



WA-GREET 0.6a Supplemental Document and Tables of Changes

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March 8, 2022

Prepared under contract for the Washington Department of Ecology

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Contents

1. Introduction.....	3
2. Summary of Changes.....	4
WA-GREET model.....	4
Simplified Tier1 Calculators	5
3. Petroleum Products.....	6
Crude Refining	6
Petroleum Fuels Refining.....	8
4. Electricity	10
5. Appendix A: WA Baseline Crude Analysis.....	14
Introduction	14
Summary.....	14
Crude Oil Sources.....	16
Crude Oil CI Values	18
6. Appendix B: Crude CI Lookup table	21
7. Disclaimer.....	26

List of Tables and Figures

Table 1. Average Washington Crude CI.....	7
Table 2. OPGEE Based 2017 Baseline Crude CI.....	8
Table 3. Key Input Parameters for State-wise 2017 Baseline Petroleum Fuels CI.....	9
Table 4. Comparison of Electricity Subregions in WA-GREET model.....	11
Table 5. Allocation of WA Fuel Mix Disclosure to GREET Resource Categories	12
Table 6. Fuel Shares for Grid Mix Subregions Added to WA-GREET.....	13
Table 7. 2018 WAMX Fuel Shares for Electricity from "Other" Resources.....	13
Table 8. Crude Oil Inputs to Washington Refineries, 2017	16
Table 9. Crude Oil Inputs to Montana Refineries, 2017	16
Table 10. Crude Oil Inputs to Utah Refineries, 2017	17
Table 11. Washington Crude Sources and Carbon Intensity, 2017	19
Table 12. Montana Crude Sources and Carbon Intensity, 2017	19
Table 13. Utah Crude Sources and Carbon Intensity, 2017	20
Table 14. Crude CI Lookup table for 2017 Washington Crude	21
Figure 1. Baseline Crude Oil Average Calculation Methodology	15

1. Introduction

The Washington Clean Fuels Standards (CFS) uses a “well-to-wheel” life cycle analysis (LCA) to calculate the carbon intensity (CI) of all transportation fuels. To determine each fuel pathway’s CI, the greenhouse gas (GHG) emissions from all steps in the fuel’s life cycle are summed, adjusted to carbon dioxide equivalent (CO₂e), and divided by the fuel’s energy content in megajoules. Carbon intensity is expressed in terms of grams of CO₂ equivalent per megajoule (gCO₂e/MJ).

The CIs are calculated based on a modified version of the CA-GREET3 model, developed by California Air Resources Board (CARB) to support the California Low Carbon Fuels Standards¹. CA-GREET3 model was developed by CARB by progressive modification to the GREET1 model² developed by Argonne National Laboratory (ANL). ANL publishes yearly updated version of GREET1 model. CA-GREET3 model was based on GREET1_2016 model.

Oregon Department of Environmental Quality (DEQ), during the development of Oregon’s Clean Fuels Program, adopted the latest available CA-GREET model and modified it to develop Oregon specific OR-GREET model³. Washington Department of Ecology followed similar approach to modify the latest available CA-GREET3 model to develop a Washington specific WA-GREET model. This model functions as the basis of CI calculation of the baseline fuels as well as low carbon fuel pathways to be developed under the Washington Clean Fuels Standards program.

This document provides the function of supporting documentation for WA-GREET. For more background information, please refer to the available documentation for GREET1_2016⁴ and CA-GREET⁵ models should. This document provides details of the modifications made to the CA-GREET3 version to create the WA-GREET model.

In addition to development of WA-GREET, 8 simplified tier1 calculators were also developed for the Washington CFS. For this purpose, the simplified tier1 calculators from California’s LCFS were re-adopted and modified to align with the developed WA-GREET model.

¹ See LCFS Life Cycle Analysis Models and Documentation (<https://ww2.arb.ca.gov/resources/documents/lcfs-life-cycle-analysis-models-and-documentation>)

² See ANL GREET1 (Fuel-Cycle) Models (https://greet.es.anl.gov/greet_1_series)

³ See Oregon CFP Carbon Intensity Values (<https://www.oregon.gov/deq/ghgp/cfp/Pages/Clean-Fuel-Pathways.aspx>)

⁴ See CA-GREET3.0 Supplemental Document and Tables of Changes at CARB Website, see footnote 1

⁵ See Summary Updates for GREET1_2016 (PDF) available at <https://greet.es.anl.gov/files/summary-updates-2016>

2. Summary of Changes

WA-GREET model

This section describes the summary of major modifications made to the CA-GREET3.0 model to develop the Washington specific WA-GREET model. Majority of the structure, flow, and standard values from CA-GREET3 have been retained in WA-GREET. Most of the changes pertain to modifying the parameters specific to the Washington, for example addition of a new grid mix region for average Washington grid. The following list highlights the key details about the WA-GREET and crucial modifications made to CA-GREET3.0. Details are included in the following sections.

