# WA-GREET 0.7a Supplemental Document and Tables of Changes

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# 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 ($CO_2e$), and divided by the fuel's energy content in megajoules. Carbon intensity is expressed in terms of grams of $CO_2$ equivalent per megajoule ($gCO_2e/MJ$).

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 Standards.[1] CA-GREET3 model was developed by CARB by progressive modification to the GREET1 model[2] 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 model.[3] 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_2016[4] and CA-GREET[5] models. 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.

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[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 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 website.[6] 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.

- 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

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[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

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-specific standard emission factors in the calculators were updated to reflect Washington-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.

## Washington Utility CI Calculator

WA Clean Fuel Standard allows the use of utility specific carbon intensity for power use for certain purposes outside of biofuel pathways. For this purpose, a new calculator was developed by Life Cycle Associates external to the WA-GREET to allow calculation of the CI for a given specific utility within Washington. The list of considered utilities and their corresponding electricity generation mix is derived from the annual Washington utility mix disclosure report.[8] This report is also available through the Washington Department of Commerce website and is separate from the statewide fuel mix disclosure report. The latest available data is from the year 2020 which can be used for the first year of the WA CFS notwithstanding the rulemaking and determination by Washington Department of Ecology.

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[8] WA Utility Mix Disclosure Data, (https://www.commerce.wa.gov/growing-the-economy/energy/fuel-mix-disclosure/)

The calculator adopts the self-reported utility mix disclosure data, transforms it into GREET compatible form and calculates the lifecycle well-to-plug emissions from the electricity generated by the user-selected utility. The calculator requires the user to select the desired utility by using the "Claimant ID" of the utility as reported under the raw utility mix disclosure report, also available in the calculator for reference. The calculator also supports the input of a user-defined electricity mix. More details on the calculator and the overall methodology of electricity life cycle carbon intensity calculation are available in the separate report prepared under this contract on Washington electricity.[9]

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[9] Unnasch S., and L. Goyal. (2022) Well to Plug GHG Emissions for Electric Power Generation-Washington Electricity Mix. Life Cycle Associates Report LCA.6207.230.2022, Prepared under Washington Ecology Contract C2200132

# 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 Washington 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 data[10] 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 Washington 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) data[11] 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 by 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.

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[10] 2013 data provided by Hedia Adelman, Washington State Department of Ecology
[11] 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[12] | Mode | CA CI | Distance Adjustment | WA CI |
|---|---|---|---|---|---|
| North Dakota | 23% | Rail | 9.73 | -1.03 | 8.70 |
| U.S. 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** |

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[12] 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 (%)** | | | |
| U.S. Gasoline | 88.60% | 88.60% | 88.60% |
| State Gasoline | 88.60% | 88.60% | 88.60% |
| U.S. 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 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 are highlighted in blue (bold) text.

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

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

**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 | Biogas | 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 | | | | 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% | 10.83% | 7.33% | 20.26% | 17.14% |
| Cogeneration | 0.00% | - | 0.00% | - | - |
| Unspecified | 0.00% | - | 12.93% | - | - |
| Landfill Gas (Biogas) | 0.13% | 0.13% | 0.20% | 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 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 Washington[13] with a combined refining capacity of over 230 million barrels per year. Although Washington 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 data[14] 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 (including finished fuel imports from Montana and Utah).

**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 (OPGEE2.0c)[15] model adjusted for transport to Washington by mode. The Washington crude oil mix was established using DOE's Energy Information Administration (EIA) data[16] combined with refinery survey data from the Washington Research Council.[17]  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 volume-averaging was not necessary.

Canadian crude oil can be derived from oil sands and upgraded before introducing it to the pipeline or it can by conventional crude oil. For this analysis and in the absence of field-specific data, this analysis utilized methodology implemented by the Oregon Department of

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

[14] 2013 data provided by Hedia Adelman, Washington State Department of Ecology

[15] Stanford University, under contract with the California Air Resources Board (CARB), is in the process of updating the OPGEE model and oil field data for the 2024 California LCFS Amendments. The final version of the model has not been released at the time of this analysis and was not accessible to our team. Trinity recommends the use of the latest available OPGEE model version for future crude oil average CI updates for the Washington CFS.

[16] EIA Company Level Imports sorted for Washington refineries, https://www.eia.gov/petroleum/imports/companylevel

[17] Washington Research Council, The Economic Contribution of Washington State's Petroleum Refining Industry in 2017, February 2019.

Environmental Quality (DEQ) during 2015 baseline crude oil CI determination in support of the 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.

