

Waste, Residue and By-Product Definitions for the California Low Carbon Fuel Standard

Final Report

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Abbreviations and Acronyms

ARB	California Air Resources Board
CI	Carbon Intensity
CO2	Carbon Dioxide
CO2E	Carbon Dioxide Equivalent
DGS	Distillers' Grains with Solubles
EPA	US Environmental Protection Agency
EU	European Union
GHG	Greenhouse Gas
GREET	Greenhouse gas Regulatory Energy and Emissions Tool
GTAP	Global Trade Analysis Project
ICCT	The International Council on Clean Transportation
iLUC	Indirect Land Use Change
LCA	Lifecycle Analysis
LCFS	Low Carbon Fuel Standard
UK	United Kingdom
US	United States
PFAD	Palm oil Fatty Acid Distillates
RED	Renewable Energy Directive
RFS	Renewable Fuel Standard
RTFO	Renewable Transport Fuel Obligation

Executive Summary

The desire to reduce greenhouse gas (GHG) emissions in the transportation sector has sparked the development of regulations aimed at both reducing fuel consumption and displacing conventional transportation fuels with lower carbon emitting fuels. Biofuels are currently the dominant alternative fuel displacing conventional fuel consumption. In California, the Low Carbon Fuel Standard (LCFS) is one such innovative regulation developed to incentivize the production and sale of alternative transportation fuels and reduce the carbon intensity (CI), and subsequently GHG emissions, of transportation fuels. Carbon intensity refers to the GHG emissions emitted per unit of transportation fuel consumed and is calculated on a lifecycle basis.

Under the LCFS, the specific feedstock and how it is handled during the lifecycle analysis (LCA) is extremely important. LCA is the process used to quantify the energy and emissions during feedstock production and recovery, fuel production, fuel transport, and combustion of a transportation fuel. While the United States (US) Environmental Protection Agency (EPA) Renewable Fuel Standard (RFS) has a GHG reduction threshold for biofuels to meet, the LCFS gives incentives based directly on the quantified CI of the specific biofuel including both direct and indirect emissions (i.e., indirect land use change (ILUC), substitution and displacement). The effectiveness of the LCFS as a tool to incentivize the use of the alternative fuels that can deliver the largest carbon benefits is directly linked to whether the CI values assigned to each fuel provide a true representation of the emissions impacts of increasing production of those fuels. This, in turn, is dependent on the methodological choices made in the LCA for each fuel. Within the LCA, feedstock categorization is important because it determines how much of the feedstock production emissions are allocated to the transportation fuel and whether indirect emissions are considered that would occur by displacing that feedstock from its current economic sector. For instance, it is normal in LCA that when a feedstock material is considered a 'residue' of another production process, that emissions resulting upstream in that production process should not be assigned to the residual material.

New feedstocks for alternative fuels (e.g., corn oil for biodiesel) are being developed to meet the demand for low CI fuels. Their categorization is often not straightforward and can evolve and change. The California LCFS at this time does not have clear guidelines and principles for distinguishing how these feedstocks should be categorized and evaluated during the LCA process and what, if any, non-ILUC indirect emissions should be included in the LCA.

ICF has developed recommendations for rules and guidelines to categorize biofuel feedstocks and how direct and indirect emissions upstream of fuel production should be estimated within an LCA for the LCFS. Emissions during the biofuel production process from any feedstock should be allocated in some way to the resulting biofuel. ICF recommends that an in-depth economic and supply chain analysis be performed for each new feedstock proposed to ARB. The purpose of the analysis is to understand how the feedstock is produced, the other products generated during its production, and the relative value of the biofuel feedstock to these other products. The qualitative and quantitative understanding of the supply elasticity (i.e., responsiveness of the supply of a biofuel feedstock to demand or price) and value of the biofuel feedstock compared to the other products allows the biofuel feedstock to be categorized as either a primary product or a secondary product of the process to produce them.

Primary products are the dominant value products of the process with elastic supply with demand. Primary products that are biofuel feedstocks include corn starch for ethanol production, soy oil for biodiesel production and palm oil for renewable diesel production. If the feedstock is categorized as a primary product, the results of the economic analysis for the other products of the process will help determine whether any of the other products of the process are primary co-products, or if it is a singular primary product. Direct emissions for primary products are estimated by allocating the upstream and process emissions to produce them. Indirect emissions estimated for primary products could include ILUC and substitution emission credits from secondary products.

Secondary products are the products of a process that have inelastic supply with demand where even if the market value of a secondary product increases one would not expect more of it to be produced from that process. The economic value of secondary products is the determining factor between the two subcategories: by-products; and wastes and residuals. By-products are secondary products with significant economic value, and wastes and residuals are secondary products with little or no economic value. Direct emissions for secondary products are estimated by allocating process emissions unique to producing the secondary product (e.g., corn oil extractor emissions to corn oil, but no other ethanol production emissions). Direct emissions for wastes and residuals can include diversion emissions credits or debits resulting from diverting the disposal of a waste or residual to a useful biofuel feedstock. Indirect emissions estimated for secondary products could include displacement emissions from producing and utilizing a replacement feedstock when an economically valuable feedstock is removed from the market for biofuel production.

The initial plan was to develop quantitative feedstock value thresholds to distinguish the categories in a similar fashion to the UK Renewable Transport Fuel Obligation (RTFO) that differentiates co-products from wastes and residuals with a value threshold around 15% of the main product. As the analysis progressed it became apparent that specific value thresholds were arbitrary to market dynamics at the point when an application was submitted and could potentially lead to manipulation. ICF chose to recommend the qualitative, and potentially more market research intensive, approach of supply elasticity to separate primary from secondary products.

Table ES-1 summarizes the feedstock categories and biofuel feedstock direct and indirect emission estimation methodologies to be included in the LCA. It is important to reiterate that these emissions estimation methodologies are for upstream and process emissions to produce a biofuel feedstock and emissions during the biofuel production process from any feedstock should be allocated to the biofuel. For example, municipal solid wastes (MSW) would be categorized as a waste and have zero upstream emissions but all energy and emissions to convert the MSW to renewable natural gas (RNG) is allocated to the final RNG product.

Table ES-1. Biofuel Feedstock Categories and Emission Estimation Methodologies

Feedstock Category for Biofuel Production	Definition	Direct Emissions Estimation Methodology	Indirect Emissions Estimation Methodology
Primary Product(s)	Main product(s) of the production process with elastic supply	Allocation of upstream and process emissions	iLUC, substitution from secondary products
By-Products	Secondary product with inelastic supply and significant economic value	Allocation of process emissions to directly produce the feedstock; no upstream emissions	Displacement Method
Wastes and Residuals	Secondary product with inelastic supply and little to no economic value	No upstream emissions; credits for Diversion	Displacement Method, if necessary

ICF performed four case studies of existing biofuel feedstocks utilizing the developed rules and guidelines. The ICCT identified the four biofuel feedstocks for the case studies: tallow, corn oil, used cooking oil and palm oil fatty acid distillate (PFAD). As an example, tallow, the animal fat produced during the rendering process of animal carcasses after meat collection, contributes only 1.7% - 2.8% of the total marketable value of beef cattle. Tallow demand is unlikely to drive increased livestock production, and so tallow is determined to be inelastic with demand. Tallow does have significant economic value, though, with per-unit prices approximately 20% - 35% of beef prices on a per-ton basis. Because tallow production is inelastic with demand, tallow is categorized as a secondary product, and because it has significant economic value, further categorized as a by-product. Direct emissions for tallow as a biofuel feedstock include emissions from the rendering process, but not upstream emissions from livestock production. Indirect emissions are determined from a displacement analysis. The main existing uses of tallow are in animal feed and in the oleochemical industry. In fact, indirect emissions for the feedstocks in all four case studies were found to predominantly come from displacement of animal feed. To reduce circular logic in the case that one inelastic animal fat feedstock could displace another (i.e., tallow used as a biofuel feedstock replaced by corn oil, PFAD or used cooking oil), elastic vegetable oils (i.e., soy oil, canola oil or palm oil) or corn animal feed were identified as the replacement feedstock in the animal feed market, and the vegetable oil that is displaced varies by region. Palm oil was identified as the replacement feedstock for tallow use in the oleochemical industry. The displacement analysis thus allocates indirect emissions from the production of corn or vegetable oils to the biofuel feedstocks in these case studies. Table ES-2 summarizes the results of all four case studies and the full case studies can be found in Section 5.