- Total two new electricity mix regions were added. One mix represents the Washington's average grid mix based on WA Disclosure data available at Washington Department of Commerce website⁶. The Oregon grid mix directly from OR-GREET3 was adopted as the second new grid mix region to allow better alignment across the two programs. This makes the total subregions in WA-GREET to 32. Additional details are included in the section 4 below.
- The baseline year for the Washington CFS program is 2017, as specified in the regulation. For the baseline crude, the crude oil CI values developed by CARB using the Oil Production Greenhouse Gas Emission Estimator (OPGEE2.0)⁷ model were adjusted for transport to Washington. The Washington specific crude slate for 2017 was used. Carbon intensity calculation for gasoline and diesel refining are based on US average gasoline and diesel refining inputs originally included in the model by ANL. The Washington electricity mix for 2017 is used for baseline CI values. WA-GREET uses 2017 as the target simulation year (on Inputs sheet) for the baseline CI calculations. This is described in more detail in section 3 of this document.
- Except for the calculation of the baseline gasoline, diesel, and jet CI values, WA-GREET uses 2018 as the baseline year to accommodate the latest available Washington electricity grid mix from 2018. The fuel shares for the 2018 Washington grid mix were also calculated based on the Washington fuel mix disclosure data.
- No changes have been made to the transportation distance for petroleum fuels from existing values in CA-GREET3.0 due to unavailability of state specific data.
- The EF sheet in CA-GREET consists of reduced form emission factors (EF) as calculated in the model for easier export of EF to the tier 1 simplified calculators. Additions were made to this section to include more of the key emission factors, to make future updates of simplified calculators easier, and to add transparency to the standard values that go into the tier 1 calculators.

⁶ WA Fuel Mix Disclosure Data, <https://www.commerce.wa.gov/growing-the-economy/energy/fuel-mix-disclosure/>

⁷ See LCFS Crude Oil Life Cycle Assessment | California Air Resources Board (<https://ww2.arb.ca.gov/resources/documents/lcfs-crude-oil-life-cycle-assessment>).

- 2 additional copies of WA-GREET were further modified to model the CI of diesel and gasoline imported into Washington from Montana and Utah. These versions are not intended for biofuel pathway CI calculations. More details are included in the Petroleum section of this document.

Simplified Tier1 Calculators

The following is the list of all the 8 simplified tier1 calculators developed for the Washington CFS program.

- Starch and Fiber Ethanol (WA-tier1-sfe-calculator.xlsm)
- Sugarcane-derived Ethanol (WA-tier 1-sugarcane-etoh-calculator.xlsm)
- Biodiesel and Renewable Diesel (WA-tier1-bdrd-calculator.xlsm)
- LNG and L-CNG from North American Fossil Natural Gas (WA-tier1-nang-calculator.xlsm)
- Biomethane from North American Landfills (WA-tier1-lfg-calculator.xlsm)
- Biomethane from Anaerobic Digestion of Wastewater Sludge (WA-tier1-wws-calculator.xlsm)
- Biomethane from Anaerobic Digestion of Dairy and Swine Manure (WA-tier1-dsm-calculator.xlsm)
- Biomethane from Anaerobic Digestion of Organic Waste (WA-tier1-ow-calculator.xlsm)

The following list includes the major changes to the tier1 calculators

- Washington and Oregon grid mix regions were added to the list of available electricity region selection in calculators where applicable. Emission factor for these were based calculated in WA-GREET.
- All standard existing emission factors were updated to match the corresponding EF as calculated in WA-GREET. In most cases, the change was minor.
- All California state specific standard emission factors in the calculators were updated to reflect Washington state specific EF (using 2018 Washington electricity mix in WA-GREET).
- A few of the standard EF which used in the calculator but were not represented on the EF Tables sheet were added to the sheet and were used as reference in the calculator. This allows for a more consistent flow of calculation and easier update to the standard values in the calculators.

3. Petroleum Products

This section summarizes the approach for estimating Washington baseline crude CI, and subsequently the CI of Washington gasoline, diesel, and jet. Although the state is an overall net exporter of refined products, some gasoline and diesel are imported from Montana and Utah into eastern Washington. The most recent available pipeline transfer data⁸ indicate that 6% of diesel consumed in Washington is refined in Montana and transported to Washington via the Yellowstone pipeline and 10% is refined in Utah and transported via the Tesoro pipeline.

Crude Refining

The petroleum fuels imported into the state from Montana and Utah were also incorporated in the baseline petroleum fuels CI values. First, a separate average crude CI values was calculated for Washington, Montana as well as Utah each. This was achieved by adjusting the 2017 Annual Crude CI analysis by CARB under California Crude. For more details on the calculation, crude CI lookup table, and intermediate steps, please refer to the “WA Baseline Crude Analysis Memo” included as an appendix to this document. A summary of the crude CI analysis is included in this section. For additional details on data sources and intermediate calculations, please refer to the “WA baseline crude CI analysis” included as Appendix A. This analysis was an update of a 2014 study conducted by Life Cycle Associates to assess average Washington Crude CI using the same approach as intended for Washington CFS.

The analysis relied on California crude oil CI values developed with the Oil Production Greenhouse Gas Emission Estimator (OPGEE2.0) model adjusted for transport to Washington by mode. The Washington crude oil mix was established using DOE’s Energy Information Administration (EIA) data⁹ combined with refinery survey data from the Washington Research Council. Given that EIA does not report crude imports by oil field, the average CI was calculated by volume-weighting California crude oil volumes consumed in 2017 under the LCFS program for foreign crude oil sources. This represents only about 8% of the crude oil input for Washington. The other major sources of crude including Alaska North Slope and North Dakota Bakken had only one CI in OPGEE, therefore no additional calculations were needed.

Canadian crude oil can be derived from oil sands and upgraded before introducing it to the pipeline or it can be conventional crude oil. For this analysis and in the absence of field-specific data, this analysis utilized methodology implemented by the Oregon Department of Environmental Quality (DEQ) during 2015 baseline crude oil CI determination in support of the Oregon Clean Fuels Program (CFP). The list of 60+ Canadian oil fields in OPGEE was first separated into oil sands vs conventional crude and their CI values were averaged separately for each category. Transportation distance adjustments were then applied using appropriate seas distance and rail calculators.

