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CO_2 Capture and Conversion: India's Pathway to Net Zero Emission

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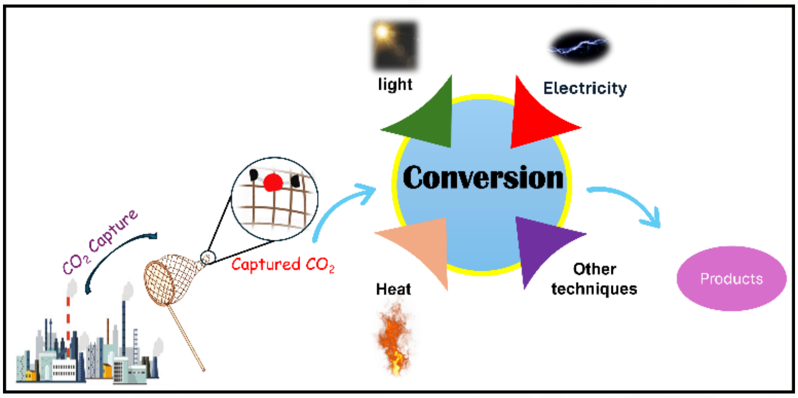
Abstract

India ranks third globally in CO_2 emissions, behind the United States and China. Therefore, the nation is committed to addressing the increasing CO_2 concentration in the atmosphere. In this article, we have briefly described the techniques which can help India in its journey to a net zero-emission future. The reaction setups and the advantages and disadvantages of each method are overviewed.



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1. Introduction

Carbon dioxide (CO_2) emissions have grown dramatically since the Industrial Revolution because of human activities such as deforestation, burning of fossil fuels like coal and oil, and gas use. India is a major contributor to global CO_2 emissions due to its massive population and rapid economic expansion. With almost 2.7 billion metric tons of CO_2 emissions in 2021, India ranked third globally in terms of emissions, after the United States and China. India is now at the forefront of the global climate conversation because of its substantial contribution. India has responded by pledging to lessen its carbon footprint and pursuing the Paris Agreement's goal of net-zero emissions. Under the Paris Agreement, 2016, India expressed its commitment by submitting its Intended Nationally Determined Contribution (INDC). India aims to reduce its emission intensity to 33-35% by 2030 according to 2005. It also clarifies that India needs to accelerate its actions to meet this target through various technologies. Carbon Capture and Utilization (CCU) is one of the most notable efforts to reduce CO_2 emissions among the various initiatives undertaken by the country. Research centres in India are actively pursuing this, with financing from the government and business sectors. Notably, the Department of Science & Technology (DST) is the primary funder of India's first two Centres of Excellence in Carbon Capture and Utilization (NCoE-CCU at IIT Bombay and NCCCU at JNCASR Bangalore).Both IIT Bombay and JNCASR, Bengaluru have begun their best efforts by initiating CO_2 capture and its selective conversion to methanol in collaboration with Thermax Limited and Coal India Limited respectively. These facilities concentrate on extracting CO_2 from diverse sources in thermal power plants and use a variety of methods to transform it into high-quality methanol selectively. The by-product carbon monoxide will be used to synthesise other products like acetic acid, polycarbonates etc.

Despite the numerous techniques available for carbon capture and conversion, this article will briefly explain key catalytic conversion techniques such as thermochemical, electrochemical, and photochemical methods that can help propel India's dream of achieving net-zero emissions.

2. CO_2 capture

As the first step, CO_2 from various sources will be collected using various techniques. Pre-combustion capture, post-combustion capture, and oxy-fuel combustion technology are the three broad categories into which CO_2 capture technology pathways may be separated. Among these methods, post-combustion capture is a well-established technology in the industry, known for its effective CO_2 selectivity and capture efficiency. Since India has various biomass sources, they can be converted into char, CO, CO_2 and various other gases. These gases can be captured selectively for further utilization through various techniques. Many industrial sectors in India have started post-combustion capture technologies to address their greenhouse gas emissions. The National Thermal Power Corporation (NTPC) has taken several initiatives in various thermal power plants. The best example is Vindhyachal Super Thermal Power Station, the largest power plant in India. They have begun to capture CO_2 from the flue gas that comes out of their coal-fired power stations.

