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Review of Carbon Capture, Utilization, Transportation and Storage

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Abstract: Greenhouse gases (CO_2, O_3, CH_4, etc) wrap around the earth and capture solar energy, causing global warming, climate change, and the imbalance of the ecology system. The Earth will one day be unable to bear this pressure. In order to solve this problem, scientists work day and night to develop Carbon Capture, Utilization, Transportation and Storage (CCUS) technology. It is an effective method for carbon emission reduction at present and an important strategic choice for environmental protection in the future. However, due to the high cost, high risk and immature characteristics, the technology still needs to be optimized and improved. In view of these three drawbacks, this paper gives the corresponding suggestions: increase the profit by utilization to compensate for the high cost; if the risk is high, set up strict implementation standards and strengthen management; open the scientific research information when the technology is not mature so that all developed and developing countries can participate in the event. CCUS can cope with the world's environmental problems and slow down the pace of global warming. In order to employ the technology on a large scale, scientists can focus on reducing the cost and publicizing some critical information.

Keywords: carbon capture, carbon transportation, storage

1. Introduction

With the advancement of the society, the population growth and overuse of fossil fuels lead to the excessive emission of carbon dioxide. Thus, it triggers a serious environmental problem--global warming -- that the whole world needs to solve together. Modern scientists adopt CCUS technology based on Carbon, Capture, and storage (CCS) to reduce the environmental contamination caused by CO_2. CCS technology refers to the capture and storage of carbon dioxide produced by fossil fuels to achieve long-term carbon dioxide isolation from the atmosphere [1]. Instead of storing the gas permanently in geological sites, CCUS is a technology that purifies captured carbon dioxide and puts it back into industry for reuse. According to calculations, CCS will contribute 15%-55% of the emission's reductions in the world before the year of 2100 [2]. Although carbon dioxide emissions can be avoided in origin and government offsets are available, the method is not yet widely used. This paper discusses CCS and CCUS technologies by summarizing previous literatures, finds out some technical defects, proposes possible solutions and future development directions, and hopes that these actions can solve the world's burning issue and delay global warming.

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2. Carbon Capture Technology

2.1. The Capture of CO_2

Biological method, physical method and chemical absorption method are the main strategies for carbon dioxide capture. There are three technical routes of carbon capture: post-combustion decarbonization, pre-combustion decarbonization (industrial separation), oxygen-rich combustion decarbonization and direct air carbon capture. Among them, pre-combustion physical adsorption is the most promising carbon capture technology.

2.1.1. Capture Methods

Biological method: nature has its own unique mean of capturing carbon -- photosynthesis. It is the process by which green plants and certain other organisms transform light energy into chemical energy. As shown in Figure 1, during photosynthesis in green plants, light energy is captured and used to convert water, carbon dioxide, and minerals into oxygen and energy-rich organic compounds [3]. Over time, researchers have studied the capture of carbon dioxide by algae and the simultaneous restoration of wastewater by CO_2 sequestration.

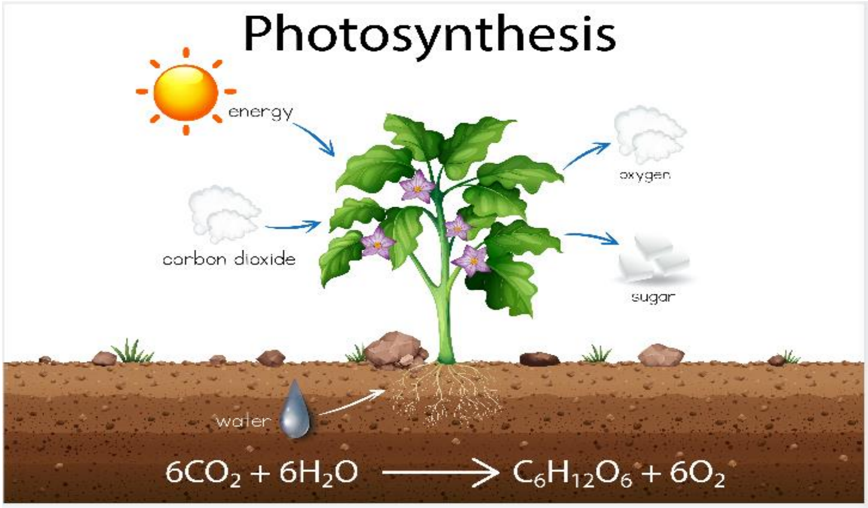

Figure 1: The process of photosynthesis [4].

Physical Absorption Method: The operation of physical absorption is based on Henry's Law. CO_2 is absorbed under a high pressure and a low temperature, and desorbed at reduced pressure and increased temperature [5]. The existing absorbent is water, methanol, propylene carbonate, etc., which can separate carbon dioxide from the gas.

Chemical absorption method: alcoholamine, potassium alkali and ammonia water are the current industrial selection of alkaline chemical solvents to absorb carbon dioxide. Typical chemical solvent absorption methods include ammonia absorption method, hot potassium alkali method and organic ammonia method, among which organic ammonia method is the best.