Table ES-2. Case Study Results

Feedstock	Biofuel Category	Direct Emissions	Indirect Emissions
U.S. Inedible Tallow	By-Product	Allocation of rendering process emissions between the primary co- products	Displacement of animal feed with corn and oleochemicals with palm oil
U.S. Inedible Corn Oil	By-Product	Allocation of DGS pressing emissions in dry milling	Displacement of DGS (animal feed) with corn
Southeast Asia PFAD	By-Product	No allocation of upstream or process emissions	Displacement of animal feed fat with vegetable oils such as soy oil or palm oil
U.S. Used Cooking Oil	By-product	No allocation upstream or process emissions	Displacement of animal feed fat in the form of yellow grease with vegetable oils such as soy oil

1 Purpose and Overview

The California LCFS is an innovative regulation developed to incentivize the production and sale of alternative transportation fuels and reduce the carbon intensity, and lifecycle GHG emissions, of transportation fuels. Low carbon fuel standards are not volume or blending mandates that require a singular type of fuel to be consumed, but are fuel agnostic regulations with the goal being a market-based approach to reducing the carbon intensity of the transportation fuel mix. Carbon intensity (CI) refers to the GHG emissions emitted per unit of transportation fuel consumed, frequently in units of grams of carbon dioxide equivalent per megajoule of fuel (gCO_2e/MJ). The GHG emissions are calculated on a lifecycle basis to include emissions associated with fuel extraction, production, storage, transport and eventual consumption. Some biofuel feedstocks also include emissions from indirect effects such as land use change. Potential fuels that could be used to achieve the standards include ethanol, biodiesel, renewable diesel, hydrogen, electricity, natural gas, propane, and biogas.

Each fuel's CI is used to determine the quantity of GHG reduction credits awarded. The LCFS is currently dominated by credit generation from fuels made from biomass feedstocks. The source and type of feedstock is integral to performing the lifecycle analysis to quantify the CI of the fuel. Some feedstocks are the primary product of the agricultural systems (e.g., corn starch for corn, sugar for sugarcane, grain from sorghum) while others are primary co-products, by-products, wastes or residuals. The categorization of a feedstock is important because it determines how much of the feedstock's production emissions are allocated to the transportation fuel and whether indirect emissions would occur by displacing that feedstock from its current economic sector. For example, soy oil and soymeal are primary co-products of the feedstock production process, therefore the feedstock production emissions (e.g., agricultural emissions including fertilizer, planting, harvesting, extraction) are allocated between them. Allocation can be done on a mass, energy, or economic basis. For agricultural sector products, allocation is traditionally (and within GREET) done on a mass basis.

Newly developed feedstocks and sources of transportation fuels (i.e., corn oil for biodiesel) are being developed to meet the demand for low CI fuels, and their categorization is often not straightforward and can evolve and change. The LCFS at this time does not have clear guidelines and principles for distinguishing how these feedstocks should be handled and evaluated during the LCA process and what, if any, indirect emissions should be included in the LCA.

To develop the rules for identifying and defining wastes, residuals and by-products, ICCT commissioned the following report to achieve three main tasks:

- Review existing policies and regulations that attempt to categorize biofuel feedstock material.
- Develop conclusions and recommendations for a set of rules for the LCFS to categorize these feedstocks.
- Produce recommendations for the set of principles to govern indirect/displacement analysis resulting from moving the feedstock to biofuels from its existing consumption in the economy.

The report also includes four short case studies for categorizing existing biofuel feedstocks. The report is organized into the following sections:

- Section 1 – Purpose and Overview
- Section 2 – Literature Review
- Section 3 – Biofuel LCA and Feedstock Definitions
- Section 4 – Rules and Guidelines for Categorizing Feedstocks and Quantifying LCA Emissions
- Section 5 – Case Studies

2 Literature Review and Consultation with Relevant Experts

2.1 Summary and Overview

The literature review found that methodologies for categorizing biofuel feedstocks and how they should be handled within in LCA is inconsistent between LCA models or regulations (or even within the same model and regulation). The two main publically available LCA models, GREET and GHGenius, include the classification of primary products (or co-products) and wastes, but they do not have an intermediate classification. ANL uses GREET to review all allocation (e.g., mass, energy and market value) and displacement methodologies between co-products for each process and favors the methodology that is conservative and limits distortion. GHGenius favors substitution emission credits for co-products that are not key to the biofuel stream.

The LCFS and British Columbia Low Carbon Fuel Requirement (LCFR) follow categorization methodologies consistent with GREET and GHGenius, respectively, since they are the tools statutorily identified for LCA calculations. In a concept paper, [1] ARB defined "wastes" as feedstocks whose "… current and foreseeable future alternative fate is final disposal. Final disposal is defined as either landfilling or destruction (through, e.g., incineration). The CIs of inputs that receive "waste" designations under the LCFS will include only the transportation, conveyance, handling, and processing steps to which those inputs are subject. This definition and handling of waste biofuel feedstocks is similar to the LCFR and the US Renewable Fuel Standard (RFS). Unique to the LCFS, ARB defined "low-value byproducts", an intermediate category between primary products (or co-products) and "wastes," as feedstocks that are "…not wastes, the markets into which they are sold (when they are not used as fuel production inputs) are limited, and the market prices they receive are low." ARB prefers use of the displacement method to account for the CI of the product that replaces it in the market after it is diverted into biofuel production.

The UK Renewable Transport Fuel Obligation (RTFO) includes only two categories for biofuel feedstocks: co-products and wastes/residuals. Unlike the LCFS, LCFR and RFS, the RTFO uses an economic value based approach to categorize biofuel feedstocks. In the RTFO, co-products are materials of economic significant which typically trade for around 15% or more of the main product in £/tonne.

The reviewed LCA reports highlight the importance of including indirect effects such as displacement emissions. Displacement emissions are the indirect emissions from producing and utilizing the replacement feedstock when an economically valuable feedstock is removed from the market. These emissions are additional to the direct biofuel pathway. The replacement feedstock, and therefore the displacement emissions, can vary by region. The replacement feedstock selected can have significant and substantive impacts on the biofuel LCA and resulting carbon intensity.

[1] http://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/030714lcfsconceptpaper.pdf

This section reviews biofuel LCA literature and focuses on the categorization of biofuel feedstocks, allocation of energy and emissions, and quantification of indirect effects. The review includes LCA models (Section 2.2), regulations (Section 2.3), and other biofuel LCA reports (Section 2.4).

2.2 LCA Models

Argonne National Laboratory (ANL) and the Greenhouse gases, Regulated Emissions, and Energy use Tool (GREET) [2345]

GREET's proposed terminology to differentiate main products (named co-products) from by-products (waste) is consistent with business concepts:

> *A by-product is a secondary product derived from a manufacturing process or chemical reaction. It is not the primary product or service being produced. In the context of production, a by-product can be defined as the 'output from a joint production process that is minor in quantity and/or net realizable value (NVR) when compared to the main products'.[6] Because they are deemed to have no influence on reported financial results, by-products do not receive allocations of joint costs. By-products also by convention are not inventoried, but the NRV from by-products is typically recognized as 'other income' or as a reduction of joint production processing costs when the by-product is produced.[7] A by-product can be useful and marketable or it can be considered waste.*

After reviewing extensive ANL documents, ANL and GREET distinguish between co-products and waste by-products when performing their LCA's but they do not have a category in the middle. Co-products are products with market value. The selection of the allocation or displacement methodology is based on a

[2] Wang, Michael, et. al., "Methods of dealing with co-products of biofuels in life-cycle analysis and consequent results within the U.S. context," Energy Policy, edition 39, 2011, pgs 5726-5736.

[3] Wang, Zhichao, et. al., "Updates to the Corn Ethanol Pathway and Development of an Integrated Corn and Corn Stover Ethanol Pathway in the GREET Model," Energy Systems Division, Argronne National Laboratory, September 2014, ANL/ESD-14/11, https://greet.es.anl.gov/publication-update-corn-ethanol-2014

[4] Han, Jeongwoo, et al., "Update to Soybean Farming and Biodiesel Production in GREET," Systems Assessment Group, Energy Systems Division, Argonne National Laboratory, October 3, 2014, https://greet.es.anl.gov/publication-soybean-biodiesel-2014

[5] Dunn, Jennifer B., et al., "Life-cycle Analysis of Bioproducts and Their Conventional Counterparts in GREET," Energy Systems Division, Argonne National Laboratory, September 30, 2015, ANL/ESD-14/9 Rev, https://greet.es.anl.gov/publication-bioproducts-lca

[6] Wouters, Mark; Selto, Frank H.; Hilton, Ronald W.; Maher, Michael W. (2012): *Cost Management: Strategies for Business Decisions*, International Edition, McGraw-Hill, p. 535.

[7] World Trade Organization (2004): *United States - Final dumping determination on softwood lumber from Canada*, WT/DS264/AB/R, 11 August 2004

comparison of each individual method or hybrid allocation and displacement methodology. In most cases, the most conservative option for allocation is chosen.[8][9]

Table 2-1 below shows the examples of biofuel pathways and their identified co- and by-products. The focus is more on the non-fuel co- and by-products from the biofuel product process compared to the larger focus of this report.

