What it All Means: CO$_2$-EOR Greenhouse Gas Life-Cycle Analysis of 22 Years of Class II UIC Field Operations and Monitoring

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Outline

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5. Greenhouse Gas Emissions Life Cycle Analysis
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• USEPA Region 5 UIC Program.

• Michigan EGLE.

• PCOR/EERC (Nick Azzolina).

• DOE-NETL LCA program.
1. Background

- Life cycle analysis for greenhouse gas emissions accounts for all emissions generated for a process.
- Emissions expressed as CO$_2$ equivalent (kg CO$_2$e).
- Combustion of fuel products from 1 barrel (42 gallon) of oil has ~430 kg CO$_2$e/bbl emission factor.
- LCA helps understand the net benefit of carbon capture and storage projects.


6,511 Million Metric tons of CO$_2$ Equivalent
2. Carbon Storage LCA Objectives

- How much greenhouse gas emissions were emitted through Carbon Capture Utilization and Storage operations?
  - capture, compression, pipeline transport, drilling, injection fugitive emissions, embodied emissions, etc.
- How CO$_2$ much was left in the ground?
- What is the net carbon balance?

Example: CO$_2$ EOR GHG Emissions

<table>
<thead>
<tr>
<th>Conventional oil production</th>
<th>Enhanced Oil Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>emits 0.51 tons of CO$_2$ per barrel</td>
<td>emits 0.54 tons per barrel. But, it also stores 0.30 metric tons of CO$_2$ underground. Thus, net emissions are 0.24 tons per barrel.</td>
</tr>
</tbody>
</table>

0.51 tons CO$_2$ - 0.30 = net 0.24 tons CO$_2$

2. MRCSP Carbon Storage LCA Objectives

- Bottom-up analysis to determine the net greenhouse gas emission footprint of CO₂ EOR for this specific operation.
- Base on site specific data on CO₂ metering, fuel, electricity, construction/wells, fugitive emissions.
3. Midwest Regional Carbon Sequestration Partnership Phase III Demonstration

Primary goal: To execute a large-scale CO$_2$ injection test to evaluate best practices and technologies required to implement carbon sequestration.
3. MRCSP Phase III Large Scale CCUS Demonstration

- **Location:** Otsego County, Michigan
- **Source of CO$_2$:** Local Natural Gas Processing Plant (Antrim Shale Gas ~15% CO$_2$ content)
- **Reservoir Type:** Closely-spaced, highly compartmentalized oil & gas fields located in the Northern Michigan’s Niagaran Reef Trend
- **Injection Goal:** 1,000,000 metric tons (U.S. emissions per person = 15-20 metric tons per year)
3. The MRCSP site included 10 reefs in different stages of the oil production life cycle.

Natural gas processing is the source of the CO₂.
4. Integration with UIC

- CO₂ injection wells were permitted through USEPA Class II regulations Region 5/Michigan EGLE (more than 10 Class II wells over 22 years).
- EPA Monitoring Reporting & Verification plan prepared for CO₂ accounting and metering for 45Q credits (monitoring, leakage, mass balance calculations).
5. LCA: Establishing Boundary Conditions

- CO\textsubscript{2} EOR is part of a bigger hydrocarbon life cycle, including upstream, gate to gate, and downstream components (i.e. “Cradle to Grave.”)
- This analysis focused on Gate to Gate portion of LCA.

![Diagram of CO\textsubscript{2} EOR life cycle stages]

- **Upstream**
  - Natural Gas Production
  - CO\textsubscript{2} Separation

- **Gate to Gate**
  - CO\textsubscript{2} Compression and Pipeline Transport
  - CO\textsubscript{2} EOR

- **Downstream**
  - Pipeline Crude Transport
  - Petroleum Refining
  - Gasoline Product Transp.
  - Gasoline Combustion
5. LCA: Establishing Boundary Conditions

**UPSTREAM**
- Antrim Gas Wells
- Chester 10 Gas Processing CO₂ Capture
- White Frost CO₂ Pipeline
- Chester 10 CO₂ Compression

**GATE to GATE**
- Dover 36 Hydrocarbon Processing Facility
- Oil/CO₂ separation, Dehydration, Compression
- Oil/CO₂ + Oil
- Produced Water
- Oil

**DOWNSTREAM**
- Transport Refining POS Transport Combustion
- Oil

**Niagaran Reefs**
- Injection-Production
5. Life Cycle Assessment of CO$_2$-EOR

- Niagaran Reefs CO$_2$ EOR operations in place since 1996.
- CO$_2$ EOR expanded to 10 reefs over ~22 years.
- 2.2 million metric tons net CO$_2$ in reefs thru 2018.
- 2.3 million barrels oil produced (294,326 metric tons).
5. LCA: Gate-to-Gate Operations Data

- Detailed Gate-to-Gate data from MRCSP, Core Energy
  - CO₂ injected, CO₂ recycle, new CO₂, oil produced, brine produced
- Emission Sources
  - Compression natural gas use (MCF), facility electricity use (kWhr), fugitive emissions (CO₂ & methane), venting/flaring, facility construction, new wells, produced water/brine injection, land use.
5. LCA: Gate-to-Gate Operations Key Input

- Example- snapshot of 2017 key input.

