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Carbon balance of CO_2-EOR for NCNO classification

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Abstract

The question of whether carbon dioxide enhanced oil recovery (CO_2-EOR) constitutes a valid alternative for greenhouse gas emission reduction has been frequently asked by the general public and environmental sectors. Through this technology, operational since 1972, oil production is enhanced by injecting CO_2 into depleted oil reservoirs in order displace the residual oil toward production wells in a solvent/miscible process. For decades, the CO_2 utilized for EOR has been most commonly sourced from natural CO_2 accumulations.

More recently, a few projects have emerged where anthropogenic CO_2 (A-CO_2) is captured at an industrial facility, transported to a depleted oil field, and utilized for EOR. If carbon geologic storage is one of the project objectives, all the CO_2 injected into the oil field for EOR could technically be stored in the formation. Even though the CO_2 is being prevented from entering the atmosphere, and permanently stored away in a secured geologic formation, a question arises as to whether the total CO_2 volumes stored in order to produce the incremental oil through EOR are larger than the CO_2 emitted throughout the entire CO_2-EOR process, including the capture facility, the EOR site, and the refining and burning of the end product.

We intend to answer some of these questions through a DOE-NETL funded study titled "Carbon Life Cycle Analysis of CO_2-EOR for Net Carbon Negative Oil (NCNO) Classification". NCNO is defined as oil whose carbon emissions to the atmosphere, when burned or otherwise used, are less than the amount of carbon permanently stored in the reservoir in order to produce the oil. In this paper, we focus on the EOR site in what is referred to as a gate-to-gate system, but are inclusive of the burning of the refined product, as this end member is explicitly stated in the definition of NCNO. Finally, we use Cranfield, Mississippi, as a case study and come to the conclusion that the incremental oil produced is net carbon negative.

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1. Introduction

The boundaries of CO_2-EOR carbon balance studies found in the literature vary significantly. The broader studies, referred to as cradle-to-grave, start with the capture of the A-CO_2 at the industrial facility. Some even start with the extraction of the feedstock that is used at the power plant, and generally include the CO_2 transport to the oil field, the EOR operation itself, the crude oil transport to the refinery and refining process, and finally, the combustion of the refined product. We have selected a few publications to illustrate the variety of boundaries (Fig. 1). Jaramillo and others [5] conducted a popular cradle-to-grave study that was published in 2009. Cooney and others [2] recently published a study that includes cradle-to-gate (including the source of the CO_2 as a natural dome), gate-to-gate (which focuses on the EOR operation, from purchased CO_2 entrance to the oil field to crude sales, and cradle-to-grave boundaries. Most of the studies found, however, are gate to gate bound.