⁸ 2013 data provided by Hedia Adelman, Washington State Department of Ecology

⁹ EIA Company Level Imports sorted for Washington refineries,
<https://www.eia.gov/petroleum/imports/companylevel>

The CI value for each crude oil source was adjusted for the difference in the transportation distance to Washington instead of California using OPGEE2.0 emission factors for crude oil transport by mode. Similar approach was followed to estimate the Crude CI for refineries in Montana and Washington.

The estimated average Washington crude CI is shown in the table below.

Table 1. Average Washington Crude CI

Location/Country	Share ¹⁰	Mode	CA CI	Distance Adjustment	WA CI
North Dakota	23%	Rail	9.73	-1.03	8.70
US Alaska	35%	Vessel	15.91	-0.16	15.75
CANADA (Conventional)	24%	Mixed	8.40	-0.10	8.30
CANADA (Oil Sands)	10%	Mixed	23.88	-0.10	23.79
ANGOLA	0%	Vessel	8.12	0.16	8.28
ARGENTINA	0%	Vessel	10.15	0.16	10.31
BRAZIL	3%	Vessel	5.86	0.16	6.02
ECUADOR	0%	Vessel	9.36	0.16	9.52
GHANA	0%	Vessel	8.08	0.16	8.24
MEXICO	0%	Vessel	7.51	0.16	7.66
NIGERIA	0%	Vessel	17.27	0.16	17.43
RUSSIA	1%	Vessel	9.39	0.00	9.39
SAUDI ARABIA	2%	Vessel	9.18	0.16	9.34
TRINIDAD AND TOBAGO	1%	Vessel	7.41	0.16	7.57
BRUNEI	0%	Vessel		n/a	n/a
PAPUA NEW GUINEA	0%	Vessel		n/a	n/a
Average WA Crude CI					12.56

¹⁰ Source: For domestic sources, WA Research Council, Economic Profile, Feb 2019. For foreign sources, EIA Company Level Imports, <https://www.eia.gov/petroleum/imports/companylevel>

Petroleum Fuels Refining

In addition to US average crude, gasoline, and diesel CI calculations, CA-GREET3 model also includes separate CI calculation for California average crude recovery, California gasoline (CA RFG), and California ultra-low sulfur diesel. The results from these do not affect the any other GREET model results or emission factor calculation.

In the WA-GREET model, the California specific crude, gasoline, and diesel modelling sections in CA-GREET3 were modified to represent Washington specific crude, gasoline, and diesel. For both WA gasoline and WA diesel, the refining parameter and inputs were modified to use the corresponding parameters and inputs from the existing US average gasoline and US low sulfur diesel refining respectively. No changes were made to jet refining parameters and inputs. This was coupled with the selection of 2017 as target simulation year in the model and 2-WAMX as the electricity mix for both feedstock and fuel region.

Next step was to align the Crude CI results as calculated by WA-GREET model with the calculated OPGEE based WA crude CI value. This was achieved by adjusting the WA crude recovery energy efficiency until the modelled crude CI value closely matched the externally calculated WA crude CI. This results in the WA-GREET calculating the average CI value for gasoline, diesel and jet produced in Washington.

The Crude CI values for MT and UT were similarly implemented in separate copies of WA_GREET model. 4-NWPP electricity mix was used in these versions of WA-GREET models as both Montana and Utah are part of the NWPP e-grid subregion. The CI values for gasoline and diesel from these models represent the CI of gasoline and diesel imported into Washington from Montana and Utah respectively for 2017 baseline year.

The three independent gasoline and diesel CIs can potentially be combined into a single value by a using weighted average calculation for the purposes of developing the CFS baseline or Lookup Table value for Washington average gasoline and diesel. The jet CI value from the WA-GREET model using WA-only crude directly represents the Washington average baseline jet CI. A new table is added to the Petroleum sheet of WA-GREET for this averaging calculation with draft values.

Table 2. OPGEE Based 2017 Baseline Crude CI

Crude Region	OPGEE Crude CI (g CO ₂ e/MJ)
Washington	12.56
Montana	20.86
Utah	9.16

After implementation in WA-GREET, the key parameters in and CI results from WA-GREET for each state are shown in the table below.

Table 3. Key Input Parameters for State-wise 2017 Baseline Petroleum Fuels CI

	Washington-only	Montana	Utah
GREET Simulation Year	2017	2017	2017
Electricity Mix Region	2-WAMX	4-NWPP	4-NWPP
GREET Crude Recovery Efficiency %	89.89%	81.59%	94.07%
GREET Crude CI (g CO₂e/MJ)	12.569	20.860	9.158
GREET Refining Efficiency (%)			
US Gasoline	88.60%	88.60%	88.60%
State Gasoline	88.60%	88.60%	88.60%
US Low Sulfur Diesel	85.87%	85.87%	85.87%
State Low Sulfur Diesel	85.87%	85.87%	85.87%
GREET CI (g CO₂e/MJ)			
Gasoline	99.47	109.61	95.82
Low Sulfur Diesel	100.83	110.02	97.86
Jet	89.98	n/a	n/a

The WA-GREET models using the MT and UT only crudes are only useful for developing the Washington Lookup table values for gasoline and diesel. For all biofuel pathway calculations, is intended to use the WA-GREET-WA model using the WA-only crude.

