Appendix 1.

Scope of Work
EU Pathway Study:
Life Cycle Assessment of Crude Oils in a European Context
Technical Scope of Work

Prepared For

Alberta Petroleum Marketing Commission

June 2011
EU Pathway Study: Life Cycle Assessment of Crude Oils in a European Context

Technical Scope of Work

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Section 1.

Introduction
The Alberta Petroleum Marketing Commission (“APMC”) has contracted Jacobs Consultancy Canada Inc. (“Jacobs Consultancy”) to carry out an EU Pathway Study – Life Cycle Assessment of Crude Oils in a European Context (the “Study”). This document presents the background and technical scope of work for the Study.

Background

California has introduced a Low Carbon Fuel Standard (LCFS) with the stated objective of reducing the carbon intensity of its transportation fuels by 10% by 2020. The European Union has followed suit with its Fuels Quality Directive of 2009, which calls for a 6% reduction in carbon emissions for transportation fuels between 2010 and 2020.

Carbon emissions are based on a well-to-wheels assessment of greenhouse gas emissions from crude oil production through consumption of transportation fuels in the vehicle. The steps in a well-to-wheels life cycle assessment (“WTW LCA”) of greenhouse gases (“GHG”) are shown in Figure 1-1.

![Figure 1-1. Simple Crude Oil Life Cycle Schematic](image)

A significant challenge in a WTW LCA of crude oils is determining the emissions from crude oil production. As there are thousands of reservoirs producing crude oil around the world, determining the GHG from producing each crude is an immense challenge. In its initial regulations, the California Air Resources Board (“CARB”) used a shortcut and treated all bitumen and thermally-derived crude oils as high carbon intensity crude oils (“HCICO”) and the
rest of the crude oils as non-HCICO. Refiners processing non-HCICO will use a look-up table to determine the WTW life cycle carbon intensity of gasoline and diesel. However, when processing crudes determined to be HCICO, they would have to determine the actual WTW life cycle GHG of gasoline and diesel from each HCICO. In other words, all gasoline and diesel from non-HCICO is assumed to have the same WTW GHG emissions, but gasoline and diesel from HCICO have carbon intensities that are specific to the crude and are determined by a WTW LCA and not from a look-up table.

The EU is considering a similar approach: Separate default carbon intensity values are defined for gasoline and diesel produced from conventional crude oils and a range of higher values is used for fuels produced from unconventional sources with differentiated values for fuels produced from oil sands, oil shales, gas-to-liquids, and coal-to-liquids. This approach treats all conventional, non-thermally-derived crude oils as low in carbon intensity, which is an over-simplification.

In 2008, Alberta Energy Research Institute (“AERI”)—now called Alberta Innvoates – Energy and Environment Solutions (“AI-EES”)—asked Jacobs Consultancy to evaluate the WTW life cycle GHG emissions for gasoline and diesel from bitumen and synthetic crude oil vs. gasoline and diesel from a handful of North American and imported crude oils (the “AERI Study”).

Results from the AERI Study showed that the actual carbon intensity of crude oil production was highly dependent on reservoir parameters such as gas to oil ratio, water to oil ratio, reservoir depth and pressure, produced gas composition, and especially the extent of venting and gas flaring. In fact, results from the Study showed that several of the crudes that are considered to be conventional crude oils had GHG emissions from production that were as high or higher than emissions from bitumen production. In addition, heavy crude oil produced in California by thermal means was shown to have a carbon intensity higher than bitumen.

Figure 1-2 shows the GHG emissions from the crudes evaluated in the AERI Study. Note that the values in Figure 1-2 have been updated subsequent to issue of the final AERI Study report.
The crudes in Figure 1-2 are defined as follows:

- **Bachaquero**, a heavy crude oil from Venezuela
- **Maya**, a heavy crude oil from Mexico
- **Arab Medium** from Saudi Arabia
- **Mars** from deepwater US Gulf Coast
- **Bonny Light** from Nigeria
- **Kirkuk** from Iraq
- **CA TEOR**, a heavy California crude oil produced via thermal enhanced oil recovery
- **Bitumen-SAGD**, a bitumen produced via steam assisted gravity drainage ("SAGD")
- **Bitumen Mining**, a bitumen from mining.

