Approaches to Developing a Cradle-to-Grave Life Cycle Analysis of Conventional Petroleum Fuels Produced in the U.S. with an Outlook to 2040

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October 6, 2015
Original NETL Petroleum LCA published in 2008; crude extraction and refining have changed significantly since

- **Published in 2008; representative of year 2005**
- **Policy Applications**
  - Energy Independence and Security Act Section 526
  - Renewable Fuels Standards
- **Known changes to crude oil mix**
- **Transition to ultra low sulfur diesel, increasing refinery hydrogen demand**
- **Research Goals:**
  - Establish an updated baseline (2014)
  - Evaluate to understand uncertainty in long-term comparisons of alternative fuels projects to the petroleum baseline
  - Utilize a transparent and flexible modeling approach
Evaluate data at the PADD level to highlight key drivers and differences in the WTT and WTW results

**Research Questions:** How do the upstream crude extraction and refining GHG emissions for finished fuels produced in the U.S. vary between PADDs? How do the PADDs compare to a national average? How does a buildup of the PADDs to create a national average compare to a national average set of inputs?
Open source tools are key to modeling transparency for crude extraction and refining

**OPGEE**\(^1\)
Primary, secondary, tertiary extraction (steam)

**GHOST**\(^2\)
Canadian Oil Sands (surface mining and in situ extraction)

**NETL CO\(_2\)-EOR**\(^3\)
Enhanced oil recovery using injected CO\(_2\)

**PRELIM**\(^4\)
Crude Oil Refining

**Sources:**
Modeling the U.S. consumption requires data for 12 foreign countries as well as operations in the U.S.

- Angola
- Brazil
- Canada
- Colombia
- Ecuador
- Iraq
- Kuwait
- Mexico
- Nigeria
- Russia
- Saudi Arabia
- Venezuela
- U.S.

<table>
<thead>
<tr>
<th>% of U.S. Mix</th>
<th>PADD 1</th>
<th>PADD 2</th>
<th>PADD 3</th>
<th>PADD 4</th>
<th>PADD 5</th>
<th>U.S. Mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S. Mix</td>
<td>6.7</td>
<td>21.8</td>
<td>51.9</td>
<td>3.6</td>
<td>15.9</td>
<td></td>
</tr>
</tbody>
</table>

Legend:
- Alaska
- California
- North Dakota
- GOM Offshore
- Texas
- Remainder

- U.S. Production
Populating upstream crude extraction parameters in OPGEE requires a variety of data sources

**U.S. Domestic Production**

- **Nehring database**
  - Select information on significant reservoirs in the US
  - Depth, API, GOR, initial pressure, and production methods
  - Over 7,000 entries representing 76% of all U.S. crude production in 2007

- **DI Desktop**
  - GOR and WOR
  - State-level production data for individual wells
  - 74% of 2014 production; approximately 300,000 wells

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

**International Production**

- **International Association of Oil and Gas Producers (IOGP)**
  - Venting and flaring rates
  - % of international production

- **Oil-Climate Index (OCI)**
  - Foreign crude parameters modeled in OPGEE
  - Foreign countries utilized: Angola, Brazil, Canada, Iraq, Kuwait, Nigeria, Russia, Venezuela

- **International Council on Clean Transportation (ICCT)**
  - Foreign crudes not included in OCI version 1 (e.g. Saudi Arabia, Mexico)
Wide range of results for extracted crude for the regions considered; process contributions differ by field/country.
Combination of EIA data sources utilized to map imports and domestic production to available crude assays

- Origin Country
- Processing PADD
- Volume
- Quality (API/S)

Import Consumption Quality and Volume by PADD

- Volume
- Quality

Domestic Consumption Quality by PADD

- State
- PADD
- Volume

Domestic Consumption Mix by PADD (Volume)

- Source
- Destination
- Volume
- Mode

Crude Slate by PADD
Blending of limited publicly available assays still yields a good approximation for U.S. crude consumption quality

