International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Carbon Capture and Sequestration: A Potential or A Hype?

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ABSTRACT

Abundance of carbon in our atmosphere in the form of CO2, a toxic asphyxiant, can be a crucial trigger for human respiration. Hence, it becomes all the more important to deal with this toxic yet useful element. For utilization of co2, the primary need is capture, transportation and storage covered by the three main technologies: post combustion, pre-combustion and oxy-fuel combustion. Despite the requisites, certain alternatives are kept on ice which can typically be expensive, both to build and operate and also energy intensive. Technologies such as ammonia-based processes, adsorption and cryogenics are nothing but extensions to certain pre-existing techniques. Carbon Capture and Sequestration (CCS), our topic of review, is already being processed in various countries for Enhanced Oil Recovery (EOR). Various geological formations such as oil fields, coal beds are potential sequestration bases but are not expected to contribute much due to certain specifications. Permanent long-term storage of CO2 and its corresponding injection into operation fields are the primary purposes. In this paper, we review the current developments and the emerging possibilities of CCS. Hindrances caused due to inadequate government policies and lack of legal initiation cause a major delay in the process too. The development of key projects is also stagnant because of the rising voices of several NGOs about the potential hazards caused due to mishandling of a CCS. Economic aspects of CCS and the proposed business models are still under scrutiny. Thus, CCS is an option still to be discovered.

Keywords: *Sequestration, carbon capture, anthracite*.

INTRODUCTION

"Take a look at the 25 warmest years that have ever been measured [since 1880]. If you're 32 years old or more, you've been alive for every single one of them. Even if you're only 20, you've been alive for the great majority of them. We, this generation of people, are living on the warmest planet that has ever been measured in the instrumental record."

Prof. Susan Solomon.

Humanity was able to build and support the modern world due to the climate created by atmospheric CO2 levels falling within the range of 280 to 350 parts per million. However, as we move away from this range, the risk of upsetting this equilibrium increases. As per NASA's findings, the atmospheric concentration of carbon dioxide (CO2) on Earth was approximately 416 parts per million (ppm) in April 2021.Which as we all know is dangerous as the high concentration of CO2 in the atmosphere has significant implications, including climate change, ocean acidification, extreme weather events, melting of ice caps and glaciers, and impact on human health.

CO2 being a greenhouse gas traps heat in the Earth's atmosphere, leading to global warming and climate change. The absorption of excess CO2 by the oceans leads to a decrease in pH levels, making them more acidic and potentially harmful to marine life.

Rising temperatures due to increased CO2 levels can result in more frequent and severe heatwaves which is evident as from the recent fact that the schools and institutions were given an emergency holiday this year by the West Bengal State Government for a week. More frequent and severe storms, floods, and droughts have made the effects of climate change closer to our eyes.

Additionally, the melting of ice caps and glaciers due to rising temperatures are actually causing sea levels to rise, increasing the risk of coastal flooding and submergence of islands. A direct example is the complete submergence of Lohachara, Suparibhanga, and Bedford Island of the Sundarbans and Ghor Amara island which also shrink to half it creating environment migrants.

Finally, burning of fossil fuels to produce energy has already resulted in increased levels of air pollution that can lead to respiratory problems, heart disease, and other health issues while its effect could be publicly seen in the Delhi.

What was once a future phenomenon is now actually happening. The effect of high concentration of CO2 is utterly being felt by every human being.

COMMITMENTS

India's commitment to addressing climate change was prominently showcased during the COP26 conference. The country presented a comprehensive set of commitments in line with the global agenda of the Paris Agreement. By 2030, India aims to increase its non-fossil capacity to 500 gigawatts, signifying a significant shift towards renewable energy sources. This commitment aligns with the global goal of limiting global warming to below 2 degrees Celsius. Furthermore, India is determined to fulfill 50 percent of its energy requirements with renewable energy by 2030, showcasing its dedication to reduce dependence on fossil fuels and promoting a sustainable energy transition. To combat carbon emissions, India has set a target of reducing one billion Tonnes of projected carbon emissions by 2030, in line with the global objective of enhancing mitigation efforts. Additionally, India plans to reduce its economy's carbon intensity to less than 45 percent by 2030, emphasizing the importance of sustainable and energy-efficient practices. These commitments demonstrate India's contribution to the global efforts outlined in the Paris Agreement, which stresses the need for ambitious targets and collective action to address climate change. India's commitment extends to achieving net-zero emissions by 2070, aligning with the long-term objective of the Paris Agreement. By aligning its policies and actions with the global agenda, India is playing a significant role in advancing efforts towards sustainable CO2 levels and mitigating the impacts of climate change. These commitments highlight India's determination to bring about transformative changes and inspire other nations to join the global movement for a greener and more sustainable future**.**