2.1.2. Capture Routes

Pre-combustion decarbonation: PCDC refers to the transfer of chemical energy of carbon in carbon-based fuel before combustion, and then separation of carbon from other energy-carrying substances [6]. The Integrated Gasification Combined Cycle (IGCC), an advanced power system that gasify carbon-rich fuels such as coals or oil residues with an efficient combined cycle, is a typical example of PCDC.

Post-combustion: it refers to the technology of separating carbon dioxide directly from flue gas after burning. This technology basically does not change the original production process but only needs to add the carbon dioxide capture devices behind the original system.The advantage is less upfront investment.

Oxygen-rich combustion: it refers to the process of oxygen production technology, which first removes nitrogen in the air, and then burns the mixture of high concentration of oxygen and the flue gas extracted from the traditional coal power station to obtain high concentration of carbon dioxide, which is easier to capture.

Direct air capture: this route is similar to nuclear waste water collection -- nuclear waste water is collected in cement tanks and buried on the ocean floor below 400 meters. The direct purification of the air effect is obvious.

2.2. CO_2 Transportation

Today there are three modes of transport, namely pipeline, tanker and ship. Different states of carbon dioxide have different properties. For example, liquid carbon dioxide is a dangerous chemical. People use different methods according to conditions and factors. In the United States, pipeline transport of carbon dioxide is the most common way; in China, tanker transport is the main mode. Figure 2 shows the advantages and disadvantages of the three modes of transportation and when they are best used.

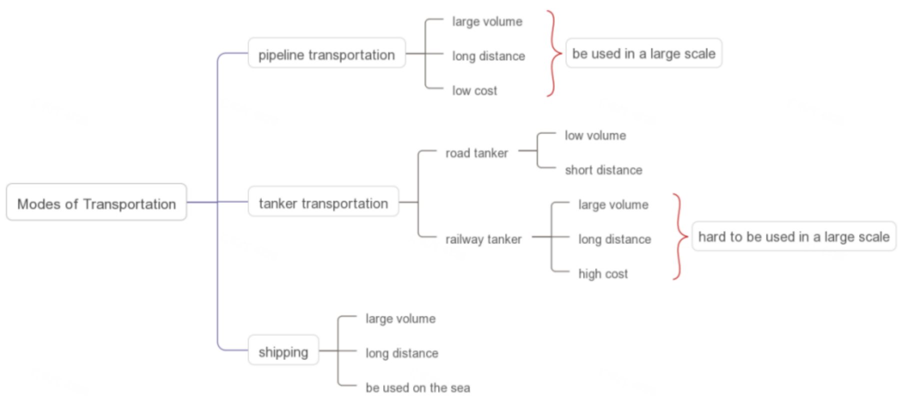

Figure 2: Modes of transportation.

2.3. CO_2 Storage

After CO_2 is captured, there are basically two ways of storing it: geological storage, which contains four types, and marine storage. Both methods have advantages and disadvantages.

2.3.1. Geological Storage

Geological sequestration involves injecting a mixture of gas and liquid carbon dioxide into geologic voids. The best structure for storing carbon dioxide is the saline formation, which is neither suitable for irrigation nor for human consumption [7]. To be more specific, there are four types of methods for carbon dioxide sequestration in geology: (1) This method is similar to sealing natural gas in a gas field: it injects carbon dioxide in a gaseous or supercritical flow form into a sealed rock with low permeability. It is also the most mainstream carbon dioxide storage technology at present; (2) dissolution storage; (3) residual gas storage; (4) carbon dioxide reacts with geological compounds

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(minerals and organic matter) to form solid minerals (such as carbonate) and then be stored [8]. Because carbon dioxide is stable, it is possible to store carbon dioxide at a concentration of 99% for more than a thousand year, if geologic voids and channels are reliable and well managed. After a thousand year, people will surely bring the usage of carbon dioxide to a new level, and there will be no need to worry about too much carbon dioxide to be arranged. Single mothballed projects, however, have little benefit and no state incentives. There are also problems with geological storage of carbon dioxide, which can suffocate people if it leaks. If a release causes carbon dioxide to enter the aquifer, it will directly pollute groundwater. The injection of carbon dioxide will increase the formation pressure and induce the formation fracture and fault movement, leading to earthquakes. All these factors restrict the progress of the sequestration project.

2.3.2. Marine Storage

Marine storage is transporting carbon dioxide to the storage site through an offshore pipeline or ship and injected the gas into the ocean floor under high pressure. This is an ideal way for long-term and large-scale sequestration, which keeping carbon dioxide out of the atmosphere for centuries. One study found that it takes about 1,600 years for the bottom water to flow to the surface, which means that even if there is a leak, scientists have a long time to fix it. Seafloor storage mainly includes shallow sea dissolution storage, deep-sea cage clathrate storage and deep-sea cage hydrate storage [6]. However,this method also has negative effects, such as ocean acidification, which affects marine ecosystems.

