A Life Cycle Analysis Perspective of ROZ – CO$_2$ Enhanced Oil Recovery

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USAE, ROZ Workshop, Washington, D.C
January 12, 2016.
Residual Oil Zone Performance Data

Crude Recovery Ratio (barrels of crude oil per tonne of CO₂ sequestered)

ROZ Data Summary

- Four counties in the Permian Basin of West Texas
- Each county divided into partitions (32 each for low and high quality)
- Crude Recovery Ranges (bbl/tonne CO₂ sequestered):
  - HQ: 1.2 – 5.2 (production wtd. mean 3.2)
  - LQ: 0.07 – 4.2 (production wtd. mean 1.5)

Research Questions

• What are the key contributions to the cradle-to-grave (life cycle) emissions for gasoline derived from crude produced via CO₂ EOR?

• How do different sources of CO₂ (natural vs. fossil) affect the ability of gasoline produced via EOR to meet reduction targets (e.g. net negative) relative to conventional petroleum?

• How does the efficiency of the EOR operation (amount of crude yielded per unit of CO₂ sequestered) affect the ability to hit those same targets?
Life Cycle of Gasoline from CO₂-EOR-Crude

Scenario shown is for 2 bbl crude per tonne CO₂ recovery ratio & a 550-MW supercritical pulverized coal power plant with 90% CO₂ capture.

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Life Cycle of Gasoline from CO₂-EOR-Crude

Power Plant Fuel & Transport
- 0.04 kg coal
- 0.1 kWh

Power Plant Captured CO₂
- 0.09 kg CO₂

Natural Dome CO₂
- 0.09 kg CO₂

CO₂ Pipeline Transport
- 0.09 kg CO₂

Displaced Electricity

Global Warming Potential (g CO₂e/MJ combusted gasoline)

CO₂ intensity of upstream CO₂

Upstream CO₂

1 MJ gasoline

EOR Crude Extraction
- 0.09 kg CO₂

CO₂ intensity of upstream CO₂

EOR Crude Refining
- crude

Gasoline Transport
- 1 MJ gasoline

Gasoline Combustion
- 1 MJ gasoline

Petroleum Baseline
- 115 g CO₂e/MJ combusted gasoline
- 72 g CO₂e/MJ combusted gasoline

Dome SCPC
CO₂ Intensity of Upstream CO₂

- Emissions downstream of EOR are static
- EOR is indifferent to CO₂ source
- CO₂ source choice determines achievable life cycle targets
- Options for sourcing CO₂ (modeled)
  - Natural Dome
  - Supercritical Pulverized Coal (SCPC)
  - Natural Gas Combined Cycle (NGCC)
  - SCPC co-fired biomass and coal
- Displacement of existing power
  - 2014 Grid Mix
CO₂ Intensity of Upstream CO₂
Comparison of All Sources

- **Fossil CO₂ is preferred to natural dome**
  - Credit for displacement of existing power

- **Adding biomass reduces upstream fuel component**
  - 30% switchgrass results in net negative upstream fuel GHG emissions

- **NGCC is a less efficient CO₂ generator**
  - For a fixed amount of CO₂, NGCC yields more power and thus receives a larger credit
  - Ratio NGCC:SCPC is 2.4:1
CO₂ Intensity of Upstream CO₂

Grid Displacement Impacts

- Dome: 0.10
- SCPC: -0.39
- SCPC/30% Biomass: 0.54
- NGCC: -0.10

2014 Grid Mix
(566 g CO₂e/kWh)

- Dome: 0.10
- SCPC: -0.94
- SCPC/30% Biomass: -1.05
- NGCC: -2.49

Fleet Coal
(1,041 g CO₂e/kWh)
Achievable targets are based on the intersection of CO₂ source technology and crude recovery.
For a fixed crude recovery ratio, determine CO₂ intensity of upstream CO₂ required to meet a specific reduction target:
- Net Zero: -1.2 kg/kg
- 50% Reduction: -0.6 kg/kg
- 25% Reduction: -0.4 kg/kg
Achievable targets are based on the intersection of CO₂ source technology and crude recovery