Life cycle WTW GHG emissions for gasoline and diesel produced from the crudes evaluated in the AERI Study are summarized in Figure 1-3. The results show that carbon intensities of gasoline and diesel from bitumen and heavy California crude oils are within 10% - 12% of carbon intensities of gasoline and diesel from conventional crude oils. Note that the values in Figure 1-3 have been updated subsequent to issue of the final AERI Study report.
CARB modified its criteria for determining which crude oils are HCICO and which are not partly as a result of the AERI Study. In the new regulations non-HCICO is identified as:

- Crude oil produced using recovery techniques other than thermal enhanced oil recovery (steam/hot water injection or in-situ combustion) or crude bitumen mining.
- Crude oil produced from a country with an average flaring rate of less than 10 standard m³/bbl as determined by the most recent NOAA/NGDC gas flaring rate data together with annual oil production data.⁴

In the new rendition of the regulations, CARB HCICO will use a default value of 20 g CO₂e/MJ for production and transport until shown to have a different value. If an HCICO can be shown to have a carbon intensity from production and transport that is less than 15 g CO₂e/MJ, the non-HCICO look-up table can be used to determine the carbon intensity values for gasoline and diesel.

The EU thus far is not differentiating crudes by this method; instead, it is proposing that oil sands are a specific category of unconventional sources. Crude produced using thermal methods but not from oil sand deposits would be considered as conventional and not attract the
penalty/differentiation. These thermally-produced crudes and all other crude oils thus are considered to be conventional crude oils irrespective of production method or flaring and actual carbon intensity.

Figure 1-4 shows that the EU currently supplies most of its crude oil from Russia, the North Sea, Africa, and the Middle East.5

Satellite surveys by the National Oceanic and Atmospheric Administration (NOAA) for the World Bank6 (Figure 1-5) show that many of the regions that supply Europe with crude oil are identified as having high gas flaring. In fact, a rough estimate indicates that as much as 50% of the EU crude supply would be classified by CARB as being HCICO.7
A more accurate way to assess carbon intensity is to properly differentiate between low- and high-intensity crudes based on a WTW LCA that takes into account actual GHG from crude oil production, including flaring, transport, refining and product delivery. Presumably the categorization of a crude oil as low-intensity or high-intensity would change if technically-sound WTW LCA results justify re-classification.

**Current Life Cycle Studies Related to EU Pathways**

Several studies have looked at bitumen and synthetic crude oil in an EU context. Both the Energy-Redefined study for ICCT\(^8\) and the Brandt study\(^9\), which is an overview of a number of studies, have tended to over-penalize bitumen while not taking into account some of the GHG emissions from the production of conventional crude oils.
The Energy-Redefined Study estimated the carbon intensity for refined products from a large number of crude oils refined in the EU. Unfortunately none of the data are available for review, and this lack of transparency makes it difficult to understand the origin of some of the Study’s numbers. One difference between this work and the AERI Study is that Energy-Redefined did not identify water to oil ratio as an important parameter in determining the energy and GHG in crude oil production. Water to oil was a significant parameter in the AERI Study—when the ratio is 5 (5 barrels of water per barrel of crude) and the reservoir depth is 15,000 ft, there may be considerable energy needed to lift this oil-water mixture to the surface.

Figure 1-6 shows the range in GHG from well to refinery gate for a number of crude oils from the Energy-Redefined Study and the AERI Study. Note that while there is fair agreement, the Energy-Redefined work gives a much lower carbon intensity for crude oils produced with no flaring and then refined, and may therefore underestimate the refining contribution to GHG.

Figure 1-7 shows the results summarized by Brandt from a number of studies on in-situ bitumen production and refining to gasoline and diesel.

Figure 1-6.  
GHG for Crude Oil Production and Well to Refinery Gate – Energy-Redefined (E-R) vs. AERI

![Figure 1-6](image-url)
Missing from the Energy-Refined Study, the AERI Study, and the studies summarized by Brandt is the impact from the latest improvements in oil sands production that significantly reduce GHG emissions.

**Improvements in Bitumen Production**

Ongoing improvements in mining and SAGD are bringing down the energy, GHG emissions, and environmental impact of these two methods of bitumen production. The major new developments in bitumen production are highlighted as follows:

- **Mining**
  - Paraffin froth treatment at the mine removes significant carbon resid which improves refining yield and reduces energy and GHG
  - Mature fine tailings recovery is reducing tailing ponds
  - Other technologies are being evaluated and deployed to reduce energy consumption and water use

- **SAGD**
  - Better heat integration and high efficiency designs reduce energy use
  - Fast SAGD makes better use of heat injected into the reservoir
- Improved lift technology—use of mechanical lift instead of gas lift
- Better reservoir pressure management
- Use of solvents reduces steam required
- Use of CO₂ to enhance oil recovery
- Improved recovery with polymer flooding
- Water reduction and reuse reducing the environmental burden

Figure 1-8 shows the potential impact on GHG emissions from improvements in SAGD. These results from a recent study show that a 20-25% reduction in GHG emissions vs. typical prior designs is feasible using many of the options highlighted above before implementing more expensive GHG reduction methods such as carbon capture and storage (CCS).

