Prospects of CO2 Utilization After Carbon Capture Process

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Abstract

It has been estimated that keeping the global temperature rise below 1.5 °C as per Paris agreement would be difficult to achieve; unless the efforts are significantly scaled up. For this purpose, both renewable energy resources and carbon capture should be employed to restrict the global warming effects. The carbon capture utilization and storage (CCUS) involves three stage: (i) carbon capture (ii) transportation and (iii) CO_2 utilization or storage. The CO_2 transportation is well established and would not significantly affect the overall CCUS project cost. Therefore, in-depth analysis is required to enhance the efficiency of carbon capture and CO_2 utilization processes in order to make CCUS projects financially viable. In this study, available and proposed CO_2 technologies are reviewed and analyzed. It is found that the enhanced oil recovery (EOR) and enhanced coal bed methane (ECBM) recovery are more feasible and can be further improved. While other utilization processes are still in the development phase but have room for improvements that can make them feasible in the future.

Keywords: Carbon Capture, CO_2 Utilization, CCUS, Feasibility

I. Introduction

In order to combat global warming threat, it was agreed in the Paris agreement to restraint the global temperature rise below 1.5 °C as compared to pre-industrial levels. However, in a report by Intergovernmental Panel on Climate Change (IPCC), concerns were made for keeping the global temperature rise below 1.5 °C (Nemitallah et al., 2020). The likelihood of extreme events due to climatic change will be intensified in case the global temperature rise surpasses the 1.5 °C threshold. Furthermore, in the yearly review meeting of UN Sustainable Development Goal 7 (SDG-7), it was concluded that the additional steps should be taken in order to meet 2030 SDG-7 objectives for energy efficiency, carbon emissions and renewable resources.

The contribution of renewable resources for the cumulative energy usage was 18.1 % in 2017. However, the renewable energy share is growing but the fossil fuels based energy will remain the major contributor in the future (Imteyaz et al., 2020). Therefore, only the deployment of renewable energy will not be sufficient and efforts need to be made in enhancing energy efficiency, usage of low carbon fuels and biofuels, and carbon capture techniques (Ali et al., 2018; Tahir, 2014). This reflects importance of deploying carbon capture technologies and it can help in minimizing the risk associated with the global temperature rise. The carbon capture technology is still in the research and development phase and requires more focus for achieving viable carbon free systems (Nemitallah et al., 2020). The carbon capture utilization and storage (CCUS) involves separating CO_2 from the fossil fuels based power plants, which is then transported for sequestration, enhanced oil recovery or the production of chemicals/fuels (Habib et al., 2015; Tahir et al., 2019). The processes involving CCUS are shown in Fig. 1.