### 2017 CO₂ Inventory

- **Total CO₂ Injected**: 615,184 metric tons
- **New CO₂ Injected**: 310,549 metric tons
- **CO₂ Recycle**: 317,174 metric tons
- **Oil Produced**: 194,861 bbl (25,040)

### 2017 Operations

- **Facility Electricity (KWH)**: 1,712,958
- **Compression Natural Gas (MCF)**: 550,734
- **Fugitive Emissions**:
  - CH₄: 530
  - CO₂: 12,539

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**Metrics:**

- **Metric Tons CO₂e**
- **Metric Tons CO₂**
- **Metric Tons CH₄**

**Key Input:**

- LCA: Gate-to-Gate Operations
- Example: Snapshot of 2017 key input.
5. LCA: Gate-to-Gate Operations Data

- Operations trends reflect CO$_2$-EOR cycles and additional reefs.
5. CO$_2$ EOR LCA Model

- Modified version of Azzolina/EERC (2016) CO$_2$ EOR LCA model framework used to calculate GHG emissions factors
- Direct measurements entered from CO$_2$ EOR system monitoring, operations, and new reef developments.

<table>
<thead>
<tr>
<th>SEGMENT</th>
<th>SUB-SEGMENT</th>
<th>PARAMETER DESCRIPTION</th>
<th>UNITS</th>
<th>LOW VALUE</th>
<th>EXPECTED</th>
<th>HIGH VALUE</th>
<th>SOURCE</th>
<th>NOTES</th>
<th>BASE CASE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gate-to-Gate</td>
<td>all Operations – Artificial</td>
<td>Crude artificial lift pump electricity rate</td>
<td>kWh / kg crude</td>
<td>1.00E-03</td>
<td></td>
<td></td>
<td>System Data</td>
<td></td>
<td>1.00E-03</td>
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<tr>
<td>Gate-to-Gate</td>
<td>all Operations – Artificial</td>
<td>Crude artificial lift pump electricity</td>
<td>kWh</td>
<td></td>
<td></td>
<td></td>
<td>Derived</td>
<td></td>
<td>25.040</td>
</tr>
<tr>
<td>Gate-to-Gate</td>
<td>all Operations – Artificial</td>
<td>Crude artificial lift pump electricity</td>
<td>MWh</td>
<td></td>
<td></td>
<td></td>
<td>Derived</td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>Gate-to-Gate</td>
<td>all Operations – Artificial</td>
<td>CO$_2$ emissions</td>
<td>kg CO$_2$</td>
<td></td>
<td></td>
<td></td>
<td>Derived</td>
<td></td>
<td>18.526</td>
</tr>
<tr>
<td>Gate-to-Gate</td>
<td>all Operations – Artificial</td>
<td>CO$_2$ emissions factor</td>
<td>kg CO$_2$ / bbl</td>
<td></td>
<td></td>
<td></td>
<td>Derived</td>
<td></td>
<td>0.1</td>
</tr>
</tbody>
</table>

