Renewable Energy Group, Inc. (REG) Carbon Intensity Report: Renewable Diesel Produced from Soy Oil, Used Cooking Oil, Animal fats, Canola Oil, and Corn oil

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Executive Summary

In 2009, the California Air Resources Board (CARB) adopted the original Low Carbon Fuel Standard (LCFS) regulation. In late 2018, CARB re-adopted the LCFS program and created a new simplified Biodiesel-Renewable Diesel (BD-RD) Calculator used in this report.

The BD-RD calculator is a simplified version of the GREET model. GREET, or Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation, is a life-cycle model developed by Argonne National Laboratory, a US Department of Energy national research lab. The GREET framework is currently the standard life-cycle model used by the US Environmental Protection Agency (EPA) and CARB to implement their respective biofuel programs. As mentioned in its name, the GREET model calculates the emission of greenhouse gases in transportation by simulating various fuel production pathways to calculate the emissions within a given supply chain. The functional unit, or result from this version of GREET model, is the carbon intensity of biodiesel or renewable diesel. Carbon intensity (CI), or the emissions intensity associated with production of a given unit of fuel is most often expressed in grams of CO_2e per megajoule of fuel.

REG has consistently expressed interest in production of renewable diesel on the West Coast and in Washington. This white paper looks at hypothetical renewable diesel plant located in Washington on coastal water with a projected nameplate capacity of 250 MMGY of renewable fuel products. This hypothetical facility will be known as RD250 and data provided in this document can vary up to 10 percent due to the unknown location of the facility. RD 250 would be designed to be a multi-feedstock plant capable of processing high free fatty acid ("FFA") renewable feedstocks and has the ability to receive renewable feedstock by truck, rail, and ocean vessel. RD 250 would use natural gas and elecitricity for process energy and produce renewable transportation fuels including renewable diesel (RD), renewable naphtha, renewable propane, and renewable jet fuel (future). In addition to those on-road products, the naturally exothermic reaction would also produce excess thermal energy to be consumed in the production of hydrogen. Finished renewable diesel fuel would leave the facility by truck, rail, or ocean vessel.

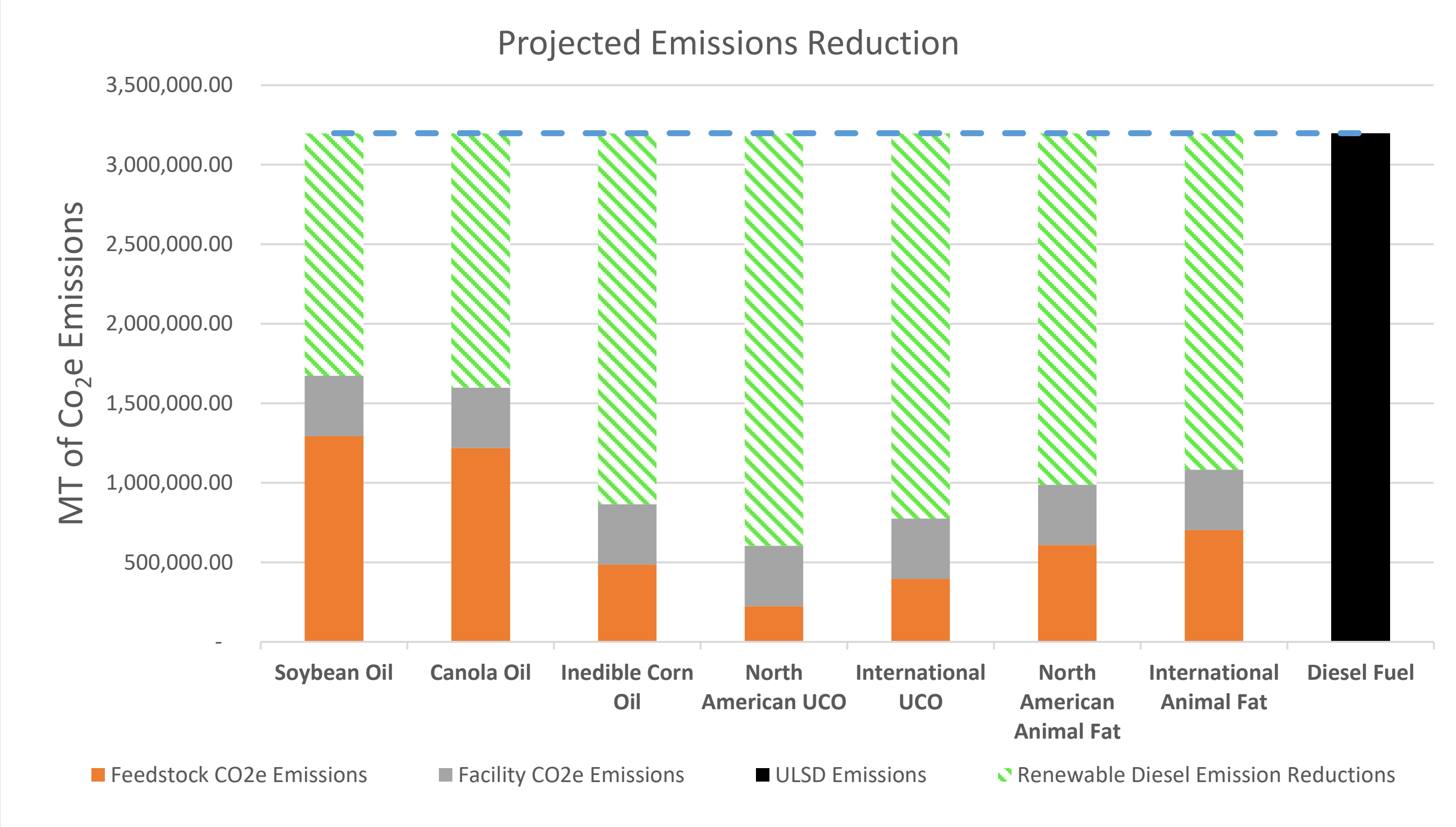
This report contains information to support the GREET model conclusions for RD produced from soy oil, used cooking oil (UCO), animal fats, canola oil, and inedible corn oil at the RD 250 facility. This report documents the modifications made to the simplified BD-RD Calculator, the data and sources utilized, and the modeled results. The data in this report is based on 12 months of estimated operating data. The table below summarizes the life cycle analysis results based on use of the CARB BD-RD calculator.

