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Emerging Techniques of Carbon Capture and Storage (CCS): A Review

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Abstract

The typical process of Carbon Capture and Storage (CCS) mainly involves the capture of carbon dioxide (CO_2) emissions from various industrial processes or from the flue or stack gas which is generated as a result of burning of fossil fuels. Therefore, the main processes of Carbon Capture and Storage (CCS) basically categorized as post-combustion carbon capture, pre-combustion carbon capture and oxy-fuel combustion systems. The first method is specially used in various steel and power plants whereas the pre-combustion carbon capture process is mainly employed in different industrial processes. Apart from these techniques, Direct Air Capture and Storage (DAC) method is also used in order to capture CO_2 directly from ambient air. The main characteristics of the CCS process includes capturing CO_2 from the point sources of where it is been produced such as, smokestacks of iron and steel factories and then transporting the captured CO_2 to the storage site for subsequent sequestration. The captured CO_2 is firstly compressed to a liquid form and then it is being transported via ship or in a pipeline to store beneath the ground where it is geologically sequestrated by injecting it into porous rock formations in geological basins.

Keywords: *Carbon Capture and Storage (CCS); Pre-combustion carbon capture process; Post-combustion carbon capture; Direct Air Capture and Storage (DAC); Carbon Sequestration; Geological Basins.*

1. Introduction

In the recent era Carbon Capture and Storage (CCS) technologies have successfully resolved the major challenges associated with greenhouse gas emissions from industrial combustion processes. In this typical process carbon dioxide (CO_2) is been captured before it is released into the atmosphere. The captured CO_2 is then stored underground in various geological formations. As Carbon capture and storage (CCS) captures the CO_2 emissions from various potential sources so it in-turn reduces global warming to a greater extent. The process basically comprises off three-step namely capturing of the CO_2, transportation and storage. The considerable amount of CO_2 could be captured from various industrial sources such as from power generation which contributes approximately 40% of total CO_2 emissions [1]. Carbon capture and storage technologies comprises of a set of techniques that are used to reduce greenhouse gas emissions from various point and nonpoint sources including industrial processes and power generation units [2, 3]. The main process of CO_2 capture can be done in various stages like at pre-combustion stage, at post-combustion stage, at oxy-fuel combustion stage and direct air capture stage [4, 5]. The storage process is followed by Carbon transportation which is widely done through pipeline transportation, shipping transportation, and road and rail transportation etc [6, 7]. Once the captured carbon is being transported to a specific site then that carbon can be further utilized in various fields such as, in the field of oil/gas recovery, chemicals and fuels utilization and agriculture utilization.

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Through these technologies captured CO_2 is being converted into valuable products which promoting a circular carbon economy [8]. In order to prevent further emission CO_2 is stored through geological storage, mineral carbonation storage, terrestrial storage, and ocean [9, 10]. Therefore as a whole CCS technologies offer a combination of techniques that can be widely used to reduce greenhouse gas emissions from various potential sources. But apart from these advantages there are some economic and regulatory challenges associated with this technology. In the present review paper a complete overview of various recent advancements associated with CCS technologies are discussed in details.

2. Effect of Carbon dioxide emissions on atmosphere

The emission of carbon dioxide (CO_2) from various sources is responsible for global warming [11]. Due to burning of fossil fuels, deforestation and increasing urbanization have significantly increased the concentration of CO_2 in the atmosphere [12]. Therefore, it is very necessary to implement various CO_2 capturing technologies which generally capture CO_2 from stationary and large industrial processes, such as power generation. These technologies are known as carbon capture and storage (CCS) and when it is coupled with the effective utilization of captured carbon then it is called as carbon capture utilization and storage (CCUS) [13]. In addition to reducing the CO_2 concentration in the atmosphere CCUS also helps to reduce emissions of other GHG pollutants. It also uses hydrogen as a carbon-free fuel as a reliable low carbon energy supply. But CCUS mainly focuses on carbon storage and it is less effective for utilizing the captured CO_2 for beneficial applications [14]. The CO_2 capture process includes effective capture technologies, transportation and storage of CO_2. The whole process offers several economical benefits like alternative power generation coupled with enhanced oil recovery for in bio-fuel production. Inspire of having so many advantages CCUs have several challenges like various risks and safety issues related to its transportation and storage.

3. Description of the carbon capture technologies

As discussed earlier, combustion of fossil fuels in industrial processes contributes most of the CO_2 emissions. The other sources may include emissions from various electricity generations and burning of residual food crops in the agricultural process especially during inter season. In the recent decade, different types of carbon capture technologies namely Pre-combustion which is generally used in steel and cement plants [15], Post-combustion and oxygen-enriched combustion are used widely in the power industries to reduce carbon concentration in the atmosphere. Apart from these, chemical extraction is also employed to separate CO_2 in coal. As an advanced method the extraction of CO_2 is also practiced from industrial process streams through chemical extraction process [16]. The last practiced CO_2 capture method involves capturing of CO_2 directly from air which is termed as Direct Air Capture (DAC) [17].

3.1 Pre-combustion Process

In this process CO_2 is mainly captured from fossil fuel feed stocks before they are burned to produce energy. This process is specially used for coal gasification and various gas-reforming. In this process, the captured gases are converted to water gas which comprises of H_2, CO, and CO_2. After this CO_2 is being separated from the captured as mixtures through different technologies. At the end of the process, H_2 is obtained as the clean-fuel product. The concentration of the CO_2 obtained through Pre-combustion Process is relatively high. The major advantage of this process is it involves low energy consumption costs but the CO2 separation step is expensive [18].

