Life Cycle Well to Wheels Assessment of GHG Emissions from North American and Imported Crude Oils

Ian Moore – Jacobs Consultancy

Workshop Comparing Approaches to Life Cycle Analysis of Crude Oil
Centre for European Policy Studies
Brussels
March 21, 2011
• GHG regulations will impact crude choice for producing transportation fuels

• Crudes are different

• GHG associated with crude production depends on reservoir and production methods

• GHG from refining depends on crude properties and refining intensity
Agenda

• 2009 AERI Study
  – Background and project objectives
  – Methodology
  – Life Cycle analysis
    • Crude production
    • Upgrading and refining
    • Life Cycle well-to-wheels fuel cycle
  – Observations

• New developments
  – Changes in worldwide flaring
  – Advancements in bitumen production technology
  – EU crude oil pathway LCA
• Sponsor: Alberta Energy Research Institute – now called Alberta Innovates Energy and Environment Solutions (AI-EES) (part of the Government of Alberta, Canada)
• Steering team
  – Industry
  – Academia
  – Government
• Develop a robust life cycle analysis comparison of oil sands versus conventional crudes processed in US
• Address limitations in prior life cycle work by using subject matter expertise and sound technical / engineering approach
• Vet results publicly
Well-to-Wheels Life Cycle Assessment

WTW Life Cycle Emissions = WTT + TTW

Definitions
- Well-to-Wheels (WTW)
- Well-to-Tank (WTT)
- Tank-to-Wheels (TTW)
Limitations of Some Prior Life Cycle Analyses

- Incomplete and out-dated information
- Simplified, generic model representations
- Incomplete well-to-wheels analysis
- Excessive aggregation
  - No differentiation on crude properties
  - No differentiation on refinery configuration
- Inconsistent boundary conditions

Prior Life Cycle Analyses of Oil Sands vs. Conventional Crude

Prior work shows 14-41% higher WTW emissions for oil sands vs. “conventional” oil

Crudes and refineries are not created equal
Study emphasis is on areas significantly affected by crude source, type and quality

Source: CARB – Detailed California-Modified GREET Pathway for Ultra Low Sulfur Diesel (ULSD) from Average Crude Refined in California, January 2009

Focus of Our Work

GHG Contributions from Well-to-Wheels Life Cycle Analysis

Crude Production 8%
Crude Transport 1%
Crude Refining 13%
Product Transport < 0.5%

Tank to Wheel 78%

Focus of Our Work
Study Focus – Enhance Life Cycle Modeling with Crude Specific Estimates of Energy / GHG Emissions

Incorporate results from rigorous engineering analysis into GREET*
Use ISO 14040 Methodology

Crude & Bitumen Production
- Specific crudes evaluated
- Public & Jacobs data
- Rigorous modeling

Upgrading and Refining
- Reflect crude and product variations
- Jacobs experience
- Rigorous modeling

*GREET: Greenhouse gases, Regulated Emissions, and Energy use in Transportation
Crude & Bitumen Systems Considered

1. Crude Production
   → Refining
   - Transport
   - Finished Gasoline & Diesel

2. Bitumen Production
   • Mining
   • In-situ
   → Diluent
   → Diluted Bitumen
   → Refining
   - Transport
   - Finished Gasoline & Diesel

3. Bitumen Production
   • Mining
   • In-situ
   → Upgrading to Synthetic Crude
   → Refining
   - Transport
   - Finished Gasoline & Diesel
Key Crude Production Issues

- Wide variation in specific crude and bitumen production GHG emissions
  - Crude / bitumen properties
  - Reservoir characteristics
    - Depth
    - Water to oil ratio
    - Gas to oil ratio
  - Flaring and venting of produced gas
  - Treatment of produced water and gas
  - Production method and technology
    - primary, secondary, tertiary

Public availability of accurate, comprehensive production data is often limited
Study Crudes