2.4. CO_2 Utilization

After the capture of carbon dioxide, it is important to consider how to utilize resources to realize carbon emission reduction.

2.4.1. Geographical Utilization

The geological utilization of carbon dioxide is to inject the gas into underground to make energy production and resource exploitation more efficient, such as improving the recovery of oil and natural gas and exploiting geothermal energy, deep salty (halide) water, uranium ore and other types of resources.

2.4.2. Physical Utilization

Since the property and structure of carbon dioxide have not changed, physical utilization can use the captured carbon dioxide directly or in the production of industrial products, such as cola ,and refrigeration and foaming materials. However, physical utilization only temporarily delays the emission, rather than solving in origin, and these gases will still be emitted after a period of time.

2.4.3. Chemical Utilization

Chemical utilization is the process of real consumption of carbon dioxide. It is the reaction of carbon dioxide with other substances to realize chemical conversion, which forms new substances or products. These products are generally classified as organic or inorganic substances. For inorganic products, carbon dioxide is used in industry to produce chemical raw materials like soda ash, baking soda, borax, and various metal carbonates. Urea and salicylic acid exemplify the use of carbon dioxide resources, of which the former is employed in a large scale - carbon dioxide and ammonia are processed to form urea, which is used for fertilization. The other one is using carbon dioxide as a raw material to synthesize organic products-syngas, low-carbon hydrocarbons,

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oxygen-containing organic compounds, and polymers. They can be recycled in order to protect the environment.

2.4.4. Electrochemical Utilization

The discovery of carbon nanotubes opens a new way to reduce the carbon emission. Carbon nanotubes have excellent mechanical properties and thermal conductivity, and are widely used in batteries, computers, tablets and other electronic products

2.4.5. Biological Utilization

In nature, plants are photosynthesizing every hour of every day. Using plants is the most simple, effective and sustainable way to reduce the carbon emission. Microalgae in plants are selected as research objects for carbon sequestration and gas fertilization because of their short growth cycle and high photosynthetic efficiency. Fixed carbon dioxide can be converted into liquid fuels, chemicals, biofertilizers, and food and feed additives, etc.

2.4.6. Mineralization Utilization

Carbonation reaction of carbon dioxide with solid wastes rich in calcium and magnesium is used to produce inorganic chemical products, such as $CaCO_3$ or $MgCO_3$, so that a large amount of carbon dioxide is fixed in building materials.

3. Problems and Deficiencies of CCUS and Corresponding Recommendations

Although CCUS technology can improve the content of carbon dioxide in the air, it also has many problems, mainly focusing on the cost, risk, and immature technology. Based on these problems, corresponding suggestions and strategies are given [6].

3.1. High Cost

The main reason for high cost of CCS technology is that a large amount of energy is consumed in the process of capture, transport and storage, among which the capture process accounts for the largest proportion. According to statistics, it costs $52 to sequester a ton of carbon dioxide [9]. The application of this technology increases the cost of power generation by about $0.01~ $0.05/h. Therefore, only combining with usage of carbon dioxide (namely CCUS technology) can increase revenue and reduce costs.

3.2. High Risk

The main risk of CCUS technology comes from the impact of carbon dioxide emissions (mentioned above) on the ecosystem. If it leaks into the ground, it may produce an earthquake; if the leakage reaches the surface, it will affect organisms on the ground, such as the death of animals and plants and acidification of water. Fortunately, these problems do not have no solution. The selection of appropriate storage points, long-term strict monitoring and management, promulgation of relevant laws and regulations, and the designation of CCUS project permit application, certification and issuance of important assessment indicators can avoid these hazards possibly.

3.3. Immature Technology

According to *the Global Status of Carbon Capture and Storage 2020*, the number of CCS facilities which are already built and put into operation in the United States accounts for 50.0% of those in

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the world, while the number under construction or planned to be built in the United States accounts for 51.4% of constructed in the world. The total number of constructed and unestablished in the United States accounts for 50.8% of constructed in the world. It indicates that the CCS facilities in the world are mainly concentrated in the United States [10].

This means that not all countries have the capacity to implement CCUS technology, and as mentioned before, sequestration is still risky and expensive. Most technologies are not yet mature enough to be used on a large scale. It is hoped that the research focus can be placed on the cost and the realization of public research information so that more countries can participate in the development and application of CCUS technology.

4. Conclusion

This paper reviews the capture routes of CCUS technology -- post-combustion decarburization, pre-combustion decarburization (industrial separation), oxygen-rich combustion decarburization, and direct air carbon capture, storage methods -- geographical storage and marine storage, utilization methods, points out the problems of high cost, high risk, and immature technology, and then gives corresponding suggestions. However, there are also shortcomings like the principles and disadvantages of the capture process are not described in detail or some literature is older. The future of this technology is bright, and scientists now can focus on how to reduce the cost to achieve large-scale application, and publicize information to realize the purpose of global participation.

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