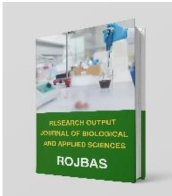

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Carbon Capture and Storage Technologies: Mitigating Climate Change

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ABSTRACT

The rapid increase in greenhouse gas emissions, particularly CO2, has accelerated global climate change, presenting a significant challenge to the environment and human society. This paper explores the role of Carbon Capture and Storage (CCS) technologies in mitigating climate change by reducing CO_2 emissions from fossil fuel-based power generation and industrial processes. It provides an overview of the science behind climate change, the types and effectiveness of CCS technologies, and the challenges and opportunities in their implementation. The discussion is supported by case studies of successful CCS projects, highlighting the potential of CCS to serve as a critical tool in global efforts to combat climate change.

Keywords: Carbon Capture and Storage (CCS), Greenhouse Gas Emissions, Climate Change Mitigation, Fossil Fuels, CO_2 Sequestration.

INTRODUCTION

Climate change is a crucial challenge caused by increasing greenhouse gas emissions. Burning fossil fuels has driven energy production, economic development, and urbanization. Global CO_2 emissions have grown significantly, with other greenhouse gases amplifying the impact [1]. Scientific links between GHG emissions and global temperature increase since 1980. Urgent action needed to stabilize GHG levels due to potential consequences on weather, agriculture, and ecosystems. International climate change agreements promote mitigation and adaptation strategies. Countries implementing initiatives to reduce GHG emissions and promote cleaner, energy-efficient technologies. In many countries, coal will remain an important energy source due to its local abundance, low price, and rich reserves. Carbon capture and storage (CCS) technologies can play a vital role in reducing CO_2 emissions from coal-based power. However, demonstrating geological storage of CO_2 is essential to build public trust and promote widespread use of CCS technologies [2].

UNDERSTANDING THE SCIENCE OF CLIMATE CHANGE

A broad understanding of the natural science behind climate change is important when studying carbon capture and storage technologies. The following sections will cover how human activities have contributed to changes in the concentration of greenhouse gases (GHGs) in the atmosphere and the processes by which these gases lead to unwanted temperature changes on Earth, commonly known as the 'greenhouse effect' [3]. Carbon dioxide (CO_2), methane (CH4), nitrous oxide (N_2O) and other compounds trap heat in the atmosphere, causing the planet to heat up. These greenhouse gases (GHGs) block radiation from escaping into space. The Sun provides the Earth with solar energy, with 30% reflected back by reflective surfaces. The remaining 70% is absorbed by the atmosphere and oceans, providing energy for life. Most absorbed energy is released as infrared radiation, which GHGs absorb and re-emit, warming the planet. Without this process, Earth's average temperature would be -18 °C instead of +15 °C. Natural levels of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) have remained relatively stable for the past 10,000 years at 264-290 ppm, 1,745-2,600 ppb and 240-270 ppb respectively; however, this changed dramatically with the start of the industrial era. The concentrations of atmospheric GHGs have been increasing rapidly because of human activities such as fossil fuel usage, land use

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changes, agriculture practices, etc. As shown in Figure 2, CO_2 concentrations rose by 43% between 1750 and 2005, N2O levels increased by 17% and CH4 concentrations doubled [4].

GREENHOUSE GAS EMISSIONS

Carbon dioxide (CO_2) is not a traditional air pollutant like sulfur dioxide or particulate matter. It can cause respiratory stress in high concentrations, but its main concern is as a greenhouse gas (GHG). Atmospheric CO2 levels have dramatically increased. According to NOAA, CO_2 concentrations have risen from 315 ppm in 1958 to 380 ppm in 2007. Since 1870, CO_2 concentration has increased by about 265 ppm (from 280 to 547 ppm) [5]. There are various household activities that increase the level of CO2 emissions. Most of them are energy-consuming activities that involve electricity generation, such as air conditioning, heating, and using electronics, understanding that the level of GHG emissions is also affected by the energy source. The sources can be categorized as renewable energy sources (RES) or fossil fuel burning. Fossil fuel combustion is the major source of CO_2, emitting approximately 77% of CO_2 emissions in 2000 alone. The coal burning contributes to almost two-thirds of the total emissions of CO_2. There were also considerable increases in CO_2 emissions in the energy sector and power sector, more than 36% and 54%, respectively. Almost two-thirds of the increase in emissions has been contributed by developing countries, especially Brazil, China, and India. China has accounted for two-fifths, while OECD and USA have remained unchanged levels of emissions in CO_2 [6]. There is substantial uncertainty in the estimates of CO_2 emissions both in the industrial processes and in the non-OECD emissions. However, it is generally agreed that for developed countries, input data are usually more complete, while for non-OECD countries, there commonly exist important gaps in data and information. For instance, although the steel and cement industries are leading industries for CO_2 emissions, they have been misreported or omitted in some databases. Because of the opposition of the related industries, accurate data can hardly be gathered [7].