- Bachaquero – Venezuela
- Maya – Mexico
- Arab Medium – Saudi Arabia
- Mars – US Gulf Coast
- Bonny Light – Nigeria
- Kirkuk – Iraq
- Kern River – California
- Oil Sands Bitumen – Canada

2007 Average US Crude Basket

- Angola: 3%
- Iraq: 3%
- Nigeria: 7%
- Mexico: 9%
- Saudi Arabia: 9%
- US Gulf Coast: 17%
- California: 4%
- Canada: 11%
- Rest of World: 13%
- Other US: 17%
- Rest of World: 13%

Source: EIA
## Concept 1 – Crude Oil and Bitumen Properties Lie on a Continuum

<table>
<thead>
<tr>
<th>Viscosity, cP</th>
<th>API°</th>
<th>Oil Type</th>
<th>Density, g/cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Condensate</td>
<td>0.802</td>
</tr>
<tr>
<td>45</td>
<td>45</td>
<td>Light Oil</td>
<td></td>
</tr>
<tr>
<td>&gt;100</td>
<td>20</td>
<td>Heavy Oil</td>
<td>0.934</td>
</tr>
<tr>
<td>10,000</td>
<td>10</td>
<td>Extra Heavy Oil</td>
<td>1.000</td>
</tr>
<tr>
<td>&gt;10,000</td>
<td>0</td>
<td>Bitumen/Oil Sands</td>
<td>1.076</td>
</tr>
</tbody>
</table>

- Bitumen is another type of crude oil
- Properties fall on a continuum
- Less light components
- More resid and carbon

Address Key Issues by Modeling Crude Production

- Jacobs crude oil production model used to predict GHG emissions for specific crudes
- Public data supplemented with Jacobs in-house knowledge
- Allows user to evaluate impact of key variables and carry out sensitivities

**Jacobs Crude Production Model**

**Variable Inputs**

**CO₂e Outputs by Category**

- Jacobs Crude Production Model: Used to predict GHG emissions for specific crudes.
- Public data supplemented with Jacobs in-house knowledge.
- Allows user to evaluate impact of key variables and carry out sensitivities.
Reservoir Characteristics for Conventional Crude Basket in Study

<table>
<thead>
<tr>
<th>Petroleum Reservoir</th>
<th>Avg Depth, ft</th>
<th>Pressure, psi</th>
<th>Thermal Steam to Oil, bbl/bbl</th>
<th>Water to Oil, bbl/bbl</th>
<th>Produced Gas, scf/bbl</th>
<th>Flared Gas (Wrld Bnk Rpt Table 4), m3 gas/bbl</th>
<th>N2 Injection, scf/bbl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bachaquero</td>
<td>5,100</td>
<td>500</td>
<td>0.5</td>
<td>0.25</td>
<td>90</td>
<td>2.0</td>
<td>-</td>
</tr>
<tr>
<td>Maya</td>
<td>9,500</td>
<td>1,600</td>
<td>-</td>
<td>3</td>
<td>340</td>
<td>0.6</td>
<td>1,200</td>
</tr>
<tr>
<td>Arab Medium</td>
<td>6,100</td>
<td>3,000</td>
<td>-</td>
<td>2.3</td>
<td>650</td>
<td>0.8</td>
<td>-</td>
</tr>
<tr>
<td>Mars</td>
<td>14,500</td>
<td>5,500</td>
<td>-</td>
<td>5.5</td>
<td>1,040</td>
<td>0.6</td>
<td>-</td>
</tr>
<tr>
<td>Bonny Light</td>
<td>8,700</td>
<td>4,300</td>
<td>-</td>
<td>2</td>
<td>840</td>
<td>27.0</td>
<td>-</td>
</tr>
<tr>
<td>Kirkuk</td>
<td>7,500</td>
<td>3,000</td>
<td>-</td>
<td>2</td>
<td>600</td>
<td>11.0</td>
<td>-</td>
</tr>
</tbody>
</table>