Table 2-1. Key Biofuel Production Pathways and Their Products[10]

Feedstock	Fuel Product	Other Products	Other Product Uses
Corn	Ethanol	DGS	Animal feed; potentially as process fuel for steam generation in corn ethanol plants
Sugarcane	Ethanol	Bagasse	Steam and electricity production in sugarcane ethanol plants
Wheat	Ethanol	DGS	Animal feed; potentially as process fuel for steam generation in wheat ethanol plants
Sugarbeet	Ethanol	Sugar beet pulp and dried slop	Animal feed; potentially as process fuel for steam generation in sugarbeet ethanol plants
Cassava	Ethanol	DGS	Animal feed; potentially as process fuel for steam generation in cassava ethanol plants
Soybeans	Biodiesel	Soy meals and glycerin	Soy meals as animal feed; glycerin as specialty chemical
Rapeseeds	Biodiesel	Rapeseed meals and glycerin	Rapeseed meals as animal feed; glycerin as specialty chemical
Palms	Biodiesel	Residual fertilizer and glycerin	Fertilizer for farming; glycerin as specialty chemical
Cellulosic biomass	Ethanol	Lignin	Steam and electricity production in cellulosic ethanol plants
Soybeans	Renewable diesel	Fuel gas and heavy oils	Energy sources for plant internal use; or energy products for sale
Corn	Butanol	DGS and acetone	DGS as animal feed or potentially as process fuel for steam generation in corn butanol plants; acetone as chemical feedstock

The lifecycle analysis of a transportation is a two-step process. After categorization, the energy and emissions then need to be allocated or attributed to the co-products. ANL and GREET have a detailed methodology for allocating energy and emissions between co-products. Within GREET development/documentation, other set of rules have been described such as:

1. Use of default energy allocation method if:
    a. co-product unsuitable for animal feed/toxic
    b. co-product suitable for use as a fuel for electricity production

[8] https://greet.es.anl.gov/publication-fn174xp1

[9] http://biodiesel.org/reports/20080301_gen-395.pdf

[10] Wang, Michael, et. al., "Methods of dealing with co-products of biofuels in life-cycle analysis and consequent results within the U.S. context," Energy Policy, edition 39, 2011, pgs 5726-5736.

2. Use of default market allocation method (5 year average retail price), if:
    a. Co-product is not suitable to be used as a fuel
    b. Displacement method is not applicable because co-product production process (e.g., glycerin from biodiesel production via transesterification) dominates the market
3. Default mass allocation method:
    a. Co-products are not energy products
    b. Fluctuations of market value want to be avoided

The following are Argonne's detailed thoughts on LCA allocation methodologies that are included in GREET[11]:

- Displacement Method
    - Data intensive: Need detailed understanding of the displaced product sector
    - Dynamic results: Subject to change based on economic and market modifications
- Allocation methods: based on mass, energy, or market revenue
    - Easy to use
    - Frequent updates not required for mature industry, e.g., petroleum refineries
    - Mass based allocation: not applicable for certain cases
    - Energy based allocation: results not entirely accurate, when co-products are used in non-fuel applications
    - Market revenue based allocation: subject to price variation
- Process energy use approach (allocating emissions at a specific process unit level within an LCA stage compared to allocating emissions of an entire stage)
    - GREET method for petroleum refineries
    - Detailed engineering analysis is needed
    - Upstream burdens still need allocation based on mass, energy, or market revenue

Argonne updated their analysis of corn ethanol and various biodiesel feedstocks with the rules above in publications in 2014 and 2015,[12] which are summarized in Table 2-2. Argonne categorized the products of the process and determined which allocation methodology was most applicable. The steps of oil extraction and biodiesel production are separated for virgin oils because considering both stages of the LCA at once can distort the results when implementing an allocation approach. Utilizing a displacement approach would yield the same LCA results for both system levels. Figure 2-1 demonstrates the two system levels for corn oil production.

[11] http://www.researchgate.net/publication/235723659_Methods_of_dealing_with_coproducts_of_biofuels_in_life-cycle_analysis_and_consequent_results_in_the_U.S._context

[12] Id. 27, 28.

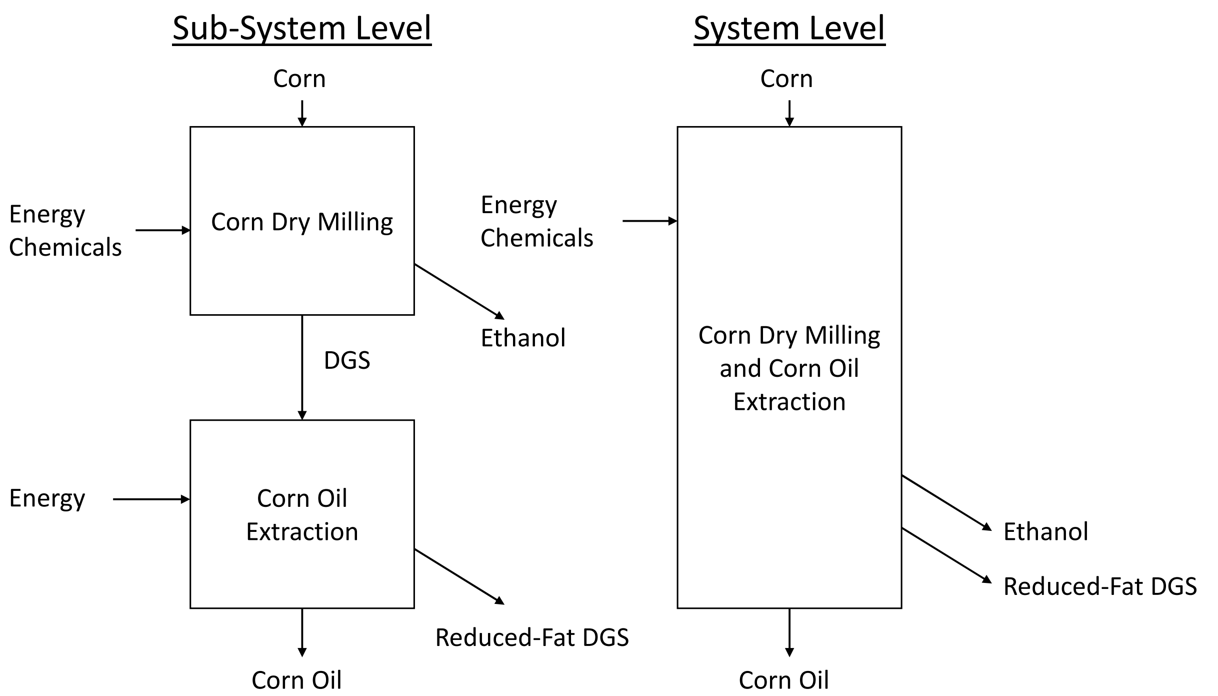

Figure 2-1. Two System Levels of Corn Oil Production[13]

Table 2-2. Updated Argonne Analysis of Corn Ethanol and Various Biodiesel and Renewable Gasoline Feedstocks

Feedstock	Process	Products	Categorization	Allocation Methodology
Soybean; Palm; Rapeseeds; Camelina	Oil Extraction	Oil (Soy, Palm, Rapeseed, Camelina); Soy Meal; Palm Expeller; Rapeseed Meal; Camelina Meal	Co-products	Default mass allocation method: 1. Displacement ratio for **meal** has to be defined 2. Meals are not energy products 3. Mass is not subject to fluctuations as market value
Jatropha	Oil Extraction	Oil; Electricity	Co-products	Default energy allocation method: 1. co-product unsuitable for animal feed/toxic 2. co-product suitable for use as a fuel for electricity production
Soy Oil	Biodiesel Production	Biodiesel; Glycerin	Co-products	Default market allocation method (5 year average retail price): 1. Glycerin is not suitable to be used as a fuel 2. Displacement method is not applicable because glycerin from biofuel production (transesterification) dominates the market

[13]Modified soy oil figure in http://biodiesel.org/reports/20080301_gen-395.pdf for corn oil

Feedstock	Process	Products	Categorization	Allocation Methodology
Renewable Diesel	Renewable Diesel Production	Renewable Diesel; Fuel Gas (hydrocarbon fuel)	Co-products	Default energy allocation method: 1. co-product suitable for use as a fuel
Renewable Gasoline	Renewable Gasoline Production	Renewable Gasoline; Fuel Gas, Light Cycle Oil, Clarified Slurry Oil (hydrocarbon fuel)	Co-products	Default energy allocation method: 1. co-product suitable for use as a fuel
N/A	Corn Agriculture	Corn Corn Stover	Main Product Waste- By-product	Default attributional method to determine corn life cycle: - Ethanol pathway that uses corn stover includes additional fertilizer requirements to substitute the corn stover nutrients that could have been reincorporated in the soil - Land use change impacts due to corn stover use were assessed negligible
Corn	Ethanol Production	Ethanol DGS sent to extraction = corn oil + low-fat DGS	Co-products	Six allocation methods: 1. Displacement Methods o All allocated to Ethanol, but DDGS Credit to Ethanol (Displacing Animal Feed), and Corn Oil Credit to Ethanol as Soy Oil or Biodiesel o All allocated to Ethanol, but DDGS Credit to Ethanol (Displacing Animal Feed). Burden Free Corn Oil o All allocated to ethanol except process allocation for DGS dry to DGS and for oil extraction to corn oil. DDGS Credit to Ethanol (Displacing Animal Feed), and Corn Oil Credit to Ethanol as Soy Oil or Biodiesel 2. Allocation by energy value 3. Allocation by market value 4. Allocation by energy value at the process level; no credits Default method 1.1 for production without corn oil extraction, and default method 4 for production with corn oil extraction.