IMPORTANCE OF CARBON CAPTURE AND STORAGE (CCS) TECHNOLOGIES

The high level of CO_2 in the atmosphere from human activities is a major challenge. We need to take immediate steps to reduce global warming by transitioning to a low-carbon economy. While some measures are being taken, such as using renewable energy sources, regulating deforestation, promoting nuclear power, and improving energy efficiency, industrialization and urbanization continue to contribute to the problem. Simply relying on alternative energy and conservation efforts may not be enough to prevent a climate disaster. Developing economies reliant on fossil fuels may have no choice but to continue using them, which further impacts the climate [8]. There is no current prescription preventing industrialization, transportation, and energy generation. Natural carbon sinks may take decades or centuries to impact CO_2 levels. Energy transition should not hinder immediate fossil fuel reduction, but rather be pursued alongside other methods. Carbon Capture and Storage technologies can offer a breather to avoid climate disaster and sustain economic activity [9]. There are two types of CCS technologies. Firstly, creative engineering and chemical process developments may enhance productivity and mitigate pollution. It may help 'green' fossil fuel industries for future viability. Inspired by natural carbon sequestration processes, mineral carbonation may be a permanent CO_2 disposal method under various conditions, with attention to economically viable methods. Ancillary engineering sedimentation developments can add alkali to ocean water for nutrient upwelling or to deepen the thermocline, directing phytoplankton blooms to cooler polar waters and carbon sequestration. Capture and storage of CO_2 through industrialized carbon sinks involve using amine or carbonate precipitation technologies. Storage is done through aquifer or saline formation injection or enhanced oil recovery. These technologies have the potential to reduce atmospheric CO_2 concentrations and fossil fuel reserves. However, progress has been slow and current technologies are outdated [10].

TYPES OF CCS TECHNOLOGIES

Carbon capture and storage (CCS) technologies offer a wide range of options generating benefits in terms of climate change mitigation as well as air quality improvements. Different strategies for CO_2 capture have their own advantages and disadvantages, especially with respect to their application to industrial processes. The advantages of each strategy depend mainly on the type of fuel consumed in energy conversion processes as well as on the operation of industrial processes, such as high temperature and high pressure. Therefore, a portfolio of technologies is needed [11]. Oxygen-fuel combustion is generally considered to be an option for new energy conversion processes. Both for existing installations and processes where the integration of additional equipment is difficult, pre-combustion decarbonization is a promising option. Where energy conversion is combined with the production of raw materials, post-combustion CO_2 capture is an option. Other capture options are of interest as well.

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Methane reforming with CO_2 capture has been studied and demonstrated extensively. Although the processes producing CO and hydrogen do not result in net CO_2 removal, they are of interest as they allow for CO_2 capture from natural gas combustion processes. High temperature CO_2 removal is an attractive option [12]. All the above processes for CO_2 removal are sufficiently developed to be at least tested in pilot experiments. Six processes have been selected, in consultation with the sponsors, for more detailed evaluation with respect to their feasibility from a technical, economic, and environmental point of view. The base scenarios consist of normal operation of the processes with pre-investment and operational costs, although some processes are currently under development or have been demonstrated at a small level. Oxygen-fuel combustion processes in a cement plant and in a steel industry are studied. Both processes aim at removing CO_2 from combustion gases in the high temperature cement kiln or in gas make-up for the Direct Reduction Furnace (DRF). In a cement plant process, combustion occurs in pure oxygen (and CO_2 recycled from flue gas) to thereby convert it to flue gas with low CO_2 in which CO_2 can be removed by a conventional, commercial technology prior to emission to the atmosphere. In the steel industry, hot gas for DRF can be produced from natural gas through partial oxidation and a shift reaction converting CO to CO_2. The gas is then quenched and sent to scrubbers for removing H_2O and acidic gases (H2S and CO_2) before emission. Another option is to remove CO_2 while maintaining H_2 and using a water gas shift reaction at high temperature and pressure [13].