TASKS AT HAND

India's energy demand is growing significantly, with a substantial portion of it being met by fossil fuels, accounting for as much as about 69%. Coal, in particular, plays a significant role, with 44% of the fossil fuel-based energy sourced from coal due to India's abundant coal reserves, ranking as the third-largest in the world. Projections suggest that India's emissions could reach approximately 5.6 billion Tones (BT) under a business-as-usual scenario, despite the country's commitment to non-fossil fuels contributing to 40% of its total installed electricity capacity as per its Intended Nationally Determined Contributions (INDC) (Section 3.3). It is estimated that India will account for around 25% of the global increased energy demand between 2017 and 2040, with coal-based energy meeting approximately 42% of this incremental demand.

These trends indicate that fossil fuels, including coal, will continue to be a significant power source for India well into the 2040s, with projected emissions peaking in 2043 (Frank, 2015). For instance, an average 500 MW thermal power plant can emit 2-3 million Tones (MT) of CO2 annually. Moreover, coal-based energy generation is expected to increase significantly, ranging from 330 GW to 441 GW in 2040, up from 175 GW in 2017 Given these projections, it becomes crucial to address the challenges posed by India's heavy reliance on fossil fuels, particularly coal, for energy generation

POSSIBLE SOLUTIONS

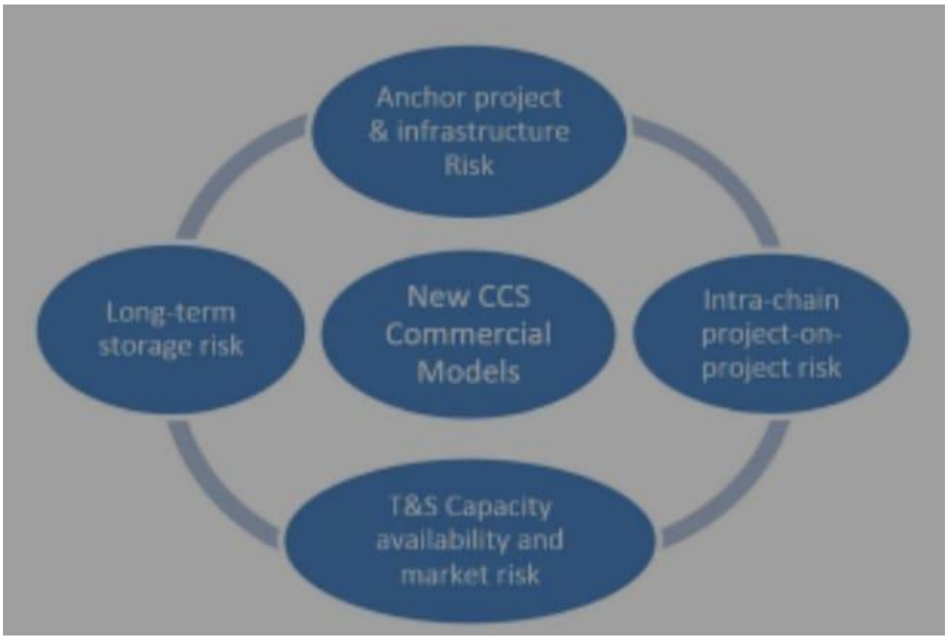

Figure 1: Multiple key-risks associated with CCS.

