Chapter 1
Advances in Carbon Capture and Utilization

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1.1 Introduction

A combination of enzyme and material which jointly capture and convert the CO_2 into methanol plausibly energizes the CO_2 utilization (Sharma et al. 2020a). The CO_2 to methanol conversion utilizes carbon better than the conventional syngas and the reaction yields fewer by-products, and the methanol produced can further be used as a clean-burning fuel, in pharmaceuticals, as a general solvent, etc. The various aspects of circular economy with present scenario of environment crisis will also be considered for large-scale sustainable biorefinery of CO_2. In this book, thirteen chapters have been included which represent the natural, conventional, and artificial systems for carbon management. The contents of the book have been divided into four sections.

The natural systems of carbon sequestration have been discussed in detail in the first section of this book. Since ancient times, fossil fuels are used in huge amount to meet the energy demands across the world. In India, the emanations from fossils fuels have developed a lot, but alternative sources are not enough to fulfil the demand.

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The emissions from fossil fuels are considered as one of the major factors leading to climate change (Kumar et al. 2019). To limit the pace of emissions of these harmful gases, various methods and approaches like reduction of energy consumption, switching to alternative fuels, have been reported. This section emphasized on the carbon capture and storage (CCS) using geological and soil-based methods. The recent advancement in CCS technology is progressively concerned with ideal design and functioning of the CCS infrastructure collectively maintaining every strategy of CCS system throughout a certain range. The attainable quality of CCS technology would reduce the reliance on sustainable power sources. CCS system also implies transfer of atmospheric CO_2 into other long-lived global pools including pedologic, oceanic, geological and biotic strata to reduce the net rate of atmospheric CO_2 increase. Since industrialization in the nineteenth century, the CO_2 concentration in the atmosphere has increased and an accord is there where a visible impact on world's climate due to mankind is forming. The CO_2 emissions from man-made sources have also been increasing in the same time frames which are known to produce greenhouse effect. CO_2 holds 82% of all the greenhouse gases present in the atmosphere. There are various techniques where CO_2 is injected into geological strata, oil wells, deep ocean, old coal mines, and saline aquifers. Furthermore, the soil is the biggest terrestrial sink of carbon (C) and store nearly three times of the atmospheric carbon pool and 4.5 times of the biotic carbon pool, and thus, maintains the global carbon cycle. Therefore, any change in the atmospheric carbon could be the result in modification of soil carbon. However, the carbon stabilization as well as subsequent sequestration in soil is greatly affected by different climatic and soil factors, such as soil type, nature of organics presents in soil, management practices, diversity of soil microorganism, rainfall, and temperature, etc. The sequestration of carbon in soil is very crucial to mitigate the effect of climate change by reducing the greenhouse gases emission and also to improve the soil quality for better crop productivity in sustainable manner (Roudi et al. 2020).

Among different developed methods, biomineralization and bioinspired storage systems are not only cost-effective but also efficient in controlling global warming and CO_2 emission. A microbial-enzymatic CCSU system can act as a green source of energy in form of electricity along with the utilization of wastewater by bacterial and algal biomass (Sharma and Kumar 2021). Instead of the whole-cell capturing systems, enzyme-based CO_2 capturing systems have also been proved efficient for various industrial applications.

Researchers are been joining their hands for the improvisation of several carbon capture materials. In the second section, superior performance of organic blended physical–chemical solvents is drawing much attention in recent times. Even some blends attained the optimal performances, advancements in the materials have not come to an end. Various types of nano-materials, nano-textured surface, and microwave regeneration techniques are being introduced to bring down the energy consumption of the setup. Amine technology for the capture of carbon dioxide has certain drawbacks including cost, energy consumption and by-products formation. Other methods such as membrane, cryogenic, biologicals are also of interest but not technically or economically feasible at large or industrial scales. In view of this, ionic liquids (ILs) are the one of the alternatives for the conventional and other technologies.

Some other methods of simultaneous wastewater treatment and carbon capture have also been explored in the third section of this book. Conventional wastewater treatment systems are not environmentally friendly as they significantly contribute to the CO_2 emission, directly as well as indirectly. It has been realized that there is an urgent need to not only reduce the emission of CO_2 but also capture it to counter the negative impacts of climate change. Microbial fuel cell (MFC) has the potential of carbon capture while treating the wastewater with an additional advantage of direct electricity production (Verma et al. 2020). On the other hand, algal technology has the potential to capture and utilize CO_2 for the production of algal oil, which can be utilized for bioenergy production (Kamyab et al. 2019a).

