# Oil Sands, Greenhouse Gases, and European Oil Supply

## Getting the Numbers Right

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**SAMANTHA GROSS,** IHS CERA Director, specializes in helping energy companies navigate the complex intersection of policy, environment, and technology. She is the manager of IHS CERA's Global Energy service. She led the environmental and social aspects of IHS CERA's recent Multiclient Study *Growth in the Canadian Oil Sands: Finding the New Balance,* including consideration of water use and quality, local community impacts, and aboriginal issues. Ms. Gross was also the IHS CERA project manager for *Towards a More Energy Efficient World* and *Thirsty Energy: Water and Energy in the 21st Century,* both produced in conjunction with the World Economic Forum. Additional contributions to IHS CERA research include reports on the water impacts of unconventional gas production, international climate change negotiations, US vehicle fuel efficiency regulations, and the California low-carbon fuel standard. Before joining IHS CERA she was a Senior Analyst with the Government Accountability Office. Her professional experience also includes providing engineering solutions to the environmental challenges faced by petroleum refineries and other clients. Ms. Gross holds a BS from the University of Illinois, an MS from Stanford University, and an MBA from the University of California at Berkeley.

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# OIL SANDS, GREENHOUSE GASES, AND EUROPEAN OIL SUPPLY: GETTING THE NUMBERS RIGHT

## EXECUTIVE SUMMARY


As reducing transportation greenhouse gas (GHG) emissions moves to the policy forefront, low carbon fuel standards (LCFS) are charting a new path for regulation. LCFS focus on the fuel, requiring a reduction in GHG emissions across its total life cycle—from production and processing through to using the fuel in a vehicle. In April 2009 the European Union adopted an LCFS by modifying its Fuel Quality Directive. The European Union now requires a 6 percent reduction in life-cycle GHG emissions for fuels used in "road transport and non-road mobile machinery" by 2020. The European Commission is now developing the methodology for calculating and reporting life-cycle emissions, with plans to finalize the policy by the end of 2011.

The European Union has released a draft proposal describing its life-cycle analysis. In IHS CERA's view the methodology is misleading and conveys a confusing picture of oil emissions. The proposal assigns one fixed GHG-intensity value for all fuels produced from crude oil—except for Canadian oil sands. The life-cycle value assigned to oil sands is 23 percent higher than the default value for all other crudes. Oil sands are not exported to the European Union (nor are they expected to be in the future), which also raises the question of why they are separated out from other crudes.

To evaluate the life-cycle GHG intensities of various crude oils, IHS CERA conducted a meta-analysis of 12 publicly available studies and found that, on average, oil sands are not as GHG intensive as the current EU proposal states. On a life-cycle basis, products derived wholly from oil sands result in GHG emissions that are 10 to 20 percent higher than the emissions estimated for the average EU crude. Oil sands products are in the same GHG intensity range as current European imports from Venezuela, Angola, and Nigeria and crudes produced using steam-assisted oil recovery from the Middle East.

Bitumen—the oil in the oil sands—is too thick to transport in its pure form. Therefore, in the hypothetical case that oil sands are imported into Europe, they would be shipped as a blend of bitumen and lighter, less carbon-intensive hydrocarbons or as synthetic crude oil. When this is taken into account, the average oil sands product likely to be imported has life-cycle GHG emissions 11 percent higher than the average EU crude oil—below the 23 percent value in the EU proposal.

The baseline GHG value of the average EU crude oil import is itself an estimate, since data are not available for many crude supplies. For instance, more than 30 percent of EU oil supply comes from countries with elevated levels of gas flaring, a characteristic indicative of higher GHG intensity, yet life-cycle data for these sources of crude are limited.

The method of differentiating oil sands crudes from all other crudes is discriminatory since it does not account for equally high-carbon conventional crude oils already used in the European Union. The proposal provides no clear basis for this distinction. Conventional and unconventional designations are poor guides for life-cycle GHG intensity, particularly for conventional sources with high emissions from venting and flaring. Indeed, the result is to present a distorted view of GHG emissions that can lead to serious errors in policymaking.


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# OIL SANDS, GREENHOUSE GASES, AND EUROPEAN OIL SUPPLY: GETTING THE NUMBERS RIGHT

*by James Burkhard, Jackie Forrest, and Samantha Gross*

## REDUCING TRANSPORTATION GHG EMISSIONS

Reducing greenhouse gas (GHG) emissions is an important policy objective for the members of the European Union. GHG emissions from the consumption of liquid fuels in transport—mainly petroleum-based fuels such as gasoline and diesel—account for about 25 percent of total GHG emissions in the European Union.

Policies to reduce transportation sector fuel use and GHG emissions can take three forms:

- **Focus on the vehicle.** Vehicle carbon emissions standards—similar to fuel economy standards—are an example of a focus on the vehicle. The European Union has mandates to strengthen vehicle carbon emissions standards by 2015.
- **Focus on the fuel.** Substitution of petroleum by lower-carbon biofuels is an example of a fuel policy. The European Union has committed to raising the share of biofuels in transportation to 10 percent by 2020 (although the absolute level of GHG emission reductions from biofuels use can be debated). Another fuel-focused policy measure is low carbon fuel standards (LCFS); the European Union has adopted this policy and is now developing the method of regulating it.
- **Focus on the mode and distance of transport.** Policies that focus on the mode or distance of transport include fuel taxes, congestion charges, pay-as-you drive insurance, greater use of mass transit, and urban planning to reduce travel. Examples are European fuel taxes and congestion charges in central London.

## LOW CARBON FUEL STANDARDS: CHARTING A NEW PATH

LCFS are charting a new path for regulation of GHG emissions in the transportation sector. LCFS focus on the fuel and require a reduction in GHG emissions from the total life cycle of a fuel. As it applies to road transport, the life cycle covers all GHG emissions related to the production, processing, transportation, and final consumption of a fuel in a vehicle. The goal is to have a fuel slate that is less GHG intensive, meaning fewer GHG emissions per unit of energy consumed.

In April 2009 the EU adopted LCFS, modifying its Fuel Quality Directive to require fuel suppliers to reduce the life-cycle GHG emissions for fuels used in “road transport and non-road mobile machinery” by 6 percent by 2020. The methodology for calculating and reporting life-cycle GHG emissions for biofuels was included in the directive. The European Union is now developing the methodology for calculating and reporting GHG emissions from other sources, including petroleum and electricity, and plans to finalize the method, reporting, and default values by the end of 2011.

Although not final, draft values for GHG life-cycle emissions of various fuel sources have been released—including some fuels not currently used in the European Union. The proposal assigns one fixed value for all crude oils with the exception of those produced from oil sands, which are also referred to as tar sands.[1] This one fixed value is inaccurate, because crude oils vary widely in their GHG emissions. The term *oil sands* refers to sand covered with water, bitumen, and clay, specifically that in western Canada (see the box "Canadian Oil Sands Primer"). The Canadian oil sands are one of the most important energy investment destinations in the world. Owing to growth in oil sands supply, Canada currently ranks sixth in global oil production. Over the next decade oil sands production is expected to double, potentially putting Canada within the top five crude oil suppliers globally. Essentially all oil sands are processed and consumed in North America. They are widely considered an important contributor to energy security and to the world's ability to withstand an oil shock. Crudes derived from oil sands are not exported to the European Union nor are they expected to be in the future.[2] This raises the question of why oil sands are separated from other crude oil sources in the draft EU GHG intensity values. The proposal does not explain this—or the reason that GHG emissions from other crude oils are not identified.