To effectively address the urgency of the situation, several potential solutions have been identified. Firstly, it is crucial to explore alternate sources of clean energy, shifting away from fossil fuels. This involves investing in renewable energy technologies such as solar, wind, and hydropower, which have significantly lower carbon emissions. Secondly, efforts should be made to reduce the intensity of CO2 production by adopting cleaner forms of combustion or opting for cleaner fuels with high carbon content, such as anthracite or bituminous coal. By minimizing the carbon emissions associated with energy production and consumption, significant progress can be made in mitigating the impact on CO2 levels. Finally, the development and implementation of efficient carbon-capture and sequestration technologies play a vital role. These technologies aim to capture CO2 emissions from industrial processes and power generation and store them underground or utilize them for various purposes, preventing their release into the atmosphere. By focusing on these three approaches – exploring clean energy alternatives, reducing CO2 production intensity, and advancing carbon-capture and sequestration technologies – we can effectively tackle the challenge at hand while striving for a sustainable and low-carbon future.

Now looking at alternative sources which are pretty good like the solar or wind energy as alternative source of energy. According to a study, only 1.7-2.5% of India's landmass would be required to meet zero net emission the with the likes of the solar or wind energy as alternative source of energy. According to the study only 1.7-2.5% of India's landmass would be required to meet zero net emission the pavement of electric vehicles with the hand of Telsa in the world has made transition to electric vehicles a very effective process. With electric rails and metro all their alternative sources are very much a financially affordable reality. Now with work going on opting for cleaner our main focus in this review article would be on the Carbon Capture and Sequestration technologies.

VALIDATION OF CCS

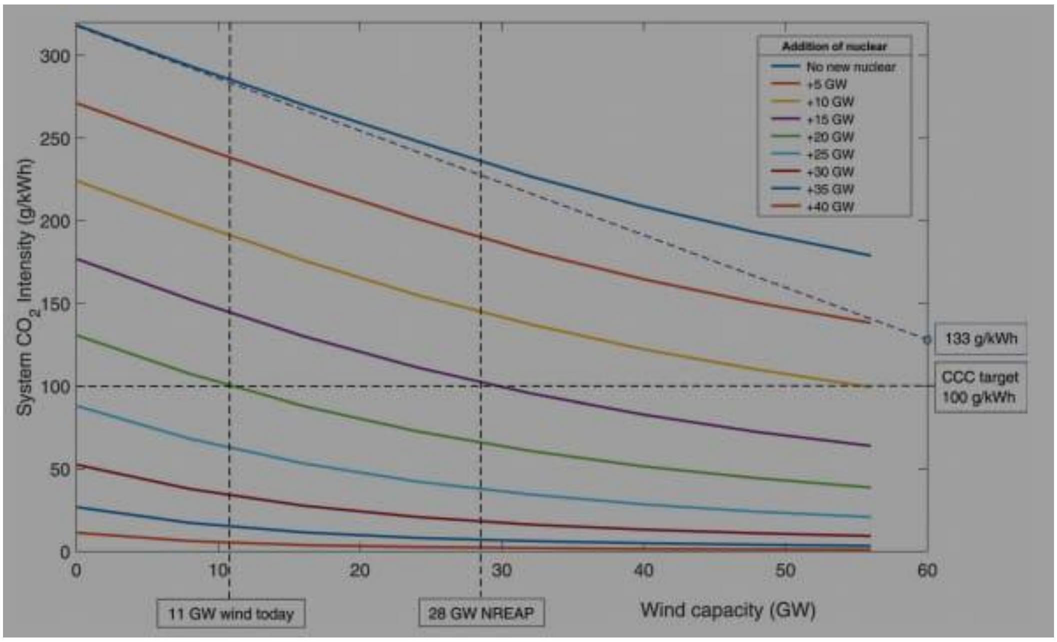

Figure 2:The CO2 emissions as a function of wind and nuclear build.

A compelling argument was made for stabilizing CO2 levels in the low 300s, as suggested by Selin. The development of Indian cities and infrastructure occurred during the "great acceleration" starting around 1950, a period of rapid global economic growth. At that time, CO2 levels were just surpassing 300 parts per million (ppm), and the early impacts of climate change were barely noticeable. Consequently, many aspects of our built environment, such as city flood defenses, were designed based on outdated assumptions about the frequency and intensity of floods. However, in today's world, higher CO2 levels contribute to rising sea levels, more severe storms and increased flood risks thereby rendering these defenses inadequate.