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 Montana,[18] which contains information on crude oil sources for Montana refineries. Similarly, for Utah, state-level data was used from the Utah Department of Natural Resources[19] 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).
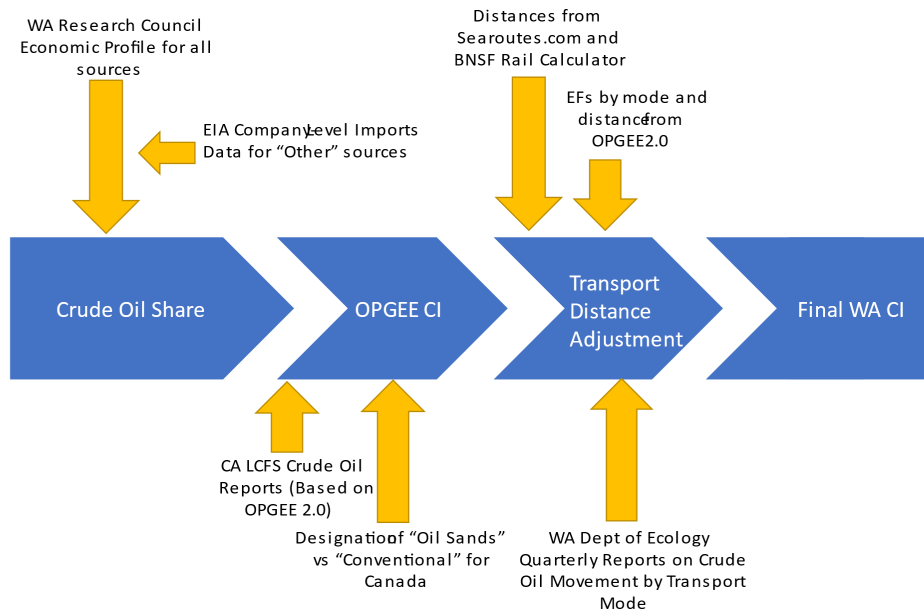


**Figure 1.** Baseline Crude Oil Average Calculation Methodology

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[18] Department of Natural Resources and Conservation of the State of Montana, Oil and Gas Conservation Division, Annual Review, 2017.
[19] See https://www.bing.com/newtabredir?url=https%3A%2F%2Fopendata.utah.gov%2Fapi%2Fviews%2Fcq4t-mt5r%2Frows.pdf%3Fapp_token%3DU29jcmF0YS0td2VraWNrYXNz0.

**Regional Detail**

The CI of crude oil affect the GHG emissions for several parameters in the WA CFS. The groupings of regional petroleum resources and electricity mix are shown in Table 8. The regional crude oil is adjusted for each region in combination with the electricity mix.

The first set of parameters determine the 2017 baseline CI values for the CFS. The crude oil CI for Washington affect the CI for gasoline, diesel and jet fuels. The CI for petroleum product is calculated separately in WA-GREET with the regional selection of electric power shown in the table. The WA mix is applied to electric power for petroleum fuels in the state while the NWPP mix is applied to gasoline and diesel imported from Utah and Montana.

Ethanol and soy oil are part of the 2017 baseline. These were calculated with the U.S. average electricity mix. Look up table values are calculated with the regional mix shown below.

**Table 8.** Regional Petroleum and Electric Power Source used to Calculate Carbon Intensity

| Scenario Year | Regional Mix for Power Generation | | Products | Crude CI | Location | Crude Extraction Efficiency |
|---|---|---|---|---|---|---|
| | Feed | Fuel | | | | |
| 2017 Petroleum Baseline | | | | | | |
| 2017 | US | WA | Gasoline, Diesel, Jet | 12.567[20] | WA | 90.02% |
| 2017 | US | NWPP | Gasoline, Diesel | 20.86[21] | MT | 88% |
| 2017 | US | NWPP | Gasoline, Diesel | 9.56[22] | UT | 92% |
| 2017 | US | US | Ethanol | 9.45 | US | 98% |
| 2017 | US | US | Soy Biodiesel | 9.45 | US | 98% |
| | | Average | Blended Gasoline | Blending Calculator | | |
| | | Average | Blended Diesel | Blending Calculator | | |
| WA Look Up Table Values | | | | | | |
| 2018 | US | WA | CNG, LNG, Hydrogen | 9.45 | WA | N/A |
| 2018 | US | US | Propane | 9.45 | US | N/A |
| 2018 | US | WA | Electricity, Avg, Utility | 9.45 | WA | N/A |
| 2018 | US | WA | Hydrogen, all | 9.45 | | N/A |

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[20] Crude CI calculated using OPGEE and used in WA-GREET as input to adjust the crude recovery energy efficiency

[21] Crude CI calculated using OPGEE and used in WA-GREET as input to adjust the crude recovery energy efficiency

[22] Crude CI calculated using OPGEE and used in WA-GREET as input to adjust the crude recovery energy efficiency

## 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 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 9.** 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 10).