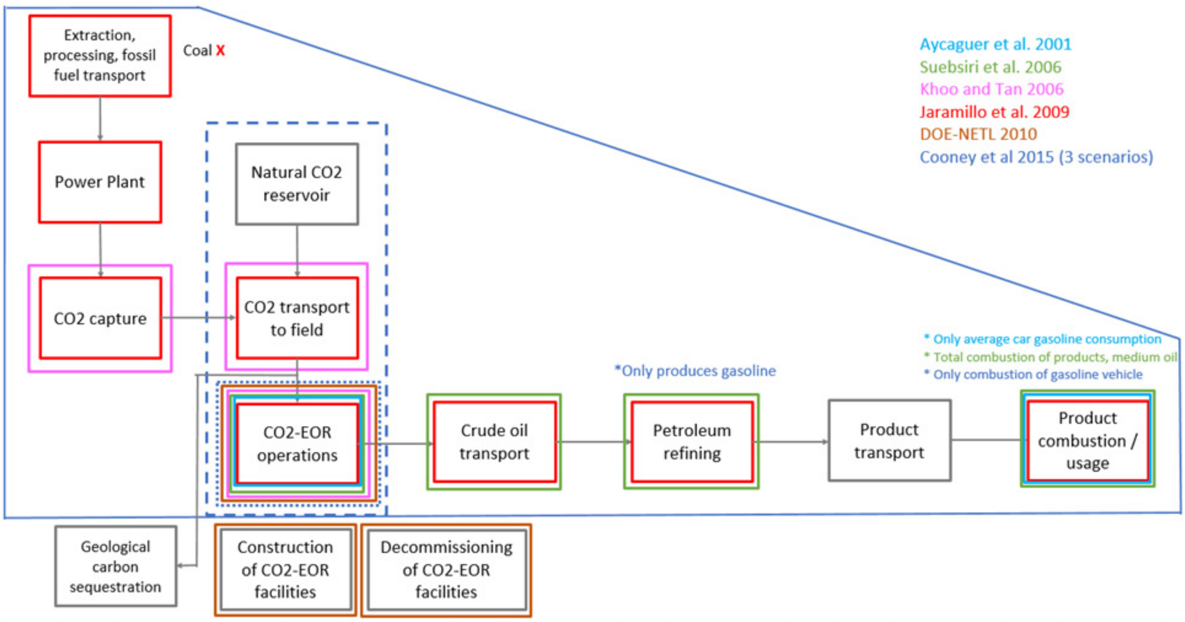


Fig. 1. Examples of CO_2-EOR system boundaries found in the public literature

All these different studies not only differ in their boundaries, but they also differ in the functional units used to estimate a certain metric representative of an environmental impact.

2. The gate-to-gate system

For the purposes of this paper, we focused our analysis on the CO_2-EOR operations (gate-to-gate) as a sub component of the cradle-to-grave system that will be used for the NETL funded study. However, we will include emissions associated with the refining and burning of the end product.

Within the gate-to-gate boundary, as illustrated in Fig. 2, the purchased CO_2 (regardless of the source) enters the gate and crude oil exits through the other gate. The purchased CO_2 joins the recycled CO_2 and the combined stream gets injected into the oil bearing formation at a pressure that is generally 80% of the fracture pressure of the rock. The CO_2 enhances production through diverse physical mechanisms, and both oil and CO_2 get produced.

