Fuel Pathway Lifecycle Analysis – Endicott's Sabine Facility Producing Biodiesel from Used Cooking Oil

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 completed and undergoing commissioning and ramp-up to full production as of this writing. Therefore, this LCA is prospective in nature and reflects the expected operational characteristics of the facility.

During continuous operations, Sabine will use a variety of inedible, waste fats and oils from both animal and vegetable sources. However, this LCA addresses a single feedstock to be employed, namely used cooking oil (UCO). Endicott is in the process of conducting life cycle analyses for additional feedstocks to be used at Sabine. The Pathway Report for these multiple feedstocks will adhere to guidance provided in ARB's "Mixed Feedstock Biodiesel Guidance" methodology.

Sabine is located in east Texas in the city of Port Arthur. The biorefinery construction is completed, and commissioning and ramp-up are underway. The facility's nameplate capacity is 30 million gallons per year of high-purity biodiesel. During the development of this facility, Endicott formed a joint venture (JV) with independent petroleum refiner HollyFrontier Corporation. The resulting 50/50% JV is called Sabine Biofuels II, LLC.

The Endicott Process

The Endicott process has [redacted] basic steps. The [redacted] vacuum distillation. This is followed by [redacted] reactive distillation. For some feedstocks [redacted]. Waste fats and oils with lower acid content (e.g. inedible beef UCO, yellow grease, etc.) are first [redacted] and then distilled; while those waste fats and oils with high acid content (e.g. fatty acid distillates) are simply distilled [redacted]. This front end flexibility allows the processing of feedstocks across the entire spectrum of natural fats and oils with impunity. In all cases, the output [redacted] then proceeds to [redacted] reactive distillation using the patented Davy process to produce high-purity methyl esters in the form of Endicott's G2 Clear®.

Endicott developed and patented the Endicott Process, which – unlike traditional biodiesel that desires pure triglyceride molecules to produce methyl esters – [redacted] then convert the [redacted] to high-purity biodiesel. When waste fats or oils have higher triglyceride content, they [redacted]; however, when waste fats or oils have higher free fatty acid content they [redacted]. This means that all waste fats and oils – from 0% free fatty acid content to 100% fatty acid content – can be consumed agnostically by the Endicott Process, in any combination on a continuous basis. Used cooking oil, as a biodiesel feedstock, contains a

relatively high level of triglycerides [redacted]. The lifecycle analysis conducted for the conversion of UCO to biodiesel using the Endicott process therefore incorporates all [redacted] process steps.

[redacted] Therefore, in the life cycle analysis, a conservative rail transport distance has been factored into the LCA analysis to accommodate the maximum expected distance from the UCO source to a [redacted] fat splitter and then to Port Arthur.

As previous noted, this [redacted] hydrolysis is [redacted], close to the source of Midwestern UCO. Endicott has accounted for the energy consumption values for this step as part of our LCA.

The Endicott Biodiesel production process is shown schematically in Figure 1.

[redacted]

Sabine Biofuels II, LLC: The First Facility to use the Endicott Process

During the development of its first biodiesel facility, Endicott formed a joint venture with independent petroleum refiner HollyFrontier Corporation. The resulting [redacted] JV is called Sabine Biofuels II, LLC. [redacted]

The Well-To-Tank (WTT) Life Cycle Analysis of the biodiesel (BD) fuel pathway from Used Cooking Oil (UCO) using the Endicott process includes rendering of UCO, [redacted] of the rendered UCO, transportation of the resulting processed UCO to the Sabine facility, conversion to biodiesel and transporting the finished fuel for use in a vehicle. The Tank-To-Wheel (TTW) analysis includes actual combustion of this fuel 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 Midwest UCO.. Because UCO is a waste product, its production is not included within the system boundary. In this report, UCO generated in the Midwest is transported by heavy duty diesel truck to a rendering plant in the Midwest. The alternative fate of UCO is transport to a landfill, which is assumed to be the same transport distance on average as UCO transport to a rendering plant. Since the net difference in GHG emissions is zero, the transportation of UCO to a rendering plant is not included within the system boundary and thus this transport segment does not contribute to the overall CI of Endicott's biodiesel production..

Lifecycle Analysis

A Life Cycle Analysis Model called the Greenhouse Gases, Regulated Emissions, and Energy use in Transportation (GREET) developed by Argonne National Laboratory was utilized to develop a WTW analysis of the conversion of Used Cooking Oil (UCO) into biodiesel. The CA-GREET model (GREET model utilizing certain California-specific parameters) and pathway documents published by ARB staff are available from the Low Carbon Fuel Standard (LCFS) website at www.arb.ca.gov/fuels/lcfs/lcfs.htm. The CA-GREET model was employed for determination of the carbon intensity associated with Endicott's UCO to biodiesel pathway.