The same holds true for our food system, which relies on assumptions that rainfall and temperature will resemble 20th-century patterns. Given this, one could argue that aiming for atmospheric CO2 levels similar to those of a few decades ago, between 300 and 350 ppm, would be ideal.

Unfortunately, reverting to lower CO2 levels is not a feasible solution. While the planet possesses natural carbon sinks like oceans, forests and soils that gradually remove CO2 from the atmosphere, this process is slow. It can be likened to a bathtub with a slow drain; even if the faucet is turned off, it would take a considerable amount of time for the water already in the tub to drain out. In the case of the atmosphere, this means that even if humanity were to immediately cease CO2 emissions, the excess carbon already present would continue to impact the climate for centuries or even millennia before being fully removed. Basing this argument with the fact that CCS decreases the carbon footprint of fuels by approximately 90% making an effective technology for transition to cleaner fuels a very effective step India a very high coal dependent country.

CCS (CARBON CAPTURE AND SEQUESTRATION)

CCS stands for Carbon Capture and Storage. It is a technology that involves capturing carbon dioxide (CO2) emissions from large-scale industrial processes, such as power plants and manufacturing facilities, and storing them underground to prevent their release into the atmosphere.

The process of CCS typically consists of three main steps:

CAPTURE

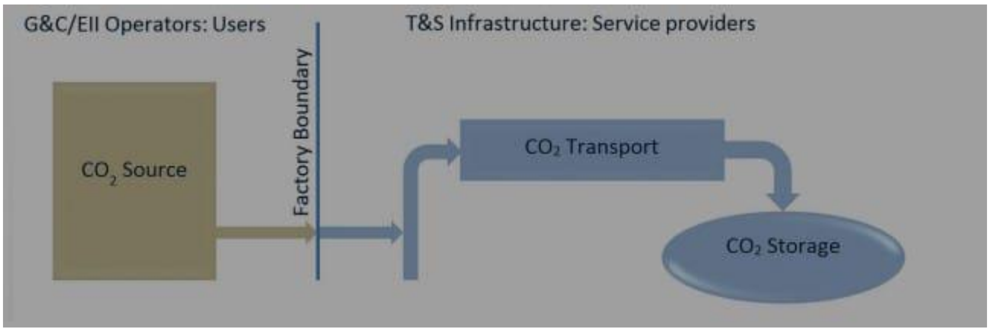

Figure 3: A CCS process example

Carbon capture technologies encompass various methods to reduce carbon dioxide (CO2) emissions from industrial processes and power generation. These techniques can be categorized into different types: pre-combustion capture, post-combustion capture, oxy-combustion capture, Chemical Looping Combustion (CLC), and Direct Air Capture (DAC).

1. **Pre-combustion capture**: Pre-combustion capture is a technique that involves capturing carbon dioxide (CO2) before the fuel is burned. This method is commonly employed in coal gasification or natural gas reforming processes.

a. Integrated Gasification Combined Cycle (IGCC): IGCC is a process that begins with the gasification of coal or other carbon-based fuels at high temperatures, resulting in the production of a syngas—a mixture of carbon monoxide and hydrogen. The syngas is then subjected to a cleaning step to remove impurities. Subsequently, the gas is reacted with steam, converting carbon monoxide (CO) and some CO2 into additional hydrogen and CO2. The captured CO2 can be extracted from the gas stream before combustion takes place. Typically, solvent-based absorption or membrane separation techniques are employed to separate the CO2 from the gas stream.

b. Integrated Reformed Combined Cycle (IRCC): IRCC involves the reforming of heavy hydrocarbons found in natural gas to produce a syngas. This syngas undergoes a purification process to remove impurities. The remaining CO2 can be captured before combustion occurs. Like IGCC, solvent-based absorption and membrane separation techniques are commonly utilized for the separation and capture of CO2 in IRCC.

