Exploring the Feasibility and Viability of Carbon Capture and Utilization & Storage (CCUS) as a Key Solution to Mitigate Climate Change.

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***Abstract*— The paper offers an in-depth analysis of the current state of CCUS technological capabilities, including methods for transfer, utilization, and storage. The investigation looks at the social, ecological, and financial factors determining how CCUS technology is used. The research also examines at the regulatory and policy frameworks that facilitate the development and implementation of CCUS projects. The results indicate that CCUS can make a substantial difference in curbing emissions of greenhouse gases and accomplishing climate goals. The research highlights the need for additional study and development in this field while outlining the opportunities and challenges related to CCUS.**

***Keywords*— Carbon Capture Utilization & Storage (CCUS), Carbon Climate Change Mitigation, Carbon Dioxide Emissions Reduction, Feasibility, Viability, Economic Benefits, Environmental Benefits, Challenges Limitations High Costs, Energy requirements, Limited storage capacity, Regulatory framework.**

I. INTRODUCTION

Carbon Capture, Utilization, and Storage (CCUS) technology has emerged as a promising solution to mitigate greenhouse gas emissions and combat climate change. CCUS technology involves capturing carbon dioxide (CO_2) emissions from industrial processes through enhanced oil recovery & direct air capture of CO_2, utilizing CO_2 as a feedstock for the chemical production of biomass, plastics, construction materials, and storing CO_2 in geological formations or other storage options. The potential of CCUS technology to reduce carbon emissions and support sustainable development has attracted significant attention from policymakers, industry, and research communities. The selection of the most appropriate method depends on factors such as feedstock availability, the process's energy and chemical demands, and the products' economic viability.

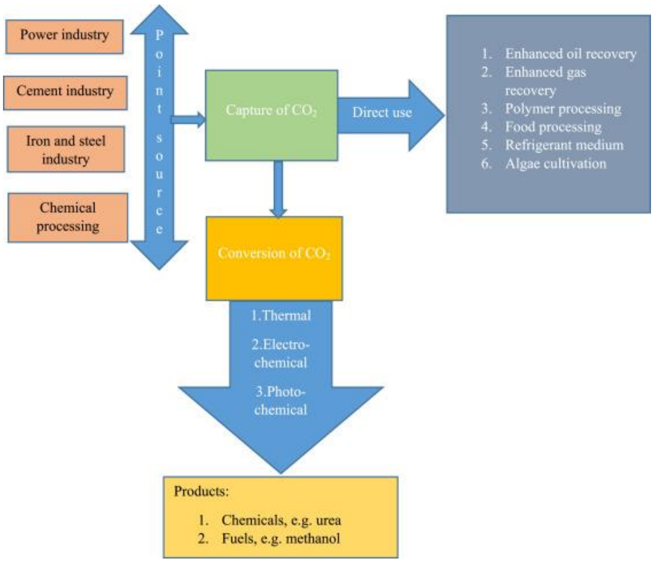


Fig1.CO2 capture and utilization (CCU) pathways.

II. LITERATURE REVIEW

A. History and technology of CCS

Carbon dioxide capture technology has been used since the 1920s to separate marketable gases from the rest. The concept of carbon capture dates back to the 1970s, but it was not until the early 1990s that significant research and development began. The first pilot project of CO2 capture was launched in Norway in 1996, and since then, several large-scale CCUS projects have been developed worldwide. The United States, Canada, and Australia have been at the forefront of CCUS technology, and many of the largest CCUS projects are located in these countries. More recently, investment in CCS is being driven by the oil and gas industries as well as cement, iron and steel, and chemical production industries in the push for decarbonization.

B. Costs and limitations of CCUS

There are several costs and limitations associated with the implementation of CCUS plants. As the CCU technology is in its initial phase, the cost of producing the specific end product is high & depends on the scale of the project. Here are some of the main costs and limitations of CCUS plants. The cost of CCS is one of the major barriers to its widespread implementation. The cost of carbon capture can be as high as $100 per ton of CO_2, depending on the technology used and the characteristics of the source of emissions. The Cost operating factor for a CCUS is majorly its capital costs, operating costs, and energy costs. In addition, the transportation and storage of carbon dioxide can also be expensive, especially for long distances. There are also concerns about the energy requirements of CCS technology, which can reduce the overall energy efficiency of power plants and other industrial facilities. The scale, infrastructure, public acceptance, and technology maturity.