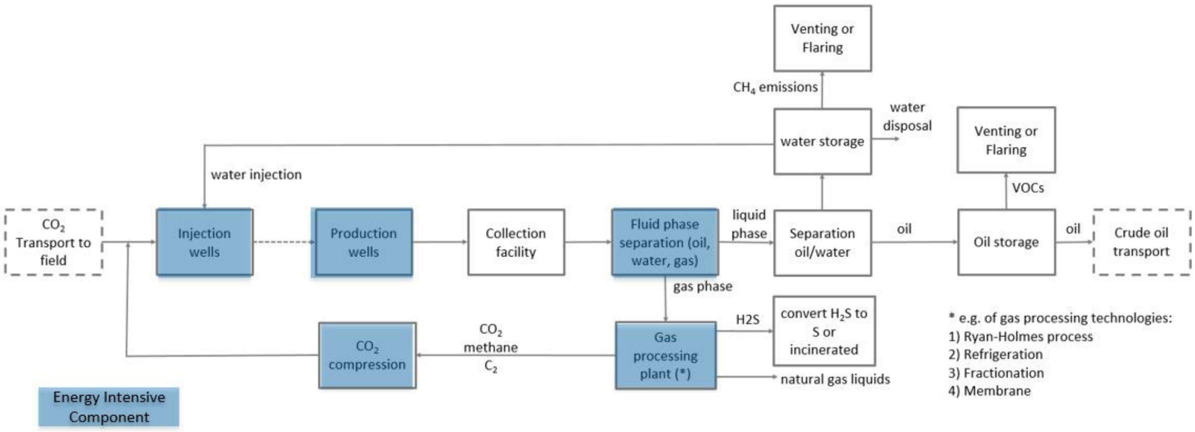


Fig. 2. CO_2-EOR gate-to-gate system

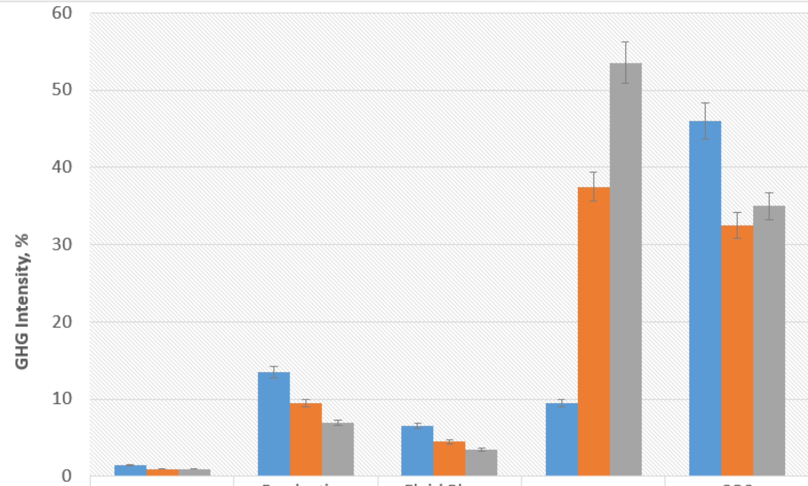
Commonly, water is also injected into the formation in a CO_2/water alternating fashion in order to control the highly mobile CO_2 and prevent fingering. In other words, the water helps the displacing front become more uniform, or piston like, thus improving the sweep efficiency of the flood and preventing early CO_2 breakthrough. This water also gets produced. All fluids go to the fluid phase separation facility where liquids separate from gases. Water and oil separate. The oil exits the system, but the water goes to a gathering facility for further use. Water is gathered not only because it is needed for the water alternating gas cycle but also for possible injection into other economic sand units that are part of the EOR development and need to be pressurized to minimum miscibility pressure (MMP) before CO_2 injection starts.

Gases on the other hand go to a separation facility, where the CO_2 is separated from other gases (hydrocarbon gases, hydrogen sulphide). Then the CO_2 gets compressed into a supercritical fluid and recycled back into the oil reservoir. The cycle continues until an economic limit is reached.

3. Environmental impact per energy intensive component within the gate-to-gate system

As mentioned before, diverse functional units that represent an environmental impact are found in the literature. Some years ago the preferred unit was kilowatt hour (kWh) used per barrel of oil produced. But in recent years there seems to be more consensus in the use of mass of CO_2 equivalent per barrel of oil produced.

In order to compare similar studies, we normalized the different functional units as a percentage of their totals to reflect a greenhouse gas intensity factor per EOR component. As expected, the energy intensive components of the EOR system are the components that are responsible for making the fluids flow at the required rates, pressures, and fluid phase. We identified 4 critical processes at the EOR site (Fig. 2): 1) Injection/production, 2) Production separation, 3) CO_2 separation, and 4) CO_2 compression. According with Fox [4], and Conney and others [2], the most critical component is either the gas separation or the CO_2 compression, depending on the process used to separate the gas. If membrane separation is used, the gas processing plant would have an environmental impact of 49 to 57% of the entire EOR operation. However, if fractionation or refrigeration is used, the gas processing plant would only have an impact of 8 to 11%, making CO_2 compression the most critical parameter at 40 to 54% of overall impact (Fig. 3). This last scenario is consistent with Fox's study [4], which indicates that for the year 2007, CO_2 compression accounted for 50 % of the total power demand. We have noticed a difference, however, in the relative greenhouse has intensity reported for water management (or fluid handling). According with the SACROC study, water handling at the surface accounted for 20% of the total power demand of the operation, which is significantly higher than what we have seen in other studies. Another aspect we haven't found covered is the fact that CO_2 EOR is likely to be selected for application in depleted oil fields, where the reservoir pressure is likely to be well under the minimum miscibility pressure. This requires an initial pressure build up that is usually achieved through water injection. In our experience, this initial water injection can be significant. Also in our experience, and as Fox suggests, the energy required for water management might be underestimated in some studies. Of course this depends on the assumed purpose of the produced water in these studies.