**GATE-TO-GATE: WELL OPERATIONS – CO$_2$ COMPRESSION AND INJECTION ELECTRICITY**

| Gate-to-Gate | CO$_2$ Compression and Injection | Compressor power factor | MW /[tonne recycled CO$_2$/day] | 2.70E-03 | | | | NA, Cooney et al. (2015) | 2.70E-03 |
| Gate-to-Gate | CO$_2$ Compression and Injection | Compressor power | MW | | | | Derived | | 2.35E+00 |
| Gate-to-Gate | CO$_2$ Compression and Injection | Compressor energy | MWh | | | | Derived | | 29.533 |
| Gate-to-Gate | CO$_2$ Compression and Injection | CO$_2$ emissions | kg CO$_2$ | 29136000 | 29136000 | 29136000 | System Data | Combustion data from Core 35 | 29.136,000 |
| Gate-to-Gate | CO$_2$ Compression and Injection | CO$_2$ emissions factor | kg CO$_2$ / bbl | 349.5 | | | Derived | | 349.5 |
| Gate-to-Gate | CO$_2$ Compression and Injection | CO$_2$ pump power factor | MW /[tonne injected CO$_2$/day] | 0.00E+00 | 0.00E+00 | 0.00E+00 | System Data | See Line 115 | 0.00E+00 |
| Gate-to-Gate | CO$_2$ Compression and Injection | CO$_2$ pump power | MW | | | | Derived from the pump power | | 0.000 |
| Gate-to-Gate | CO$_2$ Compression and Injection | CO$_2$ pump energy | MWh | | | | Derived from the pump power | | 0.000 |
| Gate-to-Gate | CO$_2$ Compression and Injection | CO$_2$ emissions | kg CO$_2$ | 6591500 | 6591500 | 6591500 | System Data | Gas Processing data from Core 35 | 6,591,500 |
| Gate-to-Gate | CO$_2$ Compression and Injection | CO$_2$ emissions factor | kg CO$_2$ / bbl | 33.8 | | | Derived | | 33.8 |
| Gate-to-Gate | CO$_2$ Compression and Injection | CO$_2$ emissions (total) | kg CO$_2$ | | | | Derived from the sum of combustible gases and fugitive emissions | | 35,727,500 |
| Gate-to-Gate | CO$_2$ Compression and Injection | CO$_2$ emissions (total) | kg CO$_2$ / bbl | | | | Derived from the CO$_2$ emissions factor | | 383.3 |

**GATE-TO-GATE: WELL OPERATIONS – CO$_2$ COMPRESSOR FUGITIVE EMISSIONS**

| Gate-to-Gate | CO$_2$ Compressor | Compressor CO$_2$ emissions rate (direct to atmosphere) | kg CO$_2$ / MW-day | 63.6 | | | | NA, Cooney et al. (2015) | 63.6 |
| Gate-to-Gate | CO$_2$ Compressor | Compressor CO$_2$ emissions rate (direct to atmosphere) | kg CO$_2$ / bbl | 549 | 549 | 549 | System Data | Subpart C Core forms | 549 |

5. CO₂ EOR LCA Model Results

- Highest emission factors from compression & downstream.

<table>
<thead>
<tr>
<th>Category</th>
<th>2017 Emission Factor kgCO₂e/bbl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gate to Gate</td>
<td>198 kgCO₂e/bbl oil</td>
</tr>
<tr>
<td>Downstream</td>
<td>470 kgCO₂e/bbl oil</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>668 kgCO₂e/bbl oil</td>
</tr>
<tr>
<td>CO₂ Storage</td>
<td>-1529 kgCO₂e/bbl oil</td>
</tr>
<tr>
<td><strong>Net</strong></td>
<td>-862 kgCO₂e/bbl oil</td>
</tr>
</tbody>
</table>

**Graph:**
- Gate to Gate: 198 kgCO₂e/bbl oil
- Downstream: 470 kgCO₂e/bbl oil
- Total: 668 kgCO₂e/bbl oil
- CO₂ Storage: -1529 kgCO₂e/bbl oil
- Net: -862 kgCO₂e/bbl oil

- EOR Processing Electricity: 5.8 kgCO₂e/bbl oil
- Venting & Flaring: 7.4 kgCO₂e/bbl oil
- Crude oil transport: 4 kgCO₂e/bbl oil
- Crude oil refining: 46 kgCO₂e/bbl oil
- Fuel transport: 5 kgCO₂e/bbl oil
- Fuel combustion: 415 kgCO₂e/bbl oil
- Pipeline Transport: 0.03 kgCO₂e/bbl oil
- Compression: 183.3 kgCO₂e/bbl oil
5. LCA Model Output- “Gate to Gate”

- Large amount of variability in gate to gate EF over 20 years.

**Annual Oil Production and CO\textsubscript{2} Associated Storage**

- Total Oil Production (metric tons)
- Total CO\textsubscript{2} Storage (metric tons)
5. LCA Model Output—“Gate to Gate”

- “Gate to Gate” EOR EF = 163 kgCO2e/bbl GHG life cycle emissions factor (371,576,000 kg CO₂ / 2,290,473 BBL).

![Graph showing Gate-to-Gate Greenhouse Gas Emissions Factor (kg CO2e/bbl oil)]

PCOR EOR Model Low*

Niagaran Reef EOR

Natural Dome EOR-Adv

Canadian Oil Sands

Natural Dome EOR-Conv

PCOR EOR Model High*

After Marrriot (2013)

* Azzolina et al., (2017)
5. LCA Model Output—“Gate to Grave”

- “Gate to Grave” **net emissions** accounts for CO$_2$ stored.
- Analysis reflects ups and downs of operations.

![Graph showing net emissions from 1994 to 2018. The graph displays fluctuations in CO$_2$ emissions over the years.]
5. LCA Model Output- “Cradle to Grave”

“Cradle to Grave” results suggest there is a net negative CO₂ emissions of -159,860 metric tons.