**Table 10.** Crude Oil Inputs to Montana 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 Alberta, the split between conventional and oil sands was assumed to be 16% to 84% according to Alberta's oil production

data.[23] 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 11.** Crude Oil Inputs to Utah Refineries, 2017

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

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[23] Alberta's oil production data available at 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 CARB.[24] However, granted that the 2017 CI values were developed with OPGEE1.0, we updated all crude CI values using OPGEE2.0[25] 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 weighted using 2017 crude import volumes to California, as appropriate. As mentioned earlier, this approach was only necessary for countries that contained multiple oil fields. Over half of crude imports into Washington were represented by single-field domestic sources (e.g., Bakken and North Slope).

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) as determined by reviewing MCON summary information in OPGEE.  Similar approach was applied to Montana and Utah crudes but using 2017 Alberta oil production data to differentiate between Canada oil sands and conventional crude. This split by crude oil type was also confirmed by reviewing Canada Energy Board data on PADD 4 exports for the same year. Since there was no OPGEE CI 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. The crude CI values for Wyoming and Utah crude oil fields were obtained from Table 9 of the California LCFS Regulation. The four oil fields in Utah were simple averaged for this analysis.

## 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 g/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 g/MJ. For Canadian crude, the vessel distance to California from Vancouver was replaced with distance by vessel, pipeline and rail from Vancouver to Seattle (maintaining pipeline distance from Edmonton to Vancouver same as in OPGEE2.0). Although a vast portion of Washington crude imports from Canada are by pipeline,

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

[25] Note that OPGEE3.0 is currently under development by Stanford University. The latest model version is not yet publically available.

this analysis accounted for all three modes of transport based on Washington Crude Oil Movement Quarterly Reports for 2017.[26] As shown in Table 4, the OPGEE emission factors are four time higher for pipeline transport compared to vessel, therefore Canadian crude CI was estimated to be only 0.08 g/MJ lower than in California, with higher emission factors offsetting reduced transport distances.  Further refining to transport adjustment is possible if OPGEE modeling is performed for each field taking its crude oil API other specific transport characters such as vessel size into account.[27]

**Table 12.** OPGEE 2.0c Crude Transport Emission Factors

| Transport Mode | gCO$_2$e/MMBtu-mile |
|---|---|
| Ocean Tanker | 0.124 |
| Pipeline | 0.490 |
| Rail | 1.252 |

The same level of detail was not easily available for Montana and Utah crude oil movements; therefore, distance adjustments were not performed and California OPGEE CI results were used directly. This has a minor impact on the overall Washington petroleum fuels CI, since out of state finished fuel import contributed to only 16% of total fuel consumed in state.

### CI Results

The sources of crude oil for Washington refineries and corresponding CI values are provided in Table 13, indicating that the average value for Washington refineries is 12.57 g/MJ.[28] Composite crude CI values for Montana (20.86 g/MJ) and Utah (9.16 g/MJ) are provided in Table 6 and Table 7, 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.

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[26] Washington Department of Ecology Publication and Forms – https://apps.ecology.wa.gov/publications/UIPages/PublicationList.aspx?IndexTypeName=Topic&NameValue=Crude+Oil+Movement+Quarterly+Reports&DocumentTypeName=Publication

[27] OPGEE2.0c emission factors are based on average API of 30.

[28] 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 fields could utilize the "default" CI value which is recommended to be same as the baseline crude oil average.

**Table 13.** Washington Crude Sources and Carbon Intensity, 2017

| Country | Share | CA OPGEE2.0 CI, gCO2/MJ | Transport Adjustment, gCO2e/MJ | WA CI, gCO2e/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 14.** 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 |

**Table 15.** Utah Crude Sources and Carbon Intensity, 2017

| Country | Share | CA OPGEE2.0 CI, gCO$_2$e/MJ |
|---|---|---|
| Utah average[29] | 45% | 6.03 |
| Colorado | 9% | 6.81 |
| Wyoming | 39% | 10.98 |
| Canada | 7% | 21.41 |
| **Weighted Average** | **100%** | 9.16 |

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[29] Simple average of all Utah crude sources available in Table 9 of the California LCFS Regulation.