	Injetion Wells	Production Wells	Fluid Phase Separation	Gas Processing	CO2 Compression
Fract - Refrg	1.5	13.5	6.5	9.5	46
Ryan Holmes	1	9.5	4.5	37.5	32.5
Membrane	1	7	3.5	53.5	35

Fig. 3. GHG Intensity of EOR component per gas processing method

4. Case Study: Cranfield

We have selected Cranfield, MS as the field that will provide the case study for several reasons: (1) it provides the optimal mass accounting data set as it was required by its comprehensive SECARB Monitoring Verification and Accounting (MVA) program, (2) it is a desirable direct injection (no WAG), which is favorable for achieving NCNO, (3) pattern geometry and operations repeated systematically around field development, and (4) it provides a simpler environment than many CO_2-EOR floods.

Cranfield is a clastic oil field close to Neches, Mississippi. The field's main pay is a ~10,000 ft. deep reservoir located at the apex of a 4-way closed anticline with pre-production pressure and temperature of 4,600 psi and 150°F. The reservoir produced mostly oil with some gas from a gas cap in the 1940's and 1950's and then remained inactive until 2007 when the current owner started its operations. We used the northeastern section of the reservoir that is separated from other parts of the field by a sealing fault.

The mass of CO2 was calculated monthly using eq.1, where the mass of CO_2 equals the total mass of CO_2 injected minus the mass of CO_2 recycled back into the oil reservoir CO_2 losses at the surface, including potential leakage from well heads, flaring or venting, fugitive leaks from surface equipment, transportation offsite, or other losses of CO_2 during handing were assumed negligible.

In the case of Cranfield, as is the case in other Gulf Coast CO_2 floods, gases (CO_2 + hydrocarbon gases) produced through EOR are not separated before reinjection for economic reasons. Therefore, the mass of CO_2 recycled was corrected for the presence of impurities, mostly CH_4, in the recycled fluid stream. Another important consideration is that the concentration of impurities in the injected volumes increased with every new injection cycle, as more hydrocarbon gases were produced along with the oil and the CO_2, which was also accounted for.

$$M_{stored} = M_{total\ injected} - M_{recycle} - M_{loss\ surface} \quad \text{(Eq. 1)}$$

In addition to the reservoir mass accounting, the carbon mass balance at the EOR site, or within the gate-to-gate system, should include an account of indirect CO_2 emissions, which correspond to the CO_2 equivalent emissions associated with the electricity consumption of equipment and processes at the EOR site. Figure 4 shows energy intensive locations, where indirect CO_2 emissions were accounted for. The figure is presented as a decision diagram as to cover most common EOR site design configurations. Our estimated Cranfield indirect CO_2 emissions associated with CO_2 injection and general production are presented in figure 5. These emissions consider the energy mix used by the region's electricity provider.

