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Carbon Capture, Utilization and Storage (CCUS) Technology Development

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Abstract: Carbon capture, utilization and storage technology is one of the hot topics in the world in recent years. In the context of global climate change and energy security, reducing carbon dioxide emissions and improving energy efficiency have become the common focus of governments and scientists. Carbon capture utilization and storage technology is a technology that captures carbon dioxide and uses or stores it through various ways. This paper will discuss the development process, application scenarios and future prospects of this technology.

Keywords: Carbon capture, Carbon utilization, Carbon storage.

1. Carbon Capture Technology

1.1. Principles and processes of various carbon capture technologies

1.1.1. Traditional carbon capture technology

Traditional carbon capture technologies mainly include absorption, adsorption and membrane separation.

One of the most common carbon capture technologies is absorption, which uses a solution to absorb carbon dioxide and form carbonic acid. Common absorbents include ammonia, amines and sodium hydrocarbonic acid. The absorption method has some advantages and can efficiently remove carbon dioxide, but the absorbent regeneration process is energy intensive and requires a large amount of water. Language needs to be simplified, can not do without the transition words, etc., has been adjusted here, language students in other places can simplify themselves.[1, 2]

Adsorption method uses adsorbent to adsorb carbon dioxide to achieve carbon capture. Typical adsorbents include activated carbon, metal-organic skeleton materials (MOFs) and nanoparticles [3]. Compared with absorption method, adsorption method has lower energy consumption and higher selectivity, so it is widely studied and applied. [4] However, the regeneration of adsorbents also presents certain challenges, including high temperature roasting and pressure fluctuations.

The membrane separation method achieves the separation of carbon dioxide by forming a carbonate layer on the membrane. Membrane separation method has the advantages of energy saving, high efficiency and simplified process. [5] Common membrane materials include polyurethane, polysulfone and polycarbonate. However, the selectivity and stability of the membrane are urgent problems to be solved.

1.1.2. New carbon capture technologies

In order to overcome the limitations of traditional carbon capture technologies, researchers have also developed many new carbon capture technologies, including biological adsorption, electrochemical and photocatalytic methods.

Biosorption uses the ability of organisms such as algae, fungi and bacteria to adsorb carbon dioxide for carbon capture. [6] Compared with traditional adsorbents, the organism has higher selectivity and lower energy consumption. At the same time, organisms can also absorb carbon dioxide through photosynthesis and produce valuable compounds, such as biofuels and bioplastics. One of the main challenges of biosorbent methods is to optimize the growth conditions of organisms and improve the adsorption efficiency.

Electrochemical method uses electric current and electrode in electrolytic cell to achieve the conversion and fixation of carbon dioxide. Electrochemical methods include electrolytic reduction of carbonate and electrocatalytic reduction of carbon dioxide. Electrochemical method has the advantages of strong controllability, high efficiency and no need for additional chemicals. One of the main challenges of electrochemical methods is to reduce the energy loss in the electrolytic process of carbonate. [7]

Photocatalysis uses photocatalytic materials to convert solar energy into chemical energy and is used for the conversion and fixation of carbon dioxide, such as into organic compounds such as methanol [8]. Typical photocatalytic materials include zinc oxide, titanium dioxide and silicon photocatalysts. Photocatalysis has the advantages of wide energy sources, high efficiency and no additional energy. At present, the main challenge of photocatalysis is to improve the stability and selectivity of photocatalysts.

These new technologies have higher selectivity and lower energy consumption, but still face some challenges. In the future, we can further research and develop these technologies to achieve more efficient and sustainable carbon capture and use.

1.2. Key challenges and solutions for carbon capture technologies

Carbon capture technology is a sustainable solution that can help reduce carbon dioxide emissions in the atmosphere and slow the process of global climate change. Carbon capture technology currently faces a number of key challenges, including technology costs, energy consumption and storage issues.