# 6. Appendix B: Crude CI Lookup table

**Table 16.** Crude CI Lookup table for 2017 Washington Crude

| Country of Origin | Crude Identifier | CA Carbon Intensity (gCO$_2$e/MJ) | Crude Transport 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 |

| Country of Origin | Crude Identifier | CA Carbon Intensity (gCO$_2$e/MJ) | Crude Transport Adjustment | WA Carbon Intensity (gCO$_2$e/MJ) |
|---|---|---|---|---|
| | Bijupira-Salema | 7.18 | 0.16 | 7.34 |
| | 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 | -0.08 | 15.07 |
| | Albian Heavy Synthetic (all grades) | 23.68 | -0.08 | 23.60 |
| | BC Light | 8.11 | -0.08 | 8.03 |
| | Bonnie Glen | 8.11 | -0.08 | 8.03 |
| | Borealis Heavy Blend | 15.41 | -0.08 | 15.33 |
| | Boundary Lake | 8.11 | -0.08 | 8.03 |
| | Bow River | 9.42 | -0.08 | 9.34 |
| | Cardium | 8.11 | -0.08 | 8.03 |
| | Christina Dilbit Blend | 12.71 | -0.08 | 12.63 |
| | Christina Synbit | 18.66 | -0.08 | 18.58 |
| | Cold Lake | 17.87 | -0.08 | 17.79 |

| Country of Origin | Crude Identifier | CA Carbon Intensity (gCO$_2$e/MJ) | Crude Transport Adjustment | WA Carbon Intensity (gCO$_2$e/MJ) |
|---|---|---|---|---|
| | Conventional Heavy | 9.42 | -0.08 | 9.34 |
| | CNRL Light Sweet Synthetic | 25.27 | -0.08 | 25.19 |
| | Federated | 8.11 | -0.08 | 8.03 |
| | Fosterton | 9.42 | -0.08 | 9.34 |
| | Gibson Light Sweet | 8.11 | -0.08 | 8.03 |
| | Halkirk | 8.11 | -0.08 | 8.03 |
| | Hardisty Light | 8.11 | -0.08 | 8.03 |
| | Hardisty Synthetic | 36.39 | -0.08 | 36.31 |
| | Husky Synthetic | 32.66 | -0.08 | 32.58 |
| | Joarcam | 8.11 | -0.08 | 8.03 |
| | Kearl Lake | 12.89 | -0.08 | 12.81 |
| | Kerrobert Sweet | 8.11 | -0.08 | 8.03 |
| | Koch Alberta | 8.11 | -0.08 | 8.03 |
| | Light Sour Blend | 8.11 | -0.08 | 8.03 |
| | Light Sweet | 8.11 | -0.08 | 8.03 |
| | Lloyd Blend | 9.42 | -0.08 | 9.34 |
| | Lloyd Kerrobert | 9.42 | -0.08 | 9.34 |
| | Lloydminster | 9.42 | -0.08 | 9.34 |
| | Long Lake Heavy | 30.54 | -0.08 | 30.46 |
| | Long Lake Light Synthetic | 40.12 | -0.08 | 40.04 |
| | Mackay Heavy Blend | 20.43 | -0.08 | 20.35 |
| | Medium Gibson Sour | 8.11 | -0.08 | 8.03 |
| | Medium Sour Blend | 8.11 | -0.08 | 8.03 |
| | Midale | 8.11 | -0.08 | 8.03 |
| | Mixed Sour Blend | 8.11 | -0.08 | 8.03 |
| | Mixed Sweet | 8.11 | -0.08 | 8.03 |
| | Moose Jaw Tops | 8.11 | -0.08 | 8.03 |