C. Previous research on CCUS

Over the past few decades, researchers have developed several CO2 capture technologies, including post-combustion capture, pre-combustion capture, and oxyfuel combustion. These technologies have been proven to be effective in capturing CO2 from industrial processes. . Previous research on CCS has focused on several areas, including the technical feasibility of CCS. CCUS has also been used for enhanced oil recovery (EOR), which involves injecting CO2 into oil reservoirs to enhance oil recovery. CCUS is seen as a key technology for decarbonizing industrial processes that are difficult to electrify, such as cement and steel production. Research has shown that CCUS could potentially reduce emissions from these sectors by up to 90%.

D. Environmental impacts of CCS

CCUS has the potential to be a key technology in the transition to a low-carbon economy, helping to reduce greenhouse gas emissions and mitigate the worst impacts of climate change. Reducing greenhouse gas emissions from industrial processes that are difficult to decarbonize, such as cement and steel production. Providing a cost-effective way to reduce emissions from power plants that rely on fossil fuels for electricity generation. Enabling the continued use of fossil fuels while reducing their carbon footprint. Creating new markets for captured CO2 by using it for enhanced oil recovery or producing value-added products. Reducing the need for new renewable energy infrastructure by complementing renewable energy sources during times of low generation. Providing a source of hydrogen for fuel cells and other industrial applications. Helping to meet climate targets of achieving net zero carbon emissions till 2050 by removing CO2 from the atmosphere and storing it underground & utilizing the same captured carbon for making specific end products.

Carbon dioxide (CO2) can be stored underground in depleted natural gas reservoirs or other geologic formations as a way to mitigate greenhouse gas emissions. However, there is a risk that the stored CO2 could leak back into the atmosphere, either through natural geological processes or human-induced disturbances. One potential cause of CO2 leakage is movement in tectonic plates. Tectonic plate movement can cause fractures or other types of geological disturbances that could potentially release stored CO2 from underground reservoirs. Other potential causes of CO2 leakage include faults or fractures in the reservoir rock, wellbore integrity issues, and natural gas migration pathways. These risks can be mitigated through careful site selection, well design and construction, and ongoing monitoring and verification of the storage site.

E. Government aids and economic implications of CCUS

Governments around the world are increasingly recognizing the importance of carbon capture, utilization, and storage (CCUS) in achieving net-zero carbon emissions and are providing various forms of support and economic aid to promote the development of CCUS.

- In the United States, the Biden administration has proposed a $6 billion investment in CCUS as part of its infrastructure plan. This includes support for the development of new CCUS projects, the expansion of existing projects, and the construction of CO2 pipelines and other infrastructure.
- The European Union has established the Innovation Fund, a program that provides funding for low-carbon technologies, including CCUS. The fund has a budget of €10 billion for the period 2020-2030, with a significant portion earmarked for CCUS.
- The UK government has recently launched a £1 billion program to support the development of CCUS and other low-carbon technologies. The program includes funding for the construction of new CCUS projects, as well as research and development into new CCUS technologies.
- The Canadian government has committed $319 million over seven years to support the development of CCUS technologies. The funding will support research and development, as well as the construction of new CCUS projects.
- The Australian government has announced a $50 million investment in a new carbon capture and storage fund, aimed at supporting the development of new CCUS projects.
- In Norway, the government has established a comprehensive framework for CCUS, including a carbon tax and other incentives for the development of CCUS projects. The government has also established a fund to support the development of new CCUS technologies.

Government support and economic aid for CCUS are critical for promoting the development of this important technology and accelerating the transition to a low-carbon economy. By providing financial incentives and other support, governments can help to overcome the high costs and technical challenges associated with CCUS and make this technology a more viable option for reducing greenhouse gas emissions.