CHALLENGES AND OPPORTUNITIES IN IMPLEMENTING CCS

CCS tech faces hurdles despite climate benefits. CO2 emissions must be reduced, advances needed for new tech. Challenges in implementing novel energy systems. CCS technologies can play a significant role in reducing greenhouse gas emissions in most industrial sectors, including fossil fuel production, cement, chemistry, electricity and heat generation, oil refining, steel, and iron. Although most current efforts to increase energy efficiency and use renewable energy will help reduce emissions, they cannot do so sufficiently alone and the high-volume use of fossil fuels must also be decarbonized. However, only a very small number of mitigation technologies have been deployed at significant scale so far as a result of multiple overlapping barriers [14]. There is strong interest in CCS technologies, but only two commercial capture facilities and a few demonstration projects are under construction. High costs limit CO_2 storage projects. CO_2 geological storage is limited by suitable rock formations and regulatory uncertainties. Projects developed in certain jurisdictions may not be replicable. Incentive mechanisms like credits or trading schemes can stimulate opportunities, but strict regulations are needed. Demonstrations projects improve public awareness of CCS technologies. Technological progress will enhance CCS technologies and their deployment. Expected incremental progress can bridge convergence towards large-scale deployment. However, knowledge in emerging technologies may take longer, increasing risk of stranded assets. There is also a risk of being locked into high-emission pathways incompatible with climate goals. Climate research and tools must be used with caution due to simplifications and uncertainty. CCS implementation relies on assumptions about natural gas supply, influencing infrastructure, industry, investment, and social acceptance [15].

CASE STUDIES OF SUCCESSFUL CCS PROJECTS

Since 1972, over 25 large-scale industrial CCS projects have been implemented across the world, with many currently planned or under construction. Some of these projects are highlighted below.

Sleipner, North Sea

The Sleipner T project in Norway is a pioneer in commercial carbon capture and storage (CCS). Equinor operates it, capturing and storing 1 million tonnes of CO_2 annually from natural gas processing at the Sleipner West field. Since 1996, over 17 million tonnes of CO_2 have been injected into saline aquifers in the Utsira formation, located 2,600 metres below sea level. This deep depth allows the CO_2 to be in a supercritical state, occupying less space than in its gaseous state [16].

Weyburn-Midale, Canada

The Weyburn-Midale CO_2 storage project in Saskatchewan, Canada is the world's largest anthropogenic CO_2 storage project. It captures CO_2 from a gasification plant in North Dakota and transports it over 320 km by pipeline to oil fields in Saskatchewan. The project has stored over 20 million tonnes of CO_2 to date. CO_2 is injected into the oil reservoirs at rates of 5,500 tonnes per day at Weyburn and 1,200 tonnes per day at Midale. Over 20 million tonnes of CO_2 have been injected into the fields between 2000 and 2014 [17].

Gorgon, Australia

The Gorgon project is a large natural gas project off the coast of Western Australia. It includes a carbon capture and storage program that will inject 3.4 million tonnes of CO_2 per year into deep geological formations below Barrow Island. This project is part of the Gorgon LNG project and is one of the world's

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largest greenhouse gas abatement projects. The captured CO_2 will be compressed and injected into the Dupuy formation, a limestone formation with high storage capacity. The project will focus on design, construction, operation, and monitoring of the CCS program and associated infrastructure [18].