- The CO₂ intensity of a given source (e.g. NGCC or SCPC) is not a function of the crude recovery ratio
- More aggressive target can be achieved as the CO₂ intensity becomes more negative or the crude recovery ratio is reduced

![Graph showing CO₂ intensity and crude recovery ratio](image)
Achievable targets are based on the intersection of CO₂ source technology and crude recovery

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- More aggressive target can be achieved as the CO₂ intensity becomes more negative or the crude recovery ratio is reduced
- The type of electricity displaced is key to determining the CO₂ intensity and achievable reductions (fleet coal at 1,041 g CO₂e/kWh)
Variability in CO₂ Intensity Due to Displacement Mix

- A given source of CO₂ can span a range of CO₂ intensities according to the assumptions regarding the type of displaced electricity.
- This range can inform the types of reduction targets that may be achievable.
As the grid decarbonizes, the CO₂ intensity of upstream CO₂ increases

- As capture is implemented, the grid becomes less GHG intensive
- Hypothetical example depicts range from fleet coal (1,041) to a carbon constrained grid (163)
- This analysis can help determine the grid GHG intensity at which it is no longer possible to hit a target
- Under full fossil capture, transportation would likely shift away from conventional technology
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Key Conclusions

• Life cycle net negative carbon crude oil can be produced from CO₂ EOR pathways
• The percentage reduction from the petro baseline depends on the source of CO₂ and the efficiency of the EOR operation
• Displacing carbon intensive power by capturing CO₂ at an alternative plant increases the credit
• Sources of CO₂ that are inefficient at generating captured CO₂ per unit of power (or other output) result in a larger credit
• As the electricity sector becomes less carbon intensive, the life cycle GHG profile for EOR crude will increase
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LCA is well suited for energy analysis

- Draws a more complete picture than one focused solely on stack or tailpipe emissions
- Allows direct comparison of dramatically different options based on function or service
- Includes methods for evaluating a wide variety of emissions and impacts on a common basis
- Brings clarity to results through systematic definition of goals and boundaries
LCA of complex systems requires co-product management to apportion burdens

- Objective of LCA is to assign ownership of environmental burdens to a single function
- When more than one product exits the system boundary of an LCA, it is necessary to redefine the boundaries or apply an assignment that splits life cycle burdens among products
- NETL has studied the system (captured fossil power coupled with CO₂-EOR) extensively and recommends system expansion with displacement
  - System expansion alters system boundaries to include all co-products
  - With displacement, the system receives a credit for the GHGs emitted via the conventional product route for co-products
  - This analysis expands the boundaries of the system to include displacement of one of the co-products, leaving us with the desired product (power or fuel)
Evaluating the Climate Benefits of CO$_2$-Enhanced Oil Recovery Using Life Cycle Analysis

- Detailed models are necessary to give confidence to broader system applications
- CO$_2$-EOR is a GHG-intensive way of extracting crude compared to conventional extraction methods
- Linking EOR with anthropogenic CO$_2$ yields a benefit due to the displacement of uncaptured electricity
- Crude recovery impacts depend on the source of CO$_2$ (natural vs. fossil)
- Inefficient CO$_2$ generators are best (NGCC vs. SCPC): increasing efficiency will increase the amount of power generated per unit of CO$_2$ captured and sent to EOR

Other NETL CCUS-related publications

• Gate-to-Gate Life Cycle Inventory and Model of CO₂-Enhanced Oil Recovery (Sept. 2013)
  – Full process detail and comparison of four gas processing technologies

• Gate-to-Grave Life Cycle Analysis Model of Saline Aquifer Sequestration of Carbon Dioxide (Sept. 2013)

• Cradle-to-Gate Life Cycle Analysis Model for Alternative Sources of Carbon Dioxide (Sept. 2013)
  – Three potential sources considered: natural dome, ammonia production, natural gas processing

• All reports accessible via: www.netl.doe.gov/LCA