2. **Post-combustion Capture**: Post-combustion capture is a method in which CO2 is captured from the flue gas emitted after fuel combustion. This approach can be retrofitted to existing power plants and industrial facilities.

a. Solvent-based absorption: In the post-combustion capture process, the flue gas is brought into contact with an amine-based solvent, which selectively absorbs CO2. The solvent is then heated to release the captured CO2, which can be compressed for transportation and storage. The solvent is regenerated and reused in a closed-loop system, enhancing the efficiency of the capture process.

b. Membrane separation: Membrane separation involves the use of specialized membranes that allow for the selective transport of CO2 across their surface. When the flue gas passes through these membranes, the CO2 molecules permeate through while other gases are left behind. The captured CO2 can be subsequently pressurized for storage or utilized in various applications.

3. **Oxy-combustion capture**: Oxy-combustion capture involves burning fossil fuels in an oxygen-rich environment instead of air. By using oxygen rather than nitrogen from air, oxy-combustion produces a flue gas stream primarily composed of CO2 and water vapor, making it easier to capture and store the CO2.

The process requires the separation of oxygen from air, and technologies like air separation units or membrane systems are used for this purpose. Oxy-combustion can be advantageous for new power plants as it eliminates the need for traditional flue gas treatment methods. However, retrofitting existing plants for oxy-combustion capture can be challenging and expensive due to technical complexities and higher temperatures involved.

4. **Chemical looping combustion (CLC**): Chemical looping combustion is an innovative approach that utilizes metal oxides as oxygen carriers. The process involves two interconnected chambers: an oxidation chamber and a reduction chamber.

In the oxidation chamber, the metal oxide reacts with air to release oxygen while converting itself into a reduced metal state. The resulting metal oxide is then transported to the reduction chamber, where it reacts with the fuel, generating heat and producing CO2 and water vapor. The reduced metal is then recycled back to the oxidation chamber to repeat the cycle.

Chemical looping combustion offers advantages such as inherent CO2 separation without the need for additional separation processes. It also has potential cost benefits compared to other capture methods.

5. **Direct air capture (DAC):** Direct air capture technologies extract CO2 directly from the atmosphere, offering the potential to remove CO2 emissions that have already been released. DAC systems typically employ chemical processes or sorbent materials to selectively capture CO2 from ambient air.

In the DAC process, ambient air is drawn into the system, where it encounters a sorbent material or a chemical absorbent that captures the CO2. Once the CO2 is captured, it is separated from the sorbent or absorbent through heating or other chemical processes. The captured CO2 can be permanently stored in geological formations, such as deep underground reservoirs, achieving carbon dioxide removal. Alternatively, it can be used in various applications, such as food processing or combined with hydrogen to produce synthetic fuels.

TRANSPORTATION

The success of CCS projects relies on a robust and efficient transport infrastructure to move captured CO2 to storage or utilization sites.

CO2 Transport Modes

CO2 can be transported using various modes, including barges, pipelines, ships, trains, and trucks. Among these options, pipelines and ships offer scalability and cost-effectiveness, making them the most favorable choices for large-scale CO2 transport.

Pipelines for CO2 Transport Pipelines are crucial for supporting the widespread deployment of CCS. They enable the transportation of CO2 captured from multiple sources. The Alberta Carbon Trunk Line in Canada, for instance, has a capacity of 14.6 Mt CO2/year and is designed for future expansions. Similar multi-user CO2 pipeline networks are being developed globally, such as the Midwest Carbon Express in the United States and the Delta Corridor connecting parts of Germany and the Netherlands.

Ships for CO2 Transport While small-scale merchant CO2 shipping has been demonstrated, large-scale shipping of CO2 is still under development. The Northern Lights project is currently constructing two ships for CO2 transport, and other projects are designing additional vessels. Barges for inland waterway transport are also being considered. CO2 transport by ship or barge requires specific conditioning in terms of phase, temperature, and pressure. CO2 terminals are necessary for loading, unloading, and proper conditioning of CO2 for further transport and injection.

SEQUESTRATION

The final stage of this process is the sequestration of carbon into carbon sinks, which allows for the permanent storage of the captured and transported carbon, effectively mitigating its impact on the environment. Broadly carbon sequestration could be classified into two categories, one being biotic and the other being abiotic sequestration.