Table 1: Lifecycle GHG Emission

Life Cycle Stage	**Emissions, g/MJ**
Soy Oil RD	**53.06**
Canola Oil RD	**50.75**
Inedible Corn Oil RD	**27.84**
North America Used Cooking Oil RD	**19.67**
International Used Cooking Oil RD	**24.99**
North America Animal Fats RD	**31.65**
International Animal Fats RD	**34.63**

Based on results from the CARB BD-RD calculator, the figure below illustrates GHG emissions associated with renewable feedstock production and transportation (in orange), operation of the facility and renewable fuel product transportation (in grey), and fossil fuel GHG emissions displaced (in green). At reasonable expectations for renewable feedstock mix, operation of the facility would reduce life-cycle GHG emissions by over 2 million metric tons CO_2e per year compared to equivalent fossil fuels.

Figure 1: Projected Emissions Reduction



To put 2 million metric tons CO_2e in perspective, using information from U.S. EPA's "Inventory of U.S. Greenhouse Gas Emissions and Sinks 1190-2016", this is roughly the annual CO_2e emissions from 450,000 passenger cars. This facility would roughly reduce CO_2e by the same amount as if removing all passenger cars in Whatcom, Skagit, Okanogan, and Chelan counties of Washington State.

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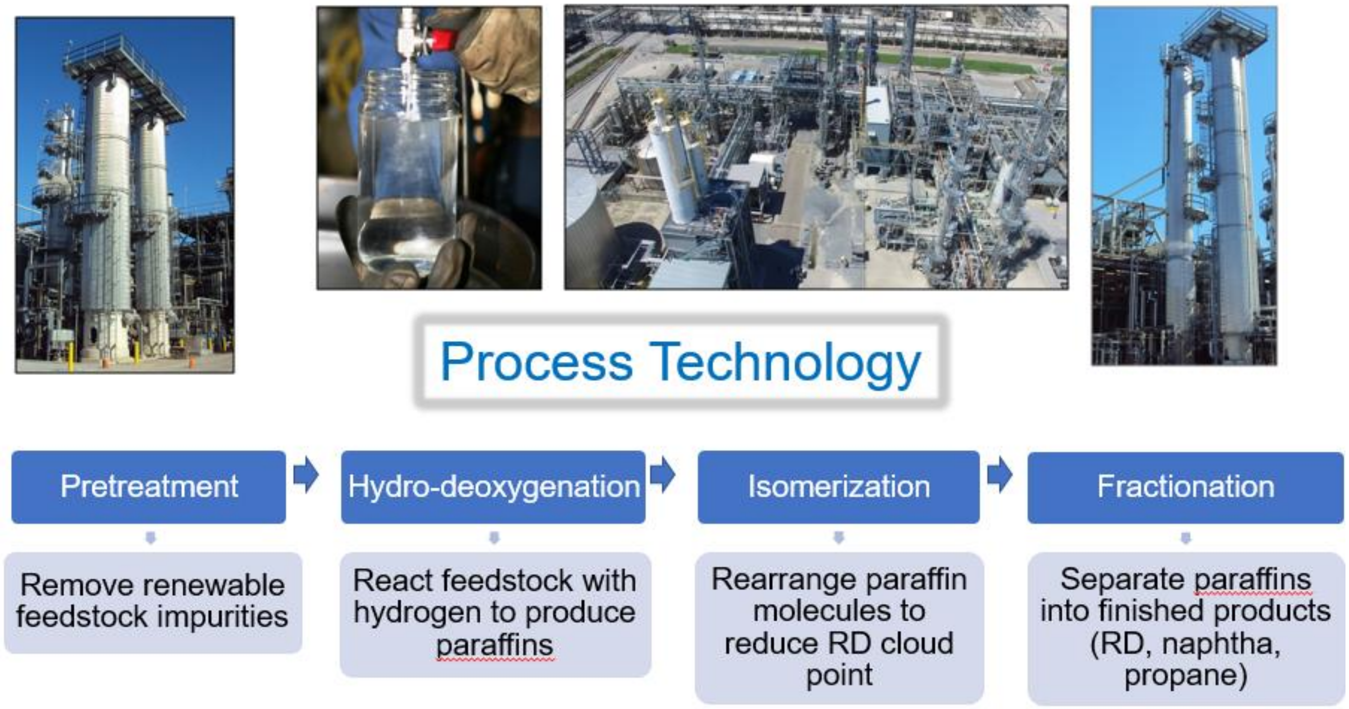
1. Pathway Overview

This report calculates the cradle-to-grave CO_2e emissions for seven renewable feedstocks converted to renewable fuels and used as transportation fuel. All emission factors utilized in this analysis are on a life cycle basis. This means that this report does not segregate emissions as scope 1, 2, or 3. For example, the emission factor used for this report, associated with the natural gas used to produce hydrogen includes all emissions associated with natural gas extraction, processing, transportation and leakage. Due to the inclusive nature of these emission factors, the results presented in this report are likely to be more conservative than AP-42 or 40 CFR Part 98 emission factors. RD 250 fuels would be sold into incentivized markets led by California. California's model is considered the most sophisticated of the various incentivized markets. This report is based on California's GREET model.

1.1 Facility Overview

RD 250 is a hypothetical 250 MMGY renewable diesel facility capable of processing renewable feedstocks including, but not limited to soy oil, used cooking oil, animal fats, canola oil , and inedible corn oil locaed on coastal waters in Washington State. Engineering estimates project that this facility would process over 1.8 billion pounds of feedstock to produce over 220 million gallons of RD per year with the balance of fuel produced being renewable propane, renewable naphtha, and (future) renewable jet fuel. For air permitting purposes, we are estimating the facility to be capable of 325 MMGY renewable fuel production for "potential". For purposes of this GHG discussion, the "potential" 325 MMGY production could happen if processes outperform the design basis. That outperformance shows better GHG performance than the nameplate capacity, on a per gallon basis. The conservative approach for GHG is to discuss the nameplate operating scenario. The nameplate scenario is considered for this report. This facility would not be capable of or permitted to process petroluem oils.

Figure 2: REG BioSynfining^{TM} Overview. Images are of REG Geismar.



