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Insight into the development of silica-based materials as photocatalysts for CO_2 photoconversion towards CH_3OH: A review and recent progress

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A B S T R A C T

High exploitation of fossil fuel energy has resulted in substantial CO_2 emissions into the atmosphere, leading to severe global warming. Tremendous strategies have been developed to explore possible approaches in minimizing the content of CO_2 in the atmosphere. CO_2 photoconversion into CH_3OH has been put forward as a promising strategy since anthropogenic CO_2 is utilized to generate valuable CH_3OH assisting by clean solar energy. Silica-based materials have emerged as potential candidates for photocatalysts is accredited to their mesoporous framework with a large surface area, flexible tunability pore sizes, excellent thermal stability, and capability to suppress metal particle growth. Thus, this review encompasses the current progress on applying and developing silica-based materials as photocatalysts for CO_2 photoconversion into CH_3OH. Apart from that, fundamental aspects of the mechanism, the factors affecting performance, and the efficiency of silica-based materials in CO_2 photoconversion to CH_3OH are also comprehensively highlighted. The difficulties and prospects of CO_2 photoconversion into CH_3OH via silica-based materials are also discussed. In general, the most recent scenarios recommended further investigation to explore these materials since CO_2 photoconversion to CH_3OH has not been adequately investigated in the literature.

1. Introduction

According to the British Petroleum's (BP) *Statistical Review of World Energy 2020*, fossil fuels account for around 84% of global primary energy usage [1]. The continued consumption of fossil fuels to satisfy global energy demands has significantly amplified carbon dioxide (CO_2) content in the atmosphere. Although CO_2 is also recognized as environmentally abundant and can be considered harmless, the high content of CO_2 in the atmosphere sparks serious world's environmental problems such as climate crisis and ocean acidification [2]. According to the International Panel on Climate Change (IPCC), atmospheric CO_2 levels could reach 590 parts per million by 2100, with a 1.9 °C rise in global mean temperature [3]. Hence, it is vital to uncover an alternative approach to mitigate the CO_2 content in the atmosphere. The diminution of CO_2 in the atmosphere can be handled by various techniques, including carbon capture and storage (CCS) and CO_2 utilization [4,5]. To date, enormous scientific efforts to utilize this anthropogenic CO_2 into value-added products have been widely reported in the literature, such as thermochemical [6], biological [7], electrochemical [8], and photocatalytic [9] approach.

Although various CO_2 transformation technologies have been explored, the photocatalytic approach, known as artificial photosynthesis, has attracted significant attention in academic fields since this economic and eco-friendly approach can convert undesirable CO_2 into valuable products using solar energy. Among the valuable products, the CO_2 photoconversion into methanol (CH_3OH) has gained significant interest owing to CH_3OH's broad applications in critical industrial sectors such as feedstock for chemicals synthesis, fuels for transportation, and power generation [10,11]. The CO_2 photoconversion was first explored in 1978 by Halmann with the presence of water (H_2O) and P-type gallium phosphide as a photocathode [12]. Since this artificial photosynthesis effort resulted in positive findings, many attempts have

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