4. Electricity

The Argonne version of the model uses the 10-region North American Electric Reliability Corporation (NERC) to develop region-specific GHG emissions for electricity generation. In developing CA-GREET, however, CARB used the U.S. EPA's Emissions & Generation Resource Integrated Database (eGRID) to determine the impact of stationary electricity use in fuel and feedstock production. The eGRID contains 26 subregions to capture subregional variabilities in GHG emissions for electricity generation and is used by CARB in fuel pathway CIs to ensure consistency across all subregions, in and outside of the state.

The conversion to the 26 eGRID subregional mixes in CA-GREET3.0 was accomplished by modifying the electricity resource mixes and subregions in the Fuel_Prod_TS tab of CA-GREET3.0 and the associated links to the Inputs tab. CARB also added U.S Average, User Defined, Brazilian Average and Canadian Average mixes, in addition to the 26 eGRID subregions, for a total of 30 subregional electricity mixes.

Oregon DEQ, while developing OR-GREET model, modified the CA-GREET model to include a new subregion to represent the specific grid mix of the state making the total subregions to 31. WA-GREET model further expands on the subregions, retaining the ORMX mix from OR-GREET and adding a new subregion, WAMX, to represent the average grid mix in the Washington. This increases the total subregions in WA-GREET to 32.

The following table shows the comparison of the Grid mix subregions list in CA_GREET3, OR_GREET3 and WA_GREET models. The changes from CA-GREET3 (in blue):

- OR_GREET3 column
 - Subregion 2 – ORMX
 - Subregion 31 – user-defined
- WA_GREET column
 - Subregion 2 – WAMX
 - Subregion 31 – ORMX
 - Subregion 32 – user-defined

Table 4. Comparison of Electricity Subregions in WA-GREET model

Subregion	CA-GREET3.0	OR-GREET3.3	WA-GREET
1	US Ave	U.S Ave	U.S Ave
2	User Defined	ORMX	WAMX
3	CAMX	CAMX	CAMX
4	NWPP	NWPP	NWPP
5	AZNM	AZNM	AZNM
6	RMPA	RMPA	RMPA
7	MROW	MROW	MROW
8	SPNO	SPNO	SPNO
9	SPSO	SPSO	SPSO
10	ERCT	ERCT	ERCT
11	MROE	MROE	MROE
12	SRMW	SRMW	SRMW
13	SRMV	SRMV	SRMV
14	RFCM	RFCM	RFCM
15	RFCW	RFCW	RFCW
16	SRTV	SRTV	SRTV
17	SRSO	SRSO	SRSO
18	NEWE	NEWE	NEWE
19	NYUP	NYUP	NYUP
20	RFCE	RFCE	RFCE
21	NYLI	NYLI	NYLI
22	NYCW	NYCW	NYCW
23	SRVC	SRVC	SRVC
24	FRCC	FRCC	FRCC
25	AKMS	AKMS	AKMS
26	AKGD	AKGD	AKGD
27	HIOA	HIOA	HIOA
28	HIMS	HIMS	HIMS
29	Brazilian	Brazilian	Brazilian
30	Canadian	Canadian	Canadian
31		User Defined	ORMX
32			User Defined
	30 Subregions	31 Subregions	32 Subregions

Washington fuel mix disclosure data consists of yearly in-state electricity production data aggregated by the fuel type. However, the categorization of this dataset does not directly align with the fuel source categorization in GREET model. GREET does not have the resource

categories used in Washington fuel mix disclosure data for “Waste”, “Co-generation”, “landfill gas”, “Other”, and “Unspecified”.

The fuel share corresponding to these categories were included by allocating “cogeneration”, “landfill gas”, and “unspecified” to natural gas, and “Waste” and “other” to Residual oil. The allocation is shown in the following table.

Table 5. Allocation of WA Fuel Mix Disclosure to GREET Resource Categories

WA Fuel Mix Disclosure Categories	GREET Fuel type Categories								
	Residual oil	Natural gas	Coal	Nuclear power	Biomass	Hydro electric	Geothermal	Wind	Solar PV
Hydropower						x			
Coal			x						
Cogeneration		x							
Natural Gas		x							
Nuclear				x					
Biomass					x				
Petroleum	x								
Waste	x								
Geothermal							x		
Landfill Gas		x							
Wind								x	
Other	x								
Solar									x
Unspecified		x							

The 2017 and 2018 WAMX grid mix following the above-described allocation is shown in the following table as incorporated in the WA-GREET model, along with the retained ORMX mix from OR-GREET3.

Table 6. Fuel Shares for Grid Mix Subregions Added to WA-GREET

Fuel Type	2017 WA Disclosure	2017 WAMX Mix	2018 WA Disclosure	2018 WAMX Mix	ORMX Mix
Residual oil	0.11%	0.33%	0.02%	0.10%	0.08%
Other	0.18%	-	0.05%	-	-
Waste	0.04%	-	0.04%	-	-
Coal	13.39%	13.39%	10.22%	10.22%	32.78%
Natural gas	10.83%	10.96%	7.33%	20.46%	17.14%
Cogeneration	0.00%	-	0.00%	-	-
Unspecified	0.00%	-	12.93%	-	-
Landfill Gas	0.13%	-	0.20%	-	-
Nuclear power	4.19%	4.19%	4.75%	4.75%	3.08%
Biomass	0.60%	0.60%	0.45%	0.45%	0.36%
Hydroelectric	67.68%	67.68%	59.16%	59.16%	39.76%
Geothermal	0.00%	0.00%	0.00%	0.00%	0.12%
Wind	2.84%	2.84%	4.58%	4.58%	6.57%
Solar PV	0.00%	0.00%	0.28%	0.28%	0.11%

GREET further aggregates the fuel shares for hydroelectric, geothermal, wind, and solar PV into a single category referred to as “Others”. WAMX values for GREET’s “Other” category of resource mix can be calculated using the adjusted fuel shares calculated above. The following table shows the resulting fuel shares for the “Other” category in WA-GREET for 2018 WAMX mix.

