Carbon Life Cycle Analysis of CO$_2$-EOR for Net Carbon Negative Oil (NCNO) Classification

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Presentation Outline

• Project overview
  – Goals and objectives
  – Methodology
• Accomplishments to date
• Expected Outcomes
• Summary
Problem Statement

- Is CO$_2$-EOR a valid option for greenhouse gas emission reduction? Are geologically stored carbon volumes larger than direct/indirect emissions resulting from CO$_2$-EOR operations?
Project Overview: Goals and Objectives

**Goal:** To develop a clear, universal, repeatable methodology for making the determination of whether a CO$_2$-EOR operation can be classified as Net carbon Negative Oil (NCNO)

**Objectives:**

- Identify and frame critical carbon balance components for the accurate mass accounting of a CO$_2$-EOR operation.
- Develop strategies that are conducive to achieving a NCNO classification.
- Develop a comprehensive, yet commercially applicable, monitoring, verification, and accounting (MVA) methodology.
Related Literature

Life Cycle Inventory of CO₂ in an Enhanced Oil Recovery System

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Abstract

Life Cycle Inventory of CO₂ in an Enhanced Oil Recovery System

Reducing Carbon Dioxide Emissions with Enhanced Oil Recovery Projects: A Life Cycle Assessment Approach

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Evaluating the Climate Benefits of CO₂-Enhanced Oil Recovery Using Life Cycle Analysis

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Supporting Information

ABSTRACT: This study uses life cycle analysis (LCA) to evaluate the greenhouse gas (GHG) performance of carbon dioxide (CO₂) enhanced oil recovery (EOR) systems. A detailed gate-to-gate LCA model of EOR was developed and incorporated into a cradle-to-gate boundary with a functional unit of 1 MJ of combusted gasoline. The cradle-to-gate model includes two sources of CO₂: natural and anthropogenic (fossil fuel). The latter is assumed to be captured and sequestered in CO₂ underground storage (US). The results show that EOR projects can achieve significant reductions in CO₂ emissions compared to conventional EOR systems. The use of captured CO₂ reduces the overall greenhouse gas emissions by approximately 40%, depending on the specific EOR system and CO₂ source. The study also highlights the potential for CO₂ capture and storage to mitigate the impacts of climate change and contribute to the goal of reducing greenhouse gas emissions.
Selection of system boundaries for NCNO classification: Cradle-to-Grave

- Extraction, processing, fossil fuel transport
  - Power Plant
  - CO2 capture
    - Natural CO2 reservoir
    - CO2 transport to
      - CO2-EOR operations
      - Crude oil transport
      - Petroleum refining
      - Product transport
      - Product combustion

- Geological carbon sequestration
- Construction of facilities

**Selected system boundary**

**Study focus**
Methodology: Select Field Setting

• (Cranfield, Mississippi)
  – It provides the optimal mass accounting data set as it was required by its comprehensive SECARB MVA program
  – It is a desirable direct injection (no WAG), which is favorable for achieving NCNO
  – Pattern geometry and operations repeated systematically around field development
  – Provides a simpler environment than many CO$_2$-EOR floods
Methodology: Numerical Simulation

- Utilize Cranfield pattern calibrated models to:
  - Run numerical simulations for different novel and standard CO₂ injection scenarios (WAG, direct CO₂ injection)
  - Evaluate how the variability of CO₂ utilization ratios for the different injection scenarios affects the identified system components.
  - Understand the carbon balance evolution from start of injection to completion.
Methodology: Develop MVA Plan

• Use predictive flow and pressure elevation results to develop a generic but comprehensive MVA plan that is based on:
  – existing regulatory monitoring requirements
  – existing best practices
  – a number of proposed and suggested processes that are currently being considered for possible future regulatory or credit trading conditions
Accomplishments to Date

Identification of critical CO₂ emission components within the EOR site

GHG Intensity

- Injection wells
- Production wells
- Collection facility
- Fluid phase separation (oil, water, gas)
- Separation oil/water
- Gas processing plant (*)
- CO₂ compression
- CO₂ transport to field

- Water injection
- CO₂ compression
- CO₂ transport to field

- Water storage
- CH₄ emissions
- Venting or Flaring
- Water disposal
- Venting or Flaring

- DOE-NETL: 2013, 2015 (Skone, Conney)
  a) Fract-Ref: 10-17%
  b) R: H: 5-6%
  c) Membr: 2-5%

- SACROC case 2007: 30%
- SACROC case 2007: 20%

- DOE-NETL 2009: 5-10%

- SACROC case 2007, 2009 (Skone, Conney)
  a) Fract-Ref: 5-6%
  b) R: H: 3-6%
  c) Membr: 0-1%

- DOE-NETL: 2009: 8% (OTHERS)

- DOE-NETL: 2009: 5-10%

- SACROC case 2007: 50%

- Gas processing technologies:
  1) Fractionation
  2) Refrigeration
  3) Ryan-Holmes
  4) Membrane
GHG Intensity per EOR Component

