NATIONAL ENERGY TECHNOLOGY LABORATORY

Consideration of Crude Oil Source in Evaluating Transportation Fuel GHG Emissions

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Introduction

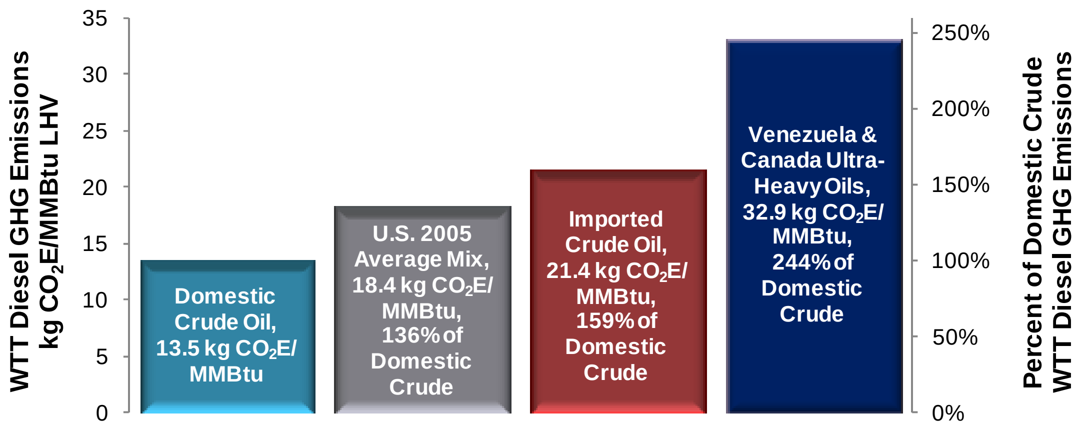
The National Energy Technology Laboratory (NETL) has estimated the life cycle greenhouse gas (GHG) emissions for petroleum-based fuels consumed in the U.S. for the baseline year 2005 consistent with the definition of "baseline lifecycle greenhouse gas emissions" in the Energy Independence and Security Act of 2007 (EISA 2007). The full life cycle GHG emissions for diesel fuel are 95.0 kg CO_2E/MMBtu LHV[1] which is comprised of 18.4 kg CO_2E/MMBtu for well-to-tank (WTT) activities and 76.7 kg CO_2E/MMBtu for combustion of fuel in the vehicle.

Further analysis reveals that diesel fuel from imported crude oil results in WTT[2] GHG emissions that are, on average, 59% higher than diesel from domestic crude oil as shown in Exhibit 1. Furthermore, diesel fuel from Canada and Venezuela ultra-heavy crude oil – a subset of the imported crude oil used as feedstock to U.S. petroleum refineries in 2005 – has WTT GHG emissions 144% higher than diesel from domestic crude oil.

Trends in exploration and production point to future growth in these heavy crude oil sources which demand more energy to extract and refine. It is possible that subjecting alternative fuels to year 2005 average GHG emissions limits could result in an overall increase in GHG emissions. Furthermore, some alternative fuels have societal benefits other than GHG emissions including reduced trade deficit, increased domestic jobs, and improved energy security.

This report provides a high-level summary of the results for (1) baseline life cycle GHG emissions from transportation fuels and (2) the impact of crude oil source on GHG emissions for production of fuels. Additional details on the modeling approach and findings of each analysis are contained on the NETL web-site: www.netl.doe.gov/energy-analyses.

Exhibit 1. Diesel Fuel WTT GHG Emission Profiles for Crude Oil-Specific Sources (Year 2005)



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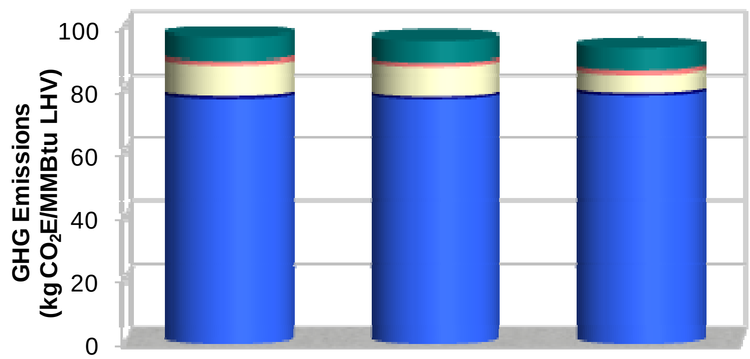
[1] Results are in kilograms carbon dioxide equivalents (kg CO_2E) per million British Thermal Units (MMBtu) on a lower heating value (LHV) basis. Carbon dioxide (CO_2), methane and nitrous oxide were the GHGs determined to have environmental relevance to the life cycle GHG emissions of petroleum-based transportation fuels. The 2007 Intergovernmental Panel on Climate Change 100-year global warming potentials were used to convert methane and nitrous oxide to CO_2E.