GHGenius and the British Columbia Renewable and Low Carbon Fuel Requirement

GHGenius uses the concept of main products (streams that are key in the biofuel pathway), co-products for additional products, and wastes and residuals. GHGenius focuses on the biofuel pathway and the streams key to the biofuel production are considered the main products. This simplifying methodology eliminates the need for other methods or intermediate categories like by-products. Co-products are products of significance that can be handled either through allocation of process energy or via displacement (system expansion). The term 'waste' is used for some pathways, and for these pathways a product does not have emissions attributed to it (i.e., burden free). Burden free means the waste has no allocated upstream emissions.

Between co-products, the model uses the different methodological approaches such as allocation in energy, mass, or market value basis as well as displacement (system expansion method). GHGenius utilizes multiple approaches within a pathway. The selection of the method is determined based on the type of impact the co-product use can create. Table 2-3 below identifies feedstocks, products, categorization, and GHGenius allocation methodologies for selection biofuel processes.

Table 2-3. GHGenius Biofuel Pathway Categorization and Methodology[14],[15]

Feedstock	Process	Products	Categorization	Allocation Methodology
Palm Fruit	Oil Extraction	Palm Oil and Palm Kernel oil Palm Kernel meal Empty fresh fruit bunches Shell and fibrous residues	Main Product Co-product Residues Residues	Energy allocation for the crude palm oil and the palm kernel oil (both assumed to be converted into biodiesel)
Canola / Soybeans	Oil Extraction	Oil Soy meal	Main product Co-product	Mass allocation. System expansion to account for soy meal "generated distorted results"[16]
Canola Oil/ Soybean Oil	Biodiesel Production	Biodiesel Glycerin	Co-products	Mass allocation is used as a default. Displacement approach for glycerin co-product has a large impact on results (fuel with negative values) resulting in mass allocation was used.[17]

[14] http://www.ghgenius.ca/reports/FinalReportPalmOilUpdate.pdf

[15] http://www.ghgenius.ca/reports/BiofuelAnalysis2010.pdf

[16] Ibid 14, pgs 66-67.

[17] Ibid 14, pgs 66-67.

Feedstock	Process	Products	Categorization	Allocation Methodology
Corn	Ethanol Production	Ethanol DGS sent to oil extraction = corn oil + low-fat DGS	Main product Co-product	Corn oil used both for animal feed and for biodiesel production. Ethanol attributional LCA, and credits EtOH for DGS co-product. Credit is determined by the emissions for corn and soybean meal production displaced by the distillers' grains. EtOH would be credited by net energy use reduction in the EtOH plant due to corn oil extraction (i.e., difference in energy requirement within DGS dryer and corn oil extraction). Emission credit for the corn oil is assumed equal to that of the complete DDG in the corn pathway on a mass basis. i.e., EtOH plant that only produces DDG has same credits that one that produces corn oil and DDG.[18]
Animal Carcass	Rendering	Tallow Meat and bone meal	Main Product Co-product	Emissions credit to tallow for meat and bone meal displacing soybean meal[19]

The main difference between GHGenius and GREET's approaches is that GHGenius allocates all rendering energy to tallow and includes a displacement credit of soybean meal for the meat and bone meal, and GREET allocates rendering energy and emissions between tallow and the meat and bone meal. The difference is based on GHGenius' propensity for a displacement compared to GREET's for allocation. This results in a significantly lower carbon intensity for tallow biodiesel in GHGenius (estimated -21 gCO2e/MJ)[20] compared to GREET (31 gCO2e/MJ)[21].

2.3 LCA Based Regulations and Related Documents

California Air Resources Board and the LCFS[22][23]

ARB has very similar definitions and methodologies to GREET since ARB uses a modified version of the GREET model for the regulation. The LCFS does not have hard rules for categorizing biofuel feedstocks as

[18] Ibid 14, pg 68.

[19] Ibid 15, pg 79.

[20] GHGenius version 4.03a, http://www.ghgenius.ca/downloads/GHGenius403anomenu.zip

[21] GREET1_2015, https://greet.es.anl.gov/files/greet-2015

[22] http://www.arb.ca.gov/fuels/lcfs/workgroups/workgroups.htm#pathways

[23] http://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/030714lcfsconceptpaper.pdf

primary products, by-products or wastes/residuals. Categorization usually occurs on a pathway-by-pathway basis and to be consistent with GREET.

Primary products or co-products are allocated all of the upstream emissions and process emissions because they are the main products of the process. By-products or wastes are allocated zero upstream emissions. Mass and energy allocation as well as displacement is used throughout the different pathways. ARB does make an exception for "process-based allocation." This is where the emissions of a specific process, and no emissions upstream of the process, are allocated to the biofuel feedstock. An example is tallow where if rendering is co-located with animal processing, the emissions from only the rendering process are allocated to tallow.

Corn oil is also an example of another category of products called secondary or incremental products. These are products produced from existing processes that are later added. For the secondary or incremental products, such as corn oil, the LCA takes into account an additional/marginal assessment of the energy and GHG footprint (or process allocation). In addition, the crediting methodology is reevaluated. For corn oil from dry milling/wet DGS, the reduction in wet DGS credits from the corn oil produced (displacement) is added to the corn oil feedstock. In addition, for dry milling/dry DGS the decreased energy required to dry the DGS after pressing the corn oil is also allocated to the corn oil.

In the ARB LCFS concept paper,[24] there was an attempt to identify more clearly what are wastes and residuals and how they should be handled in an LCA. ARB attempted to define wastes as those feedstocks whose "… current and foreseeable future alternative fate is final disposal. Final disposal is defined as either landfilling or destruction (through, e.g., incineration). The CIs of inputs that receive "waste" designations under the LCFS will include only the transportation, conveyance, handling, and processing steps to which those inputs are subject. Waste inputs would inherit no CI increment from the processes that originally generated them." ARB also categorized residual biomass as biomass consisting of "…agricultural, forest, or other types of residues. To qualify for consideration under the tier two process, such residues will have to be certified as having been sustainably harvested."

There was also discussion in the concept paper of "low-value byproducts." These biofuel feedstocks are "…not wastes, the markets into which they are sold (when they are not used as fuel production inputs) are limited, and the market prices they receive are low. " ARB prefers use of the displacement method to account these biofuel feedstocks. Instead of a having a zero CI prior to feedstock processing, "it should, instead, receive the CI of the product that replaces it" in the market after it is diverted into biofuel production.

Table 2-4 presents ARB has handled specific pathways. [25] ARB has remained consistent with GREET, which is discussed in detail above, in terms of allocation methodology for conventional ethanol and biodiesel.

[24] Ibid 23.