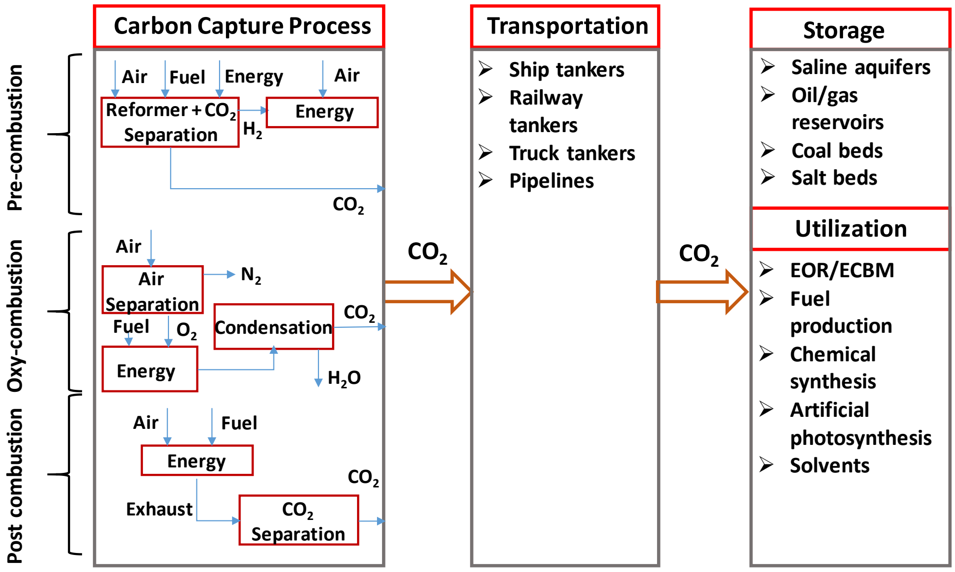

Fig. 1: Stages and processes in CCUS

There are three configurations of carbon capture namely (i) pre-combustion (ii) oxy- fuel combustion and (iii) post-combustion (Imteyaz and Tahir, 2019). These processes raises the overall cost of the power plant by 70 % – 80 % (Leung et al., 2014). For transportation, the impurities from captured CO_2 are removed to avoid corrosion and added cost (Wang et al., 2011). The CO_2 is then compressed and transported via pipelines, tanker trucks, railway tankers or ships. The CO_2 transportation by pipelines has the minimal cost of around 5 – 8 USD/ton (Chandel et al., 2010). However, the transportation cost does not significantly affects the CCUS project cost. The collected CO_2 can be stored in geological sites or can be utilized for enhanced oil recovery or in chemical industries. The CO_2 utilization techniques are young and significant research is needed to make these processes economic viable. In this work, available and proposed CO_2 utilization techniques available in the literature are presented. In addition, the feasibility of these techniques are discussed, and challenges and recommendations are highlighted at the end. The CO_2 storage is not included in this survey.

II. Review of CO_2 utilization techniques

The carbon dioxide can be utilized as the raw material for producing chemicals and fuels. In addition, it can also be used as the solvent in an industrial process or can be used for enhanced oil and fuel gas recovery as shown in Fig. 2 (Baena-Moreno et al., 2019). These utilization techniques can have a positive impact on overall CCUS project.

For chemicals production, the CO_2 reacts with organic compounds to form carbonates/carbamates via carboxylation process (Yuan et al., 2017). Although the conventional processes are broadly used, the CO_2 reaction with organic substances give better fixation with less energy requirements. Feroci et al. (Feroci et al., 2003) analyzed the electrochemical production of carbamate esters and they found that the CO_2 utilization can reduce the cost of raw materials with better yield and low energy requirements. The use of phosgene to produce isocyanates is well established, cost-effective and efficient. However, because of health and environmental effects, alternatives should be established. One of which is CO_2 for isocyanate production; but the most of the related studies are not yet commercialized and are limited to pilot-scale (Wang et al., 2017). Another application of CO_2 utilization is urea production, which primarily needs ammonia and carbon dioxide. Generally, natural gas is the primary raw material to produce both ammonia and carbon dioxide; however, additional CO_2 can be used as stripping agent to further enhance the urea yield (Pérez-Fortes et al., 2014). The other processes involving CO_2 include linear and acyclic carbonates, and polymers production that shows eco-friendly synthesis (Martín et al., 2015). One of the key advantage of producing polymers from CO_2 is that they are biodegradable but the thermal/mechanical properties and the process efficiency needs to be improved for commercialization (Taherimehr and Pescarmona, 2014). In addition, the polycarbonate synthesis can be entirely renewable.

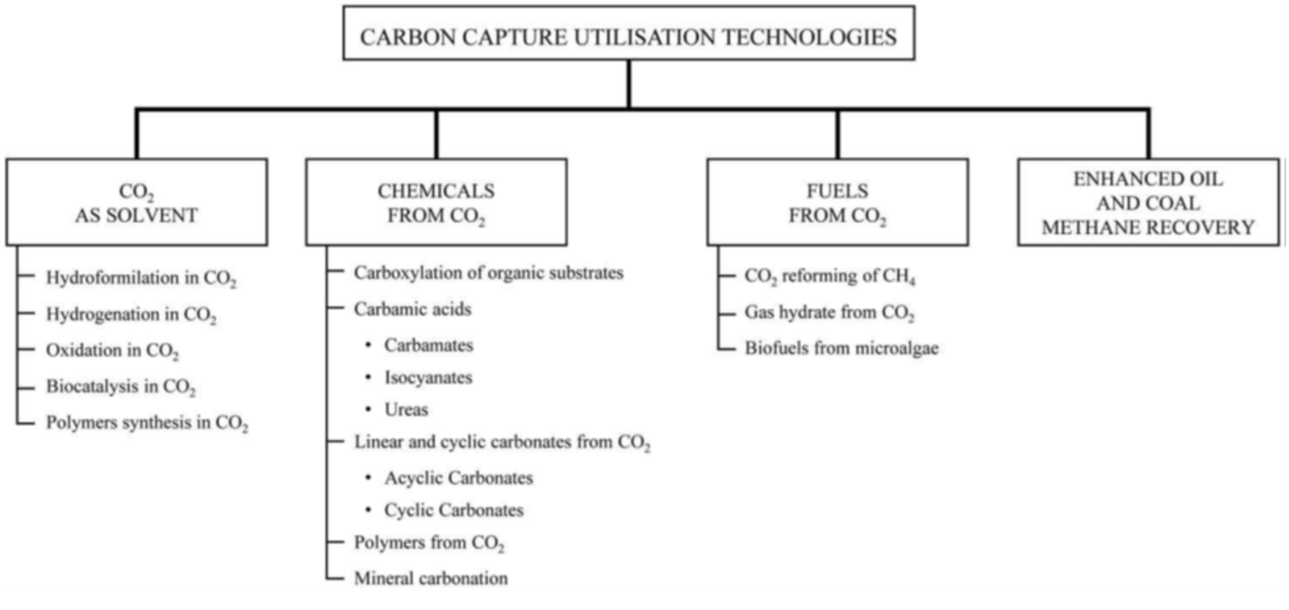

Fig. 2: CO_2 utilization techniques (Baena-Moreno et al., 2019)