III. METHODOLOGY

1. Post-combustion capture process

The post-combustion capture process is a technology used to capture carbon dioxide (CO2) from industrial processes, particularly from the flue gas emitted by power plants, refineries, and other industrial facilities. In the post-combustion capture process, the flue gas from industrial processes is first treated to remove impurities such as sulfur dioxide (SO2) and nitrogen oxides (NOx). The treated gas then enters an absorption column where it comes into contact with a chemical solvent, such as an amine solution. The solvent reacts with the CO2 in the gas, capturing it and separating it from the other components of the flue gas. Once the CO2 is captured, the solvent is regenerated using heat, which releases the captured CO2, allowing it to be collected and transported for storage or utilization. The process can be repeated multiple times, allowing for continuous capture of CO2 from the flue gas stream.

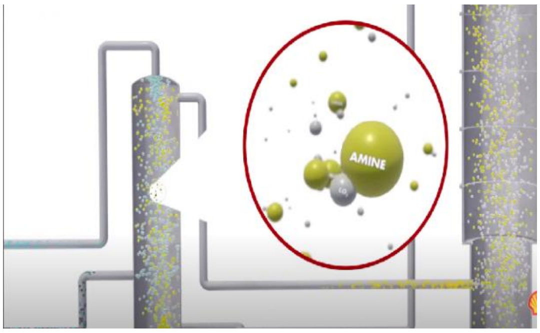


Fig 2. Mixing of aniline with the flue gas for CO_2 separation

Post-combustion capture is considered to be a mature technology, with many commercial-scale installations around the world.
Shell's Quest CCS (Carbon Capture and Storage) project is located at its Scotford Upgrader facility in Alberta, Canada. The project was commissioned in 2015 and is the first CCS project of its kind in the oil sands industry. The Quest project is designed to capture and store up to 1.1 million tonnes of CO2 per year from the Scotford Upgrader, which processes bitumen from the oil sands into synthetic crude oil. The CO2 captured by the Quest project is transported via pipeline to a storage site located more than 2 kilometers underground, where it is injected into a sandstone formation called the Basal Cambrian Sands.

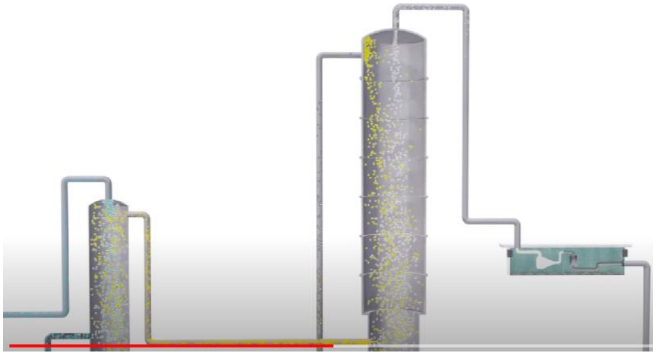


Fig 3. Carbon is captured & separated from the aniline in a distillation column.

This storage site is located near the Scotford Upgrader, which reduces the transportation distance and associated costs. The Quest project uses a post-combustion capture process, which involves capturing CO2 from the flue gas of the Scotford Upgrader. The captured CO2 is then compressed and transported via pipeline to the storage site. The Quest project uses a combination of proven technologies, including amines for CO2 capture, compressors, and pipelines, to capture and transport CO2. The Quest project is a significant investment for Shell, costing approximately $1.35 billion CAD. The project was partially funded by the Government of Canada and the Government of Alberta, which provided a combined $865 million CAD in funding. The project is expected to reduce greenhouse gas emissions from the Scotford Upgrader by up to 35% or 1 million tonnes of CO2 per year, which is equivalent to taking more than 175,000 cars off the road.
Through the post-combustion capture process, we can reduce the amount of carbon released into the atmosphere but, cannot reduce already present carbon in the atmosphere. for eliminating the present carbon in the atmosphere from the emission of transport vehicles we can use the direct air capture method.

