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Review

# Advancements in carbon capture technologies: A review

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ABSTRACT

The increase in the level of greenhouse gases into the environment, specifically carbon dioxide ($CO_2$), leads to global warming, and limiting its emission has been a primary concern to achieve carbon neutrality by 2050. Among the various methods of decarburization, carbon capture and storage/utilization has become paramount concerns for its separation from exhaust gases. In this paper, widespread technological solutions for $CO_2$ capture and separation are presented and discussed to reduce carbon footprint from the source. The review elucidates various recent technologies under development, including the emerging ones with ionic liquids (ILs), membranes, and hybrid systems to tackle energy and environmental issues, along with challenges challenges for their readiness to use. Ionic liquids have appreciably drawn attention for $CO_2$ separation as a less energy-intensive and feasible alternative for solvents. Further, it has been found that the hybrid system/process significantly decreases the energy penalty and could emerge if added with ILs/nanoparticles. Finally, future $CO_2$ capture technologies using nanofluids, phenoxide salt, and micro-encapsulation have been explored and would be effective future technologies.

## 1. Introduction

Coal has been the most significant power generation source worldwide, leading to carbon dioxide ($CO_2$) emission into the environment, which was ~180–280 ppm before industrialization. From 1750 to 2011, $CO_2$ emission into the atmosphere reached 2040 ± 310 Gt $CO_2$. Intergovernmental panel on climate change report (IPCC, 2007) predicted that due to uncontrolled emission of greenhouse gases (GHGs), the environment temperature might increase by 1.1–2.9 °C at a lower emission rate or 2.4–6.4 °C with a higher emission rate at the end of 21st century. Among GHGs, $CO_2$ emission is a major contributor to global warming (57.0%), followed by $CH_4$ (20.0%), CFCs (15.0%), and $N_2O$ (~6.0%). The $CO_2$ emissions into the atmosphere from industries and fossil fuel combustion contributed to ~78% of the total GHGs emissions during 1970–2010 (IPCC, 2014). The increased $CO_2$ emission by 1.7% was observed globally in the year 2018 due to higher energy demand, reaching 33.1 Gt $CO_2$ with an increased atmospheric concentration of 407.4 ppm, which was higher by 2.4 ppm compared to the year 2017 (International Energy Agency, 2021). The decline in $CO_2$ emissions by 5.8% (~2.0 Gt) was observed in the year 2020 due to the pandemic but is expected to increase further with increased demand for fossil fuels in coming years. The increase in $CO_2$ emissions by various energy sectors in the last decade is shown in Fig. 1 and found highest in power plants with a substantial increase. Cao et al. (2020) reported that to encounter the global energy demand, the utilization of ~78% of fossil fuels will continue to use in the near future.

The entry into the Kyoto protocol and United Nations Framework Convention on Climate Change (UNFCCC) raised public concern for the reduction of GHGs emission, without interfering with the country's economic development. To limit the rise in global temperature to <2.0 °C at the end of 21st century, with further attempts to limit it to <1.5 °C, Paris agreement came in 2015 (Fawzy et al., 2020). At present, ~52% of total global $CO_2$ emissions are from China (30%), the USA (15%), and India (7%), while 13% from European countries and 35% from the rest of the world (IEA, 2019). To restrict the warming below 1.5 °C, GHGs emissions should be decreased to 45% by 2030, with carbon neutrality by 2050 compared to the present scenario (Wienchol et al., 2020; Ochedi et al., 2021). Therefore, the actions for controlling the anthropogenic $CO_2$ emissions are a more urgent initiative to achieve the projected potential of $CO_2$ capture as 4.7–37.5 Gt$CO_2$/annum by 2050.

Among the various comprehensive routes of decarburization (i.e., population control, use of energy-efficient technologies, energy conservation, geo-engineering, clean fuels, deployment of renewable

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