Developing an Approach for the Life Cycle Analysis of Conventional Petroleum Fuels: Outlook to 2040 – Crude Extraction and Transport

Greg Cooney
Booz Allen Hamilton
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NETL Petroleum LCA published in 2008 set the baseline for fuel consumed in the U.S.

- **Published in 2008; representative of year 2005**
- **Policy Applications**
  - Energy Independence and Security Act Section 526
  - Renewable Fuels Standards
- **Data:**
  - Crude extraction profiles based on PE International data
  - Refining impacts based on EIA data; allocation at unit process level
- **Well-to-Tank: 16.3 – 20.4% of total LC emissions**

![Life Cycle GHG Emissions Chart](chart.png)
Crude extraction and refining have changed significantly since the 2008 NETL Baseline

- Known changes to crude oil mix (source, extraction method, and quality)
- Transition to ultra low sulfur diesel, increasing refinery hydrogen demand
- Research Goals:
  - Establish an updated baseline
  - Evaluate to understand uncertainty in long-term comparisons of alternative fuels projects to the petroleum baseline
  - Utilize a transparent and flexible modeling approach

Domestic crude production increases due to the tight oil boom; imports decline

- U.S. domestic share peaks at 62% in 2016
- Daily crude consumption is flat throughout
- Canadian imports increase (shift towards oil sands); all other imports drop off

- Tight oil accounts for 50% of U.S. domestic production by 2015
- EOR share of production doubles over the forecast period
Modeling Environmental Impacts: Cradle-to-Gate Crude Extraction Tools

- **OPGEE**
  Primary, secondary, tertiary extraction (steam)

- **GHOST**
  Canadian Oil Sands (surface mining and in situ extraction)

- **NETL CO₂-EOR**
  Enhanced oil recovery using injected CO₂
Modeling Environmental Impacts: Cradle-to-Gate Crude Extraction Tools

- **OPGEE - Oil Production Greenhouse Gas Emissions Estimator**
  - Used to model U.S. (non-EOR) and international production (except CA Oil Sands)
  - Engineering based model that accounts for seven main stages of operation:
  - Key parameters:
    - Water-Oil Ratio (WOR)
    - Flaring Rate
    - API
    - Steam-Oil Ratio (SOR)
    - Gas-Oil Ratio (GOR)
    - Depth
    - Production Rate

Modeling Environmental Impacts: Cradle-to-Gate Crude Extraction Tools

- **GHOST** – GreenHouse gas emissions of current Oil Sands Technologies
  - Process-based model
  - Based on information from technical experts and confidential operating data collected from the industry
  - Model includes three primary bitumen recovery and extraction technologies (SAGD, surface mining, and CSS) and two upgrading technologies (delayed coking and hydrocracking)
  - Key parameters:
    - Extraction method
    - Steam-Oil Ratio (SOR)
    - Product type – Dilbit, Synbit, Syncrude
    - Flare/vent rate
    - Cogen/no cogen
Modeling Environmental Impacts: Cradle-to-Gate Crude Extraction Tools

- **NETL CO₂ – Enhanced Oil Recovery Model**
  - Injection of CO₂ to improve the recoverability of crude oil by reducing viscosity, swelling crude oil, and lowering interfacial tension
  - Based on reservoir and fluid calculations from DOE PROPHET model
  - WAG (water-alternating gas) injection scheme
  - Options for surface gas processing: refrigeration/fractionation, Ryan-Holmes, membrane
  - Does not include the impacts for the source of the carbon dioxide (this analysis assumes the source is a natural dome)
  - Key parameters:
    - Injection pressure
    - Formation leakage
    - Crude recovery (bbl/tonne CO₂ sequestered)

NETL CO₂-EOR
Enhanced oil recovery using injected CO₂
Tuning the model parameters is key to representing the desired areas/methods of extraction

• **Nehring database (proprietary)**
  – Select information on significant reservoirs in the US
  – Depth, API, GOR, initial pressure, annual oil & gas production, and secondary/tertiary recovery methods
  – Over 7,000 entries representing 76% of all U.S. crude production in 2007

• **ARI database (proprietary)**
  – WOR, reservoir pressure decline

• **North Dakota Oil and Gas Division for Bakken Shale**
  – Flare rate, GOR, WOR, production, EUR

• **NETL models and Oil and Gas Journal for CO₂-EOR**
  – Permian Basin
  – Injection pressure, crude recovery ratio
  – NGL recovery methods
U.S. Crude Extraction GHG Results

Modeling Notes:
- Diamond – production weighted average
- Any necessary water treatment prior to disposal or reinjection takes place near the production well
- Large databases (Nehring and ARI) allowed us to come up with national production weighted parameter values for crude extraction
- Mass allocation (crude and natural gas)
- Limited field/well level data for Tight Oil and EOR
U.S. Crude Extraction GHG Results

Crude Extraction GHG Emissions (kg CO₂e/bbl)

100-yr AR-5 GWP

Gas Injection | Water Injection | Steam Injection | U.S. Weighted Average | Other Onshore | Alaska | Offshore | Tight Oil | EOR

