



Review

Recent Advances in Catalyst Design for Carboxylation Using CO₂ as the C1 Feedstock

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Abstract: Carbon dioxide is ideal for carboxylation reactions as a renewable and sustainable C1 feedstock and has significant recognition owing to its low cost, non-toxicity, and high abundance. To depreciate the environmental concentration of CO₂, which causes the greenhouse gas effect, developing new catalytic protocols for organic synthesis in CO₂ utilization is of great importance. This review focuses on carboxylation reactions using CO₂ as a C1 feedstock to synthesize value-added functionalized carboxylic acids and their corresponding derivatives via catalytically generated allyl metal intermediates, photoredox catalysis, and electrocatalysis with a focus on recent developments and opportunities in catalyst design for carboxylation reactions. In this article, we describe recent developments in the carboxylation of C–H bonds, alkenes, and alkynes using CO₂ as the C1 source for various reactions under different conditions, as well as the potential direction for the further development of CO₂ utilization in organic synthesis.

Keywords: carboxylation; carbon dioxide; carbon capture; C1 feedstock; carboxylic acids



Citation: Shah, S.R.; Mazumdar, N.J.; Centeno-Pedraza, A.; Deka, D.; Artioli, N.; Manyar, H. Recent Advances in Catalyst Design for Carboxylation Using CO₂ as the C1 Feedstock. *Catalysts* **2023**, *13*, 1489. <https://doi.org/10.3390/catal13121489>

Academic Editors: Carl Rodshaw and Maria Manuel B. Marques

Received: 26 October 2023

Revised: 29 November 2023

Accepted: 29 November 2023

Published: 30 November 2023



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1. Introduction

The rapidly increasing greenhouse gas concentrations in the environment, resulting in the current climate crisis, are a cause of huge concern. Over the past few decades, carbon dioxide emissions have drastically expanded due to an increase in the usage of fossil fuels and deforestation, with a world annual average environmental concentration of 418.37 ppm in 2023 [1]. Figure 1 shows that, from 1959 to 2022, the level of CO₂ concentration increased severely, with a 0.5% growth rate annually [2]. Controlling the amount of CO₂ in the atmosphere is a global challenge that needs to be resolved with the utmost priority. There has been increasing pressure on manufacturing industries to produce efficient methods for reducing CO₂ emissions [3]. Since it is an abundant, non-toxic, non-combustible, renewable supply of carbon that is highly functional and an eco-friendly chemical reagent, carbon dioxide is a very attractive C1 building block in organic synthesis.

In a continuation of our group's interest in decarbonization, CO₂ utilization, and environmental catalysis [4–20], we have attempted herein to review the recent progress made in carboxylation reactions for the synthesis of a variety of functionalized carboxylic acids and their derivatives. For the use of CO₂ as a C1 feedstock in organic synthesis, it is very essential to capture CO₂ in the C–C formation and produce value-added functional groups, such as carboxylic acids, lactams, carbonates, and lactones [21]. It is particularly challenging to employ due to its thermodynamic stability and kinetic inertness. Therefore, employing CO₂ as a substrate faces numerous issues, such as high-pressure or high-temperature reaction conditions. Despite the substantial progress that has been made, there are still a lot of restrictions in this area regarding the scope of the substrate, the reaction

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