Table 7. 2018 WAMX Fuel Shares for Electricity from "Other" Resources

WAMX "Other" Resource	%
Hydroelectric	92.39%
Geothermal	0.01%
Wind	7.16%
Solar PV	0.44%
Others	0.00%
Total	100.00%

While California has its own subregion under eGRID, Oregon and Washington fall under the NWPP eGRID subregion. Note that during the addition of the Oregon state grid mix to OR-GREET3, the NWPP mix was retained as-is in the OR-GREET3 model. With the development of WA-GREET model, 2 states have now been carved out of NWPP mix, potentially distorting the accuracy of the new NWPP subregion in WA-GREET. However, to maintain consistency with the California LCFS and Oregon CFP programs, the existing NWPP mix has been retained.

5. Appendix A: WA Baseline Crude Analysis

Introduction

There are five refineries in Washington¹¹ with a combined refining capacity of over 230 million barrels per year. Although the state is an overall net exporter of refined products, some gasoline and diesel are imported from Montana and Utah into eastern Washington. The most recent available pipeline transfer data¹² indicate that 6% of diesel consumed in Washington is refined in Montana and transported to Washington via the Yellowstone pipeline and 10% is refined in Utah and transported via the Tesoro pipeline. The remaining portion of diesel fuel is assumed to be refined in Washington. The following describes quantification of 2017 baseline crude oil average carbon intensity (CI) values for petroleum products refined in Washington, Utah and Montana. These CI values are then used in GREET modeling to calculate look-up table CI values for petroleum fuels consumed in Washington.

Summary

The general approach to determine the average crude oil CI value for Washington refineries is summarized in Figure 1 below. Without performing crude oil CI modeling, this analysis relied on California crude oil CI values developed with the Oil Production Greenhouse Gas Emission Estimator (OPGEE2.0) model adjusted for transport to Washington by mode. The Washington crude oil mix was established using DOE's Energy Information Administration (EIA) data¹³ combined with refinery survey data from the Washington Research Council¹⁴. Given that EIA does not report crude imports by oil field, the average CI was calculated by volume-weighting California crude oil volumes consumed in 2017 as reported under the LCFS program for foreign crude oil sources. This represents only about 8% of the crude oil input for Washington. The other major sources of crude including Alaska North Slope and North Dakota Bakken had only one CI in OPGEE, therefore no additional calculations were needed.

Canadian crude oil can be derived from oil sands and upgraded before introducing it to the pipeline or it can be conventional crude oil. For this analysis and in the absence of field-specific data, this analysis utilized methodology implemented by the Oregon Department of Environmental Quality (DEQ) during 2015 baseline crude oil CI determination in support of the Oregon Clean Fuels Program (CFP). The list of 60+ Canadian oil fields in OPGEE was first separated into oil sands vs conventional crude and their CI values were averaged separately for each category. Transportation distance adjustments were then applied using appropriate sea distance and rail calculators.

¹¹ British Petroleum Cherry Point, Shell Oil Anacortes, Tesoro Anacortes, Phillips 66 Ferndale, and US Oil Tacoma.

¹² 2013 data provided by Hedia Adelman, Washington State Department of Ecology

¹³ EIA Company Level Imports sorted for Washington refineries,
<https://www.eia.gov/petroleum/imports/companylevel>

¹⁴ Washington Research Council, The Economic Contribution of Washington's Petroleum Refining Industry in 2017, February 2019.

The crude oil CI calculation for Montana refineries utilized annual review data published by the Department of Natural Resources and Conservation of the State of Montana¹⁵, which contains information on crude oil sources for the state refineries. Similarly, for Utah, state-level data was used from the Utah Department of Natural Resources¹⁶ to determine crude oil inputs. OPGEE CI values were then used directly without any distance adjustments given the uncertainties in specific crude oil transport logistics and the minimal impact on the overall CI calculations for Washington petroleum fuels (jet, gas, and diesel).

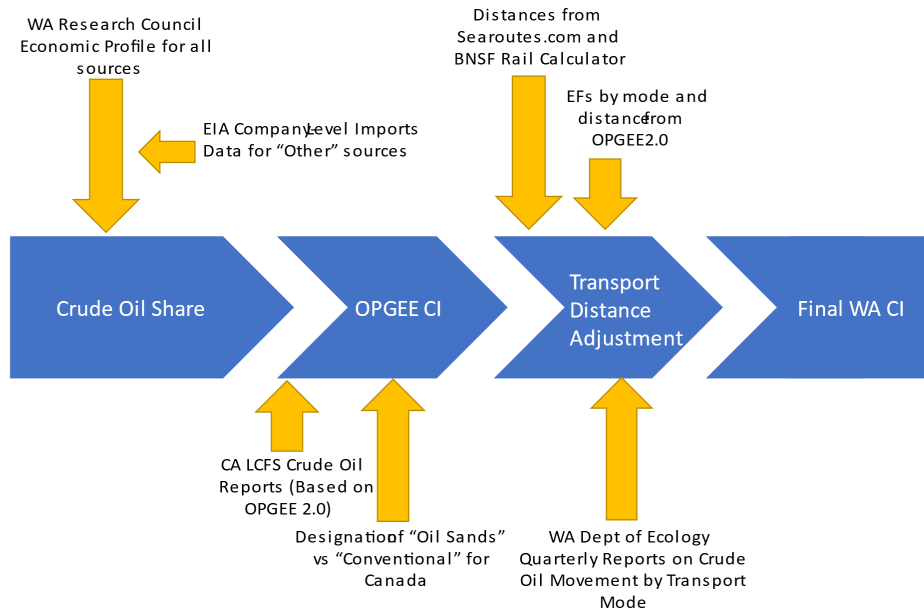


Figure 1. Baseline Crude Oil Average Calculation Methodology

¹⁵ Department of Natural Resources and Conservation of the State of Montana, Oil and Gas Conservation Division, Annual Review, 2017.