[25] http://www.arb.ca.gov/fuels/lcfs/workgroups/workgroups.htm#pathways

Table 2-4. ARB LCFS Pathway

Feedstock	Process	Products	Categorization	Allocation Methodology
Sorghum / Corn	Ethanol Process	Ethanol Wet or Dry DGS	Co-products	Stand-alone LCA for EtOH and displacement credits due to DDGS (DDGS replaces corn as an animal feed as opposed to feed corn, soybean meal, and urea as GREET)
Corn	Ethanol Production	Corn Oil Wet DGS	Secondary or incremental product	Assumed equipment retrofitted into existing EtOH plants. Thus: - Corn oil is classified as secondary or incremental product. - Apportioning none of the GHG emissions associated with the production of EtOH to corn oil. - CI includes only the additional energy required to operate the corn oil extraction equipment (Process Level Allocation) - CI considers the reduction in the DGS co-product credit for corn EtOH due to corn oil extraction
Corn	Ethanol Production	Corn Oil Dry DGS	Secondary or incremental product	Same as above plus: - CI includes the additional/marginal energy savings that occur as a result of operating the corn oil equipment (i.e., savings during DGS drying because of reduction in mass of DGS entering dryers and improved efficiency in DGS heat transfer) - Calculations exclude the CI displacement associated with market effects of modifying DGS from a high fat and energy content product to a high protein content product.
Used Cooking Oil	Rendering	Cooking oil biofuel feedstock	Co-product	Process-based allocation
Canola / Soy	Extraction of oil	Oil Meal	Co-products	Mass allocation of upstream and process emissions, same as GREET
BD Feedstock	Biodiesel production	Biodiesel Glycerin	Co-products	Energy allocation, same as GREET
Tallow	Renewable Diesel	Renewable Diesel Propane-rich off-gas	Co-products	Displacement of natural gas within the same pathway to produce the hydrogen used for the renewable diesel production. It includes the rendering energy use for the production of tallow.

Feedstock	Process	Products	Categorization	Allocation Methodology
Raw Animal Waste	Rendering process	Tallow Meat Bone Meal	Co-product	Tallow as by-product from raising livestock. Energy allocation procedure used, weighted by the amounts of meat, bone meal, and tallow produced (i.e., 2:1 ratio of the calorific values for tallow compared to meat and bone meal or 94.5% energy). Two Rendering energy requirements are shown low and high energy processes.

ARB indicates that corn oil extracted at DDGS ethanol plants will enter the biodiesel production process with a CI that is not higher than the CI of corn oil extracted at WDGS ethanol plants. Therefore the WDGS pathway developed by ARB is available to biodiesel produced from WDGS or DDGS associated with corn oil.

US Renewable Fuel Standard

US EPA has approached the concept of co-products, by-products and wastes in a very similar way to GREET. In much of the EPA docket literature, there are direct references to GREET and how they handle emissions allocation. The handling of biodiesel (virgin oil, meal and glycerin), ethanol (corn and DDGS), and renewable diesel (tallow, light fuel gas and naphtha) are the same.

EPA initially utilized a simplistic definition that if the feedstock went to the landfill, prior to use in the biofuel industry, it was considered a waste. EPA recognizes that a more sophisticated definition and categorization methodology of feedstocks is needed with the evolving biofuel market. Their current thinking for categorizing biofuel feedstocks consists of a spectrum with co-products on the left and wastes on the right. EPA begins by asking waste related questions and moves left towards by-products and co-products. Below are questions that are asked of a feedstock to determine if it is a waste:[26]

- It cannot be the primary purpose of developing the feedstock (i.e., corn)
- It cannot have a well-established market or market prices
- If it is pulled out of the market that it is in, will it have a drastic impact (i.e., rendered fat for the soap market)
- It can also be considered a waste if the primary alternative is dumping the feedstock into a stationary combustion source (no current distinction is made between incineration with or without energy recovery)

When determining if a feedstock is a waste, economically the most important factor is value per unit but total value starts to matter more when considering co-product versus by-product. Co-products are allocated a portion of the upstream emissions, and by-products are not allocated upstream emissions.

[26] Personal communication with Bob Larson, Associate Director, Transportation and Climate Division, US EPA

An example is distillers' grains with ethanol that has a smaller per unit value (approximately $0.078/lb DDGS[27] compared to $1.47/gal EtOH[28]) but still a significant portion of the total value (78% ethanol and 22% DDGS)[29]. DDGS is categorized as by-product, but since the credit given is for reduced corn production (the primary feedstock), which carries upstream emissions, it essentially results in a co-product energy allocation.

In the case of PFAD, EPA has initially considered categorization as a waste, but that categorization is still under review. One related issue is that re-categorizing could result in changes to the LCA pathway for palm oil, which currently has a 17% CI reduction (based on the provisional analysis). Another point to note regarding PFAD is that grandfathered biodiesel plants in the United States and abroad are eligible to receive renewable (D6) RINs if registered under the RFS and are not required to state their feedstocks. Both palm oil and PFAD may currently be used in some of these facilities.

Lastly, EPA has categorized tallow, white grease, and brown grease as waste feedstocks for biodiesel that achieve an 86% GHG reduction compared to diesel, exceeding the 50% GHG reduction threshold necessary for eligibility as advanced biomass-based diesel. EPA does not have a strong interest in considering the re-categorization of the feedstocks unless it would result in a threshold change of achieving less than a 50% carbon intensity reduction compared to diesel, which is unlikely.

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

Endicott Biofuels LLC proposed to produce biodiesel from palm fatty acid distillates (PFAD) at their Sabine biorefinery in Texas. Endicott/Sabine's Method 2B LCFS application is currently under review by ARB. The accompanying Endicott LCA pathway report is heavily redacted and does not disclose most assumptions and justifications about the PFAD feedstock uses and market value. According to the ARB Staff Report, the facility obtains PFAD from various palm oil refineries in Southeast Asia, which is categorized as "a low-value by-product of the palm oil production process".[30] PFAD is categorized as an inedible by-product of palm oil refining due to the high content of Free Fatty Acids (FAA), which "must be separated from the source fat or oil in order to render that fat/oil edible by humans".[31]

Because it is a by-product, Endicott/Sabine allocates no indirect land use change (ILUC) impact from its use as a biodiesel feedstock because the "incremental demand for this material will have no effect on

[27] http://www.grains.org/buyingselling/ddgs; December 10, 2015 settlement, site visited December 11, 2015.

[28] https://www.eia.gov/todayinenergy/prices.cfm; December 10, 2015 settlement, site visited December 11, 2015.

[29] 5.34 lb DDGS/gal ethanol - http://www.arb.ca.gov/fuels/lcfs/022709lcfs_cornetoh.pdf

[30] CARB. December 2013. Staff Summary Method 2B Application Endicott Biofuels II, LLC Palm Fatty Acid Distillates to Biodiesel (BIOD012). Pg. 1.

[31] Endicott Biofuels. December 2013. Method 2B Application: Endicott's Sabine Facility Producing Biodiesel from Fatty Acid Distillates Generated During Palm Oil Production, LCA Report. Pg.2. http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/end-pfad-rpt-121713.pdf

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".[32]

The Endicott/Sabine pathway estimates the upstream emissions of PFAD feedstock through displacement allocation. They state that PFAD is "normally used in the U.S. as a livestock feed supplement", and therefore "inherits the GHG emissions associated with the feed that replaces it in the livestock feed market".[33] Endicott/Sabine estimated the upstream CI "by equating it with the co-product credit that dry mill ethanol plants earn for selling DGS into the livestock feed market (where it displaces corn). That credit is 11.51 gCO2e/MJ".[34]

The redactions in the application make it difficult to follow the arithmetic quantifying the total pathway CI. The ARB summary says “credit” for the displacement emissions from DGS, which can be confusing since these emissions are added to the carbon intensity of the pathway. Endicott has equated PFAD use in the U.S. market to the DGS co-product credit (displacing corn animal feed). Endicott chose an elastic supply feedstock to the animal feed market for displacement, but corn meal is not necessarily directly substitutable with PFAD. If the PFAD were converted to biodiesel in Southeast Asia, other primary uses would need to be considered for displacement.

The ICCT’s Comments to Endicott’s PFAD LCFS Method 2B Application [35]

The ICCT’s main comments to Endicott’s application are based on the value of PFAD and its characterization as a low value by-product mainly used in animal feed in the US. The ICCT believes the other main uses of PFAD in Southeast Asia, oleochemicals and soaps, should be considered for the displacement methodology. The ICCT believes a product’s existing market within applicable geographical boundaries should be considered. The global market as opposed to US market was expected to be applied for PFAD.

Another main comment is product functionality. PFAD should be considered as an energy and fat supply to animal feed and not directly exchangeable with DDGS protein feed. The market value of PFAD is significantly higher than distillers’ grains where if direct substitution could be made, it would have already occurred in the marketplace. In addition, distillers’ grains supply is relatively inelastic and an elastic feedstock to meet demand should be considered (e.g., corn or soy meal).

Lastly, the ICCT notes that “palm oil is the world’s ‘marginal oil’,” and they believe it is likely that an increase in PFAD use for biodiesel would have the follow-on effect of increasing palm oil demand, in which case there could be substantial indirect land use change consequences. The ICCT believes a more

[32] Ibid, pg.5

[33] CARB. December 2013. Staff Summary Method 2B Application Endicott Biofuels II, LLC Palm Fatty Acid Distillates to Biodiesel (BIOD012). Pg. 1.

[34] Ibid, pg.2

[35] http://www.arb.ca.gov/lispub/comm2/bccomdisp.php?listname=lcfs2a2bcomments-ws&comment_num=19&virt_num=5

comprehensive market analysis should be undertaken that would likely include indirect land use change emissions for palm oil.

