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Editorial: Reviews in carbon capture, utilization and storage: 2022

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Editorial on the Research Topic
Reviews in carbon capture, utilization and storage: 2022

Carbon dioxide is one of the gases responsible for the greenhouse effect. Fuel burning, deforestation, cement manufacture, livestock, fertilization, etc. are main sources of antropogenic CO_2 emissions, estimated to range around 36.8 Gton in 2022, with an increase of 0.9% or 321 Mt (IEA, 2022). Antropogenic carbon dioxide is not totally used in the natural cycle of carbon. Consequently, CO_2 concentration in the atmosphere has been steadily increasing during last two centuries: global average atmospheric carbon dioxide was 417.06 ppm in 2022 (NOAA Climate, 2023). If world energy demand will continue to increase fast and carbon based fuels will continue to heavily contribute to meet the global energy needs, antropogenic CO_2 emissions can reach 75 billion tons per year or more by 2,100 with an increase of CO_2 concentration in the atmosphere until levels of 800 ppm (NOAA Climate, 2023). The above figures are not sustainable as CO_2 accumulation in the atmosphere is one of the main causes of global warming. Mitigation of global CO_2 emissions is, therefore, a must for holding "the increase in the global average temperature to well below 2°C above pre-industrial levels," as outlined in the Paris Agreement 2015 (UNFCCC, 2015). Reaching this goal requires the development and integrated implementation of a variety of strategies. For instance:

Increase of the efficiency of the processes of electric energy production;
More efficient utilization of energy;
Use of alternative energy sources besides the use of fossil fuels;
Production of energy from biomasses;
Reafforestation and afforestation;
Carbon dioxide capture, utilisation and storage (CCUS).

CCUS refers to the group of technologies that remove CO_2 from waste gases and directly from the atmosphere, before either storing it into deep geological formations or utilizing it for a variety of industrial applications. CCUS can play a key role in preventing the accumulation of CO_2 emissions in the atmosphere and is currently recognized by the Intergovernmental Panel on Climate Change (IPCC, 2005) as a major strategy to achieve not only climate neutrality but also circularity and, more generally, sustainability.

CO_2 can be captured from concentrated sources (point-source carbon capture), such as power plants or some industries. However, CO_2 can also be captured directly from the atmosphere (direct air capture). Direct air capture is more energy intensive and more expensive as CO_2 concentration in the atmosphere is much lower than in flue gas. This practice is less technologically developed but it has been drawing growing interest in recent years.

If recovery technologies are to be adopted, it is necessary to define the final fate of carbon dioxide. Chemical utilization of captured CO_2 is a useful option. In principle, CO_2 can be converted into a large variety of products, such as fuels, chemicals, building materials and plastics. The potential of CO_2 as chemical source of carbon should consider several facets such as thermodinamics (CO_2 is a very stable molecule), kinetics, energy content of reagents, yield, selectivity, waste treatment. The life of the products is another very important aspect. A few of them (fuels, for instance) are carbon-neutral products, as they have a short life and will release the carbon stored in them in short time, differently from other products (polymers, building materials) that can sequester carbon for hundreds of years.

The amount of CO_2 emissions exceeds by far the current capacity for CO_2 utilization. Carbon storage provides a major option for the long-term sequestration of CO_2 and mitigation of future CO_2 emission. Captured CO_2 is injected into deep geological formations (such as depleted oil and gas reservoirs, saline formations, unmineable coal seams) which confine CO_2 for permanent storage. A well-established technology is enhanced oil recovery (EOR), which injects CO_2 into oil and gas reservoirs to increase oil extraction. EOR has been employed for decades, but the current growing interest towards decarbonization makes this technology less and less attractive as long term option.

CCUS technologies have expanded rapidly in the last few years. The global CO_2 capture capacity reached 47 million tonnes by 2022 (IDTechEx, 2023). However, this result is still unsatisfactory as meeting the Paris Agreement would require world carbon capture capacity of the order of Gton per year. The road to reach this target is disseminated of technological and economic hurdles, the overcoming of which requires a strict synergism between policy, industrial world and academia.

The present Research Topic responds to these needs and includes four contributions reviewing key Research Topic in CCUS.

Aneesh and Sam focus on cryogenic carbon capture (CCC) methods. Different desublimation-based CCC technologies (Cryogenic packed bed, Anti sublimation, External cooling loop, CryoCell process and Novel low-cost CO_2 capture technology (NLCCT) are compared. The paper also reviews the different heat and mass transfer models employed to model CO_2 frost formation. Frost modeling is essential to predict frost formation and its growth, as major limitations of the above processes are related to the continuous removal of the dry ice into storage tanks.

The use of membranes to capture CO_2 is a well-established carbon capture technique showing several advantages (low-cost, high energy efficiency, low environmental impact, easy scaling-up, moderate energy consumption). Sreenath and Sam concentrate their attention on hybrid capture systems, such as hybrid membrane cryogenic (HMC) and low-temperature membrane cryogenic (LTMC), that combine the advantages of membrane and cryogenic techniques. In the HMC process, the membrane process is used to pre-treat the flue gas for CO_2 enrichment, and the cryogenic process is used to capture the CO_2. In the LTMC process, low-temperature membrane units increase flue gas CO_2 concentration, and a cryogenic process liquefies the rich CO_2 stream. Membrane permeability and selectivity are crucial parameters which determine the CO_2 purity and recovery. The paper examines the features of different membranes used, the effect of operating conditions on the process performance and analyses the costs and energy requirements of various HMC and LTMC configurations for CO_2 capture.

Saenz Cavazos et al. focus on solid sorbent characterization for carbon capture, exploring physical and chemical properties, performance parameters, and process indicators. The paper outlines the relevant techniques used to measure Key Performance Indicators (KPIs) related to adsorption performance such as CO_2 adsorption capacity, selectivity, kinetics, ease of regeneration, stability, adsorbent cost, and environmental impact.

Takyi et al. provides an overview of Underground Coal Gasification (UCG) coupled with carbon capture storage and utilization technologies (UCG-CCS/CCU). The paper reviews the current status and technology development in implementing low carbon emission energy on UCG and, moreover, discusses the modern stage of UCG and CCS development, recent pilot operations, and current developments of the market.

Author contributions

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

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