Differentiating only oil sands crudes is controversial, since it does not include any means to account for conventional crude oils that have GHG emissions similar to the oil sands. In any case, conventional and unconventional designations are not necessarily good indications of life-cycle GHG intensity, particularly for conventional sources with high emissions from gas venting and flaring.

## MEASURING LIFE-CYCLE GHG CALCULATIONS

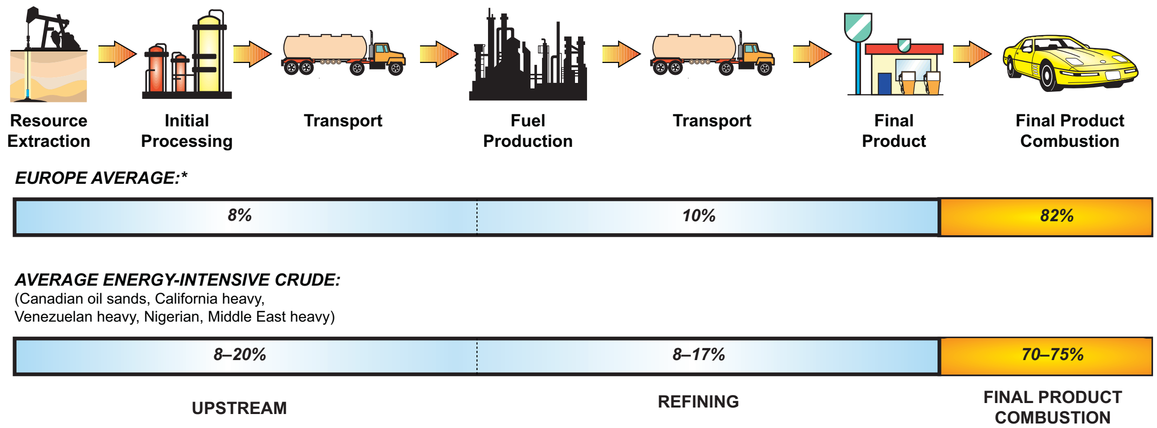
Measuring life-cycle GHG emissions for a transportation fuel is also known as a "well-to-wheels" analysis. Figure 1 illustrates the stages of the life cycle that factor into calculating the GHG emissions for petroleum fuels. A potential benefit of the well-to-wheels approach is that it allows emissions comparison among fuels with very different emission profiles. For instance, the GHG emission profile for a fuel used in a purely electric vehicle—which does not emit carbon dioxide ($CO_2$) from the tailpipe—is different from that for oil, natural gas, or biofuels. Electricity generation from a fossil fuel does emit GHG, but at stages preceding the final consumption of the energy in a vehicle.

Different fuels—oil, biofuels, gas, or electricity—have different life-cycle profiles. But in addition to life-cycle differences among different fuels, there are significant differences within an individual fuel category. Figure 1 compares the average GHG emissions profiles for crude consumed in Europe and for more carbon-intense crudes. Moreover, GHG emissions resulting from production of a single crude oil are not constant over time. More energy is needed to produce oil from more mature fields, although the extent of this increase varies

1. 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). Page 16 lists proposed default values. In addition to oil sands, the proposal includes unique GHG emission values for other unconventional supplies such as gas-to-liquids and coal-to-liquids.
2. This is based on existing and potential future market outlets for the Canadian oil sands in the United States and Asia; oil sands crudes are not expected to be transported to Europe. Some quantities of diesel fuel derived from oil sands could arrive in Europe through transatlantic trade of refined products. However, as diesel from all crude oil sources is chemically the same, identifying and tracking these volumes would be difficult.

**Figure 1**

**Life-cycle GHG Emissions for Petroleum Fuels**




Source: IHS CERA.
Note: Blue = well-to-retail tank.
*Europe baseline production emissions from "Upstream greenhouse gas (GHG) emissions from Canadian oil sands as a feedstock for European refineries", Stanford University, Adam Brandt (January, 2011), transportation, refining, and fuel combustion emissions using data consistent with IHS CERA meta analysis.
10207-2_1204

among fields. For the oil sands, GHG emissions are far from static. Since 1990 the GHG intensity of mining operations has fallen by 37 percent (on a well-to-retail pump basis); since the inception of SAGD (a decade ago), well-to-retail pump emissions have declined 8 percent per barrel.[1] In measuring GHG intensity for crude oil and the products derived from them, there is no "one size fits all."

Substantially reducing life-cycle GHG emissions from petroleum fuels is challenging. These fuels are inevitably burned, which releases $CO_2$, and the combustion stage accounts for 70 to 80 percent of the total life-cycle emissions. For this reason, the reduction in life-cycle GHG intensity must occur upstream of the vehicle in the oil production, refining, and transportation steps—the portion of the life cycle known as well-to-retail tank. To achieve the EU 6 percent emissions reduction target, petroleum fuels would need to achieve a 20 to 30 percent decrease in well-to-retail tank emissions. Even if emissions from venting and flaring in oil and gas production could be eliminated and the energy efficiency of production improved, this level of reduction from petroleum fuels is not achievable. Consequently, compliance with the LCFS would require lower-carbon alternative transportation fuels—such as biofuels, electricity, hydrogen, or natural gas—to be substituted for higher-carbon petroleum. In the next decade, we expect the numbers of alternative-fuel vehicles (such as electric cars, hydrogen cars, or natural gas vehicles) to be limited, so the EU LCFS compliance will be accomplished mostly with biofuels. In this case, the LCFS and the EU biofuels mandate are duplicative.

1. See the IHS CERA Special Report *Oil Sands Technology: Past, Present, and Future.*

## Canadian Oil Sands Primer

The immensity of the oil sands resource is its signature feature. Current estimates place the amount of oil that can be economically recovered from Alberta's oil sands at 170 billion barrels. Although oil sands are not exported to the European Union, the fact that these reserves would be large enough to meet Europe's demand for more than 30 years gives a sense of their magnitude.*

The oil sands are grains of sand covered with water, bitumen, and clay. The "oil" in the oil sands comes from bitumen, extra-heavy oil with high viscosity. Given their black and sticky appearance, the oil sands are also referred to as "tar sands." (Tar, however, is a man-made substance derived from petroleum or coal.) Oil sands are produced by both surface mining and in-situ thermal processes.

- **Mining.** About 20 percent of currently recoverable oil sands reserves lie close enough to the surface to be mined. In a strip-mining process similar to coal mining, the overburden (primarily soils and vegetation) is removed and the oil sands layer is excavated using massive shovels. The sand is then transported by truck, shovel, or pipeline to a processing facility. Slightly more than half of today's production is from mining, and we expect this proportion to be roughly steady through 2030.
- **In-situ thermal processes.** About 80 percent of the recoverable oil sands deposits are too deep to be mined and are recovered by drilling methods. Thermal methods inject steam into the wellbore to lower the viscosity of the bitumen and allow it to flow to the surface. Such methods are used in oil fields around the world to recover very heavy oil. Two thermal processes are used widely in oil sands today: steam-assisted gravity drainage (SAGD) and cyclic steam stimulation (CSS). SAGD accounted for about 18 percent of oil sands production in 2009 and is expected to increase to more than 40 percent by 2030. CSS was used for about 16 percent of oil sands production in 2009 and is expected to decline to less than 10 percent by 2030. Innovations in thermal recovery methods have reduced the amount of energy needed to recover bitumen, and such innovations are likely to continue in the future.
- **Primary.** The remainder of production is primary, or cold flow. Primary made up about 15 percent of oil sands production in 2009 and is expected to decline to less than 5 percent by 2030.

