Introduction

Several nations have committed to reaching net-zero emissions to mitigate the disastrous effects of climate change. India, too, has set up a timeline to reach net zero by 2070, announced at COP26. As a developing nation, India will need to deploy CCS to meet its goals while taking care of energy security for the growing population sustainably. Moreover, geologic formations in India offer an enormous potential for carbon sequestration [Vishal, et al., 2021]. Storage of CO_2 in depleted oil and gas fields has been identified as one of the primary pathways to advance CCS at a large scale in India [NITI Aayog, 2022]. It offers dual benefits of abatement CO_2 abatement and extraction of unrecoverable hydrocarbons simultaneously through CO_2-enhanced oil recovery (EOR). This technology can help India keep its net-zero commitment while ensuring sustainable economic progress.

In the Upper Assam Basin, a mature hydrocarbon province, CO_2-EOR demonstrates a 10% incremental recovery advantage over water flooding while enabling subsurface CO_2 storage through residual trapping and solubility mechanisms [Dutta et al., 2024]. Previous studies show that systems utilizing anthropogenic CO_2 from natural gas processing show 15-30% lower emissions per barrel of produced crude compared to conventional water flooding, primarily through avoided venting and displacement of higher-emission power generation [Jensen et al., 2018].

Before implementing a CCS project, it is vital to assess the net environmental benefit of CO_2 capture and its utilization for CO_2-EOR. Life Cycle Assessment (LCA) is a widely used methodology for analyzing these technologies for their net emissions and identifying appropriate improvements to make the process more effective. Due to the relatively low TRL of CO_2 EOR in India [Vishal, et al., 2021], no such study has been conducted incorporating the storage aspects.

Most of the current LCA models developed for CCUS are based on studies carried out in the United states and Europe. However, given the complexities involved in the Indian scenario, they cannot suitably provide accurate results when implemented for potential CCS projects in the country. There is a need for assessment of life cycle emissions based on Indian specific conditions and data. Furthermore, the feasibility and potential benefit of CO_2 EOR over water flooding in Indian basins as a primary oil recovery process must be analyzed. In this study, we aim to assess the avoided CO_2 in the process and its benefit in reducing greenhouse gas (GHG) emissions.

Method

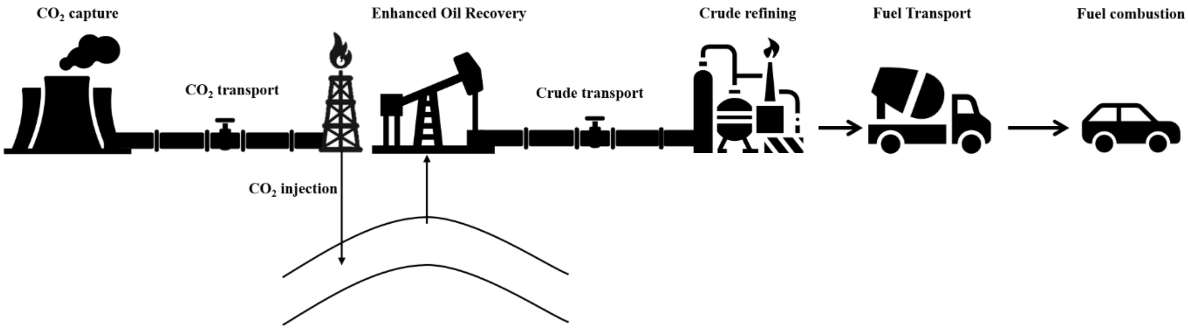

Figure 1 *A cradle-to-grave life cycle boundary for analyzing CO_2 EOR emissions.*

We develop an LCA model for CO_2 and waterflood EOR based on India-specific technologies and parameters. Our study aims to understand and compare the system boundary for CO_2- with water flood EOR using lifecycle assessment process. We carry out detailed LCA for both processes and their various sub-units to derive the potential benefit in terms of abatement of GHGs emission (Figure 1). We have selected an oil field in western India to assess the environmental impact of CO_2- as well as waterflood

EOR. This provides a much-needed comparison of the various options available to make informed decisions.

Results

The key LCA parameters influencing the total emissions include the crude recovery ratio and CO_2 utilization efficiency. Higher CO_2-oil recovery ratios reduce emissions intensity when using captured industrial CO_2, but increase it when employing geologically sourced CO_2 due to lost displacement credits for clean electricity. For water flooding, environmental impacts shift to water resource depletion risks and produced water management challenges, particularly in flood-prone regions.

EOR potential in Indian basins is significant. However, full lifecycle accounting must consider methane leakage risks during EOR operations and long-term monitoring costs. The findings underscore CO_2-EOR's dual role in India's energy transition – extending productive lifespans of mature fields while providing pilot project sites for CCS technologies critical for decarbonizing heavy industries.

Conclusions

India faces some unique challenges in CCS compared to other developed countries. To move from waterflood to CO_2 EOR as the primary recovery technoolgy for sustainable development, large-scale projects need to be identified. Our study highlights the role of CO_2 EOR in decarbonization of hard-to-abate sectors, especially the oil and gas industry. Our gate-to-gate lifecycle assessment shows the environmental benefits of CO_2 EOR.

However, the oil-producing basins are distant from India's coal-producing and utilization regions. The source of CO_2 in western India will most likely be either industrial hubs or oil refineries. In contrast, most of the CO_2 will be sourced from the cement industry or thermal power plants in eastern and central India. Currently, networks of pipelines across the vast Indian subcontinent for CO_2 transportation are almost non-existent. The transportation of CO_2 and refined oil products is unique to India and has to be analyzed accordingly for its environmental impact. Moreover, it will also have to be analyzed in conjunction with the sink availability as most of the CO_2-EOR will be carried out in the western and north-eastern parts of India.

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