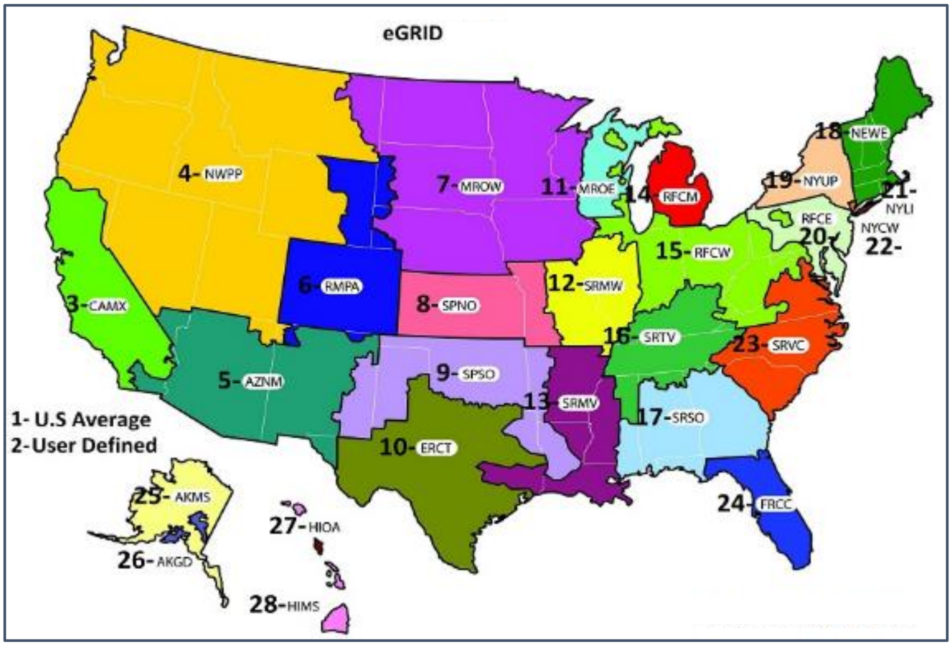
1.2 Model Design

This report calculates the carbon intensity of RD produced using a variety of renewable lipid feedstocks. The carbon intensity is generated using CARB's simplified BD-RD GREET calculator, and includes all supply chain processes from renewable feedstock collection or production to the delivery of the finished RD. The initial regional selection for the calculation is in the table below. Renewable feedstock emissions will have standard values unless otherwise specified.

In addition to standardized renewable feedstock values, it is also required to set regionally specific parameters for the analysis. For the energy that may be used throughout the life cycle of the products, a US average was selected. This provides representative emission factors for energy that may be used across our supply chain and within the biorefinery. The US average electricity grid is assumed within the default renewable feedstock emissions in the GREET model; for Washington State, EPA's E-Grid NWPP – 4 is utilized. We believe this is a very conservative assumption considering that in reality the power provided by the local utility is predominantly hydroelectricity.

Table 2: Region selection for Washington state

Section	Value Selected
2.1 Regional Electricity Mix	4-NWPP Mix
2.3 Regional Crude Mix	U.S. Average Crude
2.5 Regional Natural Gas Source	U.S Average Mix



2. Feedstock

This section of the report describes the various renewable feedstocks included in the model. The volumes of renewable feedstock below are illustrative, but allow for the calculation of representative values within the model. The model contains multiple renewable feedstocks; the total renewable feedstock consumption is calculated based on the facility's capacity and the estimated yield. The annual total for renewable feedstock is divided evenly among the different renewable feedstock types for this report. For actual operation, RD 250 would be incentivized to use the lowest CI renewable feedstocks available at any given time according to the market's models.

Table 3: Breakdown of the modeled renewable feedstock consumption

Feedstock Type	Quantity (LBS)
Soy Oil	262,989,250
Canola Oil	262,989,250
Inedible Corn Oil	262,989,250
North America used cooking oil	262,989,250
International used cooking oil	262,989,250
North America animal fats	262,989,250
International animal fats	262,989,250

2.1 Renewable Feedstock Transportation Data

This facility would receive renewable feedstocks from locations around the world. The transportation distance of the renewable feedstock to the RD facility can range from a few miles for local used cooking oil to thousands of miles. Renewable feedstocks would arrive by truck, rail, and ocean vessel. Due to the wide variety of underlying environmental properties and distances associated with different loads of feedstock, this report calculates a weighted average travel distance for each renewable feedstock type and transportation mode. However, because most programs incentivize renewable fuel based on their life cycle emission, this acts as an incentive to use local feedstock and to sell into local markets, minimizing the emissions from transportation. Since we do not have historical supply chain data, we have estimated representative values for the various feedstocks purposed in this analysis. REG experts develop these models for our currently operating biofuels facilities (including REG Geismar, REG's commercial RD plant in Louisiana) on a daily basis and use the models for renewable feedstock sourcing decisions. The incentivized low carbon fuels markets use actual values. The intent is to be conservative for this report before actual values are available.