Raw bitumen is solid at ambient temperature and cannot be transported in pipelines or processed in conventional refineries. It must first be diluted with light oil liquid or converted into a synthetic light crude oil. The two most common products derived from oil sands are

- **Upgraded bitumen.** Synthetic crude oil (SCO) is produced from bitumen in refinery conversion units that turn very heavy hydrocarbons into lighter, more valuable fractions. Although SCO can be sour, typically SCO is a light, sweet crude oil with no heavy fractions, with API gravity typically greater than 33 degrees. Currently over 90 percent of SCO production comes from mining operations.
- **Bitumen blend, or diluted bitumen (dilbit),** is bitumen mixed with a diluent, typically a natural gas liquid such as condensate. This is done to make the mixed product "lighter," lowering the viscosity enough for the dilbit to be shipped in a pipeline. Some refineries would need modifications to process large amounts of dilbit feedstock because it requires more heavy oil conversion capacity than most crude oils. Dilbit is also lower quality than most crude oils, containing higher levels of sulfur and aromatics. Today the large majority of bitumen blend is derived from in-situ thermal operations.

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*Assumes that average European petroleum demand for the next 30 years is less than 15 million barrels per day.

## Variance and Challenges in Life-cycle GHG Estimates

The idea of using life-cycle emissions to compare the GHG intensity of energy sources is attractive, but there are significant practical challenges to implementing LCFS in a manner consistent with the aim of the policy. Accurate comparisons of GHG intensity require a great deal of high-quality data combined with a comprehensive understanding of fuel production processes.

Given the differences in the data used and the types of inputs considered, evaluating and comparing life-cycle GHG emissions of fuels is complex. Estimates attained from rules of thumb or broad assessments can be helpful for general discussion but are not specific enough to support sound public policy.

Inconsistencies in study results arise from a variety of sources:

- **Data quality, availability, and modeling assumptions.** Often the data used in well-to-wheels analysis are average values or numbers estimated from limited sources. The assumptions about key data and calculations are often not transparent and differ substantially among the various models and studies.

  Data quality and availability for many international crude sources pose an additional challenge. Without accurate and verifiable data, some sources of crude oil, such as Canadian oil sands, could be unduly penalized for being more transparent about their GHG emissions than other sources. If policies that target well-to-wheels emissions use inaccurate assumptions, instead of reducing emissions they could instead shift emissions to countries or sectors with mischaracterized levels of GHG emissions. Today Europe imports crude oil from over 30 countries, and most of these countries provide multiple types of crude oil; ensuring that the data are high quality and available from all locations would be a formidable effort.

- **Allocation of emissions to coproducts.** Well-to-wheels analysis often requires attributing emissions from a process to multiple outputs of that process. Depending on how emissions are allocated to each product, the emissions for a specific product (gasoline, diesel, light petroleum gases, exported power, or even petroleum coke) can vary substantially. Allocation of emissions among numerous refinery products is a key challenge in well-to-wheels analysis, and studies vary greatly in their assumptions. Some conclude that the emissions from refining gasoline are five times higher than the emissions for refining diesel, whereas others find that emissions from refining these two products are almost the same. The difference stems from the assumptions that each study makes about refinery configuration and how to allocate emissions across the various refined products. Including emissions from all products (such as emissions per barrel of all refined products, as used in the IHS CERA analysis) reduces an important source of uncertainty in comparing various study results.

- **System boundary.** Estimates of well-to-wheels emissions require a system boundary—a determination of which emissions are counted and which are not. In estimating the GHG emissions for petroleum, the system boundary is often drawn tightly around the production facilities and the refinery. Emissions directly attributable to production are included, but studies vary on whether they include secondary or indirect emissions. Direct emissions beyond the facility gate are not included in our analysis, nor are indirect emissions. As an example, IHS CERA's life-cycle analyses of oil sands include the GHG emitted when natural gas is combusted to heat water to remove bitumen from the sands, but emissions resulting from the production of natural gas used in the steam boiler are not included (direct off-site emissions), nor are emissions resulting from construction and fabrication of the boilers where the heating occurs (indirect emissions).

## IHS CERA'S META-ANALYSIS

The IHS CERA Special Report meta-analysis *Oil Sands, Greenhouse Gases, and US Oil Supply* (first published in September 2010 and updated here for Europe) puts multiple studies into a consistent framework with the goal of providing a broader comparison than any single study. The Appendix of this Special Report describes IHS CERA's methodology and sources for calculating life-cycle GHG emissions for oil sands and conventional crude oils, as well as the method for estimating the EU "average crude" baseline.

The challenge of accurately estimating life-cycle GHG emissions is reflected in the wide range of results across the 12 studies analyzed. Estimates of well-to-retail tank emissions for specific crudes varied by as much as 45 percent (or 10 percent on a life-cycle or well-to-wheels basis). This variance is more than the 6 percent reduction that the EU LCFS policy requires. The variance among estimates reflects the level of uncertainty in estimating life-cycle GHG emissions and highlights a key challenge in regulating LCFS policies.

In the development of the IHS CERA meta-analysis, we consulted groups representing a wide range of perspectives. The participants—which represented the Canadian and US governments, regulators, oil companies, shipping companies, academia, and nongovernmental organizations—either participated in a focus group meeting or reviewed a draft version of the original report.

To download the original September 2010 study IHS CERA Special Report *Oil Sands, Greenhouse Gases, and US Oil Supply* (including a full list of report reviewers and participants), plus other IHS CERA oil sands research, please visit www2.cera.com\oilsandsdialogue.

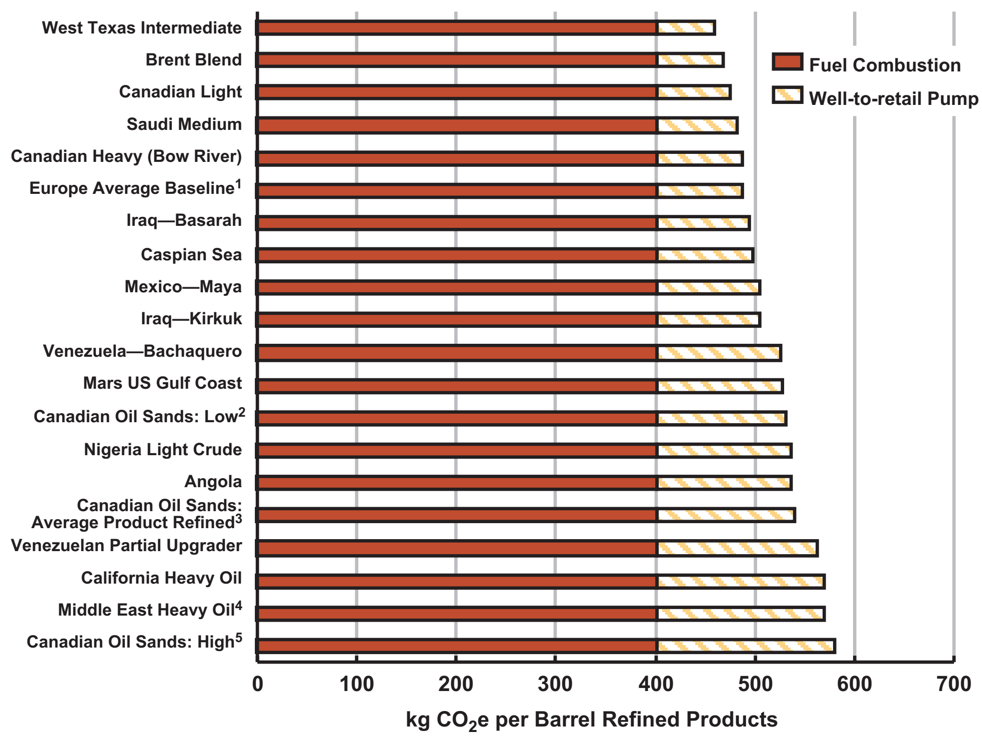
### Comparing Oil Sands Emissions to That of Other Crude Oils