UK Government, Department of Transport - Renewable Transport Fuel Obligation (RTFO) Guidance Version 8.1 and the European Union (EU) Renewable Energy Directive (RED)

In late 2011, the RTFO in the UK was amended to include the transport elements of the EU RED and the Fuel Quality Directive (FQD).[36] The literature review of the RTFO guidance and the RED has been combined here due to their significant overlap. In the RTFO guidance, the UK Department of Transport sets out the sustainability criteria for biofuels supplied under the RTFO and specifies how fuel suppliers must demonstrate compliance in order to benefit from Renewable Transport Fuel Certificates (RTFCs).

Both RTFO and RED include mandatory carbon and sustainability requirements that must be met if biofuel is to count towards European targets.[37] Under RED/RTFO, categorization is particularly important because biofuels from wastes, residues, ligno-cellulosic, and non-food cellulosic feedstocks are double counted (i.e., receive twice the benefit/credit by volume).[38] RED sustainability criteria exempts wastes and residues from land-based requirements which is an additional benefit to feedstocks that are classified as wastes and residues.

The RTFO categorizes biofuel feedstocks as either products/co-products, wastes/residues from processing, non-food cellulosic materials, or residues from agriculture, aquaculture, fisheries and forestry.[39] These distinctions determine how the feedstocks are treated within the program. In addition to the double counting incentives mentioned above, there are also two additional advantages that wastes and residues receive under RED/RTFO – they are considered to have zero GHG emissions up to the process of collection of those materials and the sustainability criteria they must fulfill are limited to GHG emissions and mass balance.[40] Table 2-5 presents a summary of which feedstocks are eligible for these advantages.

[36] UK Department for Transport. October 2015. RTFO Year 8, Carbon and Sustainability Guidance. Pg.6. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/462528/RTFO_guidance_part_two_-_carbon_and_sustainability_guidance_year_8.pdf.

[37] Ibid, pg.7

[38] Ibid, pg. 7, 10

[39] Ibid, pg. 111

[40] Ibid, pg. 110

Table 2-5. Treatments of feedstock categories under RTFO/RED[41]

Feedstock Category	Double Counting	Criteria limited to GHG and mass balance	No upstream GHG emissions
Products/co-products	✘	✘	✘
Non-food cellulosic material (excluding wastes and residues)	✓	✘	✓
Residues from agriculture, aquaculture, fisheries and forestry	✓	✘	✓
Wastes/residues from processing	✓	✓	✓

The RTFO administrator determines how the feedstocks are categorized based on interpretation of RED and definitions provided by the European Commission Communication on Practical Implementation (2010/C 160/02), as follows:

- No emissions are allocated to co-products which production did not aim for, such as straw in the case of wheat production (RED GHG accounting methodology).
- A processing residue is a substance that is not the end product(s) that a production process directly seeks to produce. It is not a primary aim of the production process and the process has not been deliberately modified to produce it (2010/C 160/02).
- Agriculture, aquaculture, fisheries and forestry residues are residues that are directly produced by agriculture, fisheries, aquaculture and forestry; they do not include residues from related industries or processing (2010/C 160/02).

Although not specifically stated in the Version 8 RTFO Guidance, the following Waste Framework Directive (WFD) definition is also considered in feedstock determinations – "a waste is any substance or object which the holder discards or intends or is required to discard".[42]

RTFO considers feedstocks that are not wastes and residues as products/co-products, noting that "in biofuel applications these will typically be crop-based materials but may also be materials that are produced at the same time as other products from a process (a co-product)".[43] Since the European Commission does not provide guidance on non-food cellulosic material and ligno-cellulosic materials, the RTFO interprets these as "non-food plants and materials such as Miscanthus".

[41] Ibid, pg. 111

[42] Aaron Berry, Head of Sustainability RTFO Unit, UK Department for Transport. July 2011. Wastes and Residues under RED current thinking.

[43] UK Department for Transport. October 2015. RTFO Year 8, Carbon and Sustainability Guidance. Pg. 112.

When determining feedstock categories, the RTFO administrator also considers and adheres to the categorization specified in the RED GHG default values.[44] For feedstocks not included in RED, RTFO considers the following criteria when determining if a feedstock is a product:

- "Products are generally materials that would be attributed GHG emissions for the purpose of calculating GHG default values for Annex V of the Directive. Materials that represent a significant economic value in relation to the main product, and that have other uses than energy applications, are likely to be considered as products."
- "The Administrator considers that materials typically trading for around 15% or more of the main product in £/tonne is an indicator of economic significance, but other factors may be taken into account, including the amount of material produced and its other uses."
- "Any material that has been intentionally modified to count as a waste (e.g., by adding waste to non-waste) is likely to be considered as a product."[45]

For fuels that RTFO categorizes as products/co-products, feedstocks are allocated upstream emissions via energy allocation, in accordance with RED:

"Where a fuel production process produces, in combination, the fuel for which emissions are being calculated and one or more other products (co-products), greenhouse gas emissions shall be divided between the fuel or its intermediate product and the co-products in proportion to their energy content."[46]

RED makes the following justification for employing the energy allocation method as opposed to the substitution method:

"Co-products from the production and use of fuels should be taken into account in the calculation of greenhouse gas emissions. The substitution method is appropriate for the purposes of policy analysis, but not for the regulation of individual economic operators and individual consignments of transport fuels. In those cases the energy allocation method is the most appropriate method, as it is easy to apply, is predictable over time, minimises counterproductive incentives and produces results that are generally comparable with those produced by the substitution method. For the purposes of policy analysis the Commission should also, in its reporting, present results using the substitution method."[47]

The table below presents the feedstocks that RTFO has categorized as products, agricultural residues, wastes and processing residues, and non-food cellulosic and ligno-cellulosic materials.

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[44] Ibid, pg. 115

[45] Ibid, pg. 114

[46] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources, pg. L140/55. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=EN

[47] Ibid, L 140/25

Table 2-6. RTFO Feedstock Categorization[48]

Feedstock	Category	Description	Reason for categorization
Acid ester	Product	Esters are produced intentionally and are therefore a product.	Feedstock is produced intentionally
Brown/ sulphite liquor	Product	This material arises during the pulping of wood. As for tall oil, it is considered a product.	Feedstock is produced intentionally?
Corn or wheat dried distillers grain (DDGS)	Product	This material's treatment in the RED GHG calculations makes clear that it is to be treated as a product.	Adheres to RED default GHG categorization
Corn oil	Product	This is a co-product from distilling corn ethanol. It has a number of potential uses and a relatively high value. This means that it is regarded as a product.	Feedstock has a number of potential uses and relatively high value
Crude tall oil	Product	Crude tall oil arises from the process of pulping coniferous wood. The pulping process involves cooking woodchip in a chemical mixture and this gives rise to a soapy material which is separated from the pulp and liquor. It is then acidified and heated to convert it into crude tall oil. Crude tall oil is a product of the pulping process.	Production process of main product is deliberately modified to produce feedstock
Glycerol (refined) from virgin oils	Product	The treatment of glycerol from virgin oils in the RED GHG calculations makes clear that it is to be treated as a product.	Adheres to RED default GHG categorization
Meal from virgin oil production	Product	The treatment of these materials in the RED GHG calculations makes clear that they are to be treated as products.	Adheres to RED default GHG categorization
Molasses	Product	This material arises from the processing of sugar cane and sugar beet into sugar. It arises on the basis of a technical decision, and is considered a product.	Production process of main product is deliberately modified to produce feedstock
Palm fatty acid distillate (PFAD)	Product	The treatment of PFAD in the RED GHG calculations indicates that it is to be treated as a product. PFAD has a significant economic value in relation to the main product (palm oil) and a variety of productive uses.	Feedstock has a significant economic value in relation to the main product (palm oil) and a variety of productive uses

[48] RTFO Guidance - List of wastes and residues, Year 8, Version 8.3. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/470412/List_of_wastes_and_residues_year_8.pdf