<table>
<thead>
<tr>
<th>EOR Component</th>
<th>Fract - Refrg</th>
<th>Ryan Holmes</th>
<th>Membrane</th>
</tr>
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<tr>
<td>Injection Wells</td>
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<td>Production Wells</td>
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<td>7</td>
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<tr>
<td>Fluid Phase Separation</td>
<td>6.5</td>
<td>4.5</td>
<td>3.5</td>
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<tr>
<td>Gas Processing</td>
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<td>37.5</td>
<td>53.5</td>
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<tr>
<td>CO2 Compression</td>
<td>46</td>
<td>32.5</td>
<td>35</td>
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</tbody>
</table>

GHG intensity of EOR components per gas processing method.
Study focus: CO$_2$ utilization ratios

CO$_2$ injection [MMCF] 

CO$_2$ Utilization [MMCF/bbl] 

CO$_2$-EOR/Storage Carbon Balance 

CO$_2$ emissions 

Oil to market 

recycle 

Brine 

Oil 

CO$_2$ 

Produced oil [bbl]
Field Study

• (Cranfield, Mississippi)
  – It provides the optimal mass accounting data set as it was required by its comprehensive SECARB MVA program
  – It is a desirable direct injection (no WAG), which is favorable for achieving NCNO
  – Pattern geometry and operations repeated systematically around field development
  – Provides a simpler environment than many CO$_2$-EOR floods
Cranfield overview:

- Clastic Mississippi field
- Apex of 4-way closed anticline
- Main pay is ~10,000 ft deep
- $P_i = 4,600$ psi, $T_i = 150^\circ F$
- Original gas cap
- Productive during 1940s and 50s
- CO$_2$ injection started in 2007
- Available mass accounting data as required by SECARB’s monitoring program.
Methodology: Numerical Simulation

• Utilize Cranfield pattern calibrated models to:
  – Run numerical simulations for different novel and standard CO$_2$ injection scenarios (WAG, direct CO$_2$ injection)
  – Evaluate how the variability of CO$_2$ utilization ratios for the different injection scenarios affects the GHG intensity of the system components (New contribution)
  – Understand the carbon balance evolution from start of injection to completion (New contribution)

• Current activities:
  ✓ Updated existing Cranfield models: added physics
  ✓ Relative permeability laboratory experiments
  ✓ History matching for historic Cranfield production (1944-1972)
Methodology: Numerical Simulation

Compositional model simulates CO$_2$ injection
Methodology: Numerical Simulation

Preliminary History Matching of Primary Production
Trapping Mechanisms

- Additional funds allowed us to add valuable work to the modeling tasks by studying the trapping mechanisms that contribute to the geological permanence of the stored CO$_2$

1. Residual/capillary trapping
2. CO$_2$ dissolution into brine
3. CO$_2$ dissolution into oil
4. Mineral trapping

Benson, 2003
New CO$_2$-brine Relative Permeability

12 Cranfield core plugs were sent to a commercial laboratory.

Relative permeability experiments will be run in 2 composite samples consisting of 6 aligned core plugs.

### Summary of Routine Core Analyses Results

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Sample Type</th>
<th>Sample Depth, feet</th>
<th>Permeability, millidarcys to Air</th>
<th>Klinkenberg</th>
<th>NCS Porosity, percent</th>
<th>Grain Density, gm/cc</th>
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<td>22</td>
<td>Horizontal</td>
<td>10452.66</td>
<td>312.1</td>
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<td>9.40</td>
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<td>2.69</td>
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Average values: 160.0, 155.0, 26.1, 2.69
Expected Outcomes

• A comprehensive carbon balance analysis of a CO$_2$-EOR operation with an accurate mass accounting methodology for determining whether the operation can be classified as NCNO.

• A recommendation of CO$_2$ surface operation and injection strategies that are conducive to achieving a NCNO classification.

• A universal MVA methodology encompassing the entire CO$_2$-EOR operation and inclusive of pre CO$_2$ injection, injection, and stabilization periods.
Summary

• Accomplishments:
  ✓ Selection of system boundaries relevant to NCNO classification: gate-to-grave
  ✓ Identification of critical CO$_2$ emission components within the EOR site
  ✓ Gathered and classifying Cranfield mass accounting data
  ✓ Built Cranfield static model
  ✓ Completed historic and EOR history matching
  ✓ Started numerical simulation tasks
  ✓ Build a model for energy consumption of the CO$_2$-EOR operation

• Future Plans:
  – Start scenario analysis
  – Link results from numerical simulations with energy consumption model
  – Develop an MVA plan
Organization Chart

Lead Organization
UT-BEG
Michael Young, Associate Director

BEG Administration

Seyyed Hosseini (Dynamic Modeling)
Research Associate

Reza Ganjdanesh
Postdoctorate Scholar

Principal Investigator
Vanessa Nuñez-Lopez
Research Scientist Associate

Tip Meckel (Static Modeling, Mass Accounting)
Research Scientist

Senior Oversight
Larry Lake, UT-PGE Faculty
Susan Hovorka, UT-BEG

Susan Hovorka (Mass Accounting, MVA)
Sr. Research Scientist

BEG Researcher
TBD
## Gantt Chart

<table>
<thead>
<tr>
<th>Task</th>
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<th>BUDGET PERIOD 1</th>
<th>BUDGET PERIOD 2</th>
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Bibliography

None yet