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CARBON DIOXIDE WASTE UTILIZATION IN AGRICULTURE

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Abstract: Carbon dioxide (CO_2) waste utilization is part of a broader strategy known as carbon capture, utilization, and storage (CCUS), which aims to reduce greenhouse gas emissions by transforming captured CO_2 into products rather than storing it. This method showcases a circular economy by reusing CO_2 captured from waste sources, helping to reduce the costs of carbon capture and promote sustainability in different industries. Carbon dioxide is vital in agriculture, aiding photosynthesis, boosting plant growth, and supporting sustainable farming. The exploration of innovative CO_2 utilization pathways, such as ensiling plants on farms, as well as many other innovations, gives the potential to create valuable products and promote sustainable agriculture.

Keywords: Sustainability, Carbon capture, Carbon removal, Circular economy, Farming

IINTRODUCTION

Carbon dioxide plays a dual role on the planet: positive and negative. It helps maintain Earth's balance by trapping some of the radiant energy received, keeping the planet warm enough to support life. Without it, Earth would be uncomfortably cold (Eldesouki et al., 2023). As the unique atmospheric source of carbon, CO_2 strongly affects crop yield and quality, and daytime CO_2 deficiency in greenhouses often limits crop productivity (Wang et al., 2022). However, rising atmospheric CO_2 levels are intensifying global warming. In the face of a changing climate, intensive efforts are needed to limit the global temperature increase to 1.5 °C. Agricultural production has the potential to play an important role in mitigating climate change (Borchers et al., 2022).

On the one hand, agriculture contributes to climate change, and on the other hand, it is acutely affected by its effects (Borchers et al., 2022). Changes in climatic and weather conditions Borchers et al., (2022) point that may contribute to a decrease in the yield of crops, among others, as a result of an increase in the frequency and intensity of extreme weather phenomena, drought, unstable wintering conditions for plants, the intensification of the harmfulness of pests, and the spread of invasive alien species (Kundzewicz et al., 2017; Graczyk et al.,2020). The negative impact of climate change also affects livestock production, causing heat stress in animals during heat waves, increasing the risk of diseases, and reducing the availability of animal feed (Rojas-Downing et al., 2017).

Carbon Dioxide Waste Utilization

CO_2 waste utilization refers to the process of capturing and using carbon dioxide (CO_2) from waste streams to create valuable products or services. This practice is part of a broader strategy known as carbon capture, utilization, and storage (CCUS), which aims to reduce greenhouse gas emissions by transforming captured CO_2 into products rather than storing it. This method showcases a circular economy by reusing CO_2 captured from waste sources, helping to reduce the costs of carbon capture and promote sustainability in different industries.

According to the International Energy Agency (2025), key applications of CO_2 utilization include:

- Sustainable building materials in the construction sector,
- Renewable fuels for the transportation industry,
- Chemical production for synthesizing polymers and fuels,
- Enhanced oil recovery in the oil and gas industry,
- Food security initiatives in agriculture.

To help offset costs, captured CO_2 can be reused to create valuable products rather than being stored solely. This method, known as carbon recycling, is part of the broader carbon capture, utilization, and storage (CCUS) framework, which aims to reach net-zero emissions by 2050 and address climate change (Endress and Houser Company, 2025). Currently, industry emits about 45 million metric tons of CO_2 annually from waste exhaust streams, accounting for roughly 0.1% of global emissions across all sectors (Liebling et al., 2025). Climate models from the Intergovernmental Panel on Climate Change and the International Energy Agency project CCUS could capture up to 1 billion metric tons of CO_2 annually by 2030, and several billion tons by 2050 (International Energy Agency, 2005). Assuming emissions from industrial and other sources remain roughly the same when this capacity is fully operational, these projections suggest it could significantly reduce atmospheric greenhouse gases (World Resources Institute, 2025) (Figure 1).

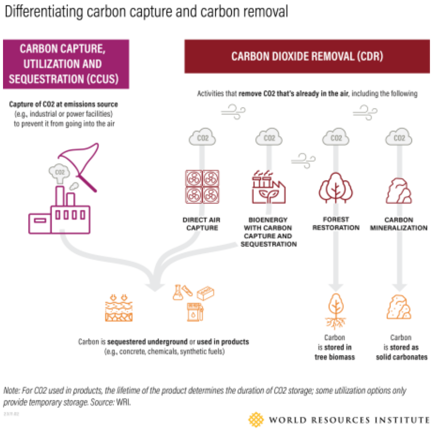

Figure 1. Differentiating Carbon Capture and Carbon Removal, World Resources Institute, 2025

While CCUS and carbon removal differ in where they collect CO_2, both processes require a designated site to store the captured carbon. This captured CO_2 whether collected from emission sources or directly from the atmosphere can be deposited underground in specific geological formations for permanent sequestration, according to the World Resources Institute (2025). Alternatively, it can be used to produce materials like concrete, chemicals, and synthetic fuels. The length of sequestration varies in these cases: for example, CO_2 from synthetic fuels is released upon combustion, whereas CO_2 from concrete is stored permanently.