3.2 Post-combustion Process

Post-combustion process separates CO_2 directly from flue gases and it produces a

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mixture of CO_2, oxygen, and N_2 compounds. The post-combustion carbon capture may be done in various ways. One of such technologies can be described through temperature-vacuum-swing adsorption process where silica is used as an adsorbent for adsorption of aqueous monoethanolamine (MEA). The said process is widely used for separating CO2 from natural gas, hydrogen, and flue gases [19]. This post combustion technology has been adapted to a greater extent mainly in cement and steel industry where the GHG emissions are considered from a point-source [20]. The advantage of Post-combustion Process includes low investment cost and the original combustion process [21].

3.3 Direct Air Capture (DAC)

Direct air capture (DAC) method involves extraction of CO_2 directly from the atmosphere at any location. This process generally captures CO_2 from steel plant. After effective capturing of atmospheric CO_2 DAC it is stored in deep geological formations or used for a variety of applications. The process typically uses some adsorbent materials which are suitable for CO_2 adsorption. Once the as is being adsorbed then it is extracted from the absorbents through a desorption process via heat treatment [22]. But this method is quite costly.

3.4 Other treatment technologies

The other CO_2 separation technologies are mainly gas absorption processes which uses various solid and liquid solvents for absorbing CO_2 from as stream. Apart from above mentioned methods, CO_2 can also be separated through various methods such as, temperature swing and pressure swing adsorption, membrane separation, electrochemical methods and membrane absorption techniques etc [23]. In the membrane separation technique a micro porous membrane is use for gas separation.

3.5 Amine-based capture processes

Apart from other conventional techniques for CO_2 removal the amine-based solvent process is implemented to absorb CO_2 directly from flue gas. The major advantage of this method is cost effectiveness [24].

4. Carbon transport technologies

Once the carbon is being effectively captured from its potential source then the captured carbon is transported from its sources to desired storage sites through various means like pipeline transportation, shipping transportation, and road and rail transportation etc. Among all these methods, pipeline transportation is the most common and cost-effective method for transporting large volumes of CO_2 over long distances [25].

5. Carbon storage technologies

Generally the captured carbon is stored in various geological formations to prevent it from being released into the atmosphere [26]. This kind of storage facility mainly includes geological storage, mineral carbonation storage, terrestrial storage, and ocean storage etc. But among all these techniques, geological storage is the most important technology for mitigating climate change by storing carbon dioxide (CO_2) deep underground in geological formations [27]. One of such storage method is storing of CO_2 in different types of volcanic rocks which are typically known as basalts. The storage of CO_2 can also be done through stratigraphic trapping where it is injected into a trap surrounded by rocks boundaries. Then the injected CO_2 penetrates though the void spaces of the rocks until it reaches the impermeable layers of rocks. Due to the variation of pore diameters some CO_2 is unable to come out of the void spaces [28]. Another suitable alternative is to store CO_2 by dissolving it into water which offers the advantage of reducing the corrosive properties of the injected gas. But on the other hand, due to the increased solubility of injected CO_2 in the rock formations it alters the pH of the system and makes the solution more acidic. The trapped CO_2 can also react with various minerals which are already stored in the earth's core and subsequent reactions with these mineral materials leads to formation of carbonate minerals. Besides all the above mentioned methods another type of geological storage of CO_2 is through saline formations in various geological structures beneath the Earth's surface. But there are several challenges associated with this storage method like chances of leakage and fractures in the rock structures which may lead to earthquake [29]. Sometimes, naturally deposited layers in the sea floor enable the escaping of trapped CO_2 into the atmosphere [30]. In addition CO_2 can also be stored in fossil-fuel reservoirs for long periods. Examples of such reserves may be onshore reserves which are mostly located near the point sources to reduce the transport costs [31]. The enhanced oil recovery (EOR) or enhanced gas recovery (EGR) during CO_2 capturing process is mainly done through injection, production, and recycling of injected fluids [32]. But in the EGR process CO_2 is injected in the geological formations with the presence of natural gas.

6. Carbon utilization technologies

Proper utilization of carbon technologies offers an effective way to transform carbon dioxide (CO_2) and other carbon-containing waste streams either into valuable products or materials [33]. Converting waste materials into reusable products also enhances the carbon economy. Some of the widespread uses of carbon utilization technologies lies in the field of enhanced oil/gas recovery (EOR and EGR). In addition to these, the captured CO_2 can also be utilized in biomass power-generation plants. Here, CO_2 is absorbed from the atmosphere by various plants. The CO_2 storage efficacy can also be enhanced by burying various bio-char and biomass materials [34].

7. Conclusions

From this review work it can be concluded that in the present decade, carbon capture utilization and storage method offers an attractive alternative to reduce carbon footprints from atmosphere. Although various techniques are available to capture the CO_2 from the atmosphere but the economic feasibility of the process depends upon the type of method used and partly on the transportation cost. The said economy can further be enhanced by utilizing the captured CO_2 for various purposes such as power generation, biofuel production and enhanced oil and gas recovery. Apart from storing in various reservoirs, the main storage method of CO_2 is storing through formations. But the major challenges associated with geological storage are chances of leakage of stored $CO_{2.}$ Whereas, in comparison to the geological storage CO_2 storage in various off shore preservers offers the advantage of low cost by reducing the transportation cost.

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