| Country of Origin | Crude Identifier | CA Carbon Intensity (gCO$_2$e/MJ) | Crude Transport Adjustment | WA Carbon Intensity (gCO$_2$e/MJ) |
|---|---|---|---|---|
| | Peace | 8.11 | -0.08 | 8.03 |
| | Peace Pipe Sour | 8.11 | -0.08 | 8.03 |
| | Peace River Heavy | 19.21 | -0.08 | 19.13 |
| | Peace River Sour | 8.11 | -0.08 | 8.03 |
| | Pembina | 8.11 | -0.08 | 8.03 |
| | Pembina Light Sour | 8.11 | -0.08 | 8.03 |
| | Premium Albian Synthetic | 29.49 | -0.08 | 29.41 |
| | Premium Conventional Heavy | 9.42 | -0.08 | 9.34 |
| | Premium Synthetic | 27.38 | -0.08 | 27.30 |
| | Rainbow | 8.11 | -0.08 | 8.03 |
| | Rangeland Sweet | 8.11 | -0.08 | 8.03 |
| | Redwater | 8.11 | -0.08 | 8.03 |
| | Seal Heavy | 9.42 | -0.08 | 9.34 |
| | Shell Synthetic (all grades) | 29.49 | -0.08 | 29.41 |
| | Smiley-Coleville | 9.42 | -0.08 | 9.34 |
| | Sour High Edmonton | 8.11 | -0.08 | 8.03 |
| | Sour Light Edmonton | 8.11 | -0.08 | 8.03 |
| | Statoil Cheecham Dilbit | 16.41 | -0.08 | 16.33 |
| | Statoil Cheecham Synbit | 21.08 | -0.08 | 21.00 |
| | Suncor Synthetic (all grades) | 27.09 | -0.08 | 27.01 |
| | Surmont Heavy Blend | 22.48 | -0.08 | 22.40 |
| | Synbit Blend | 22.64 | -0.08 | 22.56 |
| | Syncrude Synthetic (all grades) | 31.62 | -0.08 | 31.54 |
| | Synthetic Sweet Blend | 29.36 | -0.08 | 29.28 |
| | Tundra Sweet | 8.11 | -0.08 | 8.03 |
| | Wabasca | 6.88 | -0.08 | 6.80 |
| | Western Canadian Blend | 9.42 | -0.08 | 9.34 |

| Country of Origin | Crude Identifier | CA Carbon Intensity (gCO₂e/MJ) | Crude Transport Adjustment | WA Carbon Intensity (gCO₂e/MJ) |
|---|---|---|---|---|
| | Western Canadian Select | 19.04 | -0.08 | 18.96 |
| 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 |
| 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 |

| Country of Origin | Crude Identifier | CA Carbon Intensity (gCO$_2$e/MJ) | Crude Transport Adjustment | WA Carbon Intensity (gCO$_2$e/MJ) |
|---|---|---|---|---|
| | 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 |

# References

(S&T)2 Consultants, 2010. GHGenius 3.17, http://www.ghgenius.ca/.

ANL, 1999. A Full Fuel-Cycle Analysis of Energy and Emissions Impacts of Transportation Fuels Produced from Natural Gas. doi:ANL/ESD-40

ANL, 2003. Allocation of Energy Use in Petroleum Refineries to Petroleum Products: Implications for Life-Cycle Energy Use and Emission Inventory of Petroleum Transportation Fuels.

ANL, 2008. Life-Cycle Assessment of Energy and Greenhouse Gas Effects of Soybean-Derived Biodiesel and Renewable Fuels.

ANL, 2010. Well-to-Wheels Analysis of Landfill Gas-Based Pathways and Their Addition to the GREET Model.

ANL, 2011. Waste-to-Wheel Analysis of Anaerobic-Digestion-Based Renewable Natural Gas Pathways with the GREET Model.

ANL, 2013. GREET 2013: The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model. Version 1.

ANL, 2014. GREET 2014: The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model. Version 1.

ANL, 2015. GREET 2015: The Greenhouse Gases, Regulated Emssions, and Energy Use in Transportation (GREET) Model. Version 1

ARB, 2007a. California Office of the Governor: EXECUTIVE ORDER S-01-07, Sacramento, CA, 2007; http://www.arb.ca.gov/fuels/lcfs/eos0107.pdf.

ARB, 2007b. The Low Carbon Fuel Standard.

ARB, 2008. California Reformulated Gasoline Blendstock for Oxygenate Blending CARBOB from Average Crude Refined in California. Calif. Reformul. Gasol. Blendstock Oxyg. Blending CARBOB from Aver. Crude Refin. Calif. 14 SRC – G.

ARB, 2009a. California's Low Carbon Fuel Standard Final Statement of Reasons.

ARB, 2009b. Detailed California-Modified GREET Pathway for Compressed Natural Gas (CNG) from Landfill Gas, California Air Resources Board, Stationary Source Division Version: 21, February 2009.

ARB, 2009c. Detailed California-Modified GREET Pathway for Liquefied Natural Gas ( LNG ) from North American and Remote Natural Gas Sources.

ARB, 2009d. Detailed California-Modified GREET Pathway for Ultra Low Sulfur Diesel (ULSD) from Average Crude Refined in California., California Air Resources Board, Sacramento, CA: 2009. California Air Resources Board, Sacramento, CA.

ARB, 2009e. Detailed California-Modified for Liquefied Natural Gas (LNG) from Dairy Digester Resources Division,.

ARB, 2009f. Detailed California-Modified GREET Pathway for Corn Ethanol.