Table 4: Modeled transportation distance

Feedstock Type	Modeled transportation method miles
Soy Oil	Rail 1758 miles
Canola Oil	Marine 1053 miles, Rail 1053 miles
Inedible Corn Oil	Truck 1323 miles, Rail 1323 miles
North America used cooking oil	Truck 905 miles, Rail 905 miles
International used cooking oil	Marine 6070 miles
North America animal fats	Truck 500 miles, Rail 1580 miles
International animal fats	Marine 9652 miles

3. Renewable Diesel Production

The production of RD requires renewable feedstock, energy, and chemical inputs. The facility would produce RD as well as a variety of co-products, including renewable naphtha, renewable propane, and (future) renewable jet fuel. This section summarizes the inputs and outputs of the proposed facility excluding renewable feedstock (discussed above). The final pathway results are included in Table 1 of the Executive Summary.

3.1 Energy Inputs

The facility would use pipeline natural gas and grid electricity as process energy. Natural gas is used as both process energy and to supply the SMR for production of hydrogen. The table below shows the estimated energy usage during the 12 months simulation period covered in this application.

Table 5: Facility energy Inputs

Period	**Natural Gas (MMBTU)**	**Electricity (KWH)**
Annual	5,505,000	134,817,000

3.2 Chemical Inputs

The primary chemicals used by the facility would be citric acid and dimethyl disulfide (DMDS). CARB has calculated the emissions from these chemicals to be 0.03 g/MJ.

3.3 RD Production Carbon Intensity Summary

The following table summarizes the carbon intensity of the fuel production, excluding feedstock, based on assumptions included in the GREET model.

Table 6: CI values associated with renewable diesel processing and transport

Life Cycle Stage	**Value (g/MJ)**
Natural Gas	**12.54**
Electricity	**2.01**
Other Fuel	**0.00**
Chemical Use	**0.03**
Finished Fuel Transportation	**0.50**
Displacement Credit (hydrogen)	**-0.96**
Displacement Credit (steam)	**-2.24**
Renewable Diesel Production Carbon Intensity	**11.88**

4. Renewable Diesel Transportation

The facility would distribute the finished RD by ocean vessel, rail, and truck to various facilities in Washington, California, Oregon, British Columbia, and other incentivized markets. To estimate the emissions from finished fuel transportation we assumed specific shares of fuels to various end markets. We believe the value calculated is conservative for fuel that would be delivered locally.

5. Tank-to-Wheels

The tank-to-wheels emissions are the same for all RD fuels. This emission represents the amount of methane and nitrous oxide associated with the combustion of RD in a vehicle. The default value in the CARB simplified BD-RD Calculator is 0.76 CO_2e/MJ.

6. Indirect Land Use Change

Certain pathways included in this application may have an indirect land use change penalty associated with them. REG applied iLUC where required by the LCFS. No internal REG calculations were done to modify iLUC where it is applicable.

7. Summary

The emissions calculated for the individual stages sum up to an overall CI of the fuel pathway. The following table summarizes the calculated full life-cycle CI for RD produced at RD 250, including a comparison to the CI of petroleum diesel.

Table 7: RD Life Cycle CI

Life Cycle Stage*	**Soy Oil**	**Canola Oil**	**Inedible Corn Oil****	**North America UCO**	**Inter-national UCO**	**North America Animal Fats**	**Inter-national Animal Fats**	**Fossil Diesel[1] (for comparison)**
Feedstock Production	**11.32**	**23.61**	**4.99**	**7.03**	**12.35**	**19.01**	**21.99**	
Fuel Production	**11.88**	**11.88**	**11.88**	**11.88**	**11.88**	**11.88**	**11.88**	
Indirect Land Use, g/MJ	**29.10**	**14.50**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	
Tailpipe Emissions g/MJ	**0.76**	**0.76**	**0.76**	**0.76**	**0.76**	**0.76**	**0.76**	
Total Well-to-Wheel CI, g/MJ	**53.06**	**50.75**	**27.84**	**19.68**	**24.99**	**31.65**	**34.63**	**100.45**