¹⁶ See <https://opendata.utah.gov/api/views/cq4t-mt5r/rows.pdf> (PDF File).

Crude Oil Sources

Washington

Washington receives crude oil by vessel, pipeline, and rail. The Washington Research Council publishes a bi-annual Economic Profile Report summarizing crude oil inputs by origin based on refinery survey data. While the report groups all foreign sources into the “other” category, the EIA company-level crude oil imports data provide quantity of crude oil imported from foreign countries by destination state. Combining these two data sources, we were able to determine the north American and other shares of refinery crude inputs by country of origin, as shown in Table 1. Rail imports from Canada represent about a third of crude oil processed at Washington refineries, with another third coming via vessel from Alaska North Slope.

Table 8. Crude Oil Inputs to Washington Refineries, 2017

Country	Volume, 1000 bbl/day	Share	Mode
US North Dakota	133.3	23.3%	Rail
US Alaska	197.8	34.6%	Vessel
Canada Conventional	135.9	23.8%	Pipeline, Rail
Canada Oil Sands	59.5	10.4%	Pipeline, Rail
Other	45.1	7.9%	Vessel
Brazil		3.1%	Vessel
Ecuador		0.4%	Vessel
Mexico		0.2%	Vessel
Russia		1.3%	Vessel
Saudi Arabia		1.6%	Vessel
Trinidad and Tobago		0.7%	Vessel
Brunei		0.1%	Vessel
Papua New Guinea		0.4%	Vessel

Montana

According to the Montana Department of Natural Resources, the crude oil refined in Montana is largely from Canada (Table 2).

Table 9. Crude Oil Inputs to Montana State Refineries, 2017

Country	Volume, 1000 bbl	Share
Montana	1,192	2%
Wyoming	3,343	5%
Canada	61,046	93%

Since the vast portion of Canadian crude is coming from Alberta¹⁷, the split between conventional and oil sands was assumed to be 16% to 84% according to Alberta’s oil production data¹⁸. This assumption is generally in line with data reported by the Canadian Energy Board for PADD4 exports.

Utah

The most recently published data on Utah refinery crude oil sources (Utah Department of Natural Resources, 2021) is shown in Table 3 for 2017. Because Utah is in the same PADD as Montana, the mix of Canada heavy and light is assumed to be the same.

Table 10. Crude Oil Inputs to Utah State Refineries, 2017

Country	Volume, 1000 bbl	Share
Utah + other	30,395	45%
Colorado	5,763	9%
Wyoming	26,187	39%
Canada	4,967	7%

¹⁷ Based on the quarterly crude oil movement rail and pipeline reports published by Washington Department of Ecology

¹⁸ Alberta’s oil production data available at Oil Production (alberta.ca) (<https://economicdashboard.alberta.ca/oilproduction#type>)

Crude Oil CI Values

The California Air Resources Board (CARB) utilizes the OPGEE model, developed by researchers at Stanford University to quantify the carbon intensity of the crude oil recovery and transport portion of petroleum fuel pathways. Each year the CI is quantified for all of the oil fields that supply California refineries. For this analysis, we utilized the 2017 Annual Crude Oil Report from CARB¹⁹. However, granted that the 2017 CI values were developed with OPGEE1.0, we updated all crude CI values using OPGEE2.0²⁰ results for each oil field, consistent with crude oil CI for 2018 and subsequent years. Since the OPGEE model provides data for a number of oil fields in a given country, the CI values from multiple oil fields were volume-weighted, as appropriate. However, given that the Canadian crude imports into California were not representative of those to Washington (only 2% of crude oil processed in California refineries was from Canada in contrast to 33% in Washington), this analysis employed the Oregon DEQ approach and simple averaged all CI values for Canada available in in OPGEE depending on their designation (oil sand vs conventional). Same approach was applied to Montana and Utah crudes but using Alberta oil production data to differentiate between Canada oil sands and conventional crude. Since there was no OPGEE value for crude produced in Montana, this data point was omitted from the analysis impacting only 2% of the crude oil input to Montana refineries.

Distance Adjustment

The CI value for each crude oil source was adjusted for the difference in the transportation distance to Washington instead of California using OPGEE2.0 emission factors for crude oil transport by mode. For foreign crude oil sources that are imported via vessel through the Panama Canal, the difference in distance between ports of Los Angeles and Seattle of 1,346 miles was applied. This resulted in a CI increase of 0.16 gCO₂e/MJ for all countries except for Russia, where the difference in distance travelled was assumed to be negligible. Similarly for Alaskan crude, the CI was decreased by the same amount. For North Dakota, BNSF rail distance calculator was used to compute the difference in transport distance between Seattle and Los Angeles, resulting in a CI reduction of 1.06 gCO₂e/MJ. For Canadian crude, the vessel distance to California from Vancouver was replaced with distance by rail from Vancouver to Seattle (keeping pipeline distance from Edmonton same as in OPGEE). This gave Canadian crude a CI that was only 0.1 gCO₂e/MJ less than that in California since rail emission factors are ten times higher than those of a vessel. This level of detail was not available for Montana and Utah crude oil movements; therefore, distance adjustments were not performed and California OPGEE CI results were used directly.