ARB, 2009g. California-Modified for Brazilian Sugarcane Ethanol: Average Brazilian Harvesting and Electricity Co-product Co-product Resources Division, Version: 2.

ARB, 2009h. Detailed California-Modified GREET Pathway for Cellulosic Ethanol from Farmed Trees by Fermentation.

ARB, 2009i. Detailed California-Modified GREET Pathway for Co-Processed Renewable Diesel Produced from Tallow ( U . S . Sourced ).

ARB, 2009j. Detailed California-Modified GREET Pathway for Co-Processed Renewable Diesel Produced from Tallow ( U . S . Sourced).

ARB, 2010. Detailed California-Modified GREET Pathway for Sorghum Ethanol 1 – 26.

ARB, 2012. Carbon Intensity Lookup Table for Gasoline and Fuels that Substitute for Gasoline.

ARB, 2013a. Carbon Intensity Lookup Table for Gasoline and Fuels that Substitute for Gasoline.

ARB, 2013b. ARB Summary of all Fuel Pathways: Method 2A/2B Applications and Internal Priority Pathways (as of 05/29/2013):

ARB, 2014a. California Greenhouse Gas Emission Inventory [WWW Document]. URL http://www.arb.ca.gov/cc/inventory/inventory_current.htm

ARB, 2014b. Low Carbon Fuel Standard Reconsideration: CA_GREET Model Update.

ARB, 2014c. California-GREET Model, Version2.

ARB, 2014d. ARB Internal LCFS Pathway Production of Biomethane from the Mesophilic Anaerobic Digestion of Wastewater Sludge at a Publicly-Owned Treatment Works 79, 894–894. doi:10.1002/cplu.201490022

ARB, Life Cycle Associates, 2009. California-GREET Model, Version 1.8b. ARB, based on GREET 1.8b by ANL. http://www.arb.ca.gov/fuels/lcfs/lcfs.htm.

Bergerson, J., Keith, D.W., 2006. Life Cycle Assessment of Oil Sands Technologies, Alberta Energy Futures Project. ISEEE. http://www.iseee.ca/files/iseee/ABEnergyFutures-11.pdf.

Brandt, A., 2014. Oil Production Greenhouse Gas Emissions Estimator User guide & Technical documentation 1.

Brandt, A.R., 2008. Converting Oil Shale to Liquid Fuels : Energy Inputs and Greenhouse Gas Emissions of the Shell in Situ Conversion Process Converting Oil Shale to Liquid Fuels : Energy Inputs and Greenhouse Gas Emissions of the Shell in Situ Conversion Process. doi:10.1021/es800531f

Brandt, A.R., 2009. Converting Oil Shale to Liquid Fuels with the Alberta Taciuk Processor : Energy Inputs and Greenhouse Gas Emissions 6253–6258. doi:10.1021/ef900678d

Brandt, A.R., Boak, J., Burnham, A.K., 2009. Adam Brandt, Jeremy Boak, Alan Burnham, "Carbon Dioxide Emissions from Oil Shale Derived Liquid Fuels" (in press) 1 2–4. doi:10.1021/es800531f

Brandt, A.R., Farrell, A.E., 2007. Scraping the bottom of the barrel: CO2 emission consequences of a transition to low-quality and synthetic petroleum resources. Clim. Change 84, 241–263.

Brandt, A.R., Unnasch, S., 2010. Energy intensity and greenhouse gas emissions from thermal enhanced oil recovery. Energy & Fuels 24, 4581–4589.

Brennan, L., Owende, P., 2010. Biofuels from microalgae—A review of technologies for production Processing, and extractions of biofuels and co-products. Renew. Sustain. Energy Rev. 14.

Burnham, A., 2012. Life-Cycle Greenhouse Gas Emissions of Shale Gas , Natural Gas , Coal , and Petroleum.

Cai, H., Dunn, J.B., Wang, Z., Han, J., Wang, M.Q., 2013a. Life-cycle energy use and greenhouse gas emissions of production of bioethanol from sorghum in the United States. Biotechnol. Biofuels 6, 141. doi:10.1186/1754-6834-6-141

Cai, H., Dunn, J.B., Wang, Z., Han, J., Wang, M.Q., 2013b. Life-cycle energy use and greenhouse gas emissions of production of bioethanol from sorghum in the United States. Biotechnol. Biofuels 6, 141. doi:10.1186/1754-6834-6-141

Cai, H., Han, J., Forman, G., Wang, M., 2013. Analysis of Petroleum Refining Energy Efficiency of U.S. Refineries.

