A DISCUSSION ABOUT CARBON CAPTURE

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ABSTRACT

The paper discusses the challenges and opportunities of carbon capture and utilization (CCU) and carbon capture and storage (CCS) technologies. This is the process of capturing CO_2 from industrial emissions and using it to produce synthetic fuels, chemicals, and other materials, or storing it underground. The paper also discusses the potential benefits of these technologies and the challenges of these technologies, such as their high cost and the limited availability of storage sites. The authors argue that they have the potential to create jobs, improve air quality, and make fossil fuels more sustainable but also potential risks, such as the risk of leakage from storage sites. Carbon capture technologies are still in their early stages of development, but they have the potential to play a major role in reducing global heating. Continued research and development, and supportive government policies, are required for CCS play a significant role. Carbon credits can be an instrument to boost the energy transition process.

Keywords: Carbon Capture and Storage (CCS), Carbon Capture and Utilization (CCU), Carbon Credits, Energy Transition, Sustainability.

Introduction

Nutrition, hydration, respiration, and transpiration are essential for all living things. They are the basis of the carbon, hydrogen, oxygen, and nitrogen cycles in nature.

Diverse activities developed by society produce some carbon emissions or use fossil fuels. For example: power generation. The power generation model based on fossil fuels to meet the needs of economic and social development has disrupted the natural carbon cycle. The exhaustion of the current power generation model for the world is related to the fact that these non-renewable sources, such as oil, gas, and coal, are becoming increasingly scarce and expensive to extract. In addition, the large-scale burning of fossil fuels is one of the main causes of climate change, with the emission of greenhouse gases (GHG) such as carbon dioxide (CO_2).

The increasing concentration of GHG in the atmosphere contributes to global warming and climate change. The estimate for 2023 is 40.6 $Gt\ CO_2$ (billions of tons of carbon dioxide) of global emissions, the highest annual volume ever recorded. China is the country that emits the most CO_2, accounting for 30.9% of total emissions [1]. Emissions and the accumulation of GHG in the atmosphere continue to grow. Fig.1 illustrates the growth of GHG emissions over the past 150 years

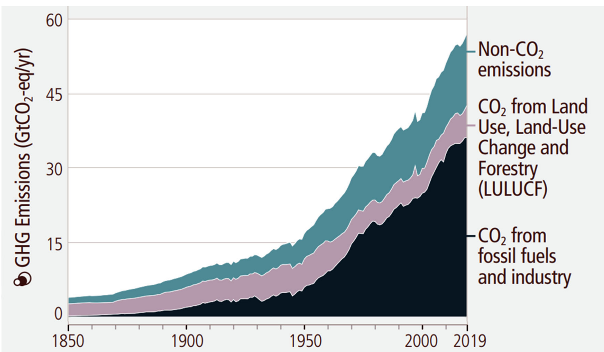

Figure 1: Anthropogenic CO_2 emissions Source: IPCC-AR6, 2023

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Limiting the GHG emissions to combat the climate change and the global warming trend has been discussed in all the recent Conference of the Parties (COP) of the United Nations Framework Conventions on Climate Change (UNFCCC) [2]. To reverse this trend and combat the global warming trend, two actions are required: reduce emissions (Net Zero economy), and carbon capture.

Scope and methodology

This article aims to bring some highlights about carbon capture and to propose a discussion about how to stop using fossil carbon and what to do with the captured carbon.

Reduce emissions - Net Zero economy

Changing the paradigm is a key factor for the energy transition. Increasing the use of renewable power sources such as wind, hydro, and solar to produce electricity on a large scale is a first step to reduce fossil carbon burning.

Energy transition includes the modernization of energy infrastructure, the promotion of green technologies, efficiency improvement of power generation process, reduction of loss and waste. and education about the importance of clean energy. It also involves changing the behavior of people and businesses in relation to energy consumption and encouraging energy efficiency.

Current and upcoming technologies are increasing their participation in the global energy matrix. However, the market is not able to provide clean air adequately. Therefore, it is the responsibility of governments to adopt measures to ensure the quality of this asset. And, since the atmosphere is affected by the action of each individual, each company, and each nation, international policies are needed. Countries, gathered under the structure of the United Nations (UN), must propose a policy to enable the energy transition of all by imposing emission limits and establishing compensatory measures.

Carbon capture and storage (CCS)

CCS is a technology that captures CO_2 from industrial emissions and stores it underground. This technology is still in its early stages of development, and there are a number of challenges that need to be addressed. These challenges include the cost of the process, the availability of storage sites, and the potential risks of leakage.