For solvent application, both liquid and supercritical states ($scCO_2$) can be used. Generally, the solvents used in industries are organic based and have higher environmental effects as well as most of them are toxic and flammable. CO_2 can be a suitable candidate as it is non-flammable and non-toxic. Marriott et al. (Marriott et al., 2015) studied the feasibly of employing $scCO_2$ and found that the capital cost would be higher as compared with conventional solvents setup; however, the lower energy requirements and environmental benefits makes it a suitable choice. Hydrogenation, hydroformylation, biocatalysis, polymer synthesis and oxidation are some processes, where the CO_2 application has been established (Aresta, 2010).

From fuel production prospective, CO_2 can be used to synthesize hydrates, biofuels and syngas. The reforming of methane with CO_2 exhibit two main advantages: (i) both are greenhouse gases and this process can reduce overall carbon emissions, and (ii) more economical as gas separation process is not required (Selvarajah et al., 2016). However, the process is more endothermic than the steam reforming that makes it energy intensive process. In addition, stable catalysts need to be developed to make this process viable. Another application of CO_2 consist of extracting methane from methane hydrates in the deep ocean by injecting CO_2 that will replace the methane and will be stored (Ota et al., 2005). The feasibility study is needed to assess the economic and environmental aspects. The algae farming requires significant amount of CO_2 that can be from atmosphere or captured from an industrial process (Demirbaş, 2008). For the algae cultivation, open ponds is the cheaper option as compared to bioreactors; however, the process require large land area (Cuéllar-Franca and Azapagic, 2015). The artificial photosynthesis can be used to convert/store solar energy in to chemical energy. The efficient conversion systems, cost and suitable catalysts are the main the hurdles for this technique (Aresta et al., 2013).

The most developed CO_2 utilization techniques is the enhanced oil recovery (EOR) and enhanced coal bed methane (ECBM) to recover remaining oil/gas from the field (Panwar et al., 2017). It has been estimated that the 40 % of the remaining oil can be can be produced after primary extraction (Blunt et al., 1993). The EOR is more developed than the ECBM process and has been employed in many regions. The economic viability of EOR by CO_2 strongly depends on CO_2 cost (Baena-Moreno et al., 2019).

III. Discussion

There are numerous options to utilize CO_2 after the carbon capture process. The CO_2 utilization in different processes has the potential to significantly reduce the carbon emissions. With the recent advances, the productivity and process efficiency of some techniques have been improved. This could lead to feasible CCUS implementation. Some of the key challenges and recommendations for the CO_2 utilization are as follows:

- Most of the studies were focused on analyzing the CO_2 utilization technique and the comparison with the conventional processes in terms of energy and economics, is lacking in the literature.
- The life cycle assessment (LCA) should be involved while assessing the feasibility of CO_2 utilization technique.
- Among the demonstrated CO_2 utilization techniques, EOR and ECBM are more economically viable; however, these have inadequate CO_2 storage capacity hence they require storage capacity improvements (Saghafi, 2010).
- The EOR process with CO_2 can be further improved financially.
- Currently the large scale artificial photosynthesis for methane and methanol production is not financially feasible and exhibit a technical challenge (Roy et al., 2010). For this purpose, more focus has been given to establish new catalysts based on nano-technology (Liu and Maroto-Valer, 2012; Tan et al., 2012).
- The chemical production from CO_2 require small CO_2 quantities that would not significantly reduce the CCUS cost (Huang and Tan, 2014).
- With respect to climate financing, the CCUS ventures are underfinanced as compared to the renewable energy resources.

IV. Conclusion

The several options available for the CO_2 utilization after the carbon capture process are discussed in this study. The captured CO_2 can be utilized to produce chemicals and fuels, can be used as solvents and to convert solar energy in to chemical energy via artificial photosynthesis. Furthermore, CO_2 can be used for enhanced oil recovery (EOR) and enhanced coal bed methane (ECBM) recovery. These technologies are well developed than the others; however, these processes can be made more efficient. Most of the CO_2 utilization techniques are still in the development phase and require more analysis and resources to make them financially viable. For the feasibility assessment, the CO_2 utilization technique should analyzed with respect to energy, economics and environmental. Furthermore, the CCUS projects are underfinanced as compared to the renewable energy ventures.

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