This fuel pathway is different from the previously distributed "Detailed California-Modified GREET Pathway for Biodiesel Produced in California from Used Cooking Oil" in that the steps for our pathway occur as follows:

- UCO is gathered and rendered in the Midwest, [redacted] and then transported via rail to the biodiesel facility in Port Arthur, Texas;
- The rendered and split UCO is then converted to fuel at our Port Arthur facility; and Once the biodiesel is produced it is transported by rail car to California

The carbon intensity difference between UCO-derived biodiesel produced in Texas and in California is primarily based on the following four factors:

1. the difference in the fuel mix used to make electricity in Texas versus those used to make electricity in California;
2. the distances the UCO must be transported to the biodiesel facility,
3. the distances the finished biodiesel must be transported for final use, and
4. 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 our LCA analysis that differed from the CA-GREET defaults is associated with feedstock and finished product transport. Based on the location of Endicott's first biodiesel production facility (Port Arthur, Texas) it is assumed that the processed UCO will travel 1500 miles via rail to Port Arthur [redacted] The biodiesel will then travel a total of 1600 miles, by rail, to a bulk terminal in California. The specific changes made to CA-GREET parameters that are specific to this LCA will be detailed later in this LCA document.

Figure 2 provides a high-level step-by-step description of the various stages in the Endicott UCO to BD pathway. The steps include UCO rendering, transport of the rendered UCO to a [redacted] facility for [redacted]) then to our biodiesel production plant. Following production of BD via the Endicott process in Port Arthur, the finished product is transported, via rail to a blending facility and thereafter to a fuel dispensing facility for final use in a heavy-duty vehicle. Since UCO is considered to be a waste product, the energy used and GHG emissions from its initial production are not included in this analysis.

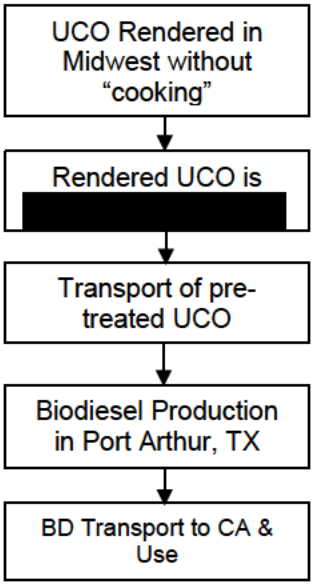

Figure 2: Discrete Components of UCO Pathway

This document provides complete details for UCO to BD wherein the rendering of the UCO does not require "cooking." The moisture inherent in cooking oil must be removed prior to its use in the Endicott process. In older rendering plants, considerable amounts of input energy are used to 'cook' the moisture out of the oil; however, Sabine will consume only UCO from modern rendering plants, where only a small quantity of input energy is required to essentially 'decant' the water from the oil. Thus this pathway is modeled as one not requiring cooking. Complete details of all parameters and calculations are included in the remainder of this document.

Table 1 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 ($gC0_2e/MJ$)
Rendering of UCO	1.01
UCO/split UCO transport to to Port Arthur, TX.	1.63
[redacted]	1.86
Biodiesel production	4.76
Transport of Biodiesel to California and Distribution	2.16
Total (Well to Tank)	11.42
Total (Tank to Wheel)	4.48
Sub-total (Well to Wheel)	15.90
GHG Avoidance from Production of Pitch	(5.85)
TOTAL Carbon Intensity (Well to Wheel)	**10.05**

Table 1: WTW GHG Emissions from Endicott Production Pathway

From Table 1 above, the GREET-based well-to-wheels analysis of biodiesel from Midwestern UCO using the Endicott Process, located at the Sabine facility in Port Arthur, Texas indicates a total carbon intensity of 10.05 gCO_2e/MJ. The following sections of this report provide a detailed discussion of the lifecycle analysis for this pathway.

Rendering and Transport of UCO in the Midwest

UCO generated in the Midwest is transported by heavy diesel truck to a rendering plant in the Midwest. The alternative fate of UCO is transport to a landfill, which is assumed to be the same transport distance on average as UCO transport to a rendering plant. Therefore, the net emissions for UCO transport to a rendering plant are assumed to be zero.

As previously mentioned, our Port Arthur facility will consume UCO only from modern rendering plants, where only a small quantity of energy is required to essentially 'decant' the water from the oil. Thus this pathway is modeled as one not requiring cooking. Also as discussed earlier, the UCO will undergo any required fat splitting (hydrolysis) at an oleochemicals facility in the Midwest. The processed and split UCO is then transported via rail a distance of up to 1,500 miles from the source of the UCO in the Midwest to the Sabine biodiesel facility.

As shown in Table 1, the carbon intensity of the UCO rendering process and transport to Port Arthur is 2.64 gCO_2e/MJ.

