Overview of Energy Life Cycle Analysis at NETL for Carbon Utilization Technologies

Timothy J. Skone, P.E.
LCA Webinar for the National Academy of Sciences, Engineering, and Medicine
Energy Life Cycle Analysis
Cradle-to-grave environmental footprint of energy systems

Mission
Develop and utilize the LCA framework and methods to support the evaluation of sustainable energy systems both in and outside of the Department of Energy

Vision
A world-class research and analysis team that integrates results which inform and recommend sustainable energy strategy and technology development

netl.doe.gov/LCA  LCA@netl.doe.gov
**Life Cycle Analysis Team**

**Tim Skone** – 18 years  
Federal Team Lead  
BS Chemical Engineering | P.E. Env. Engr.

**Greg Cooney** – 10 years  
Contractor Team Lead  
MS Env Engr | BS Chem Engr

**James Littlefield** – 17 years  
Natural gas, system & process design  
BS Chemical Engineering

**Joe Marriott** – 12 years  
Senior Advisor  
PhD Environmental Engr & Public Policy

**Matt Jamieson** – 8 years  
Power systems, CO\textsubscript{2}-enhanced oil recovery  
BS Mechanical Engineering

**Michelle Krynock** – 2 years  
Natural gas, fuel cells, coal  
BS Civil/Env Engr & Public Policy

**Derrick Carlson** – 7 years  
I/O LCA, Energy efficiency  
PhD/MS Civ/Env Engr| BS C Chemistry

**Dan Augustine** – 1 year  
Natural gas, visual analytics  
BS Energy Engineering

**Ambica Pegallapati** – 5 years  
Biofuels, bioreactor development  
PhD Env Engr| BS Civil Eng

**Greg Zaimes** – 4 years  
Energy analysis; transportation fuels  
PhD Civ/Env Eng; BS Physics

**Selina Roman-White** – 1 year  
Energy/environment  
BS Chem. Engr.

**Junior-level LCA** – 2 years  
Energy/environment  
MS Civil/Env Engr | BS Env Engr
**CO₂ Utilization at DOE Fossil Energy (FE)**

- **What is CO₂ Utilization?**
- **FE and NETL Context**

EOR is a FE/NETL supported area, but is NOT considered under the Carbon Use/Reuse Program.
Offset CO₂ capture costs, fix CO₂ in stable products, and produce services/products that reduce the release of greenhouse gas emissions to the atmosphere.

U.S. DOE FE: Carbon Use & Reuse Drivers

Biological Capture & Conversion

Fuels & Chemicals

Mineralization & Cements
What is Unique about CO₂ Utilization LCA?

• Technically...Nothing.

• Every LCA depends on the goal of the study
  “What question do you want to answer?”
  “Why are you performing the LCA?”
Question: When commercially deployed, will the CO₂U product, or derived product, result in lower greenhouse gas emissions on a life cycle basis than the state-of-the-art alternative in the market that provides the equivalent service or function to society?

Metric: Percent difference in life cycle GHG emissions on a carbon dioxide equivalent basis; IPCC, AR-5, 100-year time period.

Scope
• Geographical Representation: United States (for deployment, LCA is global)
• Temporal Representation: Year of Market Entry + Product Service Life
• Scale of Market: Product or Facility/Operation
• U.S. DOE Office of Fossil Energy Sponsored Workshop

• 40 Participants
  • LCA Subject Matter Experts (North America and Europe)
  • CO₂U Project Leads and Engineers (Industry and Academia)

• Goal: Develop consensus based LCA Guidance for DOE CO₂U Projects

• Outcome: Revised Draft LCA Guidance Document for evaluating CO₂ utilization concepts – Spring 2018
CO₂ Utilization LCA Challenges

• Emerging technologies have limited performance data, commercial performance often estimated based on research/project goals.

• Complex functional units and highly integrated system boundaries challenge results interpretation for a single product of interest.

• What is the “correct” business as usual case for comparison? Average or state-of-the-art performance? Today or 10-years in the future when deployed in the market?

• Will the product actually displace a more GHG intensive product from being produced? Or, simply be additive?