¹⁹ See LCFS Crude Oil Life Cycle Assessment | California Air Resources Board (<https://ww2.arb.ca.gov/resources/documents/lcfs-crude-oil-life-cycle-assessment>).

²⁰ Note that OPGEE3.0 is currently under development by Stanford University. The latest model version is not yet publicly available.

CI Results

The sources of crude oil for Washington refineries and corresponding CI values are provided in Table 11, indicating that the average value for Washington refineries is 12.57 gCO₂e/MJ²¹. Composite crude CI values for Montana (20.86 gCO₂e/MJ) and Utah (9.16 gCO₂e/MJ) are provided in Table 5 and Table 6, respectively. These values are combined with refining and finished fuel transport CI estimates from the GREET model based on crude type and electricity mix at the refinery.

Table 11. Washington Crude Sources and Carbon Intensity, 2017

Country	Share	CA OPGEE2.0 CI, gCO ₂ /MJ	Transport Adjustment, gCO ₂ e/MJ	WA CI, gCO ₂ e/MJ
US North Dakota	23.3%	9.73	-1.03	8.70
US Alaska	34.6%	15.91	-0.16	15.75
Canada Conventional	23.8%	8.40	-0.08	8.32
Canada Oil Sands	10.4%	23.88	-0.08	23.80
Brazil	3.1%	5.86	0.16	6.02
Ecuador	0.4%	9.36	0.16	9.52
Mexico	0.2%	7.51	0.16	7.66
Russia	1.3%	9.39	0.00	9.39
Saudi Arabia	1.6%	9.18	0.16	9.34
Trinidad and Tobago	0.7%	7.41	0.16	7.57
Brunei	0.1%	NA	NA	NA
Papua New Guinea	0.4%	NA	NA	NA
Weighted Average	100%	--	--	12.57

Table 12. Montana Crude Sources and Carbon Intensity, 2017

Country	Share	CA OPGEE2.0 CI, gCO ₂ e/MJ
Montana	2%	NA
Wyoming	5%	10.98
Canada	93%	21.41
Weighted Average	100%	20.86

²¹ A small amount of crude also came from Brunei and Papua New Guinea. Because OPGEE did not provide CI values for oil fields in these countries they were omitted from the average. These field could utilize the “default” CI value which is recommended to be same as the baseline crude oil average.

Table 13. Utah Crude Sources and Carbon Intensity, 2017

Country	Share	CA OPGEE2.0 CI, gCO₂e/MJ
Utah Average	45%	6.03
Colorado	9%	6.81
Wyoming	39%	10.98
Canada	7%	21.41
Weighted Average	100%	9.16

6. Appendix B: Crude CI Lookup table

Table 14. Crude CI Lookup table for 2017 Washington Crude

Country of Origin	Crude Identifier	CA Carbon Intensity (gCO ₂ e/MJ)	Distance Adjustment	WA Carbon Intensity (gCO ₂ e/MJ)
Baseline Crude Average	Washington Crude Average applicable to crudes supplied during 2017			12.57
US North Dakota	Bakken	9.73	-1.03	8.70
US Alaska	Alaska North Slope	15.91	-0.16	15.75
Angola	Cabinda	8.99	0.16	9.15
	Clov	7.31	0.16	7.47
	Dalia	8.90	0.16	9.06
	Gimboa	8.86	0.16	9.02
	Girassol	9.95	0.16	10.11
	Greater Plutonio	8.72	0.16	8.88
	Hungo	8.23	0.16	8.39
	Kissanje	8.66	0.16	8.82
	Mondo	8.98	0.16	9.14
	Nemba	9.08	0.16	9.24
	Pazflor	8.02	0.16	8.18
	Sangos	7.06	0.16	7.22
Argentina	Canadon Seco	10.16	0.16	10.32
	Escalante	10.15	0.16	10.31
	Hydra	7.77	0.16	7.93
	Medanito	10.78	0.16	10.94
Brazil	Albacora Leste	5.99	0.16	6.15
	Bijupira-Salema	7.18	0.16	7.34

Country of Origin	Crude Identifier	CA Carbon Intensity (gCO ₂ e/MJ)	Distance Adjustment	WA Carbon Intensity (gCO ₂ e/MJ)
	Frade	5.63	0.16	5.79
	Iracema	5.54	0.16	5.70
	Jubarte	6.28	0.16	6.44
	Lula	6.24	0.16	6.40
	Marlim	6.76	0.16	6.92
	Marlim Sul	7.78	0.16	7.94
	Ostra	5.65	0.16	5.81
	Papa Terra	4.29	0.16	4.45
	Peregrino	4.16	0.16	4.32
	Polvo	4.31	0.16	4.47
	Roncador	6.77	0.16	6.93
	Roncador Heavy	6.45	0.16	6.61
	Sapinhoa	6.00	0.16	6.16
	Tubarao Azul	5.45	0.16	5.61
	Tubarao Martelo	5.37	0.16	5.53
Canada	Access Western Blend	15.15	-0.10	15.05
	Albian Heavy Synthetic (all grades)	23.68	-0.10	23.58
	BC Light	8.11	-0.10	8.01
	Bonnie Glen	8.11	-0.10	8.01
	Borealis Heavy Blend	15.41	-0.10	15.31
	Boundary Lake	8.11	-0.10	8.01
	Bow River	9.42	-0.10	9.32
	Cardium	8.11	-0.10	8.01
	Christina Dilbit Blend	12.71	-0.10	12.61
	Christina Synbit	18.66	-0.10	18.56
	Cold Lake	17.87	-0.10	17.77
	Conventional Heavy	9.42	-0.10	9.32
	CNRL Light Sweet Synthetic	25.27	-0.10	25.17
	Federated	8.11	-0.10	8.01