Furthermore, the climate smart agriculture is one of the key tools for carbon capture which ensures the efficiency in income generation, productivity and food security; adaptation to climate change and resilience. Although sequestration of carbon and depletion in emissions of greenhouse gases can happen with various smart agricultural practices, perhaps there are numerous challenges while making these pillars of climate smart agriculture into reality. The change in soil carbon pool can directly influence the climatic conditions of any area due to its capability to store carbon twice as much of the atmosphere. The soil is one of the principle components for capturing terrestrial carbon, so the spatial distribution map developed along with the major nutrients from the study will provide an input for agricultural land evaluation for selecting appropriate land use plans for healthy carbon budgeting in the area (Kamyab et al. 2019b).

The biological carbon cycles are not sufficient enough to switch the billions of metric tons of CO_2 emission while the biochar (a recalcitrant organic charcoal material produced from pyrolysis of biomass under limited oxygen conditions) emerging as a considerable tool for long-term sink of carbon. Biochar has many other advantages of increasing the water absorption and water holding capacity of the soil which aids to increase the fertility. The charcoal produced by incomplete burning due to the limitation of oxygen in this system captures much more natural carbon from the biomaterial. Along with the ability to lock up additional carbon, biochar can also store CO_2 in sink for thousands of years, displaces the fossil fuel use and also reduces the release of nitrous oxide (N_2O) and methane, thereby reduces the greenhouse gas emission from the atmosphere and helps in mitigating the impacts of climate change. The Western Himalayan regions are characterized by marked climatic conditions, variations in topography, soil-texture, and land-use practices. In the present scenario, the fragile landscapes of the Himalayan region are facing an ongoing concern about current and potential climate change impacts. Carbon stocks in vegetation types of western Himalayas have immense ecological significance, vital for the regional and global carbon reserves. Among the vegetation types, forests, pasture, agricultural fields, and orchards dominate in this region. The increasing human interventions, land management practices and natural ecosystem processes are the potential sources of GHGs emission in the atmosphere. Deforestation and other changes in land use cause significant exchanges of CO_2 between the land and the atmosphere. The carbon stock storage and climate change mitigation cannot be easily achieved in the high-altitude Himalayan regions, because of the type of land use available, cold climate, and the land holding capacity of the people (Sharma et al. 2020b). The sustainable management regimes for these land uses can increase their potential to act as a sink for long-term carbon storage along with providing livelihood opportunities and vulnerability of natural resources to climate change can be reduced through adoption of these management practices. Anthropogenic CO_2 discharges are viewed as the significant patron of ozone-depleting substance outflows around the world. Conversion of CO_2 into fuels or energy-rich compounds is very beneficial as it is cheaper to produce, less inflammable, can be produced from biomass and is discussed in the last section. Also, it is advantageous to many automobiles, power plants, and other industries like pharmaceuticals, fine chemical, and food production units. Methanol is gaining popularity as an alternative to petroleum-based fuels and is beneficial for a safer and cleaner environment. The enzymatic method for CO_2 conversion has attracted much attention due to its improved selectivity and yields under mild reaction conditions. CO_2 can be reduced through different methods like physical, chemical, electrochemical, photochemical and biological or enzymatic methods. Among these potential approaches, biological or enzymatic methods offer viable, effective, green and potent alternative of CO_2 conversion into value-added products because of high stereo specificity and region/chemo-selectivity of enzyme.

The development in global carbon management strategies becomes the mandate of all educational and research bodies. In fact, the public awareness and inclusion of climate change topics at elementary education is also equally important. We should focus on the techniques and methods to minimize the emission of excessive greenhouse gases. Alternatively, more green and sustainable methods should be developed to generate the energy for transport and industrial applications. The protection and conservation of natural ecosystem forest, lakes, rivers, wild fauna and flora should be increased to elevate the biotic carbon level and minimize the atmospheric release. Thus, in this monograph various developmental strategies for carbon management in our ecosystem have been highlighted in respective chapters. Specific topics covered in the monograph include:

- Carbon capture: Innovation for a green environment
- Geological carbon capture and storage as a climate-change mitigation technology
- Soil carbon sequestration for soil quality improvement and climate change mitigation
- Post-combustion of carbon capture technologies: Advancements in absorbents and nano-particles
- Carbon biocapturing system for environment conservation
- Simultaneous wastewater treatment and carbon capture for energy production
- Carbon dioxide capture by ionic liquids
- The climate smart agriculture for carbon capture and carbon sequestration: The challenges, risks and opportunities
- Quantification of the soil organic carbon and major nutrients using geostatistical approach for Lahaul valley, cold arid region of Trans-Himalaya

- Biochar: A carbon negative technology for combating climate change
- Carbon sequestration potential of different land use sectors of Western Himalaya
- Progresses in bioenergy generation from CO_2: Mitigating the climate change
- Recent advances in enzymatic conversion of carbon dioxide into value-added product.

The topics are organized in four different sections: (i) carbon capture as natural phenomenon; (ii) advance carbon management techniques; (iii) miscellaneous techniques, and; (iv) value addition techniques.

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