[2] WTT GHG emissions are associated with activities for production of the fuel (excludes fuel combustion in the vehicle or aircraft) and make up 20% or less of the total life cycle well-to-wheels/wake GHG emissions. For this analysis, comparisons are made on a WTT basis as the GHG emissions from combustion of petroleum-based fuels are not expected to be impacted by crude oil source.

Baseline Life Cycle Greenhouse Gas Emissions for Transportation Fuels

NETL has estimated the life cycle GHG emissions for petroleum-based fuels consumed in the U.S. for the baseline year 2005. The results of this analysis are shown in Exhibit 2 for gasoline, diesel and jet fuel. Results are presented by life cycle stage and in terms of WTT and well-to-wheels/wake (WTW) GHG emissions. WTT GHG emissions are associated with activities for production of the fuel (from extraction of the crude oil to delivery of the fuel to the vehicle or aircraft) and make up 20% or less of the total life cycle WTW GHG emissions profile. Combustion of the fuel in the vehicle or aircraft accounts for the remaining 80% or more of the WTW GHG emissions.

Exhibit 2. Baseline Well-to-Wheels/Wake Life Cycle Greenhouse Gas Emissions for Petroleum Transportation Fuels Sold or Distributed in the U.S. in the Year 2005 (kg CO_2E/MMBtu LHV)



	Key	Life Cycle Stage	Conventional Gasoline[3]		Conventional Diesel[4]		Kerosene-Type Jet Fuel[5]	
Well-to-Wheels/Wake; Well-to-Tank		Crude Oil Extraction[6]	7.3	8%	6.6	7%	6.8	7%
Well-to-Wheels/Wake; Well-to-Tank		Crude Oil Transport[6]	1.4	1%	1.3	1%	1.3	1%
Well-to-Wheels/Wake; Well-to-Tank		Refinery Operations	9.8	10%	9.5	10%	6.0	6%
Well-to-Wheels/Wake; Well-to-Tank		Finished Fuels Transport	1.1	1%	0.9	1%	1.0	1%
Well-to-Wheels/Wake		Combustion of Fuel	76.6	80%	76.7	81%	77.7	83%
		Total: Well-to-Tank (WTT)	19.9	20%	18.4	19%	15.1	16%
		Total: Well-to-Wheels/Wake (WTW)	96.3	100%	95.0	100%	92.9	100%

3 Conventional gasoline excludes oxygenates.

4 Conventional diesel fuel excludes all distillate with greater than 500 parts per million (ppm) sulfur. Note that ultra-low sulfur diesel specifications requiring sulfur content of less than 10 ppm were not in place in 2005.

5 Kerosene-type jet fuel does not include aviation gasoline or kerosene.

6 Also included are the GHG emissions associated with acquisition of natural gas liquids and unfinished oils. These two components made up approximately 6% of the input to U.S. refineries in 2005.

The development and analysis of the 2005 baseline GHG emissions is fully detailed in the NETL Petroleum Baseline report.[7] Key methodology and data sources for activities with the greatest influence on the life cycle GHG emissions for production and use of the fuels are discussed here.

Crude oil extraction (7-8% of WTW GHG emissions):

- Conventional crude oil was modeled using country-specific GHG emissions data from PE International.[8]
- Extraction and pre-processing of Canadian oil sands were evaluated independent of conventional Canadian crude oil and applied to the estimated quantity processed by U.S. refineries in 2005.[9]

Refining operations (6-10% of WTW GHG emissions):

- GHG emissions from acquisition and combustion of fuel in the refinery and from acquisition of purchased power, steam and hydrogen are included.
- Total emissions from refinery operations were derived primarily from Energy Information Administration (EIA) data on reported fuels consumption in 2005.[10]
- Total GHG emissions for refinery operations were allocated between all refinery co-products at the refinery process unit level based on estimates of energy and hydrogen requirements for each fuel.[11]

Combustion of fuel (80-84% of WTW GHG emissions):

- The 2005 average GHG emissions from gasoline and diesel fuel combustion in passenger vehicles were calculated by the U.S. Environmental Protection Agency's (EPA), Office of Transportation and Air Quality, Motor Vehicle Emissions Simulator (MOVES).
- Reported GHG emissions associated with combustion of jet fuel in an aircraft are consistent with the U.S. Federal Aviation Administration and the Intergovernmental Panel on Climate Change methodology.

