Method 2B Application: Endicott's Sabine Facility Producing Biodiesel from Fatty Acid Distillates Generated During Palm Oil Production

Life-Cycle Analysis Report (LCA)

Summary of CA-GREET Model inputs and Carbon Intensity Results

Introduction

This Life Cycle Analysis (LCA) provides a comprehensive well-to-wheels carbon intensity (CI) for biodiesel produced at the first biorefinery constructed by Endicott Biofuels II, LLC (Endicott). This biorefinery, called Sabine, is in operation now and ramping up to its full production rate of 30 million gallons per year. This LCA is prospective in nature and reflects the expected operational characteristics of the facility, as supported by the analysis of an independent third-party engineer.

During continuous operations, Sabine will use a variety of inedible and waste or low-valued fats and oils from both animal and vegetable sources. To date, Endicott has successfully applied to the ARB and received pending approval of its biodiesel produced at Sabine using Used Cooking Oil (UCO). Because of Sabine's flexibility, many feedstocks will be purchased and converted to high-purity biodiesel. This LCA analyzes the production of biodiesel using the inedible low-valued stream generated during the deodorization step of oil refining. [redacted]

This pathway accounts for the carbon intensity of biodiesel delivered to California blending terminals by rail from Port Arthur, Texas on the US Gulf Coast where Sabine is located. The pathway is a new biodiesel pathway; however, the existing Endicott UCO pathway already published by ARB provides the basis for several of the processing steps.

Endicott's Biodiesel Refinery, Sabine, Location and Capacity

The Endicott facility is a 30 million gallon per year biodiesel refinery that is owned by Endicott and HollyFrontier Corporation in a joint venture entity called Sabine Biofuels II, LLC. It is located in Port Arthur, Jefferson County, Texas. [redacted]

Endicott Production Process Overview

It is important to note, particularly for this feedstock LCA, that Endicott's production process – both at Sabine as well as at its future planned facilities – is very different from traditional "first generation" or "Gen 1" biodiesel plants that employ transesterification. A typical transesterification reaction in a Generation 1 biodiesel plant combines: (i) pure, edible oil feedstock, (ii) methanol, and (iii) sodium hydroxide catalyst in a single, 'batch' reaction vessel in which the glycerin molecule is broken off the oil molecule and replaced with the methanol molecule in a single reaction, forming a methyl ester. This is technically referred to as "homogeneous, base-catalyzed transesterification." The "trans-" portion of the name describes the swapping of glycerin for methanol molecules on the fat molecule. Endicott, at Sabine, employs "heterogeneous, acid-catalyzed esterification" using the Davy column to produce its methyl esters. [redacted] The last step in the Davy column is the chemical reaction that combines methanol with the FFA to make biodiesel.

Because of its unique, patented technology – including pre-treatment steps – Endicott at Sabine can easily commingle its various feedstocks, derived from any inedible natural fat or oil source, and produce high-purity biodiesel to help meet the LCFS demand for high-quality, low carbon intensity biodiesel.

In summary, the Endicott Process either (1) [redacted], or (2) [redacted] and then – in both instances – converts [redacted] into high-purity biodiesel. Free fatty acids (FFA) are present in every natural fat and oil on the planet and represent the waste, inedible portion of the fat/oil molecule. These FFAs must be separated from the source fat or oil in order to render that fat/oil edible by humans, and thus are an inedible byproduct. Because these FFAs are a byproduct, their use as feedstock for biofuel production does not lead to increased use of land for crops, plantations or animal herds and thus they do not have an indirect land use component. Endicott is committed to not using any edible natural oils to produce its biodiesel.

As stated earlier, because this pathway analysis will involve the acquisition of low-valued feedstocks that already have very high free fatty acid content [redacted]. Endicott has accounted for this energy savings in this LCA.

The Endicott Biodiesel production process is shown schematically in Figure 1. A more detailed diagram [redacted] is included in the Appendix.