Feedstock	Category	Description	Reason for categorization
Palm kernel oil	Product	Palm kernel oil is a product.	Same as PFAD
Palm oil olein	Product	The refined liquid fraction of palm oil is a product.	Same as PFAD
Palm stearin	Product	The refined solid fraction of palm oil is a co-product of palm olein. It is traded at a discount to palm oil and palm olein; making it a cost-effective ingredient in several applications.	Feedstock is a cost-effective ingredient in several applications
Sugar beet pulp	Product	This is the pulp left over following sugar extraction. Its treatment in the RED GHG calculations makes clear that it is to be treated as a product.	Adheres to RED default GHG categorization
Tallow (category 2 &3)	Product	Tallow is a product of the meat rendering process. Category 2 and 3 tallow have a high economic value and a variety of productive uses. It is a direct substitute for other products (e.g., palm oil).	Feedstock has high economic value and a variety of productive uses. It is a direct substitute for other products (e.g., palm oil). Category 2 tallow may use the waste vegetable or animal oil default GHG value. Category 3 tallow must use actual carbon values.
Virgin Oils	Product	Including, but not limited to, oils derived from palm, soy, rape and sunflower. The treatment of these materials - and of the meal produced as part of the same process - in the RED GHG calculations makes clear that these are to be treated as products.	Adheres to RED default GHG categorization
Arboricultural residues	Agricultural residue	Arboricultural residues meet the same criteria as forestry residues. See below.	Meets same criteria as forestry residues (see below)
Bagasse	Agricultural residue	Bagasse results from crushing sugarcane or sorghum. Bagasse is specifically named as an agricultural residue in the RED.	Adheres to RED default GHG categorization
Cobs	Agricultural residue	Cobs are specifically named as agricultural residues in the RED.	Adheres to RED default GHG categorization
Forestry residues	Agricultural residue	Forestry residues are identified explicitly by the RED as residues and treated as wastes/residues in the RED GHG calculations.	Adheres to RED default GHG categorization

Feedstock	Category	Description	Reason for categorization
Husks	Agricultural residue	Husks are specifically named as agricultural residues in the RED.	Adheres to RED default GHG categorization
Nut shells	Agricultural residue	Nut shells are specifically named as an agricultural residue in the RED.	Adheres to RED default GHG categorization
Straw	Agricultural residue	Straw is specifically named as an agricultural crop residue in the RED.	Adheres to RED default GHG categorization
Brown grease or FOGs removed from sewers	Wastes and processing residues	Brown grease is the grease that is removed from wastewater sent down a restaurant's sink drain. This is a waste. Material removed from sewers known as "FOG" (fats, oils and grease) should also be reported as brown grease. Brown grease may use the waste vegetable or animal oil default GHG value.	Considered a waste because it is removed from wastewater sent down a restaurant's sink drain. May use the waste vegetable or animal oil default GHG value.
Cashew nut shell liquid	Wastes and processing residues	Cashew nut shell liquid (CNSL) is a process residue. The material is squeezed from the shells of cashew nuts after the edible portion has been removed. There are other potential uses which may be affected by large scale use of CNSL for biofuel, therefore the Administrator will be keeping this decision under review.	Feedstock is not the end product that the production process directly seeks to produce. Its use for biofuels may also affect other potential uses.
Crude glycerine	Wastes and processing residues	Crude glycerine is specifically named as a residue from processing in the RED. (The RED treats refined glycerine from as a product - see above).	Adheres to RED default GHG categorization
Food waste (unsuitable for animal feed)	Wastes and processing residues	Whether from manufacturers, retailers or consumers, this will be a waste. This may include food that is; Out of date (food that has exceeded its shelf life) Out of specification (food that fails to meet the required end of use specification). As with all wastes, this material must be unsuitable for other non- energy uses. Examples include beer residue, coffee pulp and protamylasse ('potato juice').	Considered a waste because the material is unsuitable for other non-energy uses. Examples include beer residue, coffee pulp and protamylasse ('potato juice').

Feedstock	Category	Description	Reason for categorization
Grape marc & wine lees	Wastes and processing residues	Grape marc and wine lees are processing residues from the wine making industry. Whilst they are two distinct materials, they can be reported together as the GHG savings are similar and there is no benefit in requiring separate reporting.	Feedstock is not the end product that the production process directly seeks to produce.
Low grade starch slurry	Wastes and processing residues	Low grade starch slurry for which it can be demonstrated that there are no other economically viable end uses is considered a waste, and double counts. Suppliers may be asked for evidence that this material is unsuitable for other end uses, such as animal feed.	Considered a waste if it can be demonstrated there are no other economically viable end uses (e.g., animal feed).
Manure	Wastes and processing residues	Manure is treated as a waste/residue in the GHG calculations. It is specifically named as a residue in the Commission Communication on its practical implementation (2010/C 160/02).	Specifically named as a residue in the Commission Communication on its practical implementation (2010/C 160/02).
Organic municipal solid waste (MSW)	Wastes and processing residues	This is a waste. Only the biomass portion of MSW counts as a renewable fuel.	Considered a waste because there are no other economically viable end uses and purposely disposed of
Palm oil mill effluent (POME)	Wastes and processing residues	POME is a waste water/sludge arising from palm oil production. It has no economic value; current practise in SE Asia is to release to open ponds for anaerobic digestion resulting in methane emissions. The oil extracted from POME is often referred to as Palm Sludge Oil (PSO). Suppliers wishing to report either POME or PSO on ROS should use the POME category.	Considered a waste because it has no economic value
Rapeseed residue	Wastes and processing residues	Rapeseed distillation residue from the oleo-chemical industry, exceeding 50% erucic acid.	Feedstock is not the end product that the production process directly seeks to produce; little economic value

Feedstock	Category	Description	Reason for categorization
Renewable component of end-of-life tyres	Wastes and processing residues	Tyres are manufactured from a mixture of non-renewable petroleum products and natural rubber. Suppliers of fuel made from end-of-life tyres will need to have a Fuel Measurement and Sampling (FMS) regime in place, and will need to demonstrate how they have apportioned the renewability of the material in terms of the outputs from the conversion process of the tyres into fuel as the conversion process usually produces solid, liquid and gaseous fractions. End-of-life tyres are a waste.	Considered a waste because there are no other economically viable end uses and little economic value
Sewage sludge	Wastes and processing residues	Sewage sludge is a remainder of the waste water treatment process. This material is a waste.	Considered a waste because there are no other economically viable end uses and purposely disposed of
Soapstock acid oil contaminated with sulphur	Wastes and processing residues	Refiners of vegetable or animal oils who use chemical extraction processes to refine their oils give rise to soapstock acid oils that have levels of contaminants that make them unfit for human or animal consumption. This is generally sulphur from the use of sulphuric acid in the extraction process, but may also include phosphorus from phosphoric acid or sodium / potassium from the alkalis used to neutralise them. This material is a waste. Suppliers of fuel made from this material should be able to demonstrate that the material was produced by a refiner who used these methods of extraction, and may be asked to produce evidence that it was unfit for consumption.	Considered a waste because the feedstock has levels of contaminants that make them unfit for human or animal consumption
Spent bleaching earth	Wastes and processing residues	Bleaching earth is used to bleach palm oil as part of the production process. Oil extracted from spent bleaching earth is included in this category. Note that the GHG calculation must include the extraction of the oil from the spent bleaching earth.	Feedstock is not the end product that the production process directly seeks to produce. GHG calculation must include the extraction of the oil from the spent bleaching earth.

Feedstock	Category	Description	Reason for categorization
Sugar beet tops, tails, chips and process water	Wastes and processing residues	Residual streams from the processing of sugar beet that have no other economically viable end uses. Note: This material does not include the 'crown' of the sugar beet, which is not eligible for double counting.	Considered a processing residue because there are no other economically viable end uses.
Tall oil pitch	Wastes and processing residues	Tall oil pitch meets the definition of a residue for the purpose of the RED. It is specifically named as a residue in the Commission Communication on its practical implementation (2010/C 160/02).	Feedstock meets the definition of a residue for the purpose of the RED. It is specifically named as a residue in the Commission Communication on its practical implementation (2010/C 160/02).
Tallow (processed animal fats) category 1	Wastes and processing residues	Category 1 tallow is processed animal fat produced in the meat rendering process. It has a significant economic value but its legally permissible end uses are, at present, generally limited to energy generation. Category 1 tallow may use the waste vegetable or animal oil default GHG value. Note: The treatment of tallow will be kept under consideration and may be reviewed for April 2014 in relation to legislative changes and to assess the impact on other markets resulting from additional incentives for tallow based biodiesel.	Feedstock has a significant economic value but its legally permissible end uses are, at present, generally limited to energy generation. Category 1 tallow may use the waste vegetable or animal oil default GHG value.
Used cooking oil (UCO)	Wastes and processing residues	Commonly called 'UCO' or 'WCO' (waste cooking oil), this is purified oils and fats of plant and animal origin. These have been used by restaurants, catering facilities and kitchens to cook food for human consumption. They are wastes as they are no longer fit for that purpose and are subsequently used as either feedstock for the production of biodiesel as fuel for automotive vehicles and heating or as a direct fuel. Used cooking oil may use the waste vegetable or animal oil default GHG value.	Considered a waste because the oil is no longer fit to cook food for human consumption and are subsequently used as either feedstock for the production of biofuels. UCO may use the waste vegetable or animal oil default GHG value.