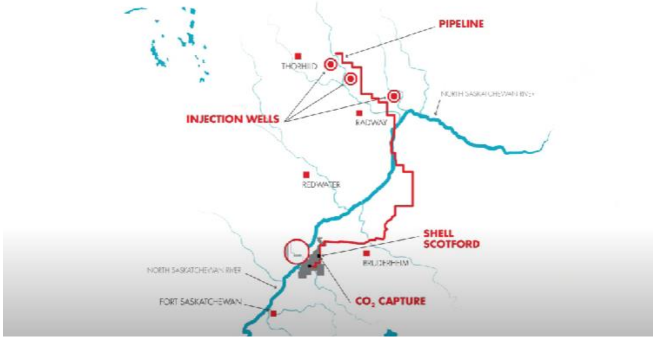


Fig 4. Transporting the captured carbon to the area of storage from the pipeline.

Fig. 5 Carbon capture facility

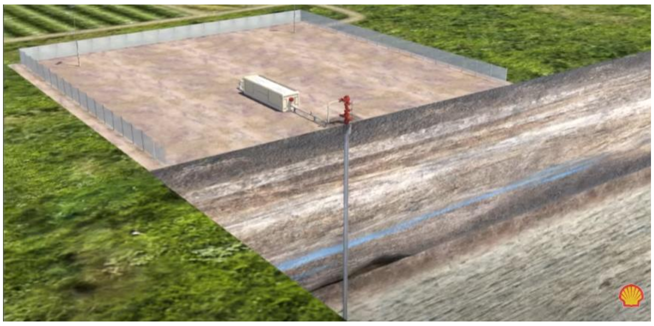


Fig. 6 Sequestration of the captured carbon under geological formation.

2. Direct-Air capture Figures and Tables

Direct air capture (DAC) is a process that captures carbon dioxide (CO2) directly from the atmosphere. The captured CO2 can then be stored or used in various applications, such as enhanced oil recovery, chemical synthesis, or as a feedstock for sustainable fuel production. Climeworks is a Swiss company that has developed and implemented a DAC technology called "Climeworks Carbon Capture" to reduce CO2 emissions.

Fig. 7 Point Carbon Capture

The Climeworks pilot project in Hinwil, Switzerland, was launched in 2017 and is designed to capture 900 tonnes of CO2 per year from the air. The project operates by using a DAC plant that uses a proprietary adsorption-desorption process to capture CO2 from the air. The captured CO2 is then compressed and delivered to a nearby greenhouse facility to enhance plant growth, thereby creating a closed-loop system. The project is designed to offset emissions from local waste incineration, and the captured CO2 can also be sold as a carbon offset or used for other purposes, such as in the beverage industry.

From a financial point of view, the Climeworks pilot project in Hinwil can be viewed as a carbon offset project. Carbon offsets are a market-based mechanism that allows individuals or organizations to offset their greenhouse gas emissions by investing in projects that reduce or remove emissions from the atmosphere. The revenue generated from the sale of carbon offsets can help finance the development and implementation of such projects, including DAC technology.

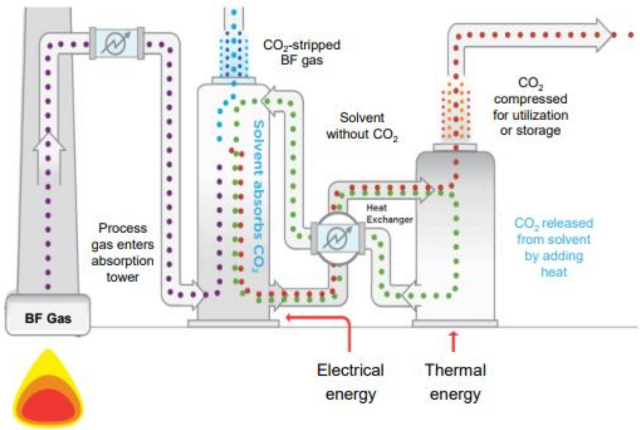


Fig.8 Process Flow diagram for conversion of flue gas to CO_2

The price of carbon offsets varies depending on the type of project and the demand for offsets in the market. Currently, the price of carbon offsets ranges from a few dollars per tonne of CO2 to over $100 per tonne of CO2. The revenue generated from the sale of carbon offsets can help finance the operational and capital costs of the Climeworks pilot project in Hinwil, as well as future DAC projects.