• Attributional vs. Consequential LCA - will the product have an effect on it’s primary market or secondary markets?
A Life Cycle Analysis Perspective of CO₂ Enhanced Oil Recovery
Life Cycle Emissions for Traditional CO2-EOR Compared to rest of U.S. crude mix

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>2005</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Prod and Transport</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(kg CO2e/bbl)</td>
<td>77.4</td>
<td>60.2</td>
<td></td>
</tr>
<tr>
<td>Crude Prod and Transport</td>
<td></td>
<td>13.0</td>
<td>10.3</td>
</tr>
<tr>
<td>(g CO2e/MJ gas)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well to Wheel</td>
<td></td>
<td>98.1</td>
<td>96.2</td>
</tr>
<tr>
<td>(g CO2e/MJ gas)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Life Cycle of Gasoline from CO₂-EOR Crude

- **Power Plant Fuel & Transport**: 206 kg coal
- **Power Plant Captured CO₂**: 440 kg CO₂, 0.54 MWh
- **Displaced Electricity**: 0 kg, 1.1 bbl crude, 0 kg CO₂, 0 kg C

Some of the injected CO₂ goes toward producing NGLs.

**EOR Crude Extraction**: 846 kg CO₂, 149 kg C

- **EOR Crude Transport**: 1.1 bbl crude, 123 kg C
- **Gasoline Refining**: 1.1 bbl crude, 1 bbl gasoline
- **Gasoline Transport**: 1 bbl gasoline
- **Gasoline Combustion**: 1 bbl gasoline

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

Life Cycle of Gasoline from CO₂-EOR Crude

Scenario shown is for 2 bbl crude per tonne CO₂ recovery ratio and a 550-MW supercritical pulverized coal power plant with 90% CO₂ capture.
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
- **Displaced Electricity**: 0.09 kg CO₂
- **CO₂ Pipeline Transport**: 0.09 kg CO₂
- **EOR Crude Extraction**: 0.09 kg CO₂
- **EOR Crude Transport**: 0.03 bbl crude
- **Gasoline Refining**: 1 MJ gasoline
- **Gasoline Transport**: 1 MJ gasoline
- **Gasoline Combustion**: 1 MJ gasoline

**Global Warming Potential (g CO₂e/MJ combusted gasoline)**
- **Dome**
- **SCPC**

**CO₂ intensity of upstream CO₂**
CO₂ Intensity of Upstream CO₂
Grid displacement impacts (power examples, same concept for industrial source)

- Fuel Upstream
- CO₂ Source
- CO₂ Pipeline
- Power Displacement

2014 Grid Mix
(566 g CO₂e/kWh)

Fleet Coal
(1,041 g CO₂e/kWh)

- Dome
- SCPC
- SCPC/30% Biomass
- NGCC

- CO₂ Intensity of Upstream CO₂ (kg CO₂e/kg CO₂)
EOR for GHG Reduction: Achievable low-carbon fuel targets are dependent on the intersection of CO₂ source GHG intensity & crude recovery efficiency.
An LCA framework allows for in-depth examination of the system where captured CO₂ from fossil power is paired with EOR/ROZ.

Key considerations are the carbon intensity of the power that is displaced by the new plant equipped with carbon capture and the willingness of the crude producer to behave like a sequestration site.

EOR for GHG Reduction: Achievable low-carbon fuel targets are dependent on the intersection of CO₂ source GHG intensity & crude recovery efficiency.
CO₂ Utilization LCA Challenges

How do they apply to CO₂-EOR?

- Emerging technologies have limited performance data, commercial performance often estimated based on research/project goals.

- Complex functional units and highly integrated system boundaries challenge results interpretation for a single product of interest.

- What is the “correct” business-as-usual case for comparison? Average or state-of-the-art performance? Today or 10-years in the future when deployed in the market?

- Will the product actually displace a more GHG intensive product from being produced? Or, simply be additive?

- Attributional vs. Consequential LCA – will the product have an effect on its primary market or secondary markets?
Emerging technologies have limited performance data, commercial performance often estimated based on research/project goals.

EOR using anthropogenic CO₂ is relatively new, residual oil zone applications are novel – performance data limited.

Complex functional units and highly integrated system boundaries challenge results interpretation for a single product of interest.

What is the “correct” business as usual case for comparison? Average or state-of-the-art performance? Today or 10-years in the future when deployed in the market?

Will the product actually displace a more GHG intensive product from being produced? Or, simply be additive?

