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Review of recent technologies for transforming carbon dioxide to carbon materials

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ABSTRACT

Since the Industrial Revolution, as fossil fuels have been applied to a wide range of fields, greenhouse gas emissions have continuously increased. In particular, in order to mitigate carbon dioxide emissions, which account for the largest percentage of greenhouse gases, various scientific technologies have been developed since the Paris Agreement launched in 2015. Representatively, CCUS (carbon capture, utilization, and storage) technology, which can convert atmospheric carbon dioxide into other high value-added materials, has been attracting attention. However, since carbon dioxide is very stable due to the double covalent bonds between carbon and oxygen atoms, various paths such as supercritical transformation, electrochemical conversion, and metal-based and inorganic substance-based conversion have been applied to convert it. This review introduces and provides a comprehensive overview of the latest studies as well as existing technologies to transform carbon dioxide into carbon materials.

1. Introduction

Greenhouse gas refers to a specific gas that absorbs or reflects infrared radiation from the earth's surface to space, raising the temperature of the earth's surface. The emission of these greenhouse gases has increased rapidly during the modern industrial period, causing large natural disasters such as desertification, glacier reduction, and increased sea levels [1]. In order to prevent such climate change, regulations on greenhouse gas emissions have been progressively adopted since the Paris Agreement in 2015. In particular, since carbon dioxide (CO_2) accounts for>80% of total greenhouse gas emissions, the regulation of CO_2 has been intensively discussed [2–4].

In this respect, numerous studies to suppress CO_2 emissions or to store the emitted CO_2 (carbon capture and storage, CCS) have been conducted [5–7]. The former entails research on limiting the use of fossil fuels, one of the main sources of CO_2 emissions, and developing alternative energy systems. In particular, instead of fossil fuels, research on renewable energy as energy generating system and research on secondary batteries as energy storage system have been conducted. The latter body of research on CO_2 storage is focused on methods of capturing the released CO_2 and then disposing or storing it in foliated rocks. Recently, however, problems such as the limit of the potential storage capacity and the possibility of leakage have been pointed out. To address the limitations of CCS technology, advanced technology for recycling the captured CO_2 (carbon capture and utilization, CCU) has emerged [8–12].

CCU technology is a generic term for technology that converts captured CO_2 into more valuable materials rather than simply storing it. The maturity of the technology is low compared to CCS, but it is strongly appreciated for its potential. In particular, the weight of 400 ppm, which is the average CO_2 concentration in the atmosphere, is about 3×10^{12} tons on the earth, and this is a great carbon resource that is quantitatively superior to that of the buried oil [2,13–16].

Recently, advanced CCU to convert CO_2 captured into highly valuable carbon-based compounds such as diamond [17,18], graphene [19], fullerene [20], carbon nanotubes (CNTs) [21,22], porous carbon [23], and carbon nanofibers (CNFs) [24,25] has been drawing a great deal of attention. However, since each atom in CO_2 is connected by double covalent bond, it is very difficult to break this bond and to convert it into another compound at room temperature. The CO_2-derived materials noted above were subjected to extreme conditions, including not only high temperature but also the high-pressure supercritical or liquid CO_2

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