in carbon capture and storage (CCS) technology. Currently, compared to land-based storage, research on seabed carbon dioxide storage is lagging behind, and if the government fails to introduce appropriate policies and regulations in time to provide the necessary support and incentives, the further development of seabed storage technology will undoubtedly be difficult.

(2) High cost: CO_2 from the initial capture to transport to storage, the total cost is huge, CO_2 capture cost is at 13 ~ 51 U.S. dollars / t and the cost of ocean storage is significantly higher than the cost of land storage, because in the sea drilling, seismic exploration and other large amounts of work than the same kind of work on land to invest in large. The cost of ocean storage is 6~31 USD/t, while the cost of land storage is 0.6~8.3 USD/t. However, the additional revenue potential of seabed storage can effectively balance the operation cost on the economic level, therefore, under the overall economic consideration, ocean storage shows a more significant attraction compared with land storage.

Therefore, this paper suggest related department can adopt corresponding strategies to cope with the bottleneck:

(1) Improve laws and regulations: China has not yet established a complete geological storage technology system and storage scheme for marine CO_2, the EU, the United States, Australia and other countries and regions are the main advocates of CCS technology, and the CCS management laws and regulations that have been issued so far include the Carbon Capture and Storage Directive of the European Union, the Guidelines for CO_2 Capture, Transport and Storage of the United States, and the Guideline for CO_2 Capture and Storage I of Australia 2009, all of which have been implemented. In the future, China is expected to introduce more special laws, regulations and policy documents for carbon storage technology to further improve the legal system of carbon storage technology.

(2) Increase scientific research investment in carbon sequestration: High costs and significant energy efficiency losses have undoubtedly become a huge obstacle to the widespread application of CO_2 seafloor sequestration technology in China. In the face of these challenges, the government urgently needs to increase investment in scientific research, and actively improve the advancement and efficiency of CO_2 subsea storage technology, in order to overcome the obstacles and promote the breakthrough progress of this field of technology.

5. Conclusion

This study underscored the critical role of offshore carbon sequestration as part of the broader Carbon Capture, Utilization, and Storage (CCUS) strategy, particularly in the context of rising global CO_2 levels due to industrialization and fossil fuel consumption. The exploration of various CO_2 ocean storage methods—namely ocean water column storage, ocean sediment storage, CO_2 replacement gas hydrate storage, and ocean fertilization—demonstrated the diverse approaches available for mitigating the impacts of climate change. Each method presents unique advantages and challenges, emphasizing the need for tailored solutions that consider specific environmental and economic contexts. The feasibility analysis of seabed sequestration technology highlighted the importance of supportive policy frameworks, thorough economic assessments, and the assessment of technological application conditions. The identification of policy backgrounds showed that clear regulatory guidelines and incentives are crucial for encouraging investment and research in offshore sequestration. Furthermore, understanding the economic costs and benefits associated with these technologies is essential for attracting stakeholders and ensuring sustainable practices.

The study also addressed the bottlenecks hindering the widespread adoption of offshore carbon sequestration technologies. Issues such as environmental concerns, technical limitations, and public acceptance can impede progress. Therefore, it is imperative to engage in comprehensive stakeholder dialogues to build trust and address misconceptions surrounding these technologies. Additionally, research efforts should focus on overcoming technical challenges through innovation and the development of more efficient and cost-effective solutions.

In light of these findings, future research should aim to advance the understanding of offshore carbon sequestration's long-term effects on marine ecosystems and climate change mitigation. Collaboration among governments, academia, and industry stakeholders will be vital in fostering the development and implementation of these technologies on a global scale. Ultimately, as nations strive to meet their greenhouse gas emission reduction targets, offshore carbon sequestration emerges as a viable and essential strategy. Its successful integration into national and international climate policies will contribute significantly to global efforts aimed at combating climate change and achieving a sustainable future for generations to come.

References

[1] C. Marchetti, On geoengineering and the CO2 problem, Climatic Change 1 (1) (1977) 59-68.

[2] H. Kheshgi, H. de Coninck, J. Kessels, Carbon dioxide capture and storage: Seven years after the IPCC special report, Mitig. Adapt. Strat. Gl. 17 (2012) 563-567.

[3] X. Zhang, K. Li, Q. Ma, Orientation and prospect of CCUS development under carbon neutrality target, China Population, Annu. Rev. Env. Resour. 31 (9) (2021) 29-33.

[4] S. Hiair, K. Ozaki, Y. Tabe, Numerical simulation for dissolution of liquid CO_2 droplets covered with Clathrate film in intermediate depth of ocean, Energ. Convers. Manage. 38 (1997) 5313-S318.

[5] P. Brewer, E. Peltzer, G. Friedrich, Experiment on the ocean sequestration of fossil fuel CO_2: pH measurement and hydrate formation, Mar. Chem. 72 (2-4) (2000) 83-93.

[6] H. Koide, Y. Shindo, Y. Tazaki, Deep sub-seabed disposal of CO_2: The most protective storage, Energ. Convers. Manage. 38 (2) (1997) 253-258.

[7] E. E. Adams, K. Caldeira, Ocean storage of CO_2, Elements 4 (5) (2008) 319-324.

[8] F. Qanbari, M. Pooladi-Darvish, S. H. Tabatabaie, CO2 disposal as hydrate in ocean sediments, J. Nat. Gas Sci. Eng. 8 (8) (2012) 139-149.

[9] J. K. Moore, S. C. Doney, Iron availability limits the ocean nitrogen inventory stabilizing feedbacks between marine denitrification and nitrogen fixation, Global Biogeochem. Cy., 21 (2) (2007) 488-501.

[10] F. M. Orr, Onshore geologic storage of CO_2, Science 325 (5948) (2009) 1656-1658.

[11] S. Bachu, M. B. Dusseault, Subsurface injection of carbon dioxide in salt beds, Water Sci. Technol. 52 (2005) 637-648.