Attributional vs. Consequential LCA – will the product have an effect on it’s primary market or secondary markets?
CO₂-EOR Performance Data

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

• EOR Industry Average Performance*
  - 2.2 barrels/tonne CO₂ sequestered

• Residual Oil Zone (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)


CO₂ Utilization LCA Challenges

How do they apply to CO₂-EOR?

• Emerging technologies have limited performance data, commercial performance often estimated based on research/project goals.

  EOR using anthropogenic CO₂ is relatively new, residual oil zone applications are novel – performance data limited.

• Complex functional units and highly integrated system boundaries challenge results interpretation for a single product of interest.

  Mixed product functional unit is more accurate for comparison but less practical for decision making – tradeoffs.

• What is the “correct” business as usual case for comparison? Average or state-of-the-art performance? Today or 10-years in the future when deployed in the market?

• Will the product actually displace a more GHG intensive product from being produced? Or, simply be additive?

• Attributional vs. Consequential LCA - will the product have an effect on it’s primary market or secondary markets?
CO₂-EOR is a Complex System to Model
Multiple products from a single interconnected system

Possible products from this system:
- Electricity
- Crude oil
- Refined fuel
- Captured CO₂
- Some combination of the above
CO₂-EOR is a Complex System to Model

If fuel is the product of interest, need to displace the electricity co-product

- Assume that demand for electricity is relatively inelastic w.r.t. changes in supply
- Could displace anything from wind at 15 g CO₂e/kWh to retiring coal at 1,300 g CO₂e/kWh
- Narrowing the range of this displacement credit requires careful thought about the long-run marginal change to the grid induced by new power generation, and testing of the range’s impact on conclusions being made in the study
Net Carbon Negative Oil LCA Study

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
CO₂ Utilization LCA Challenges

How do they apply to CO₂-EOR?

• Emerging technologies have limited performance data, commercial performance often estimated based on research/project goals.
  
  EOR using anthropogenic CO₂ is relatively new, residual oil zone applications are novel – performance data limited.

• Complex functional units and highly integrated system boundaries challenge results interpretation for a single product of interest.
  
  Mixed product functional unit is more accurate for comparison but less practical for decision making – tradeoffs.

• What is the “correct” business as usual case for comparison? Average or state-of-the-art performance? Today or 10-years in the future when deployed in the market?
  
  Comparison to the 2005 Petroleum Baseline, average fuels consumed today, future crude oil supply mix in 2040?

• Will the product actually displace a more GHG intensive product from being produced? Or, simply be additive?

• Attributional vs. Consequential LCA – will the product have an effect on its primary market or secondary markets?
Petroleum Baseline is a Snapshot in Time
Changing market dynamics and operations will shift baseline over time

What is the state of the art system for comparison?

Maximum percent changes from the 2014 WTW gasoline result are +2.1% and -1.4%
CO₂ Utilization LCA Challenges
How do they apply to CO₂-EOR?

• **Emerging technologies have limited performance data, commercial performance often estimated based on research/project goals.**
  EOR using anthropogenic CO₂ is relatively new, residual oil zone applications are novel – performance data limited.

• **Complex functional units and highly integrated system boundaries challenge results interpretation for a single product of interest.**
  Mixed product functional unit is more accurate for comparison but less practical for decision making – tradeoffs.

• **What is the “correct” business as usual case for comparison? Average or state-of-the-art performance? Today or 10-years in the future when deployed in the market?**
  Comparison to the 2005 Petroleum Baseline, average fuels consumed today, future crude oil supply mix in 2040?

• **Will the product actually displace a more GHG intensive product from being produced? Or, simply be additive?**
  What are the market consequences of producing another barrel of crude oil from CO2-EOR? 30% of the market?

• **Attributional vs. Consequential LCA - will the product have an effect on it’s primary market or secondary markets?**
**CO₂-EOR Crude Displacement**

Does displacement occur? What crude source is actually displaced?

- Graph shows GWP of CO₂-EOR through combustion taking into account possible credits for replacing crudes from different sources
- EOR crude recovery ratio is 2.2 bbls/tonne
- Plant is SCPC w/ 90% capture
CO₂-EOR Crude Displacement

Market scale affects consequences of displacement in addition to source displaced.

- Modeling specific life cycle scenarios is relatively straightforward.
- Understanding net system effects as new production displaces existing production is more complicated.
**CO₂ Utilization LCA Challenges**

How do they apply to CO₂-EOR?