Captured CO_2 can be converted into various products such as syngas, methanol, ethanol and so on. These have potential applications in industries such as energy, agriculture or transportation. For instance, syngas is used as an intermediate in producing synthetic petroleum oils for use as fuels and lubricants. Since it is combustible, it is often also used as a fuel source. Whereas methanol and ethanol are the commonly used fuel additives in combustion engines. Similarly, we can make products with higher carbon lengths such as Sustainable Aviation Fuel also known as SAF (C8-C16) with certain metal catalysts that support carbon-carbon(C-C) coupling.

3. Catalytic conversion of carbon dioxide

After capturing, the CO_2 can be converted into different products using the following methods,

3.1. Thermochemical Conversion: In this method, the reactant gases are treated at high temperatures (>200^{o}C) and pressure (10-400bar) in thermal reactors. The process can be carried out in continuous flow reactors (Figure 1a) and batch reactors (Figure 1b). In India, this method has already been explored for the synthesis of various products like Syngas ($CO+H_2O$), Methanol, Ethanol, Ethane, Ethene, Propane, etc. Easy scale-up and large product output are the factors that make the thermochemical conversion of CO_2 more attractive. However, the high temperature and pressure are raising huge safety concerns in its application. Because of these safety concerns, the reactions are carried out in reactors made of high-quality steel that can withstand vigorous reaction conditions. Also, developing more efficient catalysts can address this by carrying out the reactions at ambient temperatures and pressures. So far, several catalysts have been discovered for the efficient conversion of CO_2 at low temperatures (150-200 ^{o}C) and pressure (1atm).

3.2. Electrochemical Conversion: Electricity is the driving force to initiate the reaction in this method. The reaction setup consists of an electrochemical cell (Figure 1c) which contains different catalysts that can direct the reaction pathways selectively to a desired product at a suitable applied potential. Through electrochemical CO_2 reduction reaction (ECO_2RR), CO_2 can be converted into various products like CO, urea, methanol, ethanol, ethylene etc. Even so, the synthesis of higher hydrocarbons is still not achieved due to the limited C-C coupling. The scaleup is also quite challenging for this technique. In recent years, researchers have been working on integrating different

Figure 1: a) Fixed bed continuous flow reactors b) Batch reactor c) Electrochemical flow cell setup d) Photochemical reaction setup. (Images are taken from JNCASR, Bangalore's website.)

renewable energy sources to enhance sustainability by providing adaptable and clean power sources. This can reduce operational costs substantially. The low cost of production and surplus renewable energy sources can address the scalability of the technology and make the installation and transportation of these facilities easier.

3.3. Photochemical Conversion: Light energy drives the reduction of CO_2 into various chemicals, with semiconductor materials like TiO_2 serving as photocatalysts. The setup contains a light source which can emit light in the region of 400-700nm and the catalyst will undergo electronic excitation. This excited catalyst will interact with the CO_2 and convert it into the products. Unfortunately, there are not many choices in the product selectivity so far. Successful scaling up of the facility is extremely difficult. The need for energy-efficient light sources, slow reaction rate and low yield are the main challenges in the scaling up of the technology. Compared to the other methodologies photocatalysis suffers from its low yield. Interestingly, new attempts are made to develop the flow reactors and translucent monoliths for photocatalysis which can promise more yield compared to the single large batch reactors for their industrial applications. The need for energy-efficient light sources, slow reaction rate and low yield are the main challenges in the scaling up of the technology.

3.4. Comparison

In comparison to electrochemical and photochemical methods, thermochemical conversion processes are more widely adopted by industries, despite various safety concerns and energy-intense procedures, due to their easier scalability and higher conversion rates, capable of processing tons of CO_2 per day. Still, these drawbacks can be mitigated through the proper scale-up of electrochemical and photochemical technologies in the future. Moreover, integrating these scaled-up methods with renewable energy sources can provide the CO_2 conversion with the least environmental impacts and the cost of operation. Except forth ermocatalysis, the other methods are still in the initial levels of their Technology Readiness Level (TRL).

4. Conclusion

Even though several methods are available to address the increasing CO_2 concentrations, CO_2 capture, and its conversion are some of the best solutions. Among them, CO_2 conversion is more convenient with the thermocatalysis in large-scale applications. The other discussed methods like electrochemical CO_2 reduction and photochemical conversion are still under development. In conclusion, the article discusses the different CO_2 capture and conversion techniques which can address India's CO_2 emission.

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