Country of Origin	Crude Identifier	CA Carbon Intensity (gCO ₂ e/MJ)	Distance Adjustment	WA Carbon Intensity (gCO ₂ e/MJ)
	Fosterton	9.42	-0.10	9.32
	Gibson Light Sweet	8.11	-0.10	8.01
	Halkirk	8.11	-0.10	8.01
	Hardisty Light	8.11	-0.10	8.01
	Hardisty Synthetic	36.39	-0.10	36.29
	Husky Synthetic	32.66	-0.10	32.56
	Joarcam	8.11	-0.10	8.01
	Kearl Lake	12.89	-0.10	12.79
	Kerrobert Sweet	8.11	-0.10	8.01
	Koch Alberta	8.11	-0.10	8.01
	Light Sour Blend	8.11	-0.10	8.01
	Light Sweet	8.11	-0.10	8.01
	Lloyd Blend	9.42	-0.10	9.32
	Lloyd Kerrobert	9.42	-0.10	9.32
	Lloydminster	9.42	-0.10	9.32
	Long Lake Heavy	30.54	-0.10	30.44
	Long Lake Light Synthetic	40.12	-0.10	40.02
	Mackay Heavy Blend	20.43	-0.10	20.33
	Medium Gibson Sour	8.11	-0.10	8.01
	Medium Sour Blend	8.11	-0.10	8.01
	Midale	8.11	-0.10	8.01
	Mixed Sour Blend	8.11	-0.10	8.01
	Mixed Sweet	8.11	-0.10	8.01
	Moose Jaw Tops	8.11	-0.10	8.01
	Peace	8.11	-0.10	8.01
	Peace Pipe Sour	8.11	-0.10	8.01
	Peace River Heavy	19.21	-0.10	19.11
	Peace River Sour	8.11	-0.10	8.01
	Pembina	8.11	-0.10	8.01

Country of Origin	Crude Identifier	CA Carbon Intensity (gCO ₂ e/MJ)	Distance Adjustment	WA Carbon Intensity (gCO ₂ e/MJ)
	Pembina Light Sour	8.11	-0.10	8.01
	Premium Albion Synthetic	29.49	-0.10	29.39
	Premium Conventional Heavy	9.42	-0.10	9.32
	Premium Synthetic	27.38	-0.10	27.28
	Rainbow	8.11	-0.10	8.01
	Rangeland Sweet	8.11	-0.10	8.01
	Redwater	8.11	-0.10	8.01
	Seal Heavy	9.42	-0.10	9.32
	Shell Synthetic (all grades)	29.49	-0.10	29.39
	Smiley-Coleville	9.42	-0.10	9.32
	Sour High Edmonton	8.11	-0.10	8.01
	Sour Light Edmonton	8.11	-0.10	8.01
	Statoil Cheecham Dilbit	16.41	-0.10	16.31
	Statoil Cheecham Synbit	21.08	-0.10	20.98
	Suncor Synthetic (all grades)	27.09	-0.10	26.99
	Surmont Heavy Blend	22.48	-0.10	22.38
	Synbit Blend	22.64	-0.10	22.54
	Syncrude Synthetic (all grades)	31.62	-0.10	31.52
	Synthetic Sweet Blend	29.36	-0.10	29.26
	Tundra Sweet	8.11	-0.10	8.01
	Wabasca	6.88	-0.10	6.78
	Western Canadian Blend	9.42	-0.10	9.32
	Western Canadian Select	19.04	-0.10	18.94
Ecuador	Napo	8.31	0.16	8.47
	Oriente	10.07	0.16	10.23
Ghana	Ten Blend	8.08	0.16	8.24
Mexico	Isthmus	11.31	0.16	11.47
	Isthmus Topped	14.31	0.16	14.47
	Maya	7.85	0.16	8.01

Country of Origin	Crude Identifier	CA Carbon Intensity (gCO ₂ e/MJ)	Distance Adjustment	WA Carbon Intensity (gCO ₂ e/MJ)
Nigeria	Agbami	12.04	0.16	12.20
	Amenam	10.65	0.16	10.81
	Antan	21.98	0.16	22.14
	Bonga	5.06	0.16	5.22
	Bonny	9.91	0.16	10.07
	Brass	14.27	0.16	14.43
	EA	6.66	0.16	6.82
	Erha	10.91	0.16	11.07
	Escravos	12.00	0.16	12.16
	Forcados	8.97	0.16	9.13
	Okono	8.67	0.16	8.83
	OKWB	22.76	0.16	22.92
	Pennington	11.18	0.16	11.34
	Qua Iboe	11.45	0.16	11.61
	Yoho	11.45	0.16	11.61
Russia	ESPO	11.55	0.00	11.55
	M100	17.35	0.00	17.35
	Sokol	6.94	0.00	6.94
	Vityaz	9.60	0.00	9.60
Saudi Arabia	Arab Extra Light	9.41	0.16	9.57
	Arab Light	9.23	0.16	9.39
	Arab Medium	8.72	0.16	8.88
	Arab Heavy	7.92	0.16	8.08
Trinidad	Calypso	7.41	0.16	7.57
	Galeota	11.41	0.16	11.57

7. Disclaimer

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