- **Emerging technologies** have limited performance data, commercial performance often estimated based on research/project goals.
  
  EOR using anthropogenic CO₂ is relatively new, residual oil zone applications are novel – performance data limited.

- **Complex functional units and highly integrated system boundaries** challenge results interpretation for a single product of interest.
  
  Mixed product functional unit is more accurate for comparison but less practical for decision making – tradeoffs.

- **What is the “correct” business as usual case for comparison?** Average or state-of-the-art performance? Today or 10-years in the future when deployed in the market?
  
  Comparison to the 2005 Petroleum Baseline, average fuels consumed today, future crude oil supply mix in 2040?

- **Will the product actually displace a more GHG intensive product from being produced?** Or, simply be additive?
  
  What are the market consequences of producing another barrel of crude oil from CO₂-EOR? 30% of the market?

- **Attributional vs. Consequential LCA – will the product have an effect on its primary market or secondary markets?**
## Attributional vs Consequential LCA

### Conceptual Framework

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Attributional</th>
<th>Consequential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulatory compliance,</td>
<td>How to comply with regulations and corporate</td>
<td>Policy implications</td>
</tr>
<tr>
<td>Corporate footprint</td>
<td>footprint</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Goal</th>
<th>What are the environmental burdens of a particular product?</th>
<th>How does a new system change the world around it?</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Functional unit</th>
<th>Single product</th>
<th>Multiple products (within a defined world)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Boundaries</th>
<th>Truncated (to isolate burdens of a single product)</th>
<th>Expanded (to include indirect effects)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Uncertainty</th>
<th>Methods for isolating a single product can arbitrarily shift burdens between systems</th>
<th>Extent to which system alters the world around it</th>
</tr>
</thead>
</table>

Both types of analyses – attributional and consequential – are valid LCA approaches; context of a study must be known before determining which one is appropriate.
Attributional vs Consequential LCA
How does a supply chain affect surrounding systems?

Surrounding systems
• Competing products
• Other markets

Uncertainties
• Changes over time
• Scalability
• Producer/consumer behavior

Examples
• Ethanol (food for fuel)
• LNG exports (global energy market)
• EOR (global crude market) – maybe?

Consequential LCA attempts to consider the broader effect(s) of supply chain changes.
Attributional vs Consequential LCA

Where could a consequential LCA approach apply to a CO₂-EOR system?

• How does the displacement credit for electricity change over time as the grid decarbonizes?

• Are natural sources of CO₂ still being utilized after captured fossil sources emerge?

• Does EOR crude/fuel production displace other sources of even as world demand for continues to increase?
Emerging technologies have limited performance data, commercial performance often estimated based on research/project goals.

EOR using anthropogenic CO₂ is relatively new, residual oil zone applications are novel – performance data limited.

Complex functional units and highly integrated system boundaries challenge results interpretation for a single product of interest.

Mixed product functional unit is more accurate for comparison but less practical for decision making – tradeoffs.

What is the “correct” business as usual case for comparison? Average or state-of-the-art performance? Today or 10-years in the future when deployed in the market?

Comparison to the 2005 Petroleum Baseline, average fuels consumed today, future crude oil supply mix in 2040?

Will the product actually displace a more GHG intensive product from being produced? Or, simply be additive?

What are the market consequences of producing another barrel of crude oil from CO₂-EOR? 30% of the market?

Attributional vs. Consequential LCA – will the product have an effect on it’s primary market or secondary markets?
LCA - More Complete Picture, More Uncertainty
Timothy J. Skone, P.E.
Senior Environmental Engineer
Strategic Energy Analysis
(412) 386-4495 • timothy.skone@netl.doe.gov

netl.doe.gov/LCA
LCA@netl.doe.gov
@NETL_News
Cooney, G.; Littlefield, J.; Marriott, J.; & Skone, T. J.
• CO₂-EOR is a GHG-intensive way of extracting crude compared to conventional extraction methods
• Linking EOR with anthropogenic CO₂ yields a benefit due to the displacement of uncaptured electricity

Cooney, G., Jamieson, M., Marriott, J., Bergerson, J., Brandt, A., Skone, T.
• 98.1 vs. 96.2 g CO₂e/MJ gasoline (-2%) for 2005 to 2014
• Changing baseline values lead to potential compliance challenges with frameworks such as the EISA Section 526

Ongoing Work
• Adding CO₂ capture to refineries
• Full environmental inventory for the Petroleum Baseline
• Using field EOR data to inform models
• Inclusion of biofuels in U.S. transportation consumption

Collaborators
UNIVERSITY OF CALGARY
**Recent Natural gas-related LCA Work**

Synthesis of recent ground-level methane emission measurements from the US natural gas supply chain (2017)
Littlefield, J.; Marriott, J.; Schivley, G.; Skone, T. J.