Despite these challenges, CO_2 storage has the potential to play a significant role in reducing GHG concentration. The International Energy Agency (IEA) estimates that CCS could reduce global CO_2 emissions by up to 15% by 2050 [3]. The IEA estimates that CCS could be deployed at a commercial scale by 2030 [3]. However, this will require significant investment in research and development, as well as government policies that support CCS. The CCS process involves three main steps:

- **Capture**: The CO_2 is captured from industrial emissions, such as those from power plants, factories, and oil and gas production. There are a number of different capture technologies available, including post-combustion capture, pre-combustion capture, and oxy-fuel combustion. CO_2 of industry process can be captured as it is generated from furnace and boilers' chimneys, from fermentation processes, and from chemical reactors exhaust.

- **Transport**: The captured CO_2 is then transported to a storage site. CO_2 can be transported by pipeline, ship, or truck. CO_2 can be liquefied or solidified to enable better transport conditions. At temperatures between –56.6 and +31.1°C, and at pressures of at least 0.52 MPa, CO_2 can exist in the liquid state. At temperatures below –56.6°C, CO_2 will be in the solid state.

- **Storage**: The CO_2 is then stored underground in a secure geological formation. Potential storage sites include deep saline aquifers, depleted oil and gas reservoirs, and unmineable coal seams.

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CO_2 can be captured from the air as its concentration reached 465 ppm (parts per million) in 2020 [4]. This process is also called carbon sequestration. CO_2 can also be captured from the seawater as its effective concentration in seawater, in equilibrium with the atmosphere is 0.099 $kg\ CO_2/m^3$ (a factor 125 larger than in air) [5]. Extraction can be performed by increasing the water temperature, however, this is an expensive option. Extraction may be also accomplished by making the seawater more acidic, based on the the carbonate chemistry of CO_2 in seawater, using electrochemical extraction cells based on bipolar membrane electrodialysis [6].

Benefits and challenges

CCS has several potential benefits: it can help to reduce greenhouse gas emissions and mitigate climate change; it can help to improve air quality by reducing the amount of CO2 released into the atmosphere; it can create jobs in the clean energy sector; it can help to make fossil fuels more sustainable.

The main challenges of CCS are: it cost is still relatively high because implementing CCS technologies can be expensive due to the equipment, infrastructure, and energy required to capture and store carbon dioxide emissions; there is a limited availability of storage sites; there is a potential risk of leakage.

Mineralization

The captured CO_2 can be converted to carbonates before being placed underground. This is a process called carbon mineralization. There are two main ways to do this:

- Direct mineralization: This involves injecting CO_2 into a geological formation that contains minerals that can react with CO_2 to form carbonates. The most common minerals used for this purpose are calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$). The reaction between CO_2 and these minerals is exothermic, meaning that it releases heat. This heat can help to drive the reaction forward.

- Indirect mineralization: This involves first converting CO_2 into a more reactive form, such as bicarbonate (CO_3-). This can be done by dissolving CO_2 in water or by reacting it with a base. The bicarbonate is then injected into the geological formation, where it reacts with the minerals to form carbonates.

The choice of which method to use depends on the specific geological formation and the availability of resources. Direct mineralization is generally more efficient, but it requires a geological formation that contains the right type of minerals. Indirect mineralization is less efficient, but it can be used in a wider variety of geological formations.

Once the CO_2 has been converted to carbonates, it is much more stable and less likely to escape back into the atmosphere. This makes it a more secure way to store CO_2 underground.

Some of the benefits of converting CO_2 to carbonates before storing it underground are: it makes the CO_2 more stable and less likely to escape back into the atmosphere; it can help to prevent the formation of acid gas, which can be harmful to the environment; it can create new economic opportunities, such as the production of building materials and other products made from carbonates.

However, there are also some challenges associated with converting CO_2 to carbonates: it is an energy-intensive and expensive process which often involves the use of chemical reagents and high temperatures which increase operational costs; it requires a geological formation that is suitable for mineralization. The reaction may take a long time to fully convert all of the CO_2. This slow reaction kinetics can be a limitation in the context of rapid CCS.

Overall, converting CO_2 to carbonates before storing it underground is promising. It is a more secure way to store CO_2 and it can also create new economic opportunities. However, the related challenges must be addressed [7].

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Carbon capture and use (CCU)

Large amounts of CO_2 will be available due to the planned CSS plants, and therefore carbon dioxide can be a zero-cost (or even negative-value) feedstock for innovative conversion processes. Several opportunities exist for the conversion of CO_2 to chemicals, including synthetic fuels such as ammonia, methanol, ethanol, etc. Using captured carbon in these processes means not using fossil raw material.