First, technology cost is one of the main challenges facing carbon capture technology. At present, the main carbon capture technologies include chemical absorption, physical adsorption and biological adsorption, but these methods require expensive equipment and materials

This makes the entire carbon capture process extremely expensive. To solve this problem, novel adsorbent materials, such as metal-organic frameworks and nanomaterials, can be utilized to reduce costs and improve adsorption efficiency. Or the use of affordable materials and equipment, such as natural gas and solution absorbers, can also reduce the cost of carbon capture technology.

Second, the energy consumption of carbon capture technology is also a key challenge. Most current carbon capture technologies require large amounts of energy to drive the adsorption and desorption processes, making the entire process expensive and unsustainable. The use of chemical reactions under low temperature and high pressure conditions can reduce the consumption of drive energy. Light-driven and catalyst-assisted carbon capture technologies have also been identified as potential energy saving solutions.

Finally, the policy and regulatory environment is also a challenge for carbon capture technologies. The development of carbon capture technology requires government support and a suitable policy environment to promote technology innovation and application. At present, some countries have put forward policies and regulations to support the development of carbon capture technology, such as carbon capture use and trade system and emission reduction targets. A global policy framework and international cooperation mechanisms are also needed to facilitate the development and diffusion of carbon capture technologies.

2. Carbon Utilization Technology

Ways and technologies of CO2 utilization after carbon capture

CO2 utilization ways and technologies are the methods of using captured carbon dioxide to convert and apply in various ways.

2.1. Chemical utilization of carbon dioxide

First, carbon dioxide can be used as a raw material to make chemicals. Carbon dioxide can be converted into a range of organic chemicals, such as formic acid, methanol, and dimethyl ether. CO2 can be combined with hydrogen and react with a catalyst to form organic compounds such as methanol that are used to make chemicals and fuels. These chemicals can be widely used in industries such as pharmaceuticals, dyes and plastics, reducing the carbon dioxide emissions associated with the production of these chemicals using traditional fossil fuels.

2.2. Carbon dioxide bioutilization

Carbon dioxide can also be converted into organic matter through photosynthesis. Photosynthesis is the process by which plants absorb carbon dioxide and produce organic matter through photosynthesis. Carbon dioxide microalgae are the main photosynthetic organisms. [9, 10] Using this property, it is possible to establish artificial photosynthetic systems [11]: artificial photosynthetic membranes, photoelectric catalysis, etc., to convert captured carbon dioxide into organic matter, such as biofuels, food, etc., to realize the utilization and degradation of carbon dioxide.

2.3. Utilization of carbon dioxide mineralization

Carbon dioxide mineralization is a novel technology for carbon dioxide utilization. Carbon dioxide mineralization technology refers to the process of fixing and mineralizing carbon dioxide by alkaline earth metals. Carbon dioxide is used to synthesize stable carbonate minerals such as calcium carbonate and magnesium carbonate. This technology can be applied to waste water treatment, metal recycling, building materials and other fields, for the production of concrete, cement and other building materials. This utilization method can not only reduce carbon dioxide emissions, but also save traditional raw material consumption, thereby reducing the pressure on natural resources, converting carbon dioxide into solid and stable minerals, realizing long-term storage of carbon dioxide [12], reducing atmospheric emissions and recycling of carbon dioxide.

Although it still faces challenges such as high technical cost and large energy consumption, with the continuous progress of technology and the promotion of application, carbon dioxide utilization technology has broad prospects for development.

3. Carbon Storage Technology

Principle and implementation of carbon sequestration technology

Carbon sequestration technology is an important technology to deal with climate change and reduce carbon dioxide emissions. The principle is to reduce the contribution to the greenhouse effect by capturing CO2 from industrial exhaust or other emission sources, then compressing, transporting and storing it underground or in the ocean and mineralizing it to prevent it from entering the atmosphere.