CEC, ARB, 2007. AB 1007 State Plan To Increase the Use of Alternative Fuels California Energy Commission and California Air Resources Board.

Charpentier, A.D., Bergerson, J.A., Maclean, H.L., 2009. Understanding the Canadian oil sands industry's greenhouse gas emissions 4. doi:10.1088/1748-9326/4/1/014005

Charpentier, B.R.R., Cook, T.A., 2013. Variability of Oil and Gas Well Productivities for Continuous ( Unconventional ) Petroleum Accumulations Clouds : 2013.

CONCAWE, Edwards, R., 2007. Well-To-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context. JEC/CONCAWE/EUCAR.

Dimelu, M.U., Anyaiwe, V., 2011. Priorities of Smallholder Oil Palm Producers in Ika Local Government Area of Delta State: Implication for Agricultural Extension Service in Nigeria. World J. Agric. Sci. 7.

DOE, 2010. Report to Congress: Dedicated Ethanol Pipeline Feasibility Study.

Dunn, J.B., Mueller, S., Kwon, H.-Y., Wang, M.Q., 2013. Land-use change and greenhouse gas emissions from corn and cellulosic ethanol. Biotechnol. Biofuels 6, 51. doi:10.1186/1754-6834-6-51

Ekvall, T., Weidema, B., 2004. System boundaries and input data in consequential life cycle inventory analysis. Int. J. Life Cycle Assess. 9, 161–171. doi:10.1007/BF02994190

Elgowainy, A., Han, J., Cai, H., Wang, M., Forman, G.S., Divita, V.B., 2014. U.S. Refinery Efficiency: Impacts Analysis and Implications for Fuel Carbon Policy Implementation.

El-houjeiri, H.M., Brandt, A.R., 2012. Oil Production Greenhouse Gas Emissions Estimator.

El-houjeiri, H.M., Brandt, A.R., 2013. Open-Source LCA Tool for Estimating Greenhouse Gas Emissions from Crude Oil Production Using Field Characteristics.

Farber, D.A., 2011. Indirect Land Use Change, Uncertainty and Biofuels policy, University of Illinois Law Review,.

Forman, G.S., Divita, V.B., Han, J., Cai, H., Wang, M., 2014. U . S . Refinery Efficiency : Impacts Analysis and Implications for Policy Implementation 1–17.

Forman, G.S., Hahn, T.E., Jensen, S.D., 2011. Greenhouse gas emission evaluation of the GTL pathway. Environ. Sci. Technol. 45, 9084–9092.

Gerdes, K., Skone, T., 2009. An Evaluation of the Extraction, Transport and Refining of Imported Crude Oils and the Impact on Life Cycle Greenhouse Gas Emissions. NETL. http://www.netl.doe.gov/energy-analyses/pubs/PetrRefGHGEmiss_ImportSourceSpecific1.pdf.

Howarth, R.W., Santoro, R., Ingraffea, A., 2012. Venting and Leaking of Methane from Shale Gas Development : Response to Cathles et al . In Press : Climatic Change Article can be cited as : Howarth RW , Santoro R , and Ingraffea A ( 2012 ). Venting and leaking of methane from shale gas development : Res 1–20.

ISO, 2006. ISO management-Life cycle assessment-Requirements and guidelines, (International organization for Standardization) 14044 SRC.

James, R., Skone, T., 2012. Life Cycle Results from the NGCC LCI&C Study.

JEC, 2008. Well-to-Wheels analysis of future automotive fuels and powertrains in the European context, v 3.0. http://ies.jrc.ec.europa.eu/WTW.

JRC, 2012. BioGrace Publishable final report.

Keesom, Blieszner, J., Unnasch, S., 2012. EU Pathway Study: Life Cycle Assessment of Crude Oils in a European Context.

Keesom, W., Unnasch, S., Moretta, J., 2009. Life Cycle Assessment Comparison of North American and Imported Crudes. Jacobs, AERI. http://eipa.alberta.ca/media/39640/life%20cycle%20analysis%20jacobs%20final%20report.pdf.

Kubecka, B., 2011. Sorghum plays role in ethanol's impact.

Oregan Environmental Council, 2013. Oregan Environmental Council, Sustainable Biofuels Report, Chapter 6: Biofuel Feedstocks in Oregon.

Rosenfeld, J., Pont, J., Law, K., Hirshfeld, D., Kolb, J., 2009. Comparison of North American and Imported Crude Oil Lifecycle GHG Emissions. TIAX, AERI. http://eipa.alberta.ca/media/39643/life%20cycle%20analysis%20tiax%20final%20report.pdf.