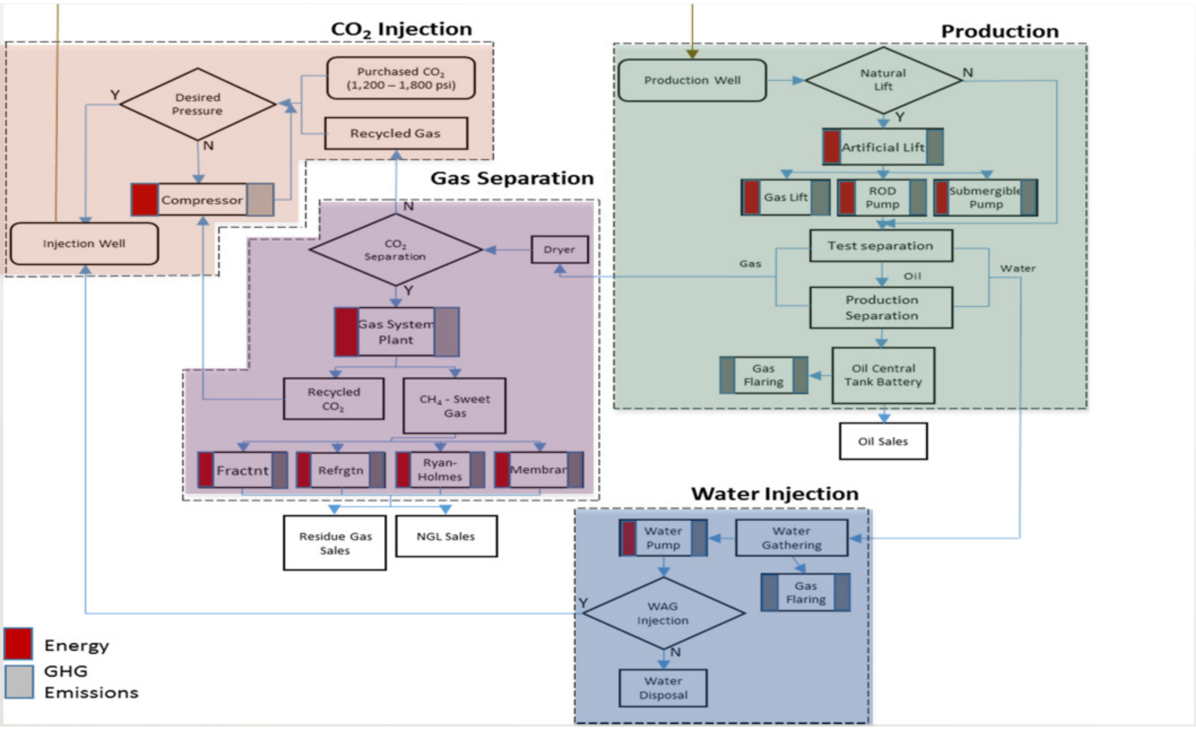


Fig. 4. Indirect carbon emission accounting locations

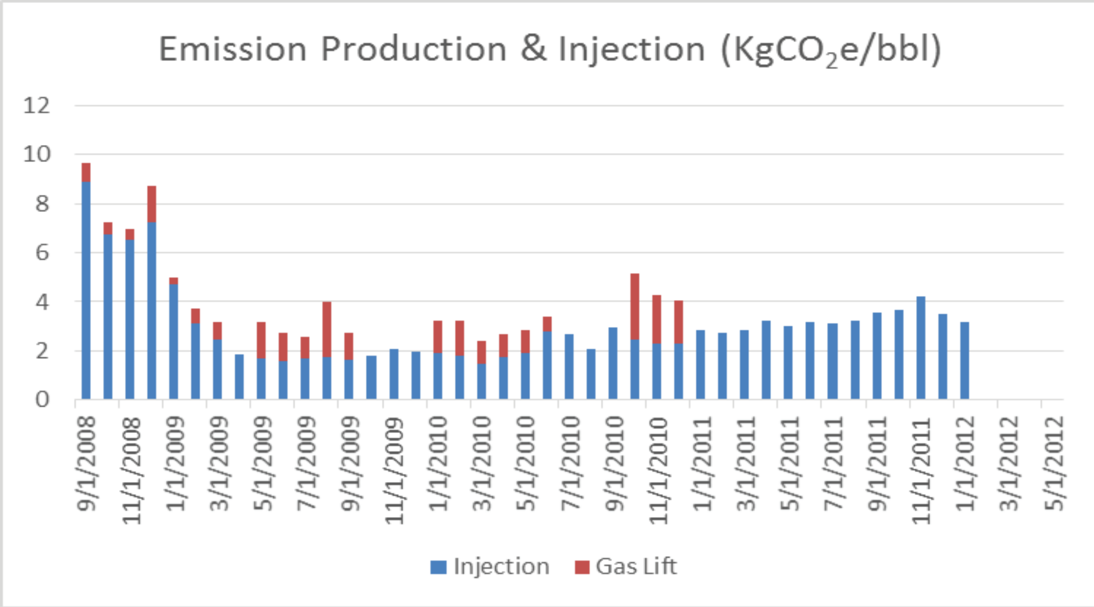


Fig. 5. Cranfield indirect carbon emissions

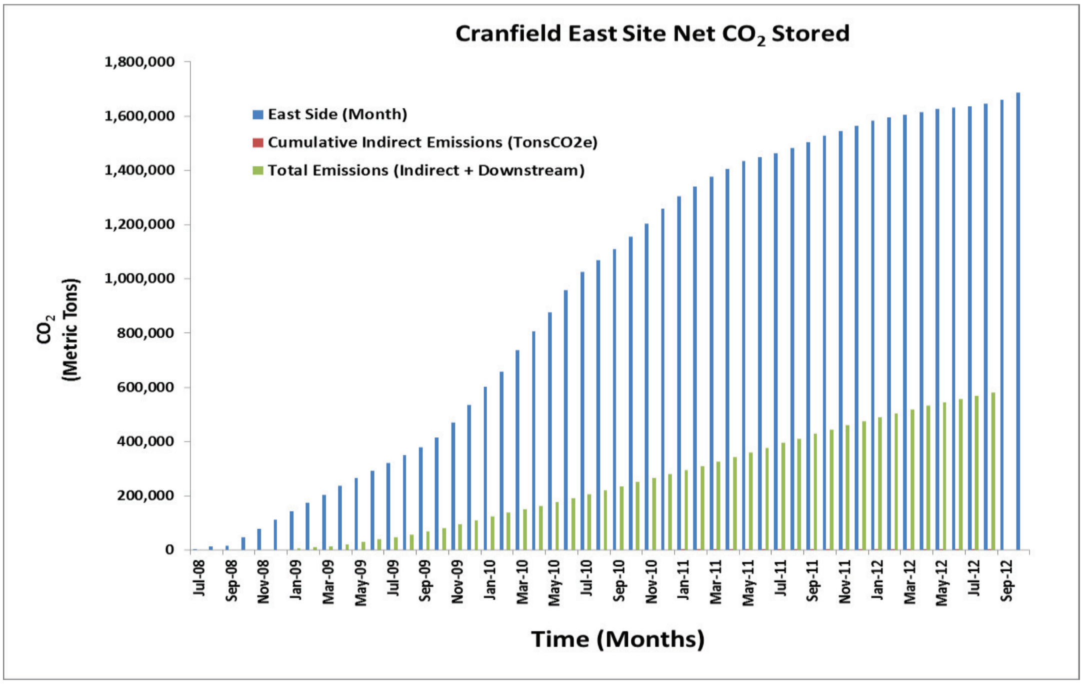


Fig. 6. Cranfield net CO2 storage volumes vs. carbon emissions

Finally, emissions downstream of the gate-to-gate system were calculated following data reported by Jaramillo [5], where 50 $KgCO_2e$/bbl are used for refining processes and 395 $KgCO_2e$/bbl are used for product combustion. Figure 6 shows the cumulative net carbon storage volumes and the cumulative total emissions (direct plus indirect) from the point of CO_2 purchase at the oil field, and including crude oil production, refining and ultimate burning. Indirect emissions at the EOR site are so small compared to the volumes of CO_2 stored, that disappear at the scale of the figure. By September 2012, 1.6 million metric tons had been stored at Cranfield's east side, and the associated emissions were estimated at 0.58 million metric tons, short of one third of the total volumes stored.

6. Conclusions

The carbon balance of CO_2-EOR is very sensitive to the selected system boundary and to the efficiency of the oil displacement. In a Gate-to-Gate analysis, the electricity consumption (purchased and generated) is responsible for almost all the emissions associated with the EOR operation itself. In the specific case of Cranfield (direct CO_2 injection, no gas separation in recycling), the CO_2-EOR operation seems to be very efficient in terms of electricity use and GHG emissions. In fact, for the selected boundary, CO_2 emissions accounted for one third of the total volumes of CO_2 stored in Cranfield, making the oil produced net carbon negative.

Acknowledgements

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