CCUS is one of many ways to reduce emissions and plays a different role from carbon removal in long-term and net-zero climate plans developed by countries or companies. Emissions reductions including CCUS and many other options should make up the vast majority of mitigation in those plans. However, carbon removal can be used to counterbalance a much smaller portion of emissions (both CO_2 and other greenhouse gases) that are too hard to abate with other means. In the longer term, carbon removal is also needed to achieve and sustain net-negative emissions to reduce the excess CO_2 in the atmosphere that is causing harmful climate impacts.

Recent reports indicate that there are approximately 50 operational CCUS projects worldwide, with around 44 currently under construction and over 500 in various planning stages (CCUS Projects Database, 2025). These active projects capture roughly 50 million metric tons of CO_2 annually ($MtCO_2$/yr) (International Energy Agency, 2025). If all projects in development reach completion, the estimated total CCUS capacity could range between 416 and 520 $MtCO_2$/yr., representing about 0.9 to 1.1% of current global greenhouse gas emissions (Global CCS Institute, 2025).

Carbon Dioxide Uses in Agriculture

Carbon dioxide is increasingly seen as a valuable resource with economic potential. Although converting CO_2 into products is still emerging, it provides a promising way to reduce emissions and combat climate change. Captured CO_2 can be converted into fuels, carbonates, polymers, and chemicals, thereby supporting a circular economy. Use our expertise and diverse products to improve your CO_2 utilization. Carbon dioxide plays a crucial role in the food and beverage industry and in agriculture by enhancing product quality, extending shelf life, and appealing to consumers. As there is a growing push for sustainable practices, capturing and reusing CO_2 presents a dual benefit: lowering emissions and boosting operational efficiency. Carbon dioxide is vital in agriculture, aiding photosynthesis, boosting plant growth, and supporting sustainable farming. The central involvement of CO_2 in agriculture is:

1**.** Photosynthesis and plant growth

CO_2 is essential for photosynthesis, the process by which plants and microbes convert light energy into chemical. During photosynthesis, plants and lithotrophic microbes absorb CO_2 from the atmosphere and use it to produce glucose and oxygen. Optimal CO_2 levels for photosynthesis range between 800 and 1200 ppm, which can significantly enhance plant growth and crop yields (Hortisensors, 2025). Plants respond positively to CO_2 levels up to 700 to 1800 parts per million, but levels above this may damage them (Figure 2).

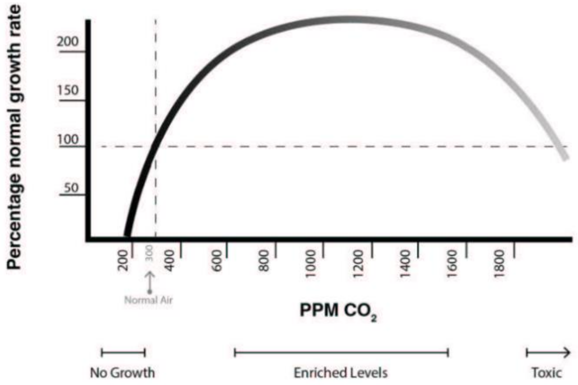

Figure 2. The relation between CO_2 concentration and the rate of plant growth.
Source: www.hydrofarm.com

2. CO_2 Fertilization effect

The phenomenon known as CO_2 fertilization leads to increased growth and yields in crops like corn and wheat due to higher CO_2 levels, Kurt Thelen (2023).

3. Carbon sequestration and soil health

Agricultural practices can capture atmospheric CO_2 in soil through methods like no-till farming, cover cropping, and crop rotation, which enhance soil health and increase carbon content (Johnson, 2026). By implementing these techniques, farmers help lower greenhouse gas emissions and improve soil fertility.

4. Monitoring and management of CO_2 levels

Farmers can utilize CO_2 sensors to track CO_2 levels in greenhouses and animal enclosures. Keeping CO_2 at optimal levels is essential for promoting healthy plant development and maintaining animal well-being. Carbon capture and storage (CCS) can be used to control CO_2 emissions from farming activities, enabling the reuse of captured CO_2 to support plant growth in controlled settings (Johnson, 2026).