Shell, 2003. Shell Middle Distillate Synthesis ( SMDS ) Update of a Life Cycle Approach to Assess the Environmental Inputs and Outputs , and Associated Environmental Impacts , of Production and Use of Distillates from a Complex Refinery and SMDS Route Client : Shell I 1–171.

Shonnard, D.R., Williams, L., Kalnes, T.N., 2010. Camelina-Derived Jet Fuel and Diesel : Sustainable Advanced Biofuels 29. doi:10.1002/ep

Stratton, R.W., Wong, H.M., Hileman, J.I., 2011. Quantifying Variability in Life Cycle Greenhouse Gas Inventories of Alternative Middle Distillate Transportation Fuels. Environ. Sci. Technol. 10, 4637–4644.

Taheripour, F., 2011. Land Use Emissions and Biofuels Policies.

UNL, 2013. University of Nebraska-Lincoln Website: http://cropwatch.unl.edu/bioenergy/soybeans.

Unnasch, S., Browning, L., CARB, M., 2000. Fuel Cycle Energy Conversion Efficiency Analysis.". Calif. Energy Comm. Air Resour. Board, Sacramento, CA.

Unnasch, S., Chan, M., 2007a. "Full Fuel Cycle Assessment: Tank to Wheels Emissions and Energy Consumption." prepared by TIAX, LLC, CEC-600-2007-003-D.

Unnasch, S., & Goyal, L. 2022. Well to Plug GHG Emissions for Electric Power Generation- Washington Electricity Mix. Life Cycle Associates Report LCA.6207.230.2022, Prepared under Washington Ecology Contract C2200132

Unnasch, S., Pont, J., 2007b. Full Fuel Cycle Assessment: Well to Tank Energy Inputs, Emissions and Water Impacts. Tiax LLC, CEC.

Unnasch, S., Riffel, B., Sanchez, S., Junquera, V., Plevin, R., 2010. Review of Transportation Fuel Life Cycle Analysis: Life Cycle Associates Report LCA.7002.24P.2010; Prepared for Coordinating Research Council, 2010.

Wang Lee, H., & Molburg, J., M., 2004. Allocation of energy use in petroleum refineries to petroleum products. . Int. J. LCA 9, 34–44.

Wang, M., 1999a. Transportation Fuel-Cycle Analysis : What Can the GREET Model Do ? presented at U . S . Environmental Protection Agency Fuel-Cycle Analysis Becomes Necessary When Comparing Different Fuels.

Wang, M., 1999b. GREET 1.5--Transportation Fuel Cycle Model, Volume 2: Appendices of Data and Results. ANL/ESD-39.

Wang, M., Huo, H., Arora, S., 2011. Methods of dealing with co-products of biofuels in life-cycle analysis and consequent results within the U.S. context. J. Name Energy Policy; J. Vol. 39; J. Issue 10 ; 2011 Medium: X; Size: 5726–5736.

Wang, M., Lee, H., Molburg, J., 2004. LCA Case Studies Allocation of Energy Use in Petroleum Refineries to Petroleum Products Implications for Life-Cycle Energy Use and Emission Inventory of Petroleum Transportation Fuels 9, 34–44.

Wang, M.Q., Han, J., Dunn, J.B.., Cai, H.., Elgowainy, A., 2012. Well-to-Wheels Energy Use and Greenhouse Gas Emissions of Ethanol from Corn, Sugarcane and Cellulosic Biomass for U.S. Use. Environ. Res. Lett. 7, 13–19.

Weidema, B., 2001. Avoiding Co-Product Allocation in Life-Cycle Assessment. J. Ind. Ecol. 4, 11–33.

Yeh, S., Kessler, J., 2013. Status Review of California ' s Low Carbon Fuel Standard Status Review of California ' s Low Carbon Fuel Standard.

Yeh, S., Witcover, J., 2014. Status Review of California ' s Low Carbon Fuel Standard January 2014 Issue Status Review of California ' s Low Carbon Fuel Standard.

(S&T)2 Consultants (2010). GHGenius 3.17, http://www.ghgenius.ca/.
ARB and Life Cycle Associates (2009). California-GREET Model, Version 1.8b, ARB, based on GREET 1.8b by ANL. http://www.arb.ca.gov/fuels/lcfs/lcfs.htm.
JEC (2008). Well-to-Wheels analysis of future automotive fuels and powertrains in the European context, v 3.0, http://ies.jrc.ec.europa.eu/WTW.
Laboratory, A. N. (2009). "The greenhouse gases, regulated emissions, and energy use in transportation (GREET) model, Version 1.8c.0."

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