- **Overall Result:** 1.7% CH₄ emission rate across the NG life cycle
- **Emission reduction opportunities:** Pneumatic devices - widespread use in production and gathering stages; Unassigned” emissions (observed, but not fully understood); Gathering Systems (new to emissions inventories, but highly aggregated)

Littlefield, J.; Marriott, J.; Schivley, G.; Cooney, G.; Skone, T. J.

- **Emphasizes the importance of boundary selection when expressing CH₄ emission rates and comparing NG to other energy sources**
- **Includes use of technology warming potential as a method for comparing cumulative radiative forcing**

**Ongoing Work**

- Creating a 2016 baseline for natural gas produced in the U.S.
- Collaboration with ONE Future
- Improved uncertainty characterization

**Collaborators**

U.S. DEPARTMENT OF ENERGY
Recent Coal-related LCA Work

Schivley, G.; Ingwersen, W.; Marriott, J.; Hawkins, T.; Skone, T. J.
- Upgrading boiler & environmental controls reduces all impacts
- Intensive biomass (hybrid poplar) can increase some impacts
- Modeling decisions (growth before or after burning) makes a difference for climate impacts when accounting for emission timing

Understanding the Contribution of Mining and Transportation to the Total Life Cycle Impacts of Coal Exported from the United States (2016)
Mutchek, M.; Cooney, G.; Pickenpaugh, G.; Marriott, J.; Skone, T. J.
- Emissions from coal mining activities are more significant in Australia and Indonesia than PRB
- PRB disadvantages: longer transport distance, lower heating value
- Non-GWP impact categories are driven by emissions from diesel combustion (transport and mining) and affected by differences in diesel regulations between exporting countries

Ongoing Work
• Creating a regionalized 2017 baseline for coal produced in the U.S.
• Options for energy in the North Slope of Alaska
• Updated advanced power plant design LCAs

Collaborators


CO₂U LCA Guidance Document Themes

• “80-20” Rule: Guidance should work for 80% of the cases but be flexible enough to accommodate the 20% that don’t fit perfectly

• Reduce the LCA effort while increasing consistency and comparability

• Transparency, Reproducibility, and Un-biased: Clear Justification and Documentation

• LCA Knowledge Level: Novice to Expert

• Primary Audience: FOA Principle Investigators

• Secondary Audience: Anyone performing a CO₂U Project LCA
Overall Result: 1.7% CH$_4$ life cycle emission rate

Aside from total emission rates, results point to top emission reduction and research opportunities
• There are scenarios where CH₄ emission rates greater than 5% are likely
• But the national average is lower (1.6% based on NETL’s 2016 report)

Source: NETL (2016) Life Cycle Analysis of Natural Gas Extraction and Power Generation
Inventory perspective

- Synthesis result, U.S. annualized: 0.29 g CH₄/MJ → 7,349 Gg CH₄/yr
- EPA 2016 Greenhouse Gas Inventory (GHGI) result for 2012 (after removing condensate tanks) is 6,716 Gg CH₄/yr
- Synthesis result is 9% higher than GHGI because
  - Different data sources are used for production emission sources
  - Synthesis includes unassigned emissions

Life cycle CO₂e perspective

- Includes CO₂ and N₂O in addition to CH₄
- 2013 Global Warming Potentials (GWP)
- 13.8 g CO₂e/MJ (100-yr GWP) and 28.6 g CO₂e/MJ (20-yr GWP)
Conclusions and Recommendations

- **Emission reduction opportunities**
  - Pneumatic devices – widespread use in production and gathering stages
  - “Unassigned” emissions (observed, but not fully understood)
  - Gathering Systems (new to emissions inventories, but highly aggregated)

- **Research opportunities**
  - Improve activity data on pneumatic devices throughout supply chain
  - Identify drivers and regional variability for unassigned emissions
  - Disaggregate gathering emissions at the category level to individual system components