- **Assumed**
- **From Reservoir Data**

Reservoir Source: Pennwell- Published in Oil & Gas Journal, December 24, 2007 GOR and reservoir pressure, WOR from literature

Using World Bank Report Table 4 in this study
Crude Oil Production Carbon Intensity – Before Accounting for Flaring

![Bar chart showing the total CO2e emissions per MJ of crude oil for different production facilities.](chart.png)

- **Bachaquero**: 4.5 g/MJ, with contributions from Nitrogen, Steam, Misc Energy, Gas Treatment, Water Treatment, Gas Reinjection, Water Reinjection, and Lifting.
- **Maya**: 5.2 g/MJ, with similar contributions.
- **ArabMed**: 6.8 g/MJ, with similar contributions.
- **Mars**: 11.3 g/MJ, with similar contributions.
- **Bonny Lt**: 8.9 g/MJ, with similar contributions.
- **Kirkuk Blend**: 7.1 g/MJ, with similar contributions.

The chart indicates the significant contribution of Nitrogen and Steam to the total CO2e emissions in several production facilities. The variations in emissions are primarily due to differences in the energy sources and processes involved in each facility.
Gas Flaring in Crude Production

Emissions With Flaring

Using World Bank Report Table 4 for this figure.
Heavy Crude Production Methods

- **Bitumen**
  - SAGD – steam assisted gravity drainage
    - Primary energy is natural gas to generate steam for injection
    - Key parameter is steam to oil ratio: bbls of cold water/bbl of oil
  - Mining
    - Primary energy is diesel fuel to power equipment
    - Natural gas and electricity are used to separate bitumen from clay
    - Study does not include land use or methane release in mine preparation
  - May import or self-generate electricity and export electricity to the grid

- **California heavy crude oil**
  - Uses an older somewhat less efficient thermal method than SAGD
  - Primary energy is natural gas
Canadian Bitumen Production in 2008

- 1.31 MM BPD total bitumen
- 0.73 MM BPD mined bitumen all to upgraders
- 0.58 MM BPD in situ (mainly thermal) production ~ 92% to refining
Bitumen Range of Steam to Oil Ratio (SOR)

Steam to Oil, bbl / bbl

Nexen, Long Lake
CNRL Primrose & Wolf Lake
Shell Peace River
IMO, Cold Lake
Suncor, Firebag
JACOS, Hangingstone
Petro-Canada, McKay
EnCana, Foster Creek & Christina Lake

Pilot data
Typical SOR in Canada

Source: EnCana Investor Presentation October 5, 2006 -
Concept 2 - Crude Oil and Bitumen Production Carbon Intensities Overlap

Emission range for heavy crudes overlaps range for some conventional crudes
Key Upgrading & Refining Issues

- Crude quality and product requirements impact
  - Processing complexity
  - Hydrogen addition
  - Energy consumption
  - Product yield and quality
  - Co-products such as coke

- Refinery configuration and technology
  - Level of conversion
  - Product slate
Concept 3 - Refining GHG tracks with API Gravity

- Refining GHG emissions highly dependent on crude gravity
  \[(\text{API} = 141.5/\text{density} - 131.5)\]

- Emissions depend on conversion – line will shift up or down depending on conversion
Concept 4 – Each Product Pays It’s Fair Share of GHG

• Track utilities to intermediate products in each step of refining
• Ensures that products “pay” their fair share of GHG emissions
• Carbon intensity (CI) depends on processing intensity
Concept 5 – CI of Transport Fuel from Heavy Crude Oils are within 10% - 12% of Those from Conventional Crude Oils
Observations from 2009 Study

- Rigorous and detailed Life Cycle analysis provides a better understanding of differences between crude oils
- GHG burden for bitumen derived transport fuels is smaller than shown in previous studies
- Life Cycle GHG emissions between bitumen and some conventional crudes overlap
- Continuing effort to reduce GHG burden of bitumen production and refining
Agenda