IHS CERA found that on a life-cycle basis, the emissions from refined products wholly derived from oil sands are 10 to 20 percent higher than the estimated average for crudes consumed in Europe. These bookend values represent a 10 percent average for the lowest GHG emissions method (mining) and a 20 percent average for the highest emissions in-situ production method (CSS). They are not meant to encompass the entire range of possible oil sands emissions but merely to provide industry average values suitable for comparison to other sources of crude oil. Oil sands life-cycle GHG emissions are similar to current European imports from Venezuela, Angola, and Nigeria and steam-assisted recovery from the Middle East, which constitute about 6 percent of current supply (see Figure 2 and Table

1).[1] The European Union's current proposal for regulating the LCFS assumes that oil sands have life-cycle emissions 23 percent higher than the default crude—a measurement that is higher than our results. When considering the incremental emissions from oil sands, it is worth considering which oil sands products are likely to be transported to and ultimately refined in Europe. As discussed above, bitumen in its pure form is too thick to transport. Consequently it is shipped as a lower-carbon dilbit blend consisting of bitumen and lighter hydrocarbons. Another option is upgrading the bitumen to SCO. Although SCO can be

**Figure 2**

**Well-to-wheels Greenhouse Gas Emissions for Oil Sands and Other Crudes**




Source: IHS CERA meta analysis of past studies: DOE/NETL 2008, GHGenius, McCann (update 2007), Jacobs-AERI (July 2009), TIAX-AERI (July 2009), RAND (2008), GREET, Syncrude 2007, Shell (2006), CAPP 2008, Suncor 2007, IHS CERA.

1. Europe baseline production emissions from "Upstream greenhouse gas (GHG) emissions from Canadian oil sands as a feedstock for European refineries," Stanford University, Adam Brandt (January, 2011)," transportation, refining, and fuel combustion emissions using data consistent with IHS CERA meta-analysis.
2. Canadian Oil Sands Low is bitumen produced from mining.
3. Average oil sands refined product, considers the mix of supply that can be transported and processed at a refinery—based on 2009 supply data (25% SAGD dilbit, 22.5% CSS dilbit, 48.5% SCO mining, 4% SCO SAGD).
4. Steam injection is used for production.
5. Canadian Oil Sands: High is bitumen produced from CSS.

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1. For the first eight months of 2010 (the most recent data available). Crude data were sourced from the European Commission Market Observatory for Energy (Registration of Crude Oil Imports and Deliveries in the European Union).

**Table 1**

**Well-to-wheel GHG Emissions for Oil Sands and Conventional Crude Oils Compared to Europe Baseline**

($kgCO_2e$ per barrel refined products)

| | Well-to-retail Pump | Well to Wheels | Difference from "Average European Crude Consumed" (percent) | Component of Europe's Supply? |
|---|---|---|---|---|
| Canadian Oil Sands: High[1] | 179 | 581 | 19 | |
| Middle East Heavy Oil[2] | 169 | 571 | 17 | yes |
| California Heavy Oil | 169 | 571 | 17 | |
| Venezuelan Partial Upgrader | 161 | 563 | 15 | yes |
| Canadian Oil Sands: Average Product Refined[3] | 139 | 541 | 11 | |
| Angola | 135 | 537 | 10 | yes |
| Nigeria Light Crude | 135 | 537 | 10 | yes |
| Canadian Oil Sands: Low[4] | 129 | 531 | 9 | |
| Mars US Gulf Coast | 126 | 528 | 8 | |
| Venezuela—Bachaquero | 125 | 527 | 8 | yes |
| Iraq—Kirkuk | 104 | 506 | 4 | yes |
| Mexico—Maya | 103 | 505 | 3 | yes |
| Caspian Sea | 97 | 499 | 2 | yes |
| Iraq—Basarah | 93 | 495 | 1 | yes |
| Europe Average Baseline[5] | 87 | 489 | 0 | |
| Canadian Heavy (Bow River) | 86 | 488 | (0) | |
| Saudi Medium | 80 | 482 | (1) | yes |
| Canadian Light | 73 | 475 | (3) | |
| Brent Blend | 68 | 470 | (4) | yes |
| West Texas Intermediate | 58 | 460 | (6) | |

Source: IHS CERA, meta analysis of past studies DOE/NETL 2008, GHGenius, McCann (update 2007) , Jacobs-AERI (July 2009), TIAX-AERI (July 2009), RAND (2008), GREET, Syncrude 2007, Shell (2006), CAPP 2008, Suncor 2007.
1. Canadian Oil Sands: High is bitumen produced from CSS.
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5. Europe baseline production emissions from "Upstream greenhouse gas (GHG) emissions from Canadian oil sands as a feedstock for European refineries, Stanford University, Adam Brandt (January, 2011)," transportation, refining, and fuel combustion emissions using data consistent with IHS CERA meta-analysis.

produced from mining or in-situ operations, over 90 percent of production comes from lower-carbon mining operations. Therefore the average oil sands product shipped to refineries has GHG emissions 11 percent higher than the estimated emissions for the average crude processed in the European Union.

The EU average crude GHG intensity baseline is uncertain. First, the baseline uses country-level emissions estimates. The margin of error associated with a country-level estimate is larger than for any individual crude oil source, owing to the numerous crude oils produced within each country and the difficulties of modeling and finding data for each crude type. The lack of country-level data for many European crude oil suppliers is a second source of error. No specific GHG emissions data were available for countries representing 35 percent of EU crude supply, and default values were assigned for these locations (see the Appendix for more details on the EU baseline calculation). If this country-level approach were applied to western Canadian crude oil, the average upstream emissions would be lower than the average GHG emissions assumed for Angola and Nigeria in the baseline calculation.

Though Europe currently imports crude oils with life-cycle GHG emissions similar to those of oil sands, the EU proposed method groups these other high-carbon crudes in the "conventional" category—providing one life-cycle figure for all crude oils, regardless of their GHG intensity. This appears to be an arbitrary decision that does not represent the reality of world oil supply; it's akin to differentiating crudes from offshore and onshore production, or crudes that are produced east of a given longitude.