34.2 | 14.7 | 70.4 | 25.3 | 8.9 | 15.2

Water Treatment | Venting and Flaring | Stabilizer Column | Downhole Pump | Frac Water Delivery | Drilling and Development | Total

37.2

128.2
Characterizing foreign crude is much more difficult because of a lack of transparent data

- Limited information available for the key parameters for foreign crude extraction
- Apply data used previously in other studies, where available for parameters like API, depth, GOR, reservoir pressure\(^1,2\)
- Use U.S. average extraction as defaults for countries where no other data is available
- Focus on venting/flaring fraction, which has been shown to be a large differentiator in extraction emissions between foreign crudes

Flaring and venting data for international crude production are sparse and inconsistent

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Method</th>
<th>Geographic Coverage</th>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOAA(^1)</td>
<td>Satellite Data</td>
<td>Worldwide (individual country level)</td>
<td>Geographic coverage; independent analysis</td>
<td>No information on vented fraction</td>
</tr>
<tr>
<td>OPEC(^2)</td>
<td>Reported data from member countries</td>
<td>Limited to OPEC countries (Algeria, Angola, Ecuador, Iraq, Kuwait, Nigeria, Saudi Arabia, Venezuela)</td>
<td>Only source to report country-specific data</td>
<td>Geographic coverage; no information on vented fraction</td>
</tr>
<tr>
<td>OGP(^3)</td>
<td>Reported data from member companies operating around the world</td>
<td>Continental/Regional (North America, South America, Europe, Africa, Middle East, Former Soviet Union, Asia/Australia)</td>
<td>Only source that reports vented data in addition to flared gas</td>
<td>Accounts for only 32% of worldwide production; regional representativeness is uneven (Europe 100%; FSU 9%)</td>
</tr>
</tbody>
</table>

Sources provide a reasonable match on the amount of gas...
Sources provide a reasonable match on the amount of gas, but compositions drive GWP.
Sources provide a reasonable match on the amount of gas, but compositions drive GWP

- Composition differences are based on assumptions required to estimate the fraction of vented and fugitive emissions data for the NOAA and OPEC sources
- Default assumption is 10% of flared volume is vented and 0.2% is fugitives\(^1\)
- OGP data source provides vented and fugitive compositions by GHG; primarily \(\text{CO}_2\)

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Cradle-to-Gate comparison of extracted and delivered crudes consumed in the U.S.

Crude Extraction GHG Emissions (kg CO₂e/bbl)  
100-yr AR-5 GWP

- Extraction
- Venting and Flaring
- Transport

U.S. - EOR: 131.6 kg CO₂e/bbl
Canadian Oil Sands: 82.7 kg CO₂e/bbl
Nigeria: 66.3 kg CO₂e/bbl
Iraq: 63.2 kg CO₂e/bbl
Angola: 50.2 kg CO₂e/bbl
U.S. - Tight: 40.6 kg CO₂e/bbl
Ecuador: 36.1 kg CO₂e/bbl
Venezuela: 35.8 kg CO₂e/bbl
Algeria: 32.4 kg CO₂e/bbl
Russia: 31.9 kg CO₂e/bbl
Kuwait: 30.1 kg CO₂e/bbl
U.S. - Other Onshore: 28.7 kg CO₂e/bbl
Brazil: 27.8 kg CO₂e/bbl
Colombia: 26.8 kg CO₂e/bbl
Saudi Arabia: 25.5 kg CO₂e/bbl
Mexico: 24.7 kg CO₂e/bbl
Canada: 23.1 kg CO₂e/bbl
U.S. - Offshore: 18.6 kg CO₂e/bbl
U.S. - Alaska: 12.3 kg CO₂e/bbl
Projected U.S. crude mix has increased GHG emissions as unconventional sources develop

- GHG intensity of extraction increases over time as more shale oil, EOR crude, and Canadian oil sands become part of the mix
- EOR share of production doubles over the forecast period (GHG-intensive)
- Behavior in 2012-2013 timeframe is due to a drop in Nigerian crude (high CH₄) and then an increase in tight and oil sands production

- As crude oil imports decrease, GHG emissions from crude transport decrease
- Majority of imports come from Canada
- As domestic production drops off after peak in 2020, imports from other countries increase, changing the direction of the plot
Next Steps

• Model finished product refining utilizing PRELIM model
  – Crudes quality is highly variable (API, sulfur, etc.)
  – Sensitive to more crude characteristics (e.g. cut points)
  – Multiple configurations

• Update transport assumptions

• Updated NETL Petro Baseline Report

• Analysis of crude changes out to 2040
  – Consider how to appropriately model uncertainty related to technology and quality changes
Contact Us

Timothy J. Skone, P.E.
Senior Environmental Engineer • Strategic Energy Analysis and Planning Division • (412) 386-4495 • timothy.skone@netl.doe.gov

Joe Marriott, Ph.D.
Lead Associate • Booz Allen Hamilton • (412) 386-7557 • joseph.marriott@contr.netl.doe.gov

Greg Cooney
Associate • Booz Allen Hamilton • (412) 386-7555 • gregory.cooney@contr.netl.doe.gov

netl.doe.gov/lca/  LCA@netl.doe.gov  @NETL_News