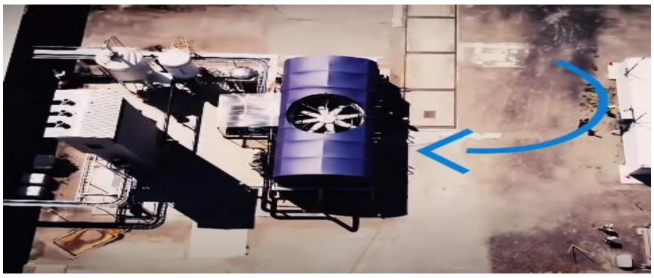


Fig. 9 Open atmosphere Carbon capture

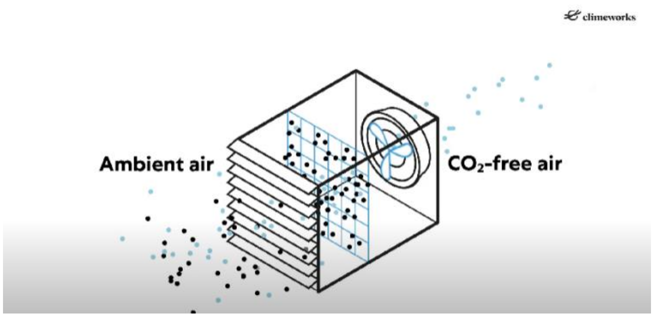


Fig. 10 Mechanism of Capturing Carbon from open air

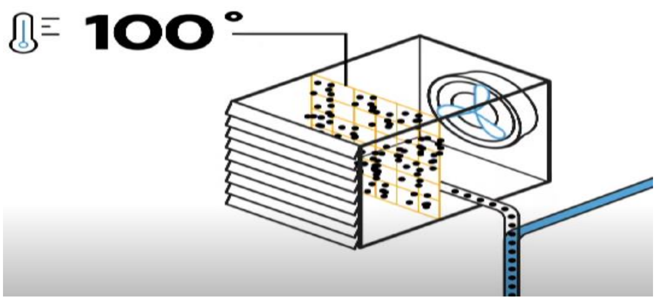
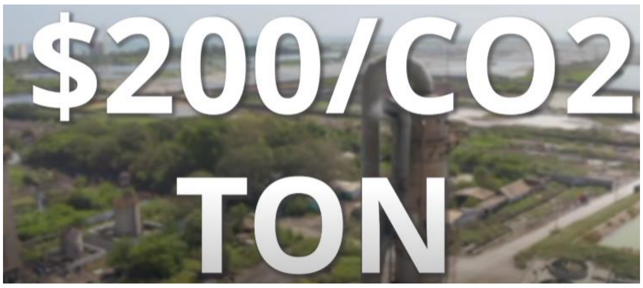


Fig.11 Captured Carbon from open air

In addition to the revenue generated from the sale of carbon offsets, DAC technology can also benefit from government incentives, such as tax credits, grants, and other forms of financial support. Governments around the world are increasingly recognizing the need to reduce greenhouse gas emissions and are providing incentives to support the development and implementation of carbon capture, utilization, and storage (CCUS) technologies, including DAC.



IV.APPLICATIONS

1. Enhanced oil recovery (EOR) is a set of techniques used to increase the amount of crude oil that can be extracted from an oil reservoir beyond the primary and secondary recovery methods. Primary recovery involves the natural pressure in a reservoir pushing the oil to the surface, while secondary recovery involves the use of water or gas injection to maintain the reservoir pressure and force more oil to the surface. EOR methods can be categorized into three main types: thermal, gas injection, and chemical.