Though the majority of European crude supply is light or medium in density, this does not necessarily imply lower carbon. A number of European crude oil supplies (including those from Nigeria, Russia, and Kazakhstan) have higher-than-average life-cycle GHG emissions from flaring (see Figure 3).[1] Though IHS CERA's meta-analysis included a life-cycle GHG emission estimate for Nigeria (which was within the range of oil sands), no prior studies included emissions estimates for Kazakhstan, and Russian data are limited. The two latter countries provide over 30 percent of EU oil supply.[2] Considering the elevated venting emissions in these countries, life-cycle emissions for their crudes could be near or in the range of those from oil sands. Figure 3 shows country-level data for flaring emissions only; it does not include venting or fugitive emissions, which are included in the estimates provided in Figure 2.

## CONCLUSION

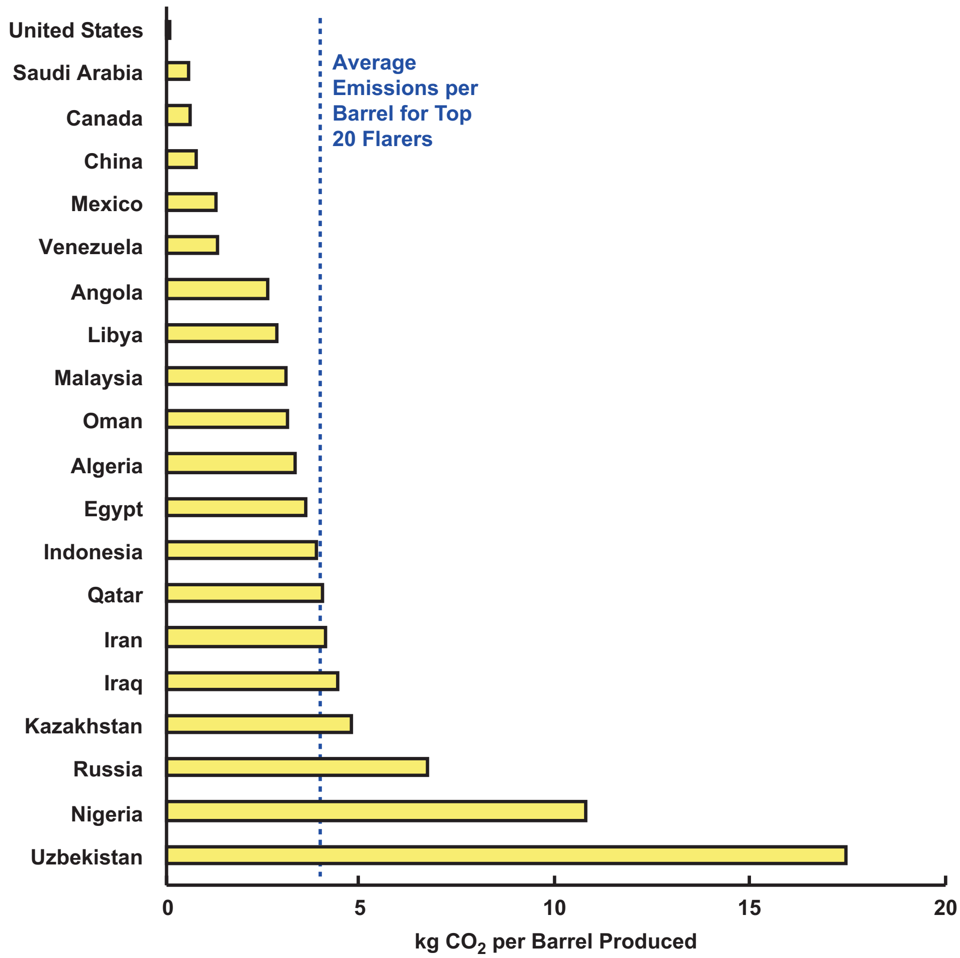
The European Union's LCFS aim to reduce the life-cycle GHG emissions from fuel used in "road transport and non-road mobile machinery." A policy framework that includes recognition of the range of life-cycle GHG emissions of various crude oils would help to achieve the LCFS goals. Conversely, a LCFS policy that does not treat higher-GHG crudes equally, or one that mischaracterizes the GHG emissions from specific fuels, would work against the policy's goal of reducing GHG emissions.

Based on our meta-analysis, on a life-cycle basis the emissions from refined products wholly derived from oil sands are 10 to 20 percent higher than the average for the crudes consumed in Europe. Although not imported to Europe (nor expected to be in the future), oil sands crudes have life-cycle GHG emissions similar to those of other imports—from Venezuela, Angola, and Nigeria and steam-assisted recovery from the Middle East. In the hypothetical

1. Average is defined as the average for the group in the Top Twenty Gas Flaring Countries identified in the World Bank 2009 flaring estimate.
2. For the first eight months of 2010 (the most recent data available). Crude data are sourced from the European Commission Market Observatory for Energy (Registration of Crude Oil Imports and Deliveries in the European Union).

**Figure 3**

**Crude Production Flaring Emissions, 2009**




Source: World Bank Global Gas Flaring Volume Estimates from Satellite Data (2009—Top 20 Countries); 2009 oil production data from IEA.
10410-2

case that oil sands would be imported to Europe, the average oil sands product transported to the refinery would have emissions 9 to 11 percent higher than the European average.

Data quality and availability for many international crude sources pose a challenge to comparing emissions among crude sources. Without accurate and verifiable data, some sources of crude oil, such as Canadian oil sands, could be unduly penalized for being more transparent about their GHG emissions than other sources. If policies that target well-to-wheels emissions use inaccurate assumptions, instead of reducing emissions they could instead shift emissions to countries or sectors with mischaracterized levels of GHG emissions. Transparency is considered a positive characteristic. But it appears that Canadian oil sands are being penalized for being more transparent about their GHG emissions than other sources. Additionally, a one-time estimate of emissions does not take innovation into account: oil sands operators have invested and continue to invest tremendous effort in reducing their GHG emissions.

LCFS are charting a new path in helping governments reach GHG-related policy objectives. Though it takes time to formulate an effective and appropriate policy to allow for data collection and verification and to ensure that all crude sources are accurately characterized, this effort would enhance policy objectives instead of working against them.

# APPENDIX: IHS CERA'S META-ANALYSIS FOR EUROPEAN BASELINE

## IHS CERA METHOD AND SOURCES

In our meta-analysis of 12 separate sources IHS CERA aims to create a common framework to compare the life-cycle emissions of oil sands and other sources of crude oil.[1] We consider the results of each study on an "apples-to-apples" basis by converting them to common units and common system boundaries. We also normalize assumptions across studies to come up with a best estimate of emissions for the various crudes. Some studies calculate only part of the well-to-wheels emissions. To compare the sources on a well-to-wheels basis, emissions for each step in crude oil processing—including crude production, crude transportation, refining, and product distribution—are required. Studies were also put on the same unit basis (some were on a per-barrel-of-gasoline basis and others were on a per-barrel-of-diesel or -of-crude basis).