Biodiesel Production and Transport

The Endicott process being used at Sabine for biodiesel production encompasses [redacted]:

1. [redacted];
2. vacuum distillation, and
3. reactive distillation using the Davy method

Low free fatty acid feedstocks – including UCO – require all three steps to yield high-purity (>99% methyl esters) G2 Clear® biodiesel; however, high free fatty acid feedstocks can bypass the first step and enter the Endicott process at step two. As previously noted, for our Sabine plant, [redacted]. The incremental transport of [redacted] UCO is accounted for in this life cycle report. Biodiesel produced in our Port Arthur facility will be transported via rail to a bulk terminal in California. From there a CA GREET default assumption of 90 miles via heavy duty truck is assumed from the bulk terminal to a refueling station. From Table 1 it can be seen that biodiesel production, transport and distribution of Endicott's biodiesel product results in an incremental carbon intensity of 8.78 g CO_2e/MJ.

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.

Biodiesel Process Energy Consumption

Table 2 presents the total energy associated with the production of one pound of biodiesel from UCO using the Endicott process (including UCO processing energy) and the individual shares of energy relative to total energy requirements.

Process/ Fuel	Total Energy	Energy Shares (%)
UCO Processing		
Natural Gas (Btu/lb UCO)	119	78.3
Electricity (Btu/lb UCO)	33	21.7
UCO Processing – Total Direct Energy (Btu/lb UCO)	**152**	
UCO Processing – Total Direct & Upstream Energy (Btu/lb UCO)	**227**	
Biodiesel Production		
Natural Gas (Btu/lb BD)	1226	54.9
Electricity (Btu/lb BD)	43	1.9
Methanol (Btu/lb BD)	966	43.2
BD Production - Total Direct Energy (Btu/lb BD)	**2235**	
BD Production – Total Direct and Upstream Energy (Btu/lb BD)	**2,951**	

Table 2: Energy Consumption from Endicott Pathway

The energy consumption information shown in Table 2 assumes the purchase and combustion of local utility-provided natural gas for Sabine's operations.

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.

- Total Btu of pitch produced: 224,000 mmBtu
- Biodiesel production: 220,200,000 lbs
- Biodiesel heat content: 16,149 Btu/lb.
- Ocean liner W-T-W GHG emissions: 97,914 g/mmBtu (per ARB)
- GHG emissions avoidance relative to biodiesel energy production:
    - 6,167.8 g/mmBtu; or
    - 5.85 g CO_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 [redacted] and distillation processes that comprise the Endicott Sabine biodiesel production process. These GREET default modifications are discussed below.

GREET Tab/Cell	Description	Default Value	Modified Value	Comment
UCO BD/B11	UCO Processing (Btu/lb. of UCO)	1073	152	Assumes UCO from modern rendering plants plus no cooking required
UCO BD/B12	FFA transesterification (Btu/lb BD)	171	430	This step in the Endicott process is assumed to be [redacted]
UCO BD/B13	UCO transesterification (Btu/lb. of biodiesel)	2,116	1,805	UCO esterification (EBF Process) (Btu/lb. of biodiesel). EBF distillation process slightly less energy-intensive that traditional transesterification
UCO BD/C41	Glycerin co-product production lb/lb BD	0.105	0.107	Based on 23.6 mm lbs/yr of glycerin production and 220.2 mm lbs/yr of BD production
UCO BD/E174	Shares of Process Fuels: Natural Gas (%) for [redacted]	90.7	94.2	Based on EBF energy balance
UCO BD/E177	Shares of Process Fuels: Electricity (%) for [redacted]	9.3	5.8	Based on EBF energy balance
UCO BD/F174	Shares of Process Fuels: Natural Gas (%) for Esterification	42.0	45.5	Based on EBF energy balance
UCO BD/F177	Shares of Process Fuels: Electricity (%) for Esterification	2.2	1.0	Based on EBF energy balance
UCO BD/F179	Shares of Process Fuels: Electricity (%) for Esterification	40.9	53.5	Based on EBF energy balance
T&D/IH93	Transport of UCO to BD plant	50 miles via truck	1500 miles via rail	Includes distance to [redacted]
T&D/GE 93	Transport of Biodiesel to California Bulk Terminal	1400 mi via rail	1600 miles via rail	From Port Arthur, Texas

Conclusions

This report presents a discussion of the lifecycle analysis conducted for the production of Endicott Biodiesel at our facility in Port Arthur, Texas using used cooking oil gathered and processed in the Midwest. Based on the information presented above the wells-to-wheels carbon intensity of Endicott's biodiesel product is as follows:

- Well-to-Tank – 11.42 g CO_2e/MJ
- Tank-to-Wheels – 4.48 g CO_2e/MJ
- GHG Avoidance from Pitch – 5.85 g CO_2e/MJ
- Total Well-to-Wheels – 10.05 g CO_2e/MJ