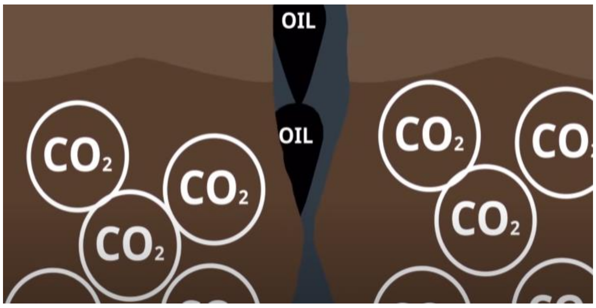


Fig. 12 Captured & Stored Carbon Applying pressure and forcing the oil toward the surface.

a) Thermal methods involve the injection of steam or other heated fluids into the reservoir to reduce the viscosity of the oil and improve its flow to the surface. One example of a thermal EOR method is a steam injection, which is widely used in heavy oil reservoirs. In this method, steam is injected into the reservoir to heat the oil, which reduces its viscosity and makes it easier to flow to the surface. This method has been successfully used in the heavy oil fields of California and Venezuela.

b)

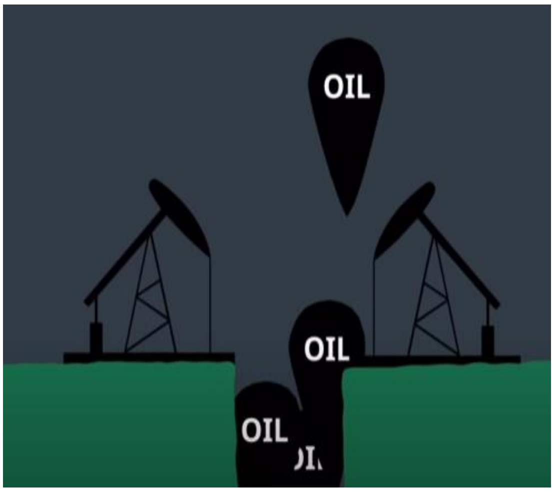
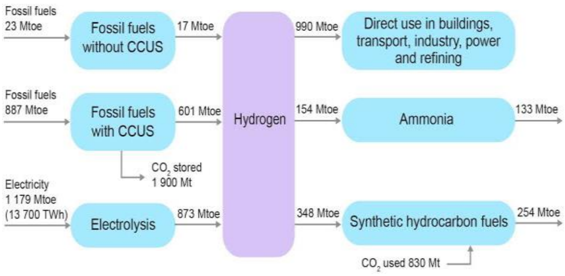


Fig. 13 Enhanced Oil Recovery

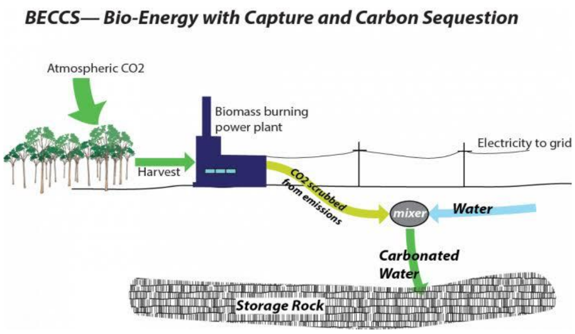
c) Gas injection methods involve the injection of gas, such as carbon dioxide (CO2) or nitrogen, into the reservoir to increase the reservoir pressure and displace the oil towards the production wells. CO2 injection is the most widely used gas injection method and has been successfully used in many oil fields around the world, including the Permian Basin in the United States and the North Sea. In some cases, the injected CO2 can also react with the reservoir rock and increase the oil recovery by reducing the oil's viscosity.

d) Chemical methods involve the injection of chemicals, such as polymers or surfactants, into the reservoir to alter the physical properties of the oil and improve its flow to the surface. One example of a chemical EOR method is polymer flooding, which involves the injection of a water-based solution containing polymer into the reservoir to increase the viscosity of the injected water and push the oil toward the production wells. This method has been successfully used in many oil fields around the world, including the Daqing oil field in China.