* Data is representative of operations at RD 250

** Inedible Corn Oil use as debit in DGS in Corn Ethanol is 10.22 g/MJ.

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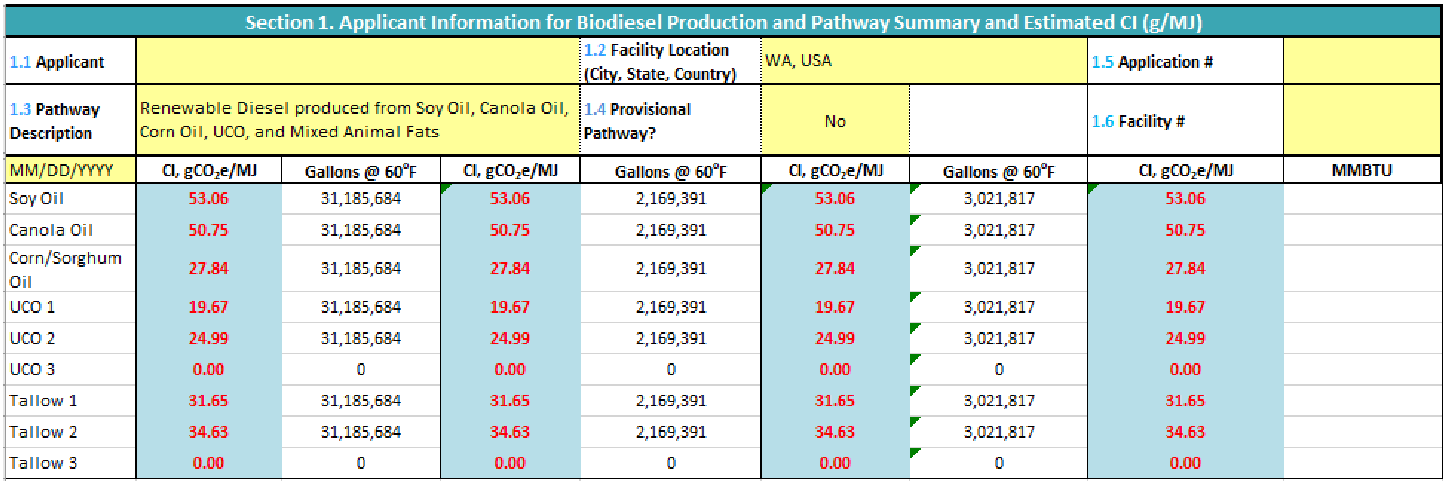
[1] https://ww3.arb.ca.gov/fuels/lcfs/fro_oal_approved_clean_unofficial_010919.pdf

8. Acronyms

- Biodiesel……………………………………………………………………BD
- California Air Resources Board ……………………………………………CARB
- Carbon Intensity……………………………………………………………CI
- Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation ……………GREET
- Free Fatty Acids……………………………………………………………FFA
- Indirect Land Use Change …………………………………………………iLUC
- Renewable Diesel……………………………………………………………RD
- Recovered Fatty Acids………………………………………………………RFA
- Used Cooking Oil……………………………………………………………UCO
- Steam Methane Reformer …………………………………………………SMR

9. Summary of CA-GREET Results



Section 1. Applicant Information for Biodiesel Production and Pathway Summary and Estimated CI (g/MJ)								
1.1 Applicant				1.2 Facility Location (City, State, Country)	WA, USA		1.5 Application #	
1.3 Pathway Description	Renewable Diesel produced from Soy Oil, Canola Oil, Corn Oil, UCO, and Mixed Animal Fats			1.4 Provisional Pathway?	No		1.6 Facility #	
MM/DD/YYYY	CI, gCO_2e/MJ	Gallons @ 60°F	CI, gCO_2e/MJ	Gallons @ 60°F	CI, gCO_2e/MJ	Gallons @ 60°F	CI, gCO_2e/MJ	MMBTU
Soy Oil	53.06	31,185,684	53.06	2,169,391	53.06	3,021,817	53.06	
Canola Oil	50.75	31,185,684	50.75	2,169,391	50.75	3,021,817	50.75	
Corn/Sorghum Oil	27.84	31,185,684	27.84	2,169,391	27.84	3,021,817	27.84	
UCO 1	19.67	31,185,684	19.67	2,169,391	19.67	3,021,817	19.67	
UCO 2	24.99	31,185,684	24.99	2,169,391	24.99	3,021,817	24.99	
UCO 3	0.00	0	0.00	0	0.00	0	0.00	
Tallow 1	31.65	31,185,684	31.65	2,169,391	31.65	3,021,817	31.65	
Tallow 2	34.63	31,185,684	34.63	2,169,391	34.63	3,021,817	34.63	
Tallow 3	0.00	0	0.00	0	0.00	0	0.00	

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