BIOTIC SEQUESTRATION

Biotic sequestration refers to the process of storing carbon through the biological activities of living organisms, particularly plants. Plants absorb carbon dioxide (CO2) through photosynthesis, serving as a medium for sequestration. This natural process relies on the symbiotic relationship between plants and animals, resulting in efficient carbon storage within the natural cycle. Biotic sequestration takes place in carbon sinks such as forests, grasslands, soil, and oceans, representing an indirect method of sequestration. It harnesses the inherent capacity of ecosystems to absorb and retain carbon, thereby contributing to efforts aimed at mitigating climate change.

FORESTS

Forests and woodlands play a vital role as exceptional natural carbon sequestration systems. Through the process of photosynthesis, plants absorb carbon dioxide (CO2) while releasing oxygen, acting as powerful purifiers. On average, forests store twice as much carbon as they emit, with approximately 25% of global carbon emissions being sequestered in forests and other vegetative forms like grasslands or rangelands (such as fields, prairies, and shrublands). Preserving and protecting these natural environments is of utmost importance in ensuring the effective capture of CO2 by carbon sinks. By prioritizing the conservation of forests and other vegetative ecosystems, we can safeguard their ability to sequester carbon, helping mitigate the adverse effects of climate change.

SOIL

Soil acts as a crucial carbon sequestration mechanism through organic matter decomposition and stabilization, playing a central role in the carbon cycle and retaining carbon as stable organic matter. Additionally, bogs, peatlands, and swamps have a unique ability to capture and store carbon as carbonates over long periods, with carbon dioxide reacting with mineral elements like calcium or magnesium. This stored carbon remains locked within geological formations for thousands of years, underscoring the importance of conserving and protecting these environments as valuable carbon sinks. Wetland ecosystems include bogs, peats, marshes and other forms of histosols. They sequester C as Soil Organic Matter. They hold ~ 20- 30% of the world soil carbon while occupying a mere 5-8% of land area.

OCEANS

Oceans are vital for carbon sequestration, hosting abundant plant life. Phytoplankton photosynthesis sequesters a significant amount of carbon, with deposition on the ocean floor. Oceans have absorbed a quarter of human-generated CO2, acting as a buffer against extreme climate events. However, this has led to ocean acidification. Ocean fertilization with iron is proposed to stimulate phytoplankton growth, increasing carbon uptake. Aquatic environments absorb about 25% of atmospheric CO2, but excessive absorption harms marine biodiversity. Protecting oceans, reducing atmospheric carbon, and addressing ocean acidification are crucial.

ABIOTIC SEQUESTRATION

Abiotic carbon sequestration refers to the process of capturing and storing carbon dioxide (CO2) from the atmosphere using non-biological or non-living means.

DEPLETED HYDROCARBON RESERVES

One of the deeply researched, explored and ready to act infrastructure is this**.** Depleted oil and gas reservoirs provide a promising opportunity for carbon sequestration. Monitoring technologies like InSAR and remote sensing can aid in detecting and managing potential issues associated with CO2 injection and reservoir behavior. CO2 injection serves two purposes: sequestration of CO2 and enhanced oil recovery from the reservoir.

Enhanced Oil Recovery (EOR) and Enhanced Gas Recovery (EGR) are techniques employed to increase oil and gas production while also facilitating carbon sequestration. EOR involves injecting CO2 into oil wells to reduce viscosity and extract remaining oil, while EGR utilizes CO2 to displace natural gas in depleting gas fields. These well-established methods have been successfully implemented worldwide for several years. These approaches are particularly suitable for carbon sequestration due to the presence of natural sealing mechanisms in the geological formations that have held oil and gas reserves for millions of years. Consequently, they offer the potential to recover significant amounts of hydrocarbons while simultaneously storing CO2. Studies evaluating the potential of CO2-EOR and CO2 storage in various basins have provided promising results. In favorable basins, it is estimated that approximately 470 billion barrels of oil could be recovered through miscible CO2-EOR, leading to the storage of around 140 billion metric tons (Gt) of CO2.

Furthermore, these basins also harbor substantial volumes of undiscovered oil resources, further enhancing the potential for CO2-EOR applications. If successfully implemented, the global potential for CO2-EOR could reach 1,070 billion barrels of oil, accompanied by a CO2 storage capacity of 320 Gt. These findings highlight the dual advantages of EOR and EGR techniques, enabling the optimization of hydrocarbon recovery while contributing to the mitigation of climate change through carbon sequestration.