<table>
<thead>
<tr>
<th>Country</th>
<th>Assay Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angola</td>
<td>4</td>
</tr>
<tr>
<td>Brazil</td>
<td>3</td>
</tr>
<tr>
<td>Canada</td>
<td>21</td>
</tr>
<tr>
<td>Colombia</td>
<td>1</td>
</tr>
<tr>
<td>Ecuador</td>
<td>1</td>
</tr>
<tr>
<td>Iraq</td>
<td>1</td>
</tr>
<tr>
<td>Kuwait</td>
<td>3</td>
</tr>
<tr>
<td>Mexico</td>
<td>2</td>
</tr>
<tr>
<td>Nigeria</td>
<td>8</td>
</tr>
<tr>
<td>Russia</td>
<td>1</td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>3</td>
</tr>
<tr>
<td>Venezuela</td>
<td>2</td>
</tr>
<tr>
<td>U.S.</td>
<td>12</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Region</th>
<th>API EIA</th>
<th>Modeled</th>
<th>Delta</th>
<th>Sulfur EIA</th>
<th>Modeled</th>
<th>Delta</th>
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</thead>
<tbody>
<tr>
<td>PADD1</td>
<td>34.3</td>
<td>33.3</td>
<td>-2.9%</td>
<td>0.86</td>
<td>0.84</td>
<td>-2.9%</td>
</tr>
<tr>
<td>PADD2</td>
<td>32.9</td>
<td>30.2</td>
<td>-8.4%</td>
<td>1.47</td>
<td>1.34</td>
<td>-8.6%</td>
</tr>
<tr>
<td>PADD3</td>
<td>31.1</td>
<td>30.8</td>
<td>-1.1%</td>
<td>1.54</td>
<td>1.32</td>
<td>-14.6%</td>
</tr>
<tr>
<td>PADD4</td>
<td>33.7</td>
<td>30.2</td>
<td>-10.5%</td>
<td>1.33</td>
<td>1.32</td>
<td>-0.5%</td>
</tr>
<tr>
<td>PADD5</td>
<td>28.4</td>
<td>28.2</td>
<td>-1.0%</td>
<td>1.41</td>
<td>1.05</td>
<td>-25.9%</td>
</tr>
<tr>
<td>US</td>
<td>31.4</td>
<td>30.7</td>
<td>-2.3%</td>
<td>1.45</td>
<td>1.28</td>
<td>-11.5%</td>
</tr>
</tbody>
</table>
Map EIA refinery operating data to the various configurations available for modeling in PRELIM

2015 Refinery Capacity Report

<table>
<thead>
<tr>
<th>PADD</th>
<th>Hydro - skimming</th>
<th>Medium Conversion</th>
<th>Deep Conversion - Coker</th>
<th>Deep Conv - Resid HC</th>
<th>Wtd. Complex Index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>FCC</td>
<td>GO HC</td>
<td>Both</td>
<td>FCC</td>
</tr>
<tr>
<td>1</td>
<td>5.8%</td>
<td>66.8%</td>
<td></td>
<td></td>
<td>12.8%</td>
</tr>
<tr>
<td>2</td>
<td>10.7%</td>
<td>17.0%</td>
<td>1.8%</td>
<td></td>
<td>46.9%</td>
</tr>
<tr>
<td>3</td>
<td>5.1%</td>
<td>7.9%</td>
<td>1.3%</td>
<td>2.7%</td>
<td>45.0%</td>
</tr>
<tr>
<td>4</td>
<td>26.6%</td>
<td>17.6%</td>
<td></td>
<td></td>
<td>55.7%</td>
</tr>
<tr>
<td>5</td>
<td>7.9%</td>
<td>9.6%</td>
<td>5.6%</td>
<td>8.6%</td>
<td>37.4%</td>
</tr>
<tr>
<td>Total</td>
<td>7.6%</td>
<td>14.6%</td>
<td>1.6%</td>
<td>3.1%</td>
<td>42.4%</td>
</tr>
</tbody>
</table>
Slight variations between PADDs on WTW and WTT basis; crude extraction 70% higher than 2005 baseline

**Well-to-Wheels**

- Extraction
- Crude Transport
- Refining

**Well-to-Tank**

- Product Transport
- Combustion
Selected References