• 2009 AERI Study
  – Background and project objectives
  – Methodology
  – Life Cycle analysis
    • Crude production
    • Upgrading and refining
    • Life Cycle well-to-wheels fuel cycle
  – Observations

• New developments
  – Changes in worldwide flaring
  – Advancements in bitumen production technology
  – EU crude oil pathway LCA
Flaring Trend is Downward - But Not Everywhere

Nigeria

Estimated Gas Flared (BCM)

Russia_Combined

Estimated Gas Flared (BCM)

Ireland

Estimated Gas Flared (BCM)

Angola

Estimated Gas Flared (BCM)

Convert flaring to CO$_2$e, and Divide by crude production to get flaring in terms of CO$_2$e/MJ of Crude

NOAA - http://www.ngdc.noaa.gov/dmsp/interest/flare_docs/
Canadian Bitumen Forecast

- Forecast to exceed 3.5 MM BPD in 2025
- Bitumen production methods continually improving

CAPP – Canadian Association of Petroleum Producers – June 2010
Improvements in Bitumen Production

• SAGD
  – Better heat integration reduces energy use
  – Fast SAGD makes better use of heat injected into reservoir
  – Improved lift technology – use of mechanical lift instead of gas lift
  – Better reservoir pressure management
  – Use of solvents reduces steam required
  – Improved recovery with polymer flooding
  – Water reduction and reuse reducing environmental burden

• Mining
  – Paraffin froth treatment at mine removes significant carbon resid which improves refining yield and reduces energy and GHG
  – Mature fine tailings recovery is reducing tailing ponds
Continued Development Driving Down GHG from SAGD

New designs reduce SAGD GHG by ~20-25%

- Minimizing Glycol
- Minimizing Stack Loss
- Organic Rankine Cycle
- Downhole Pumps (LP SAGD)

Additional Energy Reductions to achieve “Ideal”

Carbon Capture and Storage

MT CO₂ / day

Cost

$/MT CO₂

$100

$80

$60

$40

$20

$10

$0

Return

4%

5%

28%

38%

500 1,000 1,500 2,000 2,500 MT CO₂ / day

$20

$40

$60

$80

$100

$20

$40

$60

$80

$100

$100

$80

$60

$40

$20
Commercial SAGD Production with < 3 SOR Demonstrated

<table>
<thead>
<tr>
<th>Project</th>
<th>Date</th>
<th>SOR After 9 Months of Operation</th>
<th>SOR In 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foster Creek</td>
<td>1998</td>
<td>4.0</td>
<td>2.5</td>
</tr>
<tr>
<td>Surmont Pilot</td>
<td>1998</td>
<td>5.2</td>
<td>3.5</td>
</tr>
<tr>
<td>MacKay</td>
<td>2003</td>
<td>3.4</td>
<td>2.5</td>
</tr>
<tr>
<td>Christina Lake</td>
<td>2003</td>
<td>2.8</td>
<td>2.0</td>
</tr>
<tr>
<td>Long Lake</td>
<td>2003</td>
<td>11.4</td>
<td>6.9</td>
</tr>
<tr>
<td>Firebag</td>
<td>2004</td>
<td>7.3</td>
<td>3.3</td>
</tr>
</tbody>
</table>

- SOR depends on reservoir conditions, good design and operation
- SOR below 3 have been demonstrated in commercial practice
- Reducing SOR from 4 to 2 cuts GHG in half
What Next

- ~50% of EU crude supply is from regions defined by California Air Resources Board as being high carbon intensity regions
- Forthcoming LCA study for Alberta Energy to provide a transparent view of bitumen and other crudes in an EU context
  - Define crude oil production GHG for typical crudes including flaring
  - Define refining GHG using EU refining configurations
  - Define oil transport and product distribution to the EU
  - Use EU vehicle emissions
- Goal – similar detail and transparency as 2009 AI-EES LCA study
Thank You