Enhanced Coal Bed Methane Recovery (ECBMR) involves the sequestration of carbon in coal seams while enhancing the recovery of methane. Methane accounts for approximately 95% of the gases found in coal seams. The process is relatively straightforward, where CO2 is injected to replace the existing methane. This dual-purpose approach takes advantage of the coal's affinity for CO2, providing an additional benefit. By utilizing the produced methane as an energy source, it prevents its release into the atmosphere, which is crucial as methane is 23 times more potent as a greenhouse gas than CO2. This approach effectively combines carbon sequestration with energy production, contributing to mitigating climate change.

Saline aquifers, containing brackish water with excess salt, are considered less useful. However, they have potential for carbon sequestration. Measuring baseline CO2 concentration and soil carbon content in these aquifers can help assess sequestration potential. Reservoir simulation models suggest that a small fraction of the aquifer volume can be used for storage. Deep saline aquifers have greater carbon sequestration capacity compared to other geological sites. While estimates vary, these aquifers hold significant potential for carbon storage.

METAL CARBONATION

Mineral carbonation sequestration converts CO2 into stable minerals through chemical reactions with rocks or minerals rich in elements like calcium or magnesium. This process captures and stores carbon in solid carbonates, providing long-term storage. It utilizes abundant minerals like olivine or serpentine and can be optimized for efficiency. While challenges exist, ongoing research aims to improve scalability and cost-effectiveness. Mineral carbonation sequestration has significant potential for reducing CO2 emissions and combating climate change. Mineral carbonation is presumably a safer alternative to the other geological sequestration techniques since carbon is immobilized into stable carbonate.

MICROALGAE SEQUESTRATION

Microalgae carbon sequestration is a sustainable method to reduce global CO2 emissions. Recent advancements in cultivation techniques, harvesting, and CO2 sequestration capacity make microalgae a promising option for carbon emission mitigation. However, more research is needed to develop large-scale and commercial-scale applications of microalgae for carbon sequestration. Studies have shown that microalgae have higher CO2 tolerance, carbon assimilation efficiency, photosynthetic efficiency, and growth rate compared to terrestrial plants. Additionally, microalgae can be used symbiotically with bacteria in wastewater treatment plants to sequester CO2 and produce algal biomass. Further research is required to address challenges such as efficient CO2 mixing and improved algal growth in this system.

R&D in India

The Department of Science & Technology (DST) in India, have established two National Centers of Excellence (Coe) focused on Carbon Capture and Utilization (CCU). The National Centre of Excellence in Carbon Capture and Utilization (NCoE-CCU) is located at the Indian Institute of Technology

(IIT) Bombay in Mumbai, while the National Centre in Carbon Capture and Utilization (NCCCU) is based at the Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR) in Bengaluru. The centers being National Centre of Excellence – CCU, IIT Bombay, Indian Institute of technology-Delhi, National Centre in CCU- JNCASR, Bangalore, Centre of Excellence in coal research at BHEL, National Chemical Laboratory, CSIR, National Environmental Engineering Research Institute, NEERI, National Geophysical Research Institute NGRI, NETRA (NTPC Energy Technology Research Alliance). India is member of Carbon Sequestration Leadership Forum launched by the US Department of Energy. India has also collaborated with UK in CCUS technologies.