2. Synthetic fuel production: The syngas is then converted into synthetic fuels through a process called Fischer-Tropsch (FT) synthesis. In this process, the syngas is passed over a catalyst at high temperatures and pressures, which causes the CO and H2 to react and form long-chain hydrocarbons. These hydrocarbons can be further processed to produce synthetic fuels that are chemically identical to traditional fossil fuels.
3. Power Generation:CCUS can be applied to power plants to capture carbon dioxide emissions before they are released into the atmosphere. For example, the Petra Nova project in Texas captures CO2 from a coal-fired power plant, compresses it, and transports it via pipeline to oil fields for use in enhanced oil recovery (EOR). This project captures up to 1.6 million tons of CO2 per year.



4. Cement Industry:The cement industry is one of the largest emitters of carbon dioxide. CCUS technology can be used to capture CO2 from cement production and utilize it in other industrial processes or for enhanced oil recovery. For example, the Norcem cement plant in Norway captures CO2 and uses it in a nearby fish farm to enhance growth rates and reduce environmental impact.
5. Bioenergy and Biofuels:CCUS can be used to capture CO2 from bioenergy production, such as biomass power plants or biogas facilities, and store it underground. The Drax Power Station in the UK captures CO2 from biomass combustion and stores it in a nearby saline aquifer



V.POSSIBLE FUTURE RESEARCH

Captured CO2 can be used in a variety of ways, including for the production of synthetic fuels and chemicals, as a feedstock for algae-based biofuels, and for enhanced oil recovery. Future research could focus on developing new and innovative ways to utilize captured CO2, as well as optimizing existing utilization methods. Integration with renewable energy: CCUS technology could play an important role in supporting the transition to a low-carbon energy system, but it will need to be integrated with renewable energy sources to be truly effective. Future research could focus on developing integrated energy systems that combine renewable energy and CCUS technology to meet the growing demand for low-carbon energy.

VI.CONCLUSION

In conclusion, exploring the feasibility and viability of CCUS (carbon capture, utilization, and storage) as a key solution to mitigating climate change is a critical step in achieving a more sustainable future. CCUS technology has the potential to significantly reduce CO2 emissions from industrial processes and power generation, while also providing opportunities for the utilization of captured CO2 in a variety of applications.
However, despite the potential benefits of CCUS technology, significant challenges remain in terms of cost, scalability, and public acceptance. The technology requires significant investment and ongoing research and development to improve its efficiency, reduce costs, and ensure the safe and effective storage of captured CO2.
To fully realize the potential of CCUS technology, it will be essential to develop supportive policies and incentives to encourage its adoption, as well as to integrate CCUS technology with renewable energy sources to support the transition to a low-carbon economy.

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REFERENCES:

[1] G. Eason, B. Noble, and I. N. Sneddon, “On certain integrals of Lipschitz-Hankel type involving products of Bessel functions,” Phil. Trans. Roy. Soc. London, vol. A247, pp. 529–551, April 1955. *(references)*
[2] J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.
[3] I. S. Jacobs and C. P. Bean, “Fine particles, thin films and exchange anisotropy,” in Magnetism, vol. III, G. T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271–350.
[4] K. Elissa, “Title of paper if known,” unpublished.
[5] R. Nicole, “Title of paper with the only first word capitalized,” J. Name Stand. Abbrev., in press.
[6] Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, “Electron spectroscopy studies on magneto-optical media and plastic substrate interface,” IEEE Trans. J. Magn. Japan, vol. 2, pp. 740–741, August 1987 [Digests 9th Annual Conf. Magnetics Japan, p. 301, 1982].
[7] M. Young, The Technical Writer’s Handbook. Mill Valley, CA: University Science, 1989.
[8] The Carbon Capture and Storage Handbook by M. Mercedes Maroto-Valer
[9] Carbon Capture, Utilization and Storage: A Guide for State Policymakers by National
[10] IPCC Special Report on Carbon Dioxide Capture and Storage Edited by Bert Metz Ogunlade Davidson Heleen de Coninck Manuela Loos Leo Meyer
[11] Carbon Capture, Storage and Use: Technical, Economic, Environmental and Societal Perspectives by Luis M. Romeo