CO_2 as raw material for sustainable biorefineries

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Abstract

The increase in carbon dioxide (CO_2) concentrations in the atmosphere is a significant concern due to the role in global warming and climate change. Currently, the industry is responsible for approximately 40% of global CO_2 emissions [1]. To address this issue, Carbon Capture and Storage (CCS) strategies are being considered including post-combustion capture, pre-combustion capture, and oxyfuel combustion. The continuous accumulation of CO_2 in the atmosphere, mainly due to the long-term release from the combustion of fossil fuels, is one of the main causes of the increase in global temperatures and drastic climate changes [2]. Anthropogenic emissions and the associated atmospheric processes have generated a series of environmental problems, which underscores the importance of decarbonization as a fundamental objective established in the Paris agreement [3].

Numerous industrial processes are responsible for untreated CO_2 emissions that mean environmental challenges. Then, implementing CO_2 capture and storage systems for subsequent use in processes, particularly in the development of C1 biorefineries aimed at converting biomass and even CO_2 into valuable products such as platform molecules, fuels, and energy [4]. By incorporating CO_2 into these processes as raw material, the release of greenhouse gases into the environment can be mitigated [5]. This upgrading option could be better considered than just CCS. In terms of sustainability, the continuous accumulation of CO_2 in Earth planet is a way for avoiding problems in atmosphere but concentrating these gases into the hydrosphere (oceans) and the geosphere could not be considered as a sustainable solution. The current tendency for proposing real and sustainable alternatives to solve any problem is to consider any undesired waste (as sometimes CO_2 is considered) as raw material for further processing.

Converting CO_2 into valuable fuels and chemicals offers numerous benefits beyond capture. This alternative not only addresses the critical issue of environmental degradation but also presents an opportunity to generate revenue instead of allocating significant resources solely for CO_2 burial. Several methods have been investigated for the conversion of CO_2 into chemicals, including electrocatalytic or photocatalytic reduction, bio-catalysis, dry methane reforming, and catalytic hydrogenation [6]. Recent advancements in molecular catalysis for electrocatalytic CO_2 capture have shown promise in transforming CO_2 into chemicals such as carbon monoxide, formic acid, formaldehyde, and ethanol, as illustrated in **Figure 1**.

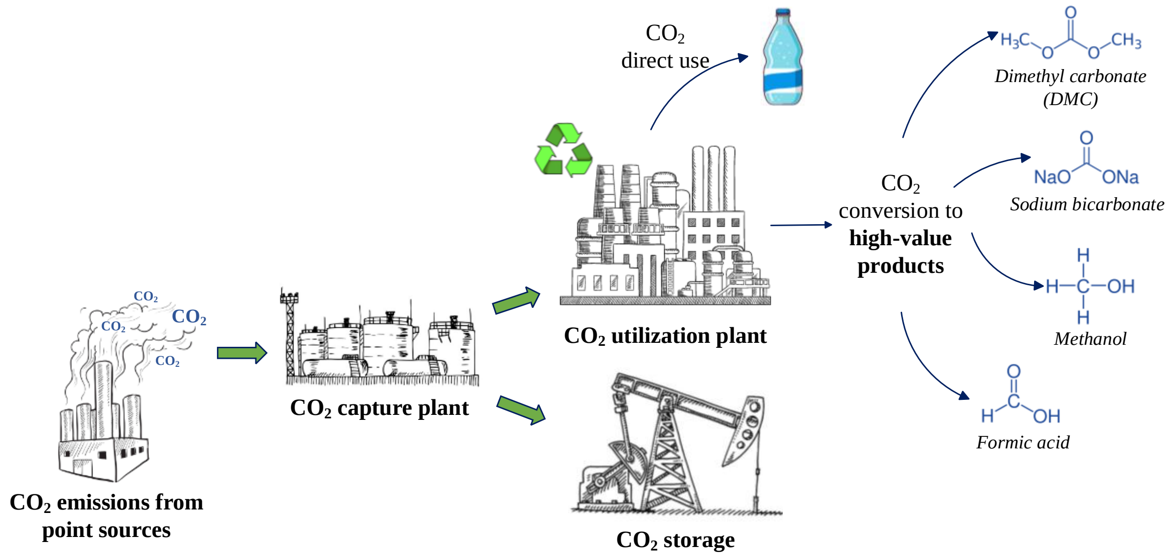

Figure 1. CO_2 capture and utilization scheme for the obtaining of value-added products.

The novelty of this research work is based on the sustainability assessment of C1 biorefineries as an alternative pathway to capture and valorize CO_2 released from industrial processes by providing a new vision about CO_2 as a raw material. Then, for this research the main objective was to assess the potential of CO_2 as feedstock in various transformation pathways under the C1 biorefinery concept by taking into consideration the production scale. The production of dimethyl carbonate at supercritical CO_2 conditions, the production of methanol by both catalytically and biologically routes by means of genetically modified organisms, formic acid by means of electroreduction using a KOH electrolyte solution, and the obtaining synthesis gas enriched in carbon monoxide using a mixture of CO_2 (15%) and air (85%) as a gasifying agent, were assessed for a Colombian context. These processes were simulated in integration schemes by using the Aspen Plus software (v. 9.0) to establish the mass and energy balances to analyze the technical and economic dimensions through mass and energy indicators (e.g., product yield, process mass intensity and overall energy efficiency) and economic metrics (e.g., net present value, payback period and internal rate of return) [7], [8]. In addition, the environmental and social impacts were evaluated to calculate the sustainability index of each proposed transformation route. The results show that the C1 biorefinery scheme that presents the greatest techno-economic, environmental, and social viability is the scheme where methanol is produced by catalytic route, formic acid is obtained, and also syngas enriched in carbon monoxide to meet the energy demands of the process. As a conclusion, the integration of CO_2 utilization processes to existing industrial processes not only helps addressing environmental concerns but also promotes the production of diverse compounds that are currently in high demand. Then, it becomes necessary to establish new processing routes in industrial plants that effectively utilize CO_2 streams as a viable raw material for production.

Keywords: *C1 Biorefineries, Carbon Dioxide, Carbon Capture and Storage, Carbon Capture and Utilization, Sustainability.*

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