Sabine 30MM GPY Biodiesel Block Flow Diagram

[redacted]

Figure 1: Discrete Components of Endicott Process, as employed at Sabine Facility

Although the Endicott Process used at Sabine has full feedstock flexibility, for the purpose of calculating carbon intensity [redacted] this lifecycle analysis will assume that [redacted] the feedstock will enter into the block diagram above [redacted] This reduces the consumption of process heat and electricity, and therefore the overall carbon intensity of biodiesel for this pathway.

Lifecycle Analysis Overview

The Well-To-Tank (WTT) Life Cycle Analysis of the biodiesel (BD) fuel pathway for this feedstock using the Endicott process includes the following steps:

Table 1: Sourcing, Processing and Transportation Lifecycle Elements

Feedstock	Alternative Use / Replacement Value	Feedstock gathering	Intermediate Transportation	Transport to Sabine	Conversion to Biodiesel	Biodiesel transportation to California and distribution
Inedible palm fatty acid	[redacted]	30 miles by heavy-duty	13,300 miles by vessel to Port of	102 miles by intra-coastal	Yes	1,600 miles by rail, 90 miles by

distillates	[redacted]	truck to coastal port	Houston	barge		truck to refueling

[redacted]

The Tank-To-Wheel (TTW) analysis includes the assumption that combustion of the biodiesel will occur in a heavy-duty vehicle for motive power. WTT and TTW analyses are combined to provide a total Well-To-Wheel (WTW) life cycle carbon intensity for Endicott's biodiesel utilizing this feedstock. Since PFAD is a low valued co-product generated during the production of edible oil, its production is not included within the analysis [redacted]

A Life Cycle Analysis Model called the California Greenhouse Gases, Regulated Emissions, and Energy use in Transportation (CA-GREET) was utilized to develop a WTW analysis of the conversion of this feedstock into biodiesel. This fuel pathway is different from previous pathways published by the Air Resources Board in the following ways:

1. The Air Resources Board has not, as of this writing, evaluated this feedstock for the production of renewable fuel;
2. The difference in the fuel mix used to make electricity in Texas versus those used to make electricity in California;
3. The various distances and modalities the feedstock must be transported to the biodiesel facility;
4. The distances the finished biodiesel must be transported for final use, and
5. The difference in the patented Endicott production process versus traditional production of biodiesel using transesterification

For this analysis, CA-GREET default parameters were employed except where specific parameters associated with Endicott's process differed from the CA-GREET defaults. One aspect of this LCA analysis that differed from the CA-GREET defaults is associated with feedstock and finished product transport. Based on the location of Endicott's Sabine biodiesel production facility the following feedstock transport, and associated transport mode was factored into the LCA:

- [redacted]
- 13,300 via Ocean Tanker from Malaysian port to the Port of Houston; and
- 102 miles via barge from Port of Houston to the Sabine plant in Port Arthur, Texas

Following production, the biodiesel will travel a total of 1,600 miles by rail to a bulk terminal in California followed by an ARB-assumed distance of 90 miles via heavy duty truck to refueling stations in California. The specific changes made to CA-GREET parameters that are specific to this LCA will be detailed later in this LCA document.

Palm Fatty Acid Distillates

Figure 2 below provides a high-level step-by-step description of the various stages in the Endicott PFAD to BD pathway. The steps include: [redacted] transport of the feedstock by oceangoing vessel to the Port of Houston, lightering and transport to Sabine in Port Arthur, Texas via 20,000 barrel barges and conversion to biodiesel. Following production of BD via the Endicott process in Port Arthur, the finished product is transported via rail to a California blending facility and thereafter to a fuel dispensing facility for final use in a heavy-duty vehicle.

Palm fatty acid distillate is an inedible, low-valued co-product generated during the deodorization step in the refining of crude palm oil into edible palm oil. Because of its extremely high (>90%) acid content it has limited uses, [redacted] Because PFAD is [redacted] co-product stream produced during the deodorization step of palm oil refining, incremental demand for this material will have no effect on primary demand for palm oil and thus will not drive increased palm plantings, just as consumption of inedible beef tallow will not cause increased use of grazing lands. Therefore, there is no indirect land use change (ILUC) impact from its use as a biodiesel feedstock.

