Assessment of Carbon Capture, Utilization, and Storage Technologies in the Bioenergy Sector: Mapping Technological Alternatives and Market Analysis in the EU27

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Introduction

Applied to bioenergy production CCUS is the chain of technologies required to capture, transport, utilize and store biogenic CO_2 from the emissions. Anthropogenic climate change, characterized by a sharp increase in atmospheric concentrations of greenhouse gases (GHG), stands as one of the foremost challenges of our era. Carbon dioxide (CO_2) emerges as the primary GHG, responsible for over 80% of total emissions [1]. Bioenergy with carbon capture utilization and storage (CCUS) emerges as a pivotal climate change mitigation tool, not only curbing biogenic CO_2 emissions but also fostering the realization of a circular economy.

Bioenergy production operates within the fast domain of the global carbon cycle, replacing a portion of fossil fuel energy. This displacement effectively prevents the transfer of carbon from the slow to the fast domain of the global carbon cycle, thereby contributing to the reduction of anthropogenic carbon dioxide emissions. Moreover, with the application of CCUS technologies, bioenergy production can achieve carbon negativity [2].

Additional drivers for CO_2 utilization indirectly support climate change mitigation efforts. CO_2 emerges as one of the few alternatives to fossil fuels as a carbon source. Even in a zero-emission economy, carbon remains indispensable for various applications. For instance, organic chemicals inherently rely on carbon for their structure and properties, rendering them impossible to decarbonize. Similarly, in sectors like aviation, carbon-containing fuels will retain their significance due to the immense challenges associated with transitioning to carbon-free energy carriers such as electricity or hydrogen. Furthermore, by enabling the utilization of renewable electricity in sectors like transportation and industry, CO_2 utilization facilitates the energy transition [3].

In principle, CO_2 could be indefinitely utilized if recaptured from the atmosphere or a biogenic source following its release. This potential positions CO_2 utilization as an integral component of a circular carbon economy, where resources are maximally utilized before being disposed of into the environment. Lastly, the exploration of novel CO_2 utilization applications presents opportunities for industrial innovation and technological leadership.

To be able to develop new CO_2 utilization and storage technologies efficiently on the short to mid-term it is of pivotal importance to have a good insight in the current situation of carbon utilization and storage in the current bio-energy sector. To achieve this crucial knowledge, a detailed mapping of technological alternatives and their current status was performed for the EU27 and additionally the current market for carbon utilization and storage in the EU27 was analyzed.

Material & methods

A comprehensive literature search was conducted using electronic databases including Google, Google Scholar, Scopus, and Web of Science. The search was conducted from 01/11/2024 to 31/12/2024, with language restricted to English. The search terms used were: carbon capture, carbon capture and utilization, carbon capture and storage, carbon capture utilization and storage, CCUS, CUS, BECCS, BECCU market for CO_2, CO_2 utilization, CO_2 storage, biogenic CO_2 utilization and Boolean operators (AND, OR) were employed to refine the search. Additionally, we manually screened the reference lists of relevant articles to identify additional studies not captured in the electronic search.

Results & Discussion

The global demand for CO_2 reached 236 million metric tonnes (Mt) in 2022, with projections indicating an increase to 520 Mt by 2035[4]. CO_2 utilization predominantly involves non-conversion pathways, including food and beverage production, metals fabrication, cooling processes, healthcare, and oil reservoir injection. In Europe, existing markets for CO_2 utilization are primarily found in the food and beverage industry, accounting for 37% of global CO_2 use. Other sectors utilizing CO_2 include greenhouse horticulture, fertilizer production, and refrigeration. Challenges in these markets include difficulties such as the lack of affordable, high-purity CO_2 in greenhouses and the need for infrastructure for CO_2 transportation[3].

Carbon Capture and Storage (CCS) opportunities exist across various sectors, including CO_2-enhanced coal bed methane projects, oil and gas fields, deep saline aquifers, deep coal seams, and mineral carbonation. Oil and gas fields offer safety advantages, while saline aquifers provide large storage capacities. Coal seams present potential storage options with enhanced methane recovery, and mineral carbonation can sequester CO2 in stable carbonate minerals suitable for use as construction materials. The global storage capacity for CCS is estimated at 390 Gt for oil and gas fields[5], 400 to 10,000 Gt for deep saline aquifers (with 30 to 577 Gt in Europe) [6], 60 to 200 Gt for deep coal seams[7], and potentially exceeding 10,000 Gt for mineral carbonates[8]. Despite this immense potential, current CO_2 capture and storage efforts only account for 0.12% of yearly emissions[9].

Conclusion

The current demand for CO_2 utilization, totaling 236 Mt, falls short of compensating for global CO_2 emissions (36.8 Gt), covering less than 1% of emissions. Hence, there is a crucial need to develop large-scale conversion routes, such as the production of fuels, chemicals, and building materials derived from CO_2, to significantly contribute to the goal of achieving carbon neutrality by 2050. Additionally, with only 0.12% of global yearly carbon dioxide emissions currently being captured and stored, it is imperative to prioritize the development of large-volume carbon capture and storage projects to facilitate progress towards carbon neutrality by 2050.

The bioenergy sector can play a crucial role in the imperative development of carbon conversion routes for utilization and large-volume carbon storage, as it represents low-hanging fruit for carbon capture. Moreover, it offers the utilization of biogenic CO_2 within its production cycle, providing the possibility of achieving true circularity

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