Figure 1-8. Continued Development Driving Down GHG from SAGD

One of the driving forces in energy reduction in SAGD is to reduce the steam to oil ratio (SOR) used. In the AERI Study the SOR was assumed to be 3, which was in the range of demonstrated performance at the time of the report. The SOR actually achieved depends on reservoir conditions, design, and operation of the production site. Subsequent commercial data (Table 1-1) show that SORs below 3 have been routinely demonstrated in commercial production. Reducing SOR from 4 to 2 cuts the GHG emissions from SAGD in half.
Limitations of Prior LCA Studies

Many WTW life cycle analyses, including the Energy-Redefined Study for ICCT, allocate total energy used in the refinery to the products. This is an approach first suggested by Michael Wang.\(^1\) In the absence of any detailed knowledge about refinery processing, this approach gives a first pass estimate of the carbon intensity of refined products. However, more detailed consideration of the relationships between processing steps often gives very different results.

The Energy-Redefined Study shows LPG from processing oil sands to have nearly one-third the carbon intensity of gasoline and one-fourth the carbon intensity of diesel fuel. Heavy products from oil sands are shown to have nearly the same carbon intensity of highly refined products like gasoline in this Study. In fact, because oil sands bitumen does not contain much material lighter than naphtha, any LPG produced from oil sands bitumen is made by cracking, and thus is actually high in carbon intensity. In addition, heavy products like coke or fuel oil see very little processing and in fact have a very low carbon intensity.

One significant difference between the AERI Study and others is that the AERI Study distributed utilities consumed in each processing step in upgrading and refining to the intermediate products, which were then either blended or processed further. In this approach, each intermediate stream carries with it the carbon intensity from the prior step. Finished products

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Table 1-1.
Commercial SAGD Production Demonstrating Cumulative Steam Oil Ratio < 3

<table>
<thead>
<tr>
<th>Project</th>
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<td>Foster Creek</td>
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<td></td>
<td>Jul-98</td>
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<td></td>
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<tr>
<td></td>
<td>Mar-10</td>
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<tr>
<td>MacKay</td>
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<td>Jul-03</td>
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<tr>
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<td>Jul-05</td>
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<tr>
<td>Christina Lake</td>
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<td>Surmont</td>
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<td>Pilot</td>
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<tr>
<td></td>
<td>Mar-10</td>
<td></td>
<td></td>
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</table>

Results are from a report for Alberta Energy\(^1\)
carry the utility and energy burdens from each intermediate processing step and reflect the actual refining intensity to produce them. Refining GHG burden for products from refining bitumen in the AERI Study are shown in Figure 1-9. The distribution of energy in refining is shown. Note the low carbon intensity of coke and the relatively high carbon intensity of LPG.

![Figure 1-9. Product Carbon Intensity from Refining Bitumen – AERI Study](image)

**Primary Study Objectives**

Given the background discussed above, the goal of this Study is to provide a fair and balanced LCA of Canadian bitumen with other major crude oils processed in the EU to produce finished products such as gasoline, jet fuel, diesel, fuel oil, and LPG. Key to meeting these objectives is determining the carbon intensities of refined products from individual crude oils, and bitumen in an EU context, which means with product specifications, transport distances, and refining configurations reflecting those predominant in the EU.

The primary objective of the Study is to provide a first-order technical assessment of European crude oil supply pathways that provides a high degree of transparency in terms of data and methodology. This Study is a “first-order” study and is not a “meta assessment” of other studies, as are the studies by the University of California-Davis, Brandt, CERA, NETL and numerous others. Further:
This Study will include the major sources of crude consumed in Europe, both indigenous and imported.

This Study will evaluate Brazilian crude oil, which is expected to be a significant crude source for the EU in the future.

For crudes used in Europe that have not been covered under the previous AERI Study but are imported into North America, this Study will also assess a North American landing point. This will include North Sea crude oil, Russian crude oil, and Brazilian crude oil.