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[7] Skone, T., Gerdes, K., *Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emissions of Petroleum-Based Fuels,* U.S. Department of Energy, National Energy Technology Laboratory, November 2008.

[8] Country-specific crude oil extraction emissions profiles purchased and extracted through *GaBi 4.0 Life Cycle Assessment Software – Professional Database,* PE International GmbH. Germany, 2007.

[9] GHG emissions profile for Canadian oil sands was developed from data reported by the primary oil sands producers to Environment Canada for year 2005. Volume of Canadian oil sands to the U.S. in 2005 was obtained from the Canadian National Energy Board.

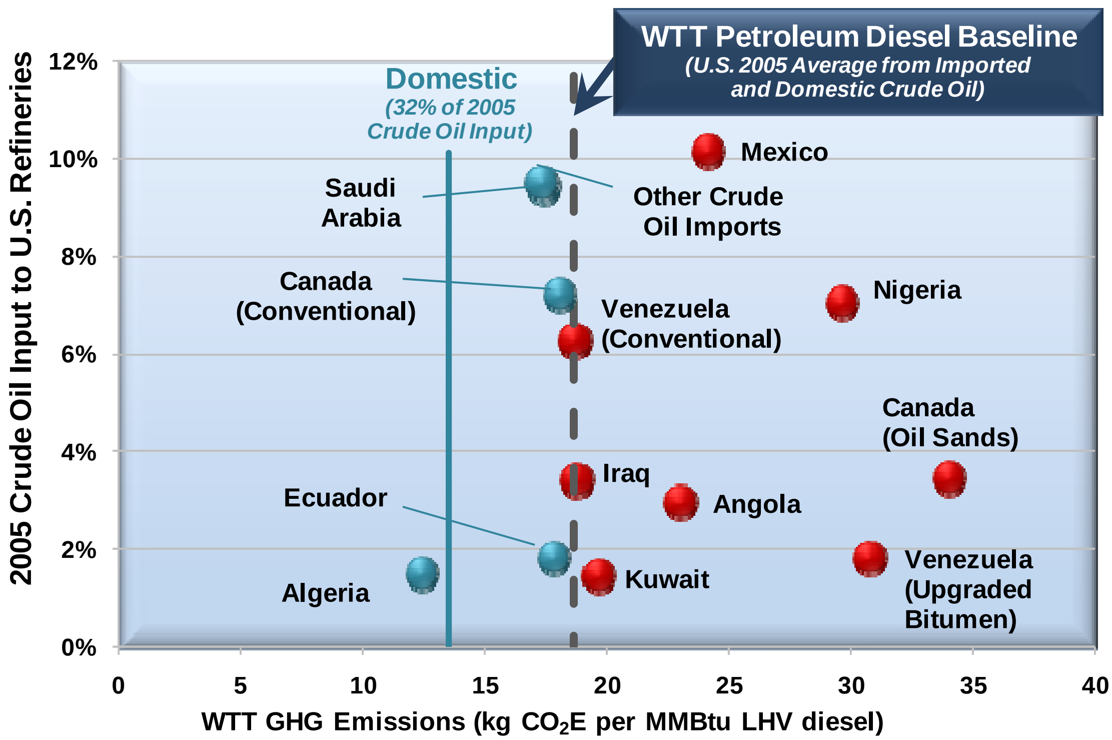
[10] 2005 fuels consumption is reported by (EIA). Fuels combustion emissions factors are primarily from the American Petroleum Institute (API). GHG emissions for acquisition of natural gas for refinery fuel and hydrogen production extracted are from *GaBi 4.0 Life Cycle Assessment Software – Professional Database,* PE International GmbH. Germany, 2007.