## UNIT OF MEASURE: GHG EMISSION COMPARISON (KILOGRAMS [KG] OF CARBON DIOXIDE EQUIVALENT [$CO_2E$] PER BARREL OF REFINED PRODUCTS)

We express GHG emissions in units of kilograms of carbon dioxide equivalent (kg $CO_2e$) per barrel of refined product produced. (The definition of refined products is explained in the section Fuel Combustion GHG Emissions.) Some life-cycle analysis studies report GHG emissions on the basis of one barrel of crude oil, gasoline, or diesel. For the studies that reported emissions on a single refined product basis, we used the original studies' assumptions about refined product yields to convert the emissions to a total barrel of refined products basis.

## APPLYING NORMALIZED VALUES: IHS CERA'S BEST ESTIMATE OF WELL-TO-RETAIL TANK GHG EMISSIONS

To ensure uniformity in crude oil comparisons in Figure 2, we normalized the data as described below.

1. IHS CERA has updated the GHG meta-analysis originally published in May 2009 with data from two recent studies commissioned by Energy and Environment Solutions, Alberta Innovates (formerly Alberta Energy Research Institute): *Life Cycle Assessment Comparison of North American and Imported Crudes,* Jacobs Consultancy, July 2009; and *Comparison of North American and Imported Crude Oil Life-cycle GHG Emissions,* TIAX LCC, July 2009. Other data sources include DOE/NETL: "Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emissions of Petroleum-Based Fuels," November 2008; McCann and Associates: "Typical Heavy Crude and Bitumen Derivative Greenhouse Gas Life Cycles," November 2001; RAND: "Unconventional Fossil-Based Fuels: Economic and Environmental Trade-Offs," 2008; NEB: "Canadian Oil Sands: Opportunities and Challenges," 2006; CAPP: "Environmental Challenges and Progress in Canada's Oil Sands," 2008; GREET: Version 1.8b, September 2008; GHGenius: 2007 Crude Oil Production Update, Version 3.8; Syncrude: "2009/10 Sustainability Report"; Shell: "The Shell Sustainability Report, 2006"; and IHS CERA data.

## Crude Production

Estimates of production GHG emissions were derived from the results of the 12 studies. Where multiple studies analyzed the same crude, we used the average value for production-related GHG emissions across the studies. If a particular crude source was analyzed in only one study, we used the value from that study directly.

Table A-1 contains a list of the crude oils we considered, our best estimate of the upstream GHG emissions for each crude, and the range of emissions estimates for each crude from the various studies.

### Calculating the Baseline for Crude Oil Processed in Europe

To establish a baseline, we used the average of production-phase GHG emissions for crudes processed in Europe from a paper by Brandt.[1] Brandt calculated EU volume-weighted average production emissions of 4.83 grams of carbon dioxide ($gCO_2$) per megajoule (converted to our basis, 29.5 kg $CO_2$ per barrel).[2] The EU average value was based on country-level emission estimates; it is an estimate of the average oil production emissions and not a precise number. The margin of error associated with this estimate is larger than for any individual crude oil source owing to the numerous crude oils produced within each country and the difficulties of modeling and finding data for each crude type.

The lack of country-level data for some European crude oil suppliers is a second source of error. We assigned default values to 8 of the 19 countries used in the baseline calculation (or 35 percent of crude supply), since no specific GHG emissions data were available (see Table A-2). If this country-level approach were applied to western Canadian crude oil, the average upstream emissions would be 53 kg $CO_2e$ per barrel of oil produced, lower than the average GHG emissions assumed for Angola and Nigeria in the European baseline calculation.[3]

Russia supplies nearly 30 percent of EU crude; however only one emissions estimate is available and it is at the country level (from DOE/NETL).[4] Considering the high level of gas flaring in Russia (based on World Bank flaring volume estimates), estimate for Russian emissions from DOE/NETL could be low (used in the baseline calculation; see Table A-2).

## Crude Transportation

All 12 original studies were based on a US location for refining and marketing. Therefore, crudes were always assumed to be transported from their origin to the US market. The

1. Adam Brandt, *Upstream greenhouse gas (GHG) emissions from Canadian oil sands as a feedstock for European refineries,* Stanford University, January, 2011. This paper used data from the US Department of Energy (DOE)/National Energy Technology Laboratory (NETL) report *An evaluation of the extraction, transport and refining of imported crude oils and the impact on life cycle greenhouse gas emissions* (2009).
2. This calculation uses a standard conversion of 6.1 gigajoule per barrel of crude oil.
3. In 2009 western Canadian crude oil production was approximately 9 percent oil sands bitumen produced using cold flow, 27 percent SCO from mining, 3 percent SCO from SAGD, 9 percent bitumen from CSS, 11 percent bitumen from SAGD, 17 percent heavy conventional, and 24 percent light conventional.
4. For the first eight months of 2010 (the most recent data available). Crude data are sourced from the European Commission Market Observatory for Energy (Registration of Crude Oil Imports and Deliveries in the European Union).

**Table A-1**

**Summary of Crude Production GHG Emissions, Average Values, and Sources**

(kg of $CO_2e$ per barrel of refined products)

| | Average Crude Oil Production and Upgrading | Range of Crude Oil Production | Sources |
|---|---|---|---|
| Canadian Oil Sands: CSS Bitumen | 83 | | TIAX-AERI (July 2009) (assumes SOR of 3.35) |
| Canadian Oil Sands: SAGD SCO (Coker) | 116 | 76–133 | TIAX-AERI (July 2009), McCann 2007, GREET, GHGenius, RAND 2008, Jacobs-AERI 2009, CAPP 2008 |
| Middle East Heavy Oil[1] | 98 | | IHS CERA (steam injection assumed) |
| Venezuelan Partial Upgrader | 103 | | McCann (update 2007) |
| Canadian Oil Sands: SAGD Bitumen | 69 | 56–80 | TIAX-AERI (July 2009), McCann 2007, GREET, GHGenius, RAND 2008, Jacobs-AERI 2009 (equivalent to SOR of 3) |
| California Heavy Oil | 85 | 63–102 | Jacobs-AERI 2009, TIAX-AERI 2009, IHS CERA |
| Canadian Oil Sands: Mining SCO (Coking) | 80 | 34–122 | TIAX-AERI (July 2009), McCann 2007, GREET, GHGenius, RAND 2008, Jacobs-AERI 2009, Syncrude 2009/10, Shell 2006, NEB(2008), CAPP 2008 |
| Angola | 82 | | DOE/NETL 2008 |
| Nigeria Light Crude | 82 | 68–93 | McCann 2007, Jacobs AERI 2009, TIAX AERI 2009 |
| Canadian Oil Sands: Mining Bitumen | 33 | 23–42 | TIAX-AERI (July 2009), McCann 2007, GREET, GHGenius, RAND 2008, Jacobs-AERI 2009, Syncrude 2009/10, Shell 2006, NEB(2008, CAPP 2008 |
| Canadian Oil Sands: SAGD Dilbit | 50 | | Calculated assuming 70% bitumen and 30% natural gas condensate (8 kgCO2e/bbl assumed for production of condensate) |
| Venezuela—Bachaquero | 41 | 31–53 | Jacobs-AERI 2009, TIAX-AERI 2009 |
| Canadian Oil Sands: Mining Dilbit | 26 | | Calculated assuming 70% bitumen and 30% natural gas condensate (8 kgCO2e/bbl assumed for production of condensate) |
| Iraq—Kirkuk | 51 | | Jacobs-AERI 2009 |
| Mexico—Maya | 32 | 16–43 | DOE/NETL 2008, Jacobs-AERI 2009, TIAX-AERI 2009 |
| Caspian Sea | 47 | | IHS-CERA |
| Saudi Medium | 13 | 1–25 | DOE/NETL 2008, Jacobs-AERI 2009 |
| Canadian Heavy (Bow River) | 15 | | TIAX-AERI 2009 |
| Canadian Light | 20 | | McCann (update 2007) |
| Alaska North Slope | 4 | | TIAX-AERI (July 2009) |
| Brent Blend | 18 | | McCann (update 2007) |

Source: IHS CERA.