The valorization of CO_2 emissions and its chemical recycling is imperative. The carbon captured mainly from industrial exhaust systems, in the form of CO_2 can be used as feedstock in several industrial processes. It can be used for filling fire extinguishers, in the food industry for beverage carbonation, and other uses. Even pure carbon can be obtained for use as a valuable raw material in the graphite industry, as carbon black in the automotive tire industry, as activated charcoal in several filtering processes, etc.

The role of black, brown, grey and blue Hydrogen production

Hydrogen gas (H_2) is seen as a vector for the energy transition, aiming at a new energy sustainability model to meet global demand as the concentration GHG in the atmosphere increases. A great growth of the world demand for this gas is expected [3]. H_2 and captured carbon are like building blocks, like "Lego pieces", for the upcoming green chemical industry.

They enable organic syntheses to obtain valuable chemicals and raw materials for the most common organic substances. Currently, the utilization of H_2 as chemical feedstock is limited to a few processes: the synthesis of urea (for nitrogen fertilizers and plastics), pharmaceutical ingredients, and polycarbonates (for plastics). However, the actual use corresponds to a few percentage of the potential (H_2) suitable to be converted to chemicals.

Several technologies are in use for the production of H_2. Natural Gas Reforming (75% of the global produced H_2) and Mineral Coal Steam Reforming or Gasification (23% of the global produced H_2) are the most used. H_2 from these technologies (without CCS) is classified as black, brown, grey. They have as by-products the emission exhaust gases containing GHG. The CO and CO_2 from the exhaust gases can be captured for use or storage. The blue hydrogen process uses CCS to trap and store this carbon from reforming technology but it have an efficiency of 60-65%, so there is 30-35% of CO_2 that will be emitted.

Carbon Credits

A carbon credit is a tradable certificate or permit that represents the right to emit one *metric ton* of CO_2 or its equivalent amount of other GHG. Carbon credits were created as a way to reward the fight against the accumulation of GHG in the atmosphere and mitigate the impact of climate change. They are intended to provide a financial incentive for businesses, governments, and individuals to reduce their carbon footprints by reducing, or removing, their emissions. There are two main types of carbon credits:

- Emissions reductions credits: These credits are issued to projects that reduce or avoid greenhouse gas emissions. For example, a project that installs energy-efficient lighting would earn emissions reductions credits for the amount of CO_2 that is avoided by using less electricity.

- Offset credits: These credits are issued to projects that remove greenhouse gases from the atmosphere. For example, a project that plants trees would earn offset credits for the amount of CO_2 that is absorbed by the trees. Offset credits embraces CCS and CCU projects.

These certificates are a tradable financial asset. Carbon credits can be traded on a market, where they can be bought and sold by businesses, governments, and individuals. The price of carbon credits can vary depending on the supply and demand for credits, as well as the perceived value of reducing GHG emissions.

The first carbon credit market was established by the Kyoto Protocol in 1997. The Kyoto Protocol is an international agreement that aims to reduce GHG emissions. It created a market for carbon credits, where countries that are over their emissions targets can buy credits from countries that are under their

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targets. Since the Kyoto Protocol, there have been a number of other carbon credit markets established around the world. These markets include the European Union Emissions Trading System (EU ETS), the California Cap-and-Trade Program, and the Regional Greenhouse Gas Initiative (RGGI).

The World Bank's report "State and Trends of Carbon Pricing" [8] recorded that 51 national and sub-national jurisdictions have adopted, or are about to adopt, carbon pricing initiatives as a way to internalize the environmental costs of GHG emissions and better signal the price of traded goods.

However, there are a number of challenges that need to be addressed in order to make carbon markets more effective. These challenges include: the high cost of carbon credits; the lack of transparency in the carbon market; the difficulty of verifying the emissions reductions or removals that are associated with carbon credits.

Despite these challenges, as the carbon market matures and these challenges are addressed, carbon credits are likely to become an increasingly important. The demand for carbon credits is expected to grow in the coming years, as more businesses and governments adopt climate change mitigation policies. They are a market-based approach that can help to incentive innovation. Carbon credits can be used to offset emissions from a variety of sources, including transportation, electricity generation, and industrial processes.

Conclusion

Capturing carbon from the atmosphere air to reduce its concentration is an issue to be seriously considered and will play a significant role in the fight against climate change. However, there are still a number of challenges that need to be addressed before CCS can be deployed at a commercial scale.

CCU and CCS must go hand-in-hand. The use of captured carbon is the priority. When use is not possible, then storage must be chosen even that storage is still a challenge. Continued research and development, and supportive government policies, are required for CCS play a significant role. The CCS, or CCU, can also qualify for carbon credits, which are a tradable financial asset.

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