[11] 2005 process unit capacities as reported by U.S. refineries to the EIA were combined with Energetics 2007 report on process unit energy consumption and a variety of sources to divide total GHG emissions between co-products.

Impact of Crude Oil Source on GHG Emissions for Production of Fuels

Building on the baseline study, NETL has analyzed the full life cycle GHG emissions of transportation fuels derived from domestic crude oil and crude oil imported from specific countries. Heuristics were used to approximate the contribution of these sources to the NETL Petroleum Baseline for the year 2005, Exhibit 3. This analysis reveals that diesel fuel from imported crude oil results in WTT[12] GHG emissions that are, on average, 59% higher than diesel from domestic crude oil (21.4 vs. 13.5 kg CO_2E/MMBtu LHV). Imported crude oils are on average heavier and contain higher levels of sulfur, and the controls on venting and flaring during crude oil production are not as good as in domestic operations. Exhibit 3 shows that Venezuela bitumen, Canada oil sands, and Nigeria stand out as having high GHG emissions compared to other sources. Acquisition costs of the crude oil from these three sources are estimated at $62 billion for 2008[13].

Exhibit 3. Crude Oil Source-Specific WTT GHG Emissions for Production of Diesel



[12] For this analysis, comparisons are made on a WTT basis as the GHG emissions from combustion of petroleum-based fuels are not expected to be impacted by crude oil source. For alternative liquid transportation fuels, the GHG emissions for combustion may vary from that of petroleum-based fuels depending on the carbon content relative to the energy content of the fuel.

[13] $62 billion is based on estimated 2008 refiner acquisition costs for this combined stream at $95/bbl. Average West Texas Intermediate crude oil spot price of $100/bbl for 2008 has dropped to $39/bbl for February 2009.

The following activities were addressed in evaluating the impact of crude oil source on WTT GHG emissions:

- Flaring and/or venting of associated natural gas during the crude oil extraction process
- Alternative crude oil extraction techniques and pre-processing requirements required for oil sands and bitumen
- Ocean transport distances for delivery of crude oil
- Varying processing requirements within the refinery for crude oils of different quality

Exhibit 4 provides the resulting WTT GHG emissions for diesel production divided into the key activities that are influenced by crude oil source. Differences between crude oil extraction practices have the greatest upward impact on the WTT GHG emissions by crude oil source with less variation due to refining and transport requirements.

Exhibit 4. Crude Oil Source-Specific GHG Emissions for Diesel

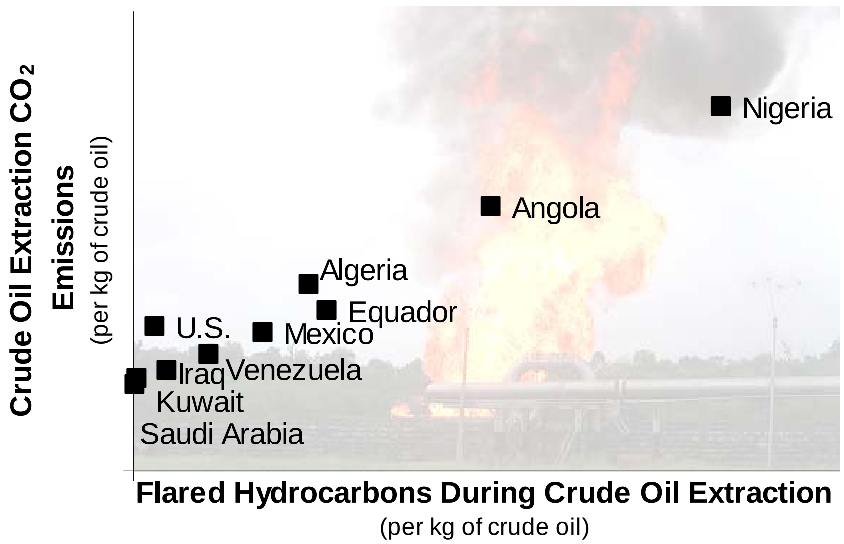
Crude Oil Source	Crude Oil Extraction and Pre-Processing	Crude Oil Transport	Diesel Refining Operations	Finished Fuel Transport	Total Well-to-Tank
	kg CO_2E/MMBtu LHV diesel				
Canada Oil Sands	19.0	0.9	13.2	0.8	34.0
Venezuela Bitumen	16.3[14]	1.1	12.5	0.8	30.8[14]
Nigeria	22.0	1.7	5.1	0.8	29.7
Mexico	6.6	1.0	15.7	0.8	24.1
Angola	14.0	1.9	6.3	0.8	23.0
Kuwait	2.8	2.7	13.2	0.8	19.6
Iraq	3.3	2.7	11.8	0.8	18.7
Venezuela Conventional	4.1	1.1	12.5	0.8	18.6
Baseline WTT[15]	***6.6***	***1.3***	***9.5***	***0.9***	***18.4***
Canada Conventional	6.0	0.9	10.3	0.8	18.0
Ecuador	5.3	1.7	9.9	0.8	17.8
Saudi Arabia	2.3	2.7	11.6	0.8	17.4
Domestic	4.2	0.7	7.7	0.8	13.5
Algeria	6.0	1.5	4.0	0.8	12.4

