

# Research on carbon dioxide treatment and utilization technology

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**Abstract.** This paper summarizes the various types of carbon dioxide treatment technology, the current situation, and the development trend, and describes the progress and challenges in the application of carbon dioxide treatment technology at the present stage. It is found that the focus of research and development should be on improving carbon capture efficiency and reducing carbon capture costs. CO<sub>2</sub> utilization technology is currently in the industrial demonstration stage, and breaking through the bottleneck of high temperature and high pressure environment, and searching for suitable catalysts to improve the carbon utilization efficiency are the key research directions in the next stage of CO<sub>2</sub> utilization technology. CO<sub>2</sub> treatment technology needs to overcome the challenges of economic profitability, technological innovation, cost reduction and efficiency enhancement, and policy subsidies and incentives. CO<sub>2</sub> bioprocessing technology will become a new mode of CO<sub>2</sub> treatment promotion in the future. This study is of reference significance for accurately grasping the research direction of CO<sub>2</sub> treatment technology, promoting the progress and innovation of CO<sub>2</sub> treatment technology, and accelerating the leapfrog development of CO<sub>2</sub> treatment technology.

## 1 Introduction

Carbon dioxide treatment (CDT) is a technology that captures carbon dioxide from the atmosphere by direct or indirect means and stores it permanently. In response to increasing global climate change, the Paris Agreement proposes to limit the increase in global average temperature to 2°C above pre-industrial levels and to work towards limiting the increase to 1.5°C [1]. In its 2017 Energy Technology Perspectives Report, the International Energy Agency (IEA) states that in order to achieve the goal of limiting global warming to 2°C by the end of the century, the energy sector will need to achieve net-zero emissions by 2060, or earlier if the goal is a lower warming (e.g., 1.75°C) [2]. The Intergovernmental Panel on Climate Change (IPCC), in its Special Report on Global Warming of 1.5°C, emphasized the critical importance of achieving net-zero carbon dioxide emissions by mid-century [3]. Decarbonization is not only necessary to achieve net-zero emissions, it is also a key means of compensating for the net-negative emissions required for over-temperature (temperatures exceeding 1.5°C) or critical temperature rise control (temperatures close to, but not exceeding,

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1.5°C), all of which relies on the large-scale use of a variety of carbon dioxide treatment methods.

Different CO<sub>2</sub> treatment methods differ significantly in terms of sequestration potential, implementation difficulty and socio-economic benefits. With the continuous development of CO<sub>2</sub> treatment technologies and the deepening of their understanding, it is no longer possible to effectively achieve the current GHG emission reduction targets by solely relying on traditional means of emission reduction. Therefore, based on the background of actively promoting carbon neutrality, systematically sorting out and analyzing the path of post-combustion carbon dioxide treatment technology, as well as synthesizing and summarizing the status quo, progress and typical cases of domestic and international carbon dioxide treatment technology under the “dual-carbon” goal, will help accelerate the pace of development of China's carbon dioxide treatment technology, and achieve carbon peak in 2030 and carbon peak in 2060 at the earliest possible date [4]. Therefore, the study and promotion of carbon dioxide treatment technology is of great significance to the realization of global climate goals.

## 2 Physical methods

Physical methods to realize carbon dioxide emission reduction mainly include carbon dioxide capture and storage (CCS), physical adsorption and supercritical CO<sub>2</sub> technology [5]. Among them, CCS captures CO<sub>2</sub> from industrial emission sources or air through adsorption, absorption or membrane separation, and compresses and stores the captured CO<sub>2</sub> in geological structures to prevent it from re-entering the atmosphere. Physical adsorption utilizes porous materials to efficiently adsorb carbon dioxide, while membrane separation technology separates carbon dioxide from gas mixtures by selectively transmitting the membrane. Direct air capture technology, on the other hand, captures CO<sub>2</sub> directly from the air, which is captured by the action of adsorbents or absorbers and then compressed and stored, and is suitable for widely distributed CO<sub>2</sub> sources with low concentrations. In addition, supercritical CO<sub>2</sub> technology utilizes the special properties of carbon dioxide in a supercritical state for capture or storage. These physical methods excel in reducing CO<sub>2</sub> emissions from industrial processes and provide important technical support for achieving carbon neutrality goals.

## 3 Biocapture

Among the many carbon utilization technologies, artificial bioconversion of CO<sub>2</sub> technology integrating synthetic biology means plays a particularly important role: on the one hand, it can effectively reduce the emission of greenhouse gases and accelerate the pace of advancement towards carbon neutral conversion; on the other hand, it also provides a key idea for solving the major topics such as food security and space exploration [6].