CARBON CAPTURE AS AN OPPORTUNITY

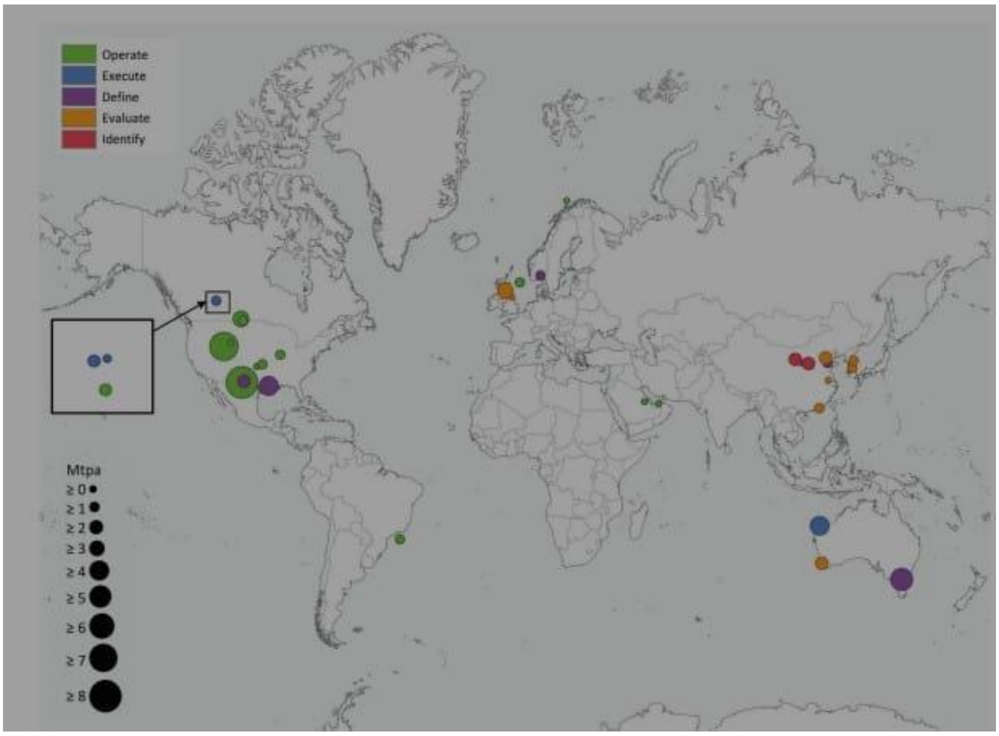

Figure 4:Commercialy powered and integrated CCS projects around the world. Data from Global CCS Institute.

As by most any technology and process cannot go far until it has an economic profit coming from it.An economic profit is projected from any such technology it is meant to come forward in the future. As World Economic Forum Future of Job Reports 2023 very clearly found that macrotrends in job creation will come from green transition of business. Which clearly has in minds the call that the future trend is accepting and realizing the need for a favorable environment. The potential market is huge. And has the transportation is a tried and tested method for many decades it will be reliable for investors to come in and invest as without invested large scale technology cannot be drawn.

INVOLVEMENT OF START UPS AND LARGE COMPANIES

A national award-winning start up Breathe Applied Sciences projects the framework that there are a lot of start-ups future and proper economic future in this direction along with government support. Well Breathe Applied Science which converts CO2 into methanol and other fuels. There are other in the market like Carbon Clean, partnering with many large enterprises in India using their amine-based solvent capture technology. Other companies like Indian Farmers Fertilizer Co-Operative, Indo Gulf Corporation Ltd, Indian Farmers Fertilizer Co-Operative and Novonanm ek (DAC).

The majority technology in this technological department has come from the large players namely NALCO, NTPC, BHEL, Dalmia Cement, ONGC, IOCL, Reliance Industries, Hindalco, Tata Steel and Tuticorin Alkali Chemicals. The majority which technology has come up in the last 10 years or so. The technology they are using mainly revolves around Amine based solvents, Microalgae carbon sequestration, enhanced oil recovery and Membrane technology for capture and methanol conversion. There is a important part which could played by these businesses.

CONCLUSION

It will be a fallacy to think that we can address aspects of ecosystem in isolation. Nature is all connected. The CCS technology must be implemented and in it there is huge potential but in hands all other technologies would have to be simultaneously incorporated as the situation is not a very good one. CCS implementation has major barrier in its sequestration and transport development in India where research has been going on and around the world Either we fasten the environmental regeneration or the faster we shall will face the dangers. We need more action and fast action.

ACKNOWLEDGEMENTS

Extended gratitude to all my co-authors Debabrata Ghosh and Subhadip Layak. Thankfulness should also be extended to our faculty members and teachers who were instrumental in raising the important concerns and proposing plausible solutions. Moreover, I want thank my project guides Mr. Jaydip Sengupta and Mrs. Sumana Sengupta for helping me out with this project.

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