Note: All CCS oil sands assume SOR of 3.35. All SAGD oil sands assume SOR of 3.

1. Steam injection is used for production.

**Table A-2**

**Country-level Data for European Baseline Production GHG Emissions**

| Region | Upstream GHG Emissions (kg$CO_2$e per barrel produced) | Volume Fraction of EU Crude Input |
|---|---|---|
| Unspecified EU production[1] | 25.62 | 0.148 |
| Russian Federation | 33.55 | 0.209 |
| Norway | 6.1 | 0.163 |
| Saudi Arabia | 14.03 | 0.095 |
| Libya[1] | 42.7 | 0.068 |
| Iran[1] | 42.7 | 0.056 |
| United Kingdom | 14.64 | 0.056 |
| Nigeria | 128.71 | 0.032 |
| Algeria | 35.38 | 0.027 |
| Kazakhstan[1] | 42.7 | 0.022 |
| Iraq | 20.13 | 0.022 |
| Denmark[1] | 25.62 | 0.016 |
| Syria[1] | 42.7 | 0.016 |
| Mexico | 39.04 | 0.015 |
| Kuwait | 16.47 | 0.012 |
| Venezuela | 24.4 | 0.011 |
| Azerbaijan[1] | 42.7 | 0.010 |
| Angola | 82.35 | 0.008 |
| Cameroon[1] | 42.7 | 0.009 |
| Egypt[1] | 42.7 | 0.005 |
| Brandt weighted average | 29.5 | |

Source: Brandt study.
1. These countries did not have a country-level GHG estimate, and a default value was applied.

**Table A-3**

**Summary of Crude Transportation GHG Emissions, Average Values, and Sources**

(kg $CO_2$e per barrel of refined products)

| | Average Crude Oil Transportation | Range of Crude Oil Transportation | Sources |
|---|---|---|---|
| Crude transported within the Continent (Europe or Caspian regions) | 5.5 | 1 to 14 | TIAX-AERI 2009, Jacobs-AERI 2009, McCann 2007, DOE/NETL 2008 |
| Crude transported from rest of the world | 9.1 | 4 to 14 | TIAX-AERI 2009, Jacobs-AERI 2009, McCann 2007, DOE/NETL 2008 |

Source: IHS CERA.

studies included a wide range of estimates for crude transport emissions. IHS CERA normalized the transportation emissions across sources of crude oil by grouping sources into two groups—overseas and North American crudes—and calculating an average value for each group (see Table A-3).

Applying these average values to Europe, the crudes transported from within Europe and the Caspian regions were assigned the "local" value, and crudes from other geographic areas were assigned the overseas value. This is a simplification, since the transport emissions from within Europe and overseas likely vary somewhat from those in North America. However, as transportation emissions make up less than 1 percent of total well-to-wheels emissions, this simplification does not cause a notable change in the relative results.

This method resulted in an estimate of average crude oil transportation emissions for crudes processed in Europe of 8 kg$CO_2$e per barrel of refined products.

## Refining

IHS CERA categorized data on the GHG emissions resulting from refining into six categories of crude oil: light conventional, medium conventional, heavy conventional, extra heavy conventional, SCO, and bitumen. We calculated the average refining emission values for each crude group using estimates from the studies, then used these average values for the IHS CERA meta-analysis (see Table A-4). These average values are an oversimplification of the complexity associated with refining. In reality refining emissions depend on the type of refinery in which the crude is processed, the volume and quality of various refined products produced, and the crude feedstock.

Although the average values are simplified, they do not introduce a significant amount of error on a well-to-wheel basis. The difference in the total well-to-wheels emissions between processing heavy crude in a complex refinery versus refining light crude in a simple refinery is less than 2 to 3 percent. Additionally, without normalizing the values to be consistent across the crudes compared, the results of our comparison could be skewed because the various study authors made different assumptions about refinery complexity.

Taking into account the mix of crudes processed in Europe, we estimate European baseline refining emissions of 47 kg$CO_2$e per barrel of refined products.[1]

For the European analysis, differences between European and North American refineries introduce an additional source of uncertainty. In Europe the refined product mix, refinery complexity, and refinery configurations are different from those in North America. Therefore the average European refining emissions are expected to be slightly different from the US values. However, refining emissions generally make up about 10 percent of well-to-wheels emissions and adjusting to a European basis only affects a fraction of this value; plus all of the crudes would require the same relative adjustment to a new (likely lower) European refining basis. Therefore the error is not expected to make a material change in the relative results.

1. For the first eight months of 2010 (the most recent data available), EU crude densities were 2 percent extra heavy, 8 percent heavy, 23 percent medium, and 69 percent light. Crude data are sourced from the European Commission Market Observatory for Energy (Registration of Crude Oil Imports and Deliveries in the European Union).

**Table A-4**

**Summary of Crude Refining GHG Emissions, Average Values, and Sources**

| | Average "Crude Refining ($kgCO_2e$ per barrel of refined products) | Range of Crude Refining ($kgCO_2e$ per barrel of refined products) | Sources |
|---|---|---|---|
| Light conventional crude (greater than 32 API) | 42 | 30–60 | TIAX-AERI 2009, Jacobs-AERI 2009, McCann 2007 |
| Medium conventional crude (greater than 26 API to 32) | 56 | 44–67 | TIAX-AERI 2009, Jacobs-AERI 2009, McCann 2007, DOE/NETL 2008 |
| Heavy conventional crude (greater than 20 API to 26) | 60 | 47–65 | TIAX-AERI 2009, Jacobs-AERI 2009, DOE/NETL 2008 |
| Extra heavy (less than 20 API) | 73 | 67–79 | TIAX-AERI 2009, Jacobs-AERI 2009 |
| SCO | 47 | 32–64 | GREET, GHGenius, RAND 2008, CAPP 2008, TIAX-AERI 2009, Jacobs AERI 2009, NEB 2008 |
| Bitumen | 85 | | Jacobs AERI 2009 |
| Dilbit | 70 | | Calculated assuming 70 percent bitumen and 30 percent natural gas condensate (30 $kgCO_2e$ per barrel assumed for refining of condensate) |

Source: IHS CERA.

## Refined Product Distribution

The range of estimates for the GHG emissions associated with the distribution of refined products from the refinery to the retail tank varied little among the studies. We used a consistent value across all crude oil sources in our best estimate (see Table A-5).

## Fuel Combustion GHG Emissions

For Europe we assumed an average refined product slate of 50 percent diesel/distillate, 25 percent gasoline, 10 percent gas liquids, and 15 percent residual fuel oil.[1]

In addition to liquid products, refineries also yield petroleum coke, a byproduct of creating the refined products. Coke can be used for a variety of applications, but the most typical use is in power generation. Because the petroleum coke is a byproduct of the refined products, and it is a substitute for using coal in power generation, the emissions from burning coke are not included in the combustion emissions within this analysis. There are some incremental

1. Source: Historical refined product data for Europe from the International Energy Agency.

emissions from substituting petroleum coke for coal in power generation, but for the purposes of this comparison the difference is not material enough to have an impact on the results.