5. Sustainable practices and innovations

Innovative agricultural methods, such as precision and regenerative farming, aim to optimize CO_2 levels and reduce emissions. These techniques improve productivity while supporting environmental sustainability by reducing the farming sector's carbon footprint. The invention of a new method and the application of CO_2 to the preservation of animal feed are inventive elements in the process of ensiling plants (Ivetić, 2015). This part makes a big difference in the commercial appeal of the idea of using additives. It represents an important and valuable invention that is easy to use, inexpensive, and safe.

Using CO_2 Waste in Agriculture

Agricultural waste can be transformed into a valuable byproduct from farming operations. It offers opportunities for sustainable agriculture, renewable energy, and environmental protection. Agricultural sustainability is a core element of the fourth industrial revolution, characterized by the use of novel technologies to reuse waste as a byproduct (Ivetić et al., 2024). However, traditional disposal methods still pose problems, causing air pollution and soil deterioration (Iftikhar et al., 2025). Using CO_2 waste in farming is a vital element of sustainable practices. Employing CO_2 waste in agriculture can improve crop yields and quality, while also tackling environmental issues.

Main points on CO_2 waste use in agriculture:

- CO_2 enrichment in greenhouses involves increasing CO_2 levels, which are often limited during daytime and can impact crop yields. Technologies such as agro-industrial symbiosis systems (AIS), carbon capture and utilization (CCU) support agricultural output and promote environmental sustainability (Wang et al., 2022).
- Sustainable recycling of agricultural waste involves managing crop residues, animal manure, and processing byproducts to ensure long-term environmental health. Each type has unique features and opportunities for sustainable management and use (Sharma et al., 2024). New methods, such as biogas production and environmental enzyme technology, are being developed to transform agricultural waste into valuable resources. These techniques support low-carbon growth, aid green energy transitions (Liu et al., 2024; Chen et al., 2025), integrate agricultural practices with global efforts toward carbon neutrality, and foster innovation in materials science. Liu et al. (2024) propose an integrated process for the co-production of cellulosic ethanol and microalgal biomass by fixing CO_2 generated from bioethanol fermentation. The techno-economic analysis shows that the integrated process is cost-effective for producing cellulosic ethanol, and this study introduces an innovative method for advancing a low-carbon circular bioeconomy.
- Sustainable management and use of agricultural waste involve converting crop residues and animal manure significant farming byproducts into valuable resources such as bioenergy, biochar, and other products. This approach enhances soil health, water retention, and nutrient availability while also sequestering carbon (Iftikhar et al., 2025).
- Carbon capture technologies are used to improve CO_2 utilization in food production, helping to lower greenhouse gas emissions from industry. These methods encompass carbon sequestration, CO_2 supplementation, and renewable energy sources on farms integration (Gabell, 2025). In recent years, activated carbons (Acs) derived from agro-waste have demonstrated excellent adsorption capacity. The production of ACs from readily available, low-cost agro-waste makes them unique materials for several environmental applications, including but not limited to CO_2 capture, dye removal, and heavy metal ion removal by adsorption (Koli et al., 2024).
- Carbon capture strategies in agriculture include improved soil management, maximizing photosynthesis, and creating biochar. These approaches support a balanced carbon cycle and boost soil health and productivity (Patel, 2025).

Agricultural production generates significant amounts of waste that can be reused as byproducts, with positive environmental impacts (Ivetić et al., 2024; Ivetić et al., 2022). These strategies not only address environmental challenges but also provide economic benefits by creating valuable products and reducing reliance on fossil fuels. Adopting sustainable practices makes agriculture more responsible and sustainable. Sustainable development is fundamental to the economic policies of many countries, especially in developing economies. With multidisciplinary support, existing CO_2 enrichment systems can address current and emerging issues, turning the efficient use of agricultural waste carbon and CO_2 in greenhouses into a sustainable solution to enhance food security and fight global warming (Wang et al., 2022). Understanding carbon sequestration mechanisms is essential for harnessing the full potential of agricultural methods to mitigate climate change (Patel, 2025). The exploration of innovative CO_2 utilization pathways, including chemical, biological, and mineralization processes, underscores the potential to create valuable products and realize substantial economic and environmental benefits (Bo et al., 2025; Hanson et al., 2025). Systems such as photosynthesis, soil carbon storage, biochar production, cover cropping, direct air capture, soil amendments, enhanced weathering, and feed ensiling can form the basis of various agricultural approaches to capture and store atmospheric CO_2.

CONCLUSION

CO_2 plays a crucial role in agriculture by supporting plant growth, increasing crop yields, and fostering sustainable farming through innovative techniques and effective management. When farmers understand and utilize CO_2 properly, they can boost productivity while tackling environmental issues. Repurposing CO_2 waste presents a promising strategy to address climate change and support a circular economy. Turning CO_2 into valuable products allows agriculture to lower its carbon footprint and move toward greater sustainability.

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