<table>
<thead>
<tr>
<th>Year</th>
<th>Upstream Capture Emissions* (metric tonnes)</th>
<th>Gate to Gate total Emissions (metric tons)</th>
<th>Downstream Total Emissions (Metric tons)</th>
<th>Total CO2 Associated Storage (metric tonnes)</th>
<th>Net CO2e Emissions (metric tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>22,872</td>
<td>7,166</td>
<td>47</td>
<td>139,037</td>
<td>-108,952</td>
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<tr>
<td>1997</td>
<td>14,142</td>
<td>10,511</td>
<td>60,767</td>
<td>97,026</td>
<td>-11,606</td>
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<td>1998</td>
<td>38,543</td>
<td>19,554</td>
<td>86,924</td>
<td>98,763</td>
<td>46,257</td>
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<tr>
<td>1999</td>
<td>1,289</td>
<td>12,025</td>
<td>48,312</td>
<td>5,941</td>
<td>55,684</td>
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<tr>
<td>2000</td>
<td>2,061</td>
<td>9,786</td>
<td>30,084</td>
<td>15,259</td>
<td>26,673</td>
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<tr>
<td>2001</td>
<td>-</td>
<td>8,759</td>
<td>31,757</td>
<td>-12</td>
<td>40,529</td>
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<tr>
<td>2002</td>
<td>72</td>
<td>8,237</td>
<td>24,005</td>
<td>665</td>
<td>31,649</td>
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<tr>
<td>2003</td>
<td>1,174</td>
<td>9,397</td>
<td>22,580</td>
<td>11,585</td>
<td>21,566</td>
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<td>2004</td>
<td>528</td>
<td>9,521</td>
<td>24,859</td>
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<td>2005</td>
<td>175</td>
<td>4,697</td>
<td>26,011</td>
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<td>2006</td>
<td>19,916</td>
<td>13,308</td>
<td>27,620</td>
<td>87,763</td>
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<td>2007</td>
<td>5,574</td>
<td>10,042</td>
<td>47,732</td>
<td>14,079</td>
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<td>2008</td>
<td>30,986</td>
<td>18,472</td>
<td>59,543</td>
<td>120,595</td>
<td>-11,594</td>
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<td>2009</td>
<td>23,417</td>
<td>17,449</td>
<td>54,040</td>
<td>56,505</td>
<td>38,402</td>
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<tr>
<td>2010</td>
<td>32,682</td>
<td>18,740</td>
<td>47,226</td>
<td>154,237</td>
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<td>2011</td>
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<td>24,530</td>
<td>57,638</td>
<td>166,463</td>
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<tr>
<td>2012</td>
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<td>26,342</td>
<td>59,147</td>
<td>159,857</td>
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<tr>
<td>2013</td>
<td>40,759</td>
<td>26,118</td>
<td>59,495</td>
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<tr>
<td>2014</td>
<td>32,740</td>
<td>26,908</td>
<td>66,357</td>
<td>144,313</td>
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<td>2015</td>
<td>34,280</td>
<td>27,971</td>
<td>91,614</td>
<td>148,202</td>
<td>5,664</td>
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<td>2016</td>
<td>40,759</td>
<td>26,118</td>
<td>59,495</td>
<td>182,417</td>
<td>-56,045</td>
</tr>
<tr>
<td>2017</td>
<td>64,433</td>
<td>38,495</td>
<td>91,614</td>
<td>298,010</td>
<td>-103,468</td>
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<tr>
<td>Total</td>
<td>478,476</td>
<td>374,147</td>
<td>1,076,867</td>
<td>2,089,350</td>
<td>-159,860</td>
</tr>
</tbody>
</table>
6. Results - Total LCA results 1996-2017

Upstream
CO₂ Capture Plant Operations
478,476 tonnes
CO₂e Generated

Gate to Gate
(compression, EOR, & gas processing)
374,147 tonnes
CO₂e Generated

Downstream
1,076,867 tonnes CO₂e Generated

Associated CO₂ Storage
-2,089,350 tonnes

Net
-159,860 tonnes
6. Conclusions

- Greenhouse gas emissions life cycle analysis helps us understand the benefits of carbon capture and storage.

- The greenhouse gas life cycle analysis highlights the value of integrating Class II UIC operations and site-specific data over a long period of CO$_2$-EOR operations.

- The system benefited from a ready source of CO$_2$, short pipeline system, natural gas fueled compression, highly contained reservoir, and basic oil processing system.

- Analysis of 22 years of CO$_2$-EOR operations and monitoring shows it is possible to have negative net emissions if you store a large amount of CO$_2$ in association with EOR operations.

(Marriott/DOE-NETL, 2013)
Thanks!

Questions?