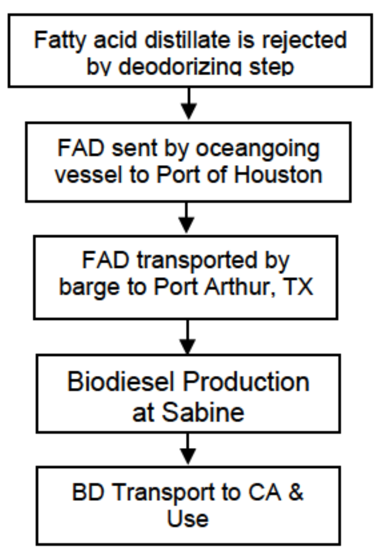

Figure 2: Discrete Components of Fatty Acid Distillate Pathway

Table 1 below provides a summary of the Well-To-Tank (WTT) and Tank-To-Wheel (TTW) GHG emissions (CO_2 equivalents) for this pathway. In accordance with Air Resources Board convention, GHG emissions are reported as g CO_2e/MJ.

Lifecycle Step	Emissions ($gC0_2e/MJ$)
Generation of PFAD	[redacted]
Heavy Duty Truck from PFAD refiner to SE Asian port	[redacted]
Oceangoing vessel transport	[redacted]
Barge transport	[redacted]
Biodiesel production	4.61
Transport of Biodiesel to California and Distribution	2.39
SubTotal (Well to Tank)	12.69
Total (Tank to Wheel)	4.48
Sub-total (Well to Wheel)	17.17
[redacted]	[redacted]
[redacted]	[redacted]
TOTAL Carbon Intensity (Well to Wheel)	**10.64**

Table 1: WTW GHG Emissions from Endicott Production Pathway

From Table 1 above, the GREET-based well-to-wheels analysis of biodiesel from Southeast Asian PFAD using the Endicott Process, located at the Sabine facility in Port Arthur, Texas, plus added CI for replacement of DDG use as animal feed indicates a total carbon intensity of 10.64 gCO_2e/MJ. The following sections of this report provide a detailed discussion of the lifecycle analysis for this pathway.

Transport of Feedstock

[redacted] Fatty acid distillates are not edible by humans and thus must be removed. Southeast Asian producers remove and aggregate this material at the refinery. Endicott [redacted] will purchase this feedstock [redacted]

Feedstock Quality Assurance

It is important to discuss Endicott's and Sabine's commitment to using only inedible fat/oil feedstocks to produce its biodiesel, and to assiduously avoid any use of palm oil. Because of Endicott's unique, patented process for producing biodiesel, it prefers high-free fatty acid inedible feedstocks and thus PFAD can be used in its pure state, with an acid content often over ninety percent (90%). Triglycerides, such as crude or refined palm oil, are not desired by Sabine and therefore, should Endicott elect to use some PFAD, all inbound feedstock lots will be tested and certified upon delivery to be 100% PFAD. Likewise, Endicott's suppliers must certify that they have not commingled the PFAD feedstock with any other oils. These records will be maintained and auditable by federal and state agencies upon request. This quality assurance program ensures that Endicott, and its facility Sabine, will receive only inedible PFAD, and never any palm oil.

Biodiesel Process Energy Consumption

The Endicott process being used at Sabine for biodiesel production encompasses three discrete steps:

[redacted]

Low free fatty acid feedstocks, such as UCO, [redacted] yield high-purity (>99% methyl esters) G2 Clear® biodiesel; [redacted] This reduces the direct and upstream Btu's per pound of biodiesel.

