

REVIEW

Recent Advances of (Bi)carbonate Electroreduction in Reactive Carbon Capture Systems

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ABSTRACT

The electrochemical reduction reaction of carbon dioxide (CO₂RR) serves as a promising approach for effectively mitigating CO₂ emissions and producing value-added chemicals. Reactive carbon capture (RCC) refers to an integration of CO₂ capture and conversion, which could bypass the energy-intensive upstream CO₂ regeneration and downstream CO₂ separation processes. This integration is particularly attractive when using alkaline adsorbents for CO₂ capture, as they are non-toxic, non-volatile, and the resulting (bi)carbonate species serve as direct feedstocks for electrolysis. This review first focuses on the technical viability of RCC based on (bi)carbonate electrocatalysis and explains several metrics related to it. We compare its industrial processes with CO₂RR and show how pH, concentration, and additives of alkaline absorbents affect the reaction. The impacts of electrode configuration, electrolyte formulation, additives, and electrolytic cell architecture on system performance are also described. Finally, prospects of this reaction pathway are presented, with the aim of accelerating this promising technology.

1 | Introduction

Fossil fuel combustion, along with a broad spectrum of industrial practices, has caused a steady rise in atmospheric CO₂ levels [1], which is primarily responsible for the severe environmental issue of global warming. Once captured using various technologies, CO₂ is either desorbed and compressed for storage, as carbon capture and storage (CCS), or directly converted into value-added products, as carbon capture and utilization (CCU). The growing abundance of low-cost renewable electricity price (less than US \$0.03 kWh⁻¹) offers a promising opportunity to generate carbon-based products and fuels through electrocatalysis reactions [2]. Electrochemical CO₂ reduction reaction (CO₂RR) is a rapidly advancing field known for its high efficiency, flexibility, and eco-friendliness. However, the gas-fed CO₂RR typically involves an energy-intensive CO₂ regeneration step and suffers from low carbon utilization efficiency, which

raises its operating costs and impedes its overall process energy savings. These factors collectively impede the large-scale deployment of gas-fed CO₂RR systems. Notably, CO₂ absorption could serve as a form of molecular activation since the captured species, such as carbamate and (bi)carbonate, are already partially activated relative to gaseous CO₂. This feature provides a unique opportunity to integrate capture with subsequent conversion, enabling the direct transformation of captured CO₂ into fuels and chemicals under mild conditions, ideally at ambient pressure [3–5]. Reactive carbon capture (RCC) technology offers an alternative approach by directly converting the captured species, and bypassing the energy-intensive CO₂ regeneration from the capture agent and presents a novel concept and technological framework in a world increasingly reliant on renewable grid electricity and diminishing use of fossil resources, while (bi) carbonate reduction reaction serves as a promising pathway (Figure 1).