[14] The GHG emissions estimate for extraction and pre-processing of Venezuela bitumen has greater uncertainty that other crude sources due to limited data availability. Uncertainty analysis provides a 90% confidence interval of 11 to 20 kg CO_2E/MMBtu LHV diesel for extraction and pre-processing and 25 to 35 kg CO_2E/MMBtu LHV of diesel for the WTT GHG emissions. The total effect of this uncertainty on the baseline WTT is less than 1%.

[15] The baseline includes imported transportation fuels to the U.S. in 2005 and does not incorporate the new Venezuelan upgraded bitumen acquisition profile. The impact of the new Venezuela profile on the 2005 national average baseline WTW GHG emissions profile for each fuel is less than 0.5%.

Exhibit 5 depicts the impact of flaring on the CO_2 emissions for crude oil extraction. A similar relationship exists for venting of natural gas and methane emissions during crude oil extraction. These emissions are higher for Nigeria and Angola because the limited dispositions for the associated natural gas in these areas results in the majority being flared or vented during crude oil production.

Exhibit 5. Crude Oil Extraction CO_2 Emissions Dependence on Associated Natural Gas Flaring



Unconventional crude oil sources including Canadian oil sands and Venezuela's ultra heavy crude bitumen require energy intensive extraction processes and pre-processing that result in GHG emissions several times greater than that for extraction of conventional crude oil. Data on Canadian oil sands operations and associated GHG emissions are readily available and were used in the baseline analysis; however, data on energy requirements or GHG emissions for Venezuela's ultra heavy oil/crude bitumen production is limited. Utilizing public information comparing the two unconventional crude oil sources, uncertainty analysis was conducted to develop a 90% confidence interval for the GHG emissions from extraction and pre-processing of the Venezuela bitumen. The predicted interval for extraction and pre-processing GHG emissions for Venezuela bitumen in 62 to 120 kg CO_2E/bbl of crude oil. The mean value of 95 kg CO_2E/bbl falls below that of the Canadian oil sands (112 kg CO_2E/bbl). This is expected as the lower viscosity of the Venezuela bitumen makes it easier to extract.

The GHG emissions associated with crude oil transport requirements are three times greater for crude oil from the Middle East than that for domestic and other North American imports. However, since the crude oil transport accounts for 7% of the WTT GHG emissions, the impact on the variability of the WTT GHG emissions is not as significant as for other activities. For the Middle East crude oils, the greater transport GHG emissions are generally offset by the low extraction GHG emissions for these crude oils.

The GHG contribution from refinery operations is dependent on the crude oil characteristics of the source country. Heuristics developed in this study, primarily from historical refining data, allowed for gross estimation of the relationship between refinery processing requirements and API gravity and sulfur content. The 2005 baseline analysis provided estimated GHG emissions associated with unit processes, such as vacuum distillation, coking and hydrogen production impacted by API gravity or sulfur content of the crude oil. API gravity and sulfur content of imported crude oil is reported by the Energy Information Administration (EIA). Exhibit 6 shows how API gravity and sulfur content are predicted to impact the diesel GHG emissions for refinery operations using the derived heuristics. Base operations are those that are not expected to be significantly impacted by API gravity or sulfur content. Algeria and Mexico are used as representative light, low sulfur and heavy, high sulfur crude oils, respectively.

Exhibit 6. Crude Oil Quality Impact on GHG Emissions for 2005 Diesel Refinery Operations