Table 2: Total Energy and Energy Shares

Category	Total Energy	Energy Shares (%)
Natural Gas (Btu/lb BD)	657.7	39.3
Electricity (Btu/lb BD)	34.6	2.1
Methanol (Btu/lb BD)	980.8	58.6
Total BD Production Direct Energy (Btu/lb BD)	**1,673.2**	**100**

Avoidance of GHGs from Production of Pitch

As previously discussed, the Endicott biodiesel production process produces, as a co-product, a high-Btu renewable fuel from its vacuum distillation processing step that is very similar in nature and heat content to No. 6 heavy fuel oil. Based on the viscosity and heat content of the pitch, it is assumed to displace No. 6 fuel oil used for transportation (such as for ocean liners). The following parameters were assumed to compute the avoided GHGs from production of pitch.

- [redacted]
- GHG emissions from No. 6 Fuel Oil: 97,764 g/mmBtu (ARB estimate)
- [redacted]

Transportation of Biodiesel

California GREET assumes that 80 percent of the biodiesel is transported by heavy duty truck a distance of 50 miles from the biodiesel plant to bulk terminals; the remaining 20 percent is distributed directly from the biodiesel plant to the consumer. Endicott Biofuels biodiesel, produced in the Port Arthur facility, will be transported via rail an estimated 1,600 miles to a bulk terminal in California. The biodiesel at the bulk terminal is assumed to then be transported 90 miles by heavy duty truck to the refueling station.

Biodiesel Consumption

The combustion of BD in a heavy-duty vehicle, based on CA-GREET assumptions, results in emissions of 4.48 gCO_2e/MJ.

Changes to CA-GREET Default Values

The Endicott biodiesel production process, as discussed in detail in this report, differs from a traditional transesterification method of biodiesel production. As such, certain energy and production parameters in the CA-GREET model were modified to more closely represent the energy and production balances associated with the three-step hydrolysis and distillation processes that comprise the Endicott Sabine biodiesel production process. These GREET default modifications are discussed below. Note that in the GREET spreadsheet, the UCO BD tab was converted to the PFAD EBF BD tab. As such the references below reflect changes made to applicable UCO default parameters in order to model the PFAD pathway.

Table 3: Modifications to CA-GREET Default Values

GREET Tab/Cell	Description	Default Value	Modified Value	Comment
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

GREET Tab/Cell	Description	Default Value	Modified Value	Comment
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GREET Tab/Cell	Description	Default Value	Modified Value	Comment
T&D/ AH6	[redacted]	[redacted]	[redacted]	[redacted]
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Conclusions

This report presents a discussion of the lifecycle analysis conducted for the production of Endicott Biodiesel at its Sabine facility using palm fatty acid distillates gathered in Southeast Asia and processed in Port Arthur, Texas. Based on the information presented above the wells-to-wheels carbon intensity of Endicott's biodiesel product is as follows:

Table 4: Summary GHG Emission Values

Feedstock	Emissions ($gC0_2e/MJ$)
Well to Tank	12.69
Tank to Wheels	4.48
[redacted]	[redacted]
Total Well to Wheels	(0.87)
[redacted]	[redacted]
Total CI of PFAD to Endicott Biodiesel	**10.64**

From Table 4 it can be seen that the total well to wheels carbon intensity associated with this biodiesel pathway product results in a carbon intensity of 10.64 gCO2e/MJ. [redacted] the W-T-W CI for Endicott's PFAD-to-Biodiesel pathway is -0.87. There are several factors responsible for the low carbon intensity value of this biodiesel. First, PFAD can be used directly into the Endicott process and does not require pre-processing energy such as that required for used cooking oil, for example; second, the biodiesel production system uses low-carbon fuels such as natural gas for process steam, and third, Endicott's patented system for biodiesel production from this feedstock generates [redacted] pitch, which is a renewable and low-carbon substitute for No. 6 fuel oil.

Appendix: Process Flow Diagram and Energy Consumption Using PFAD

Sabine 30MM GPY Biodiesel Block Flow Diagram using PFAD

[redacted]

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