To estimate the combustion emissions for one barrel of refined products, the emissions for each product were apportioned to the mix of products produced (see Table A-6). Combustion emissions for the EU baseline averaged 402 $kgCO_2$ per barrel of refined products—82 percent of the well-to-wheels total for the average EU crude.

Table A-7 shows the well-to-wheels emissions values presented in Figure 2 of this study. This table includes all sources of crude considered, including those that are not part of the European baseline.

**Table A-5**

**Summary of Refined Product Distribution GHG Emissions, Average Values, and Sources**

| | Average Crude Oil Refining ($kgCO_2e$ per barrel of refined products) | Range of Crude Oil Refining ($kgCO_2e$ per barrel of refined products) | Sources |
|---|---|---|---|
| Distribution from refinery to point of sale | 2.1 | 2–2.6 | TIAX-AERI 2009, Jacobs-AERI 2009, DOE/NETL 2008 |

Source: IHS CERA.

**Table A-6**

**Combustion Emissions for Refined Products**

($kgCO_2e$ per barrel of refined product)

| | |
|---|---|
| Gasoline | 375 |
| Diesel/distillate | 422 |
| Residual fuel oil | 495 |
| Gas liquids | 231 |
| Weighted average emissions (full barrel of products) | 402 |

Source: IHS CERA.

## Table A-7

## Summary of Well-to-wheels GHG Emissions for Oil Sands and Conventional Crudes

($kgCO_2e$ per barrel of refined product)

| | Crude Production | Crude Upgrading | Crude Transport | Crude Refining | Distribution of Refined Products | Fuel Combustion | Well-to-retail Pump | Well to Wheels | Percent Difference from Average Europe Crude Consumed | Component of Europe Supply? |
|---|---|---|---|---|---|---|---|---|---|---|
| Canadian oil sands: CCS bitumen[1] (HIGH) | 83 | 0 | 9.1 | 85 | 2.1 | 402 | 179 | 581 | 19 | |
| Canadian oil sands: SAGD SCO (coker) | 69 | 47 | 9.1 | 47 | 2.1 | 402 | 174 | 576 | 18 | |
| Middle East heavy oil[2] | 98 | 0 | 9.1 | 60 | 2.1 | 402 | 169 | 571 | 17 | yes |
| California heavy oil | 85 | 0 | 9.1 | 73 | 2.1 | 402 | 169 | 571 | 17 | |
| Canadian oil sands: SAGD bitumen | 69 | 0 | 9.1 | 85 | 2.1 | 402 | 165 | 567 | 16 | |
| Venezuelan partial upgrader | 103 | 0 | 9.1 | 47 | 2.1 | 402 | 161 | 563 | 15 | yes |
| Canadian Oil Sands: CSS Dilbit[1] | 60 | 25 | 9.1 | 70 | 2.1 | 402 | 141 | 543 | 11 | |
| Canadian oil sands: average refined product[3] | 45 | 47 | 9.1 | 58 | 2.1 | 402 | 139 | 541 | 11 | |
| Canadian oil sands: mining SCO | 33 | 0 | 9.1 | 47 | 2.1 | 402 | 138 | 540 | 11 | |
| Angola | 82 | 0 | 9.1 | 42 | 2.1 | 402 | 135 | 537 | 10 | yes |
| Nigeria light crude | 82 | 0 | 9.1 | 42 | 2.1 | 402 | 135 | 537 | 10 | yes |
| Canadian oil sands: SAGD dilbit | 50 | 0 | 9.1 | 70 | 2.1 | 402 | 131 | 533 | 9 | |
| Canadian oil sands: mining bitumen (LOW) | 33 | 0 | 9.1 | 85 | 2.1 | 402 | 129 | 531 | 9 | |
| Mars US Gulf Coast | 59 | 0 | 9.1 | 56 | 2.1 | 402 | 126 | 528 | 8 | |
| Venezuela—Bachaquero | 41 | 0 | 9.1 | 73 | 2.1 | 402 | 125 | 527 | 8 | yes |
| Canadian oil sands: mining dilbit | 26 | 0 | 9.1 | 70 | 2.1 | 402 | 107 | 509 | 4 | |
| Iraq—Kirkuk | 51 | 0 | 9.1 | 42 | 2.1 | 402 | 104 | 506 | 4 | yes |
| Mexico—Maya | 32 | 0 | 9.1 | 60 | 2.1 | 402 | 103 | 505 | 3 | yes |
| Caspian Sea | 47 | 0 | 5.5 | 42 | 2.1 | 402 | 97 | 499 | 2 | yes |
| Iraq—Basarah | 26 | 0 | 9.1 | 56 | 2.1 | 402 | 93 | 495 | 1 | yes |
| Europe average baseline[4] | 29.5 | 0 | 8 | 47 | 2.1 | 402 | 87 | 489 | | |
| Canadian heavy (Bow River) | 15 | 0 | 9.1 | 60 | 2.1 | 402 | 86 | 488 | 0 | |
| Saudi medium | 13 | 0 | 9.1 | 56 | 2.1 | 402 | 80 | 482 | (1) | yes |
| Canadian light | 20 | 0 | 9.1 | 42 | 2.1 | 402 | 73 | 475 | (3) | |
| Alaska North Scope | 4 | 0 | 9.1 | 56 | 2.1 | 402 | 71 | 473 | (3) | |
| Brent blend | 18 | 0 | 5.5 | 42 | 2.1 | 402 | 68 | 470 | (4) | yes |
| West Texas Intermediate | 5 | 0 | 9.1 | 42 | 2.1 | 402 | 58 | 460 | (6) | |

Source: IHS CERA, meta analysis of past studies DOE/NETL 2008, GHG Genius McCann (update 2007), Jacobs-AERI (July 2009), TIAX-AERI (July 2009), RAND (2008), GREET, Syncrude 2007, Shell (2006), CAPP 2008, Suncor 2007, IHS CERA.

1. Assumes SOR of 3.35 and no electricity export (source for production AERI TIAX).
2. Steam injection is used for production.
3. Average product is based on 2009 supply data (25 percent SAGD dilbit, 22.5 percent CSS dilbit, 48.5 percent SCO mining, 4 percent SCO SAGD).
4. Europe baseline production emissions from "Upstream greenhouse gas (GHG) emissions from Canadian oil sands as a feedstock for European refineries, Standford University, Adam Brandt (January 2011)", transportation, refining, and fuel combustion emissions using data consistent with IHS CERA meta-analysis.

Note: All SAGD crude production cases assume a steam-oil ratio of 3. All oil sands cases marked "Dilbit" assume that the diluent is confirmed in the refinery, with no recycle of diluents back to Alberta, and only 70 percent of the barrel is from oil sands. All oil sands cases marked ""Bitumen"" assume that the diluent is recycled back to Alberta, and all of the barrel processed at the refinery is from oil sands. All SCO cases assume 12 percent loss in upgrading, and therefore 12 percent more bitumen must be produced at the well head or mine.