A second objective is to provide an update to the AERI Study of new pathways for Alberta-based crude production reflecting current and emerging production trends, including a reflection of the types of SOR under emerging commercial SAGD projects, as shown in Table 1-1.

Emerging production trends in bitumen production include:

- Solvent addition
- Oil sands primary production methods—Cold Heavy Oil Production with Sand (CHOPS), enhanced oil recovery (EOR), polymer floods, etc.
- Sequencing (changes in pumping/production technologies for low-pressure SAGD fields from gas lift to ESPs, metal-to-metal PCPs, fast SAGD, water / chemical floods, etc.)
- Mined bitumen using paraffinic solvents (asphaltene rejection)
- Another objective of the Study is to improve on the AERI Study estimates of methane released in bitumen production from mining.

A third objective is to evaluate the availability of information required to determine GHG emissions and carbon intensity for producing a typical Canadian crude basket. To determine the characteristics (blend, API, sulphur content) and carbon intensity of this Canadian crude basket data must be gathered on:

- The total amount of crude production in Canada
- The total amount of Canadian crude oil exported to the United States, including the amount exported to each PADD
- Characteristics of the specific crude streams produced in Canada and exported to the United States: API, sulphur content, and the GHG/CI associated with producing each crude stream

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- Characteristics of the specific crude streams produced in Canada and exported to the United States: API, sulphur content, and the GHG/CI associated with producing each crude stream
Key Study Issues

There are several key issues related to the Study:

- Because the Study addresses important issues facing policymakers and energy providers, it is critical that the results, methodology and underlying data are transparent to others.
  - Use public and defendable data sources
  - Use recognized and transparent LCA methodology and model, similar to what is used in California for LCFS, in the AERI Study, and other well-vetted life-cycle studies
- Maintain focus on important issues and main objectives.
  - Control the number of cases and level of detail
  - Include but do not focus heavily on lower-priority aspects of LCA
- Define typical crude oils processed in the EU from the major supplying regions. This requires defining the GHG emissions from crude oil production including flaring and the transport distance and mode of transport of these crude oils to the EU.
- Use refining configurations and product yields that are typical to the EU.
- Use emission factors for electricity, natural gas, and emissions from the vehicles that are typical to the EU and oil producing regions.
Section 2.

Scope of Work
The primary scope of this Study is to develop a life cycle comparison of emissions from different conventional crudes vs. heavy crude oils and bitumen-derived oils as follows:

**Crudes to Be Considered**

It is anticipated that the following crude oils will be evaluated in the Study:

- **Major crude oils processed in the EU**
  - Russian crude—Urals
  - Russian intermediates—gas oil and atmospheric resid imports
  - North Sea Norway—Ekofisk
  - North Sea UK crude—Brent
  - Saudi Arabian crude—Arab Medium
  - Libyan crude—Sirte or other
  - Nigerian crude—Bonny Light
  - Iran crude—Sirri or other
  - Iraq crude—Kirkuk

- **Canadian oil sands and heavy crude**
  - Diluent-bitumen blends with bitumen refined in the EU—bitumen production via mining and via SAGD
  - Oil sands-derived synthetic crude oil refined in EU
  - Venezuelan Bachaquero heavy crude refined in EU
  - Diluent-bitumen blend refined in USGC with distillate export to Europe

- **Crude oils from the EU that are processed in the United States**
  - Russian crude—Urals
  - North Sea UK crude—Brent

- **Crude oils from new Brazilian reservoirs expected to become a major future crude supply**
  - Brazilian crude—Tupi or other (processed in both EU and United States)

These crude oils will be finalized during the Study.
### Refining Configurations

Three major European refining configurations will be considered:

- Configuration 1: conversion provided by FCC unit and Visbreaking unit
- Configuration 2: conversion provided by Hydrocracking unit and Visbreaking unit
- Configuration 3: conversion provided by FCC unit and Coking unit

The high conversion refinery configuration from the AERI Study will also be used to evaluate Russian crude, North Sea crude, and Brazilian crude in a US context and for the production of diesel export to the EU from Alberta dilbit. The location of the refinery will be the US Gulf Coast vs. the PADD II location assumed in the AERI Study. Transportation distances will be adjusted accordingly.