3.1. Geological storage of carbon dioxide

Underground storage is one of the most mature methods of carbon dioxide storage. The principle is to inject carbon dioxide gas into the underground rock, and through the control of pressure and temperature, the carbon dioxide gas is sealed in the underground rock or cap. The underground reservoirs mainly include coal seams, oil and gas fields, salt rocks and saturated gas reservoirs. The stored carbon dioxide will interact with the rock, and some of it will dissolve in the water to form an acidic solution, which will react with surrounding minerals to form carbonate minerals, thereby storing the carbon dioxide permanently underground. The underground storage of carbon dioxide has high requirements on geological conditions, and the geological environment needs to be strictly evaluated before storage. [13]

3.2. Carbon dioxide water storage

Water storage is another important way of storing carbon dioxide. Deep salt water layer is the most important geological structure. The principle is to inject supercritical carbon dioxide gas into the salt water layer [14]. Its depth should be kept below 800m. (The density is about 500 to 800kg/m3) [15] During water storage, carbon dioxide is stored in the brackish water layer through processes such as dissolution, reaction and sedimentation. Dissolution refers to the physical adsorption of carbon dioxide gas with water in the ocean to form bicarbonate ions [16]. A reaction is a chemical reaction between carbon dioxide and other dissolved substances in the salt water layer to form carbonate. Sedimentation refers to the deposition of carbon dioxide in sediments at the bottom of the water through processes such as flow, degradation and biological absorption. In Marine storage, it is mainly carried out by deep sea injection, ocean surface injection and ocean surface enhancement. Compared with underground storage, water storage has the characteristics of greater storage potential, higher safety factor, less environmental impact and longer storage cycle.[17-21]

In addition, the implementation of carbon sequestration technology also involves the transport of CO_2 and certain auxiliary technologies to ensure that CO_2 is safely, efficiently and economically transported and stored from the capture source to the storage site. CO_2 transport mainly includes pipeline transport and ship transport, of which pipeline transport is the most commonly used way. To ensure the safety of the storage formation, assistive technologies such as geological exploration, geological modeling and geological monitoring are needed to assess the suitability of the storage formation and monitor the distribution and migration of CO_2 in the storage formation. Also, the carbon dioxide needs to be compressed during transportation. Compression is the process of compressing captured CO_2 into a high-density gas for easy transportation and storage. Compression can be achieved by mechanical compression or chemical absorption to produce high pressure liquefied CO_2. Mechanical compression is to pass CO_2 into a compressor and compress it into a liquid or supercritical state by increasing the pressure. Chemical absorption compression is the use of absorbent to dissolve CO_2 in the compressor, and then through reduced pressure evaporation to precipitate it into a liquid. The process of compression can reduce the volume of CO_2 and increase the density of CO_2, thus reducing the cost of transportation and storage.

Carbon sequestration technology reduces the greenhouse effect and the impact of climate change by capturing, compressing and storing CO_2 to prevent it from entering the atmosphere. As the technology continues to develop and mature, it will play an increasingly important role in mitigating climate change and meeting carbon reduction targets.

4. Conclusion and Prospect

Carbon capture, utilization and storage technology can effectively reduce the emissions of greenhouse gases such as carbon dioxide. By capturing, separating and storing greenhouse gases such as carbon dioxide, we can prevent them from entering the atmosphere, reduce their impact on the global climate, and provide a strong support for sustainable energy industries. At present, renewable energy such as solar energy and wind energy have achieved great development, but in the early stage of sustainable energy development, traditional fossil energy still occupies a dominant position. The use of carbon capture, utilization and storage technology can reduce greenhouse gas emissions in the use of fossil energy and offer the possibility of achieving a sustainable energy transition. In addition, carbon capture, utilization and storage technology can also open up new opportunities for carbon reduction markets and carbon trading markets. As the global demand for carbon reduction increases, carbon capture, utilization and storage technology can help companies and countries achieve carbon reduction targets by storing and permanently storing carbon dioxide. However, carbon capture, utilization and storage technology still faces some challenges. First of all, its technology costs are high and requires large-scale investment support. Secondly, the storage and storage of carbon dioxide also have certain environmental risks and safety issues, which need to be scientifically assessed and closely managed.

In general, future carbon capture, utilization and storage technologies have great potential and development prospects in mitigating climate change, promoting sustainable energy development and the development of carbon trading markets. With the advancement of technology and the promotion of applications, it will play an increasingly important role in the future.

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