CONCLUSION

Carbon Capture and Storage (CCS) technologies represent a promising approach to reducing the concentration of CO_2 in the atmosphere and mitigating climate change. While renewable energy sources and improved energy efficiency are vital components of the global response to climate change, CCS offers a viable solution for decarbonizing industries that remain heavily reliant on fossil fuels. Despite significant challenges, including high costs, technological limitations, and regulatory hurdles, the successful implementation of CCS in various large-scale projects demonstrates its potential. As technological advancements continue and international collaboration strengthens, CCS could play an essential role in achieving global climate targets and securing a sustainable future.

REFERENCES

1. Rehman A, Ma H, Chishti MZ, Ozturk I, Irfan M, Ahmad M. Asymmetric investigation to track the effect of urbanization, energy utilization, fossil fuel energy and CO_2 emission on economic efficiency in China: another outlook. Environmental Science and Pollution Research. 2021 Apr; 28:17319-30. [HTML]
2. Ma J, Li L, Wang H, Du Y et al. Carbon capture and storage: history and the road ahead. Engineering. 2022. sciencedirect.com
3. Mikhaylov A, Moiseev N, Aleshin K, Burkhardt T. Global climate change and greenhouse effect. Entrepreneurship and Sustainability Issues. 2020 Jun 1;7(4):2897. researchgate.net
4. Mousavi SM, Dinan NM, Ansarifard S, Sonnentag O. Analyzing spatio-temporal patterns in atmospheric carbon dioxide concentration across Iran from 2003 to 2020. Atmospheric Environment: X. 2022 Apr 1; 14:100163. sciencedirect.com
5. Beck EG. Reconstruction of Atmospheric CO2 Background Levels since 1826 from Direct Measurements near Ground. Science of Climate Change. 2022. researchgate.net
6. Inumaru J, Hasegawa T, Shirai H, Nishida H, Noda N, Ohyama S. Fossil fuels combustion and environmental issues. InAdvances in power boilers 2021 Jan 1 (pp. 1-56). Elsevier. [HTML]
7. Adedoyin FF, Zakari A. Energy consumption, economic expansion, and CO2 emission in the UK: the role of economic policy uncertainty. Science of the Total Environment. 2020. bournemouth.ac.uk
8. Alsarhan LM, Alayyar AS, Alqahtani NB, Khdary NH. Circular Carbon Economy (CCE): A Way to Invest CO2 and Protect the Environment, a Review. Sustainability. 2021. mdpi.com
9. Martin-Roberts E, Scott V, Flude S, Johnson G, Haszeldine RS, Gilfillan S. Carbon capture and storage at the end of a lost decade. One Earth. 2021 Nov 19;4(11):1569-84. cell.com
10. Dubey A, Arora A. Advancements in carbon capture technologies: A review. Journal of Cleaner Production. 2022. sciencedirect.com
11. Bisinella V, Hulgaard T, Riber C, Damgaard A, Christensen TH. Environmental assessment of carbon capture and storage (CCS) as a post-treatment technology in waste incineration. Waste Management. 2021 Jun 1; 128:99-113. dtu.dk
12. Akpasi SO, Isa YM. Review of carbon capture and methane production from carbon dioxide. Atmosphere. 2022. mdpi.com
13. Pfeiffer A. Evaluation of the Smelting Behavior of Direct Reduced Iron. 2023. unileoben.ac.at
14. Deng Q, Ling X, Zhang K, Tan L, Qi G, Zhang J. CCS and CCUS technologies: Giving the oil and gas industry a green future. Frontiers in Energy Research. 2022 Jun 17; 10:919330. frontiersin.org
15. Vega F, Baena-Moreno FM, Fernández LM, Portillo E, Navarrete B, Zhang Z. Current status of CO2 chemical absorption research applied to CCS: Towards full deployment at industrial scale. Applied Energy. 2020 Feb 15; 260:114313. academia.edu
16. Zhang K, Lau HC, Chen Z. Extension of CO2 storage life in the Sleipner CCS project by reservoir pressure management. Journal of Natural Gas Science and …. 2022. [HTML]
17. Albertz M, Stewart SA, Goteti R. Perspectives on geologic carbon storage. Frontiers in Energy Research. 2023. frontiersin.org
18. Islam R, Sohel RN, Hasan F. Fighting climate change through technology and innovation: Reviewing actions of the petroleum industry. Offshore Technology Conference. 2022. [HTML]

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