Each crude oil will be evaluated in one of the EU refinery configurations. Three crudes will be evaluated in the two other configurations. The Russian, North Sea and Brazilian crude oils will be evaluated in the AERI Study high conversion refinery. Alberta dilbit will be evaluated in the AERI Study high conversion refinery to produce diesel for the EU.

The Study crudes and EU refinery configurations are shown in Table 2-1.

#### Table 2-1. Crude-Refinery Configurations for Study

<table>
<thead>
<tr>
<th>Country</th>
<th>Name</th>
<th>EU Config 1 - FCC Visbreaking</th>
<th>EU Config 2 HCU Visbreaking</th>
<th>EU Config 3 FCC Coking</th>
<th>AERI High Conversion</th>
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</thead>
<tbody>
<tr>
<td>1 Russia/FSU</td>
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<td>2 Norway-North Sea</td>
<td>Ekokisk</td>
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<td></td>
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<tr>
<td>3 Libya</td>
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<tr>
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<td>Bonny Light</td>
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<td>X</td>
<td>X</td>
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<tr>
<td>9 Brazil Offshore</td>
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<td>10 Venezuela</td>
<td>Bachaquero</td>
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<td>Intermediates - Mazut and Hydrotreated Gas Oil</td>
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<th>Country</th>
<th>Name</th>
<th>EU Config 1 - FCC Visbreaking</th>
<th>EU Config 2 HCU Visbreaking</th>
<th>EU Config 3 FCC Coking</th>
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**Total in Each Column** | 13 | 4 | 5 | 4

**Improvements in Bitumen Production**

Jacobs Consultancy will conduct a high-level review of the impact of the following methods to improve the efficiency of mining and SAGD on WTW life cycle GHG emissions:

- For improvements in mining, paraffin froth treatment and other potential energy efficiency improvements being considered by the industry
- For SAGD:
  - Better heat integration and high efficiency design to reduce energy use
  - Fast SAGD to make better use of heat injected into the reservoir
  - Improved lift technology—use of mechanical lift instead of gas lift
- Other in-situ production methods
  - Use of solvents to reduce steam required
  - Improved recovery with polymer flooding
  - Enhanced oil recovery with CO₂
  - CHOPS

**Identification of Data Sources**

The sources of input data for each specific crude pathway will clearly be defined, including reference to data that were sought but were not available.
Uncertainty Measurements

Where possible, a measure of uncertainty (e.g., confidence interval, box and whisker plots) resulting from data or modeling methodology will be provided on the pathway assessment.

Carbon Intensity of Canadian Crude Basket

Jacobs Consultancy will evaluate the available information on crude oil production in Canada and determine if there is sufficient detail to determine a carbon intensity for a Canadian crude basket.

Life Cycle Assessment

Jacobs Consultancy will work closely with APMC to finalize goals and scope definition and carry out the Life Cycle Assessment, including:

- **Develop Crude Production Data**—This will entail gathering publicly available information with vetting, updating, and supplementing by in-house upstream experts.

- **Develop Upgrading and Refining Data**—This includes development of simulation-based configuration models to determine the performance and emissions of this step in the life cycle for each case. Various sensitivities as agreed upon with APMC will also be explored, such as varying G/D ratio, refinery complexity, or technology basis.

- **Develop Other Data**—This includes crude, intermediate, and final product transportation and other required data.

- **Develop Utilities and Emissions Estimates**—These estimates will be developed based on the information above.

- **Perform Life Cycle Assessment**—The final assessment shall be carried out using data generated as described above.

- **Compare Results**—We will prepare comparative charts illustrating life cycle by processing stage in a consistent form with other life cycle analyses.

- **Prepare and Deliver Final Study Outputs and Deliverables**
Section 3.

Schedule and Public Meetings
Schedule

The Study commences in June of 2011 and is scheduled for completion in November of 2011.

Public Meetings

Two public meetings will be held in Europe to review results and gather stakeholder input. These meetings are tentatively scheduled for September and November (exact dates to be finalized).
Section 4.

Deliverables
The following are the primary deliverables of the Study:

- A final written report including:
  - Executive Summary
  - Study Goals and Objectives
  - Study Approach, Methodology and Basis
  - Study Results (including appropriate sensitivity analyses)
  - Study Conclusions and Recommendations
  - Supporting Data
- Interim and final public stakeholder meetings
Section 5.

References

2. EU Directive 2009/30/EC amending Directive 98/70/EC on fuel quality, Consultation paper on the measures necessary for the implementation of Article 7a(5).


4. Energy Information Administration, Crude Supply Data


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