Some scholars have reported the development of a new “genomic scalpel” that rapidly prunes and knocks out the genome of microalgae to form a highly efficient cellular factory, which can then use CO<sub>2</sub> and sunlight to customize the production of biomolecules such as biofuels or bioplastics [7]. Designing and modifying *E. coli* to use hydrogen (H<sub>2</sub>) to convert carbon dioxide (CO<sub>2</sub>) into formic acid, thereby capturing atmospheric CO<sub>2</sub> and helping to curb the greenhouse effect. Replacing molybdenum atoms with tungsten atoms in a formic acid hydrogen cleaving enzyme in *E. coli* to create a tungsten-rich environment for *E. coli* to grow [8]. A special pressurized bioreactor was then designed that was filled with H<sub>2</sub> and CO<sub>2</sub> that could be used by the *E. coli* to capture the carbon dioxide and produce formic acid from it, which could then be used to make fuels, plastics, or chemicals. A scholar has reported for

the first time the route to synthesize artificial starch from carbon dioxide, and the first time to realize the ab initio synthesis of carbon dioxide to starch in the laboratory, which is a major disruptive and original breakthrough in the field of artificial starch synthesis by human beings.

## **4 Chemical method**

### **4.1 chemical absorption**

According to the different principles of CO<sub>2</sub> separation, chemical methods can be categorized into solvent absorption, adsorption, membrane absorption, electrochemical method and hydrate method.

### **4.2 chemical transformation method**

In addition to adsorption, catalytic conversion of CO<sub>2</sub> is another promising technology for emission reduction. The catalytic conversion method is driven by a catalyst to convert CO<sub>2</sub> into other valuable chemicals or energy carriers for resource utilization [9]. Based on the type of catalyst and reaction conditions, catalytic conversion can be categorized into thermo-catalytic conversion, electrocatalytic conversion and photocatalytic conversion.

#### *4.2.1 Thermocatalytic Conversion*

Thermocatalytic conversion involves the conversion of carbon dioxide into methane, carbon monoxide, methanol and other chemicals by means of a catalyst under high temperature conditions. Common thermocatalytic reactions include methanation (also known as the Sabatier reaction) and CO<sub>2</sub> hydrogenation. In the methanation reaction, CO<sub>2</sub> reacts with hydrogen in the presence of a nickel-based catalyst to produce methane and water. The reaction is favorable due to its high conversion and relatively mild reaction conditions [10]. However, it is energy intensive and requires large amounts of hydrogen.

#### *4.2.2 Electrocatalytic Conversion*

Electrocatalytic conversion is a method of reducing CO<sub>2</sub> using electrical energy. In this process, CO<sub>2</sub> is reduced to carbon monoxide, formic acid, ethylene and other organic compounds with the help of an electrocatalyst [11]. Advantages of electrocatalytic conversion include mild reaction conditions, a wide variety of product types, and flexible reaction control. However, the efficiency of electrocatalytic conversion is usually limited by the selectivity and stability of the electrocatalyst. In addition, large-scale electrocatalytic conversion requires a large amount of electrical energy, placing a higher demand on the development of renewable energy sources.

#### *4.2.3 Photocatalytic Conversion*

Photocatalytic conversion is a method that utilizes light energy to reduce carbon dioxide. Common photocatalysts include titanium dioxide, graphene and metal-organic frameworks. In photocatalytic conversion, the photocatalyst absorbs light energy to produce electron-hole pairs, and the electrons react with the CO<sub>2</sub> molecules to produce reduction products [12]. The advantage of photocatalytic conversion is its ability to utilize solar energy directly for the reaction, making it environmentally friendly and available in a wide range of products.

However, the overall efficiency of photocatalytic conversion is generally low, and the selectivity and stability of photocatalysts need to be further improved.

## 5 Conclusion

Excessive CO<sub>2</sub> emissions are a primary driver of global climate change. To address this challenge, technologies such as adsorption and catalytic conversion have emerged as promising solutions. The adsorption method captures CO<sub>2</sub> using various types of adsorbents, offering advantages in efficiency and renewability, though it faces challenges related to selectivity and cost. Catalytic conversion methods, including thermal catalytic, electrocatalytic, and photocatalytic processes, transform CO<sub>2</sub> into valuable chemicals or energy carriers, presenting significant potential. However, issues such as efficiency, stability, and economic feasibility still require further research and improvement.

As scientific and technological advancements continue, these methods are expected to play an increasingly vital role in reducing CO<sub>2</sub> emissions and mitigating global climate change. The successful implementation of these technologies, combined with global efforts to reduce fossil fuel dependency and enhance renewable energy adoption, will be crucial in the ongoing battle against climate change.

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