Feedstock	Category	Description	Reason for categorization
Waste pressings from production of vegetable oils	Wastes and processing residues	When a vegetable material such as olives is pressed to produce vegetable oil, the pressed material consisting of pips, skins, flesh etc. remains. This may be used as a fuel. The purpose of the process is to produce oil; the pressings are therefore wastes. An example would include spent husk oil.	Feedstock is not the end product that the production process directly seeks to produce.
Waste wood	Wastes and processing residues	The treatment of waste wood in the RED GHG calculations makes clear it is to be treated as a waste/residue. The Environment Agency's statement (see the link below) provides guidance on the distinction between forestry residues and waste wood: http://www.environment-agency.gov.uk/static/documents/Research/PS_005_Regulation_of_w ood_v3.0.pdf	Adheres to RED default GHG categorization
Miscanthus	Non-food cellulosic and ligno-cellulosic material	Non-food material commonly grown as an energy crop. If it is put to another use first, e.g., as animal bedding, before being used as fuel, then it will be a waste.	Non-food material commonly grown as an energy crop. If it is put to another use first, e.g., as animal bedding, before being used as fuel, then it will be a waste.
Short rotation coppice (SRC)	Non-food cellulosic and ligno-cellulosic material	SRC is a non-food material commonly grown as an energy crop.	Non-food material commonly grown as an energy crop.

2.4 Other Biofuel LCA Reports

E4Tech. July 2011. What do the EC calculations tell us about whether materials should be treated as co-products, wastes or residues?[49]

This presentation was given by E4tech at the RTFO Expert Advisory Group meeting, Special meeting on Wastes on July 21st, 2011. The presentation first follows the European Commission palm biodiesel

[49] Presentation by Claire Chudziak of E4tech. July 2011. What do the EC calculations tell us about whether materials should be treated as co-products, wastes or residues? http://webarchive.nationalarchives.gov.uk/20120904033926/http://assets.dft.gov.uk/publications/biofuels-events-calendar/what-do-ec-calculations-tell-us.pdf

calculations to show how emissions are allocated, reiterating some of the guiding principles that are outlined in the Version 8 of the RTFO guidance:

- Materials likely to have little or no economic value outside the boundaries of the system are not allocated emissions and are therefore assumed to be residues or wastes (e.g., timber, leaves, empty fruit bunches, distillation residues etc).
- Materials with likely economic value outside the boundaries of the system are considered co-products (e.g., Palm oil, palm kernel oil, refined glycerine, free fatty acids and PFAD)

In PAS2050, emissions are determined using economic allocation. PAS2050 defines waste similar to the WFD – "materials, co-products, products or emissions which the holder discards or intends, or is required to, discard". This definition is implemented in practice by allocating no upstream emissions to the products that are discarded, which are considered wastes and assumed to be of no economic value to the person producing it. Materials that are not discarded are considered products and are subsequently allocated emissions based on their economic value. The PAS2050 definition for product differs from RED/EC guidance 2010/C 160/2 because it does not require that the material was intentionally produced.

In the WFD definition of waste, the word "discard" includes the recovery of a substance or object as well as its disposal. It is noted that if one were to use the legal interpretation of the WFD definition of waste, many feedstock materials considered co-products under RTFO/RED may be considered waste and would not be allocated emissions.

Ecometrica - Methodology and Evidence Base on the Indirect Greenhouse Gas Effects of Using Wastes, Residues, and By-products for Biofuels and Bioenergy[50]

The RED and RTFO currently do not account for indirect GHG impacts from biofuel production and this report develops a methodology for quantifying these impacts for "wastes," "residues," and "by-products" used for biofuel or bioenergy. The certainty of the indirect assessments used to quantify indirect impacts depends on multiple factors: "the number of existing uses/disposal pathways, the complexity of the markets in which the material is traded, the number of possible substitutes/alternative production systems for the material, the range of possible emissions factors for the substitutes/alternative products/existing disposal pathways, and the availability of data for these factors."[51]

More specifically the report states that:

> "Indirect GHG effects are determined by the existing uses (or disposal pathways) for the material, the possible substitutes/alternative products switched to, and the emissions resulting

[50] Brander et. al., "Methodology and Evidence Base on the Indirect Greenhouse Gas Effects of Using Wastes, Residues, and By-products for Biofuels and Bioenergy," Report to the Report to the Renewable Fuels Agency and the Department for Energy and Climate Change, 30 November 2009, report: PR-091007-A

[51] Brander (2009), pg 4

> from the production of those substitutes/alternative products (or change in emissions from waste disposal). Therefore the indirect GHG effect may be different in different localities, regions and countries, depending on these determining characteristics. For example, the current use of tallow in the US is significantly different from current tallow use in the UK, and therefore the indirect effects of using US tallow for biofuel/bioenergy may be significantly different from the use of UK tallow."[52]

Four major challenges with using indirect GHG effect factors:

1. Temporal changes: indirect effects will change over time if any of the determining factors change
2. Location variation: indirect effects may be different in different localities, regions and countries.
3. Uncertainty: the magnitude of indirect effects, and any point estimate, may be highly uncertain.
4. Circular effects: circular effects may arise when the alternative uses of the material studied are themselves biofuel/bioenergy applications which may also be assessed for their indirect effects.

The "rule of thumb" approach for defining wastes and residuals is recommended in the report: "all materials which are disposed of in the absence of biofuel/bioenergy usage may be considered "appropriate"." The report also suggests that the "rule of thumb" should be subject to exceptions and could incentivize the use of materials which will create negative indirect effects.

The definition of wastes and residuals should be based on the existing legislative definitions (e.g., the WFD definition of waste as "any substance or object which the holder discards or intends or is required to discard"), but include an additional screening test to ensure that only "wastes" and "residues" which are unlikely to involve negative indirect greenhouse gas effects will receive double-incentives under RED. The report uses the definition of wastes, residuals and by-products as materials with inelastic supply where their supply is not responsive to an increase in demand.

The report developed a methodology for quantifying indirect effects. The purpose of the methodology developed is to calculate a value for the indirect greenhouse gas effects of using materials with inelastic supply including increased emissions from alternative materials the existing user must find and emission reductions for materials with no existing use that results in reduced disposal. To limit circular effects when assessing competing biofuel and bioenergy applications, the report recommends identifying a non-energy application for the feedstock or utilizing a net indirect effect approach between the two choices.

[52] Brander (2009), pg 6-7

Table 2-7. Case Study Results for Classification of Feedstocks and Quantification of Indirect Effects

Feedstock	Categorization	Current Uses	Indirect Effect
Molasses	Inelastic supply, as it may constitute zero or close to zero of the farm gate value of sugarcane and sugar beet production	Current uses: an animal feed component (largest use), as a growth medium for yeast, in lactic and citric acid production, and in niche applications including dust suppression, food flavouring and colouring	18 – 75 gCO2e/MJ
Municipal Solid Waste	Inelastic supply because any change in the price paid or gate fee received is unlikely to influence the total quantity goods or services consumed by households	Current uses: landfill disposal. Emissions from landfill should be assumed as being the indirect impact (or benefit) of using MSW as a feedstock for biofuels or bioenergy; must take into account landfill gas capture efficiency and direct methane loses	-116.4 gCO2e/MJ
Tallow	Inelastic supply, as it constitutes zero or close to zero of the farm gate value of livestock	Current uses of tallow in the UK are: oleochemicals, soap, animal feed, biodiesel, heat, food, and pet food	24.7-84.2 gCO2e/MJ
Straw	Inelastic supply – at least largely; the primary economic purpose of cultivation for all UK cereal and oilseed crops is to obtain the seeds or grains and straw is unavoidably coproduced as part of this activity.	Current uses include incorporation back into soil, animal bedding, combustion for power (and heat), mushroom compost and specialist uses e.g., in packaging	0.3-5.1 gCO2e/MJ

The non-energy use alternative for quantifying indirect effects is applicable for the LCFS and other regulatory purposes because it reduces the potential circular nature of the analysis and prevents a preference of bioenergy feedstock between sectors (i.e., stationary and transportation). In addition, utilizing the net indirect effects approach has the potential for double counting of emission reductions compared to the conventional fuel when quantifying LCFS credits.

Ecofys. July 2011. Products, residues and waste in the UK palm oil supply chain. Analysis to inform UK guidance development.[53]

This presentation was given by Ecofys at the RTFO Expert Advisory Group meeting, Special meeting on Wastes on July 21st, 2011. It provides an overview of the palm oil supply chain and determines which

[53] Presentation by Klaas Koop of Ecofys. July 2011. Products, residues and waste in the UK palm oil supply chain. Analysis to inform UK guidance development. http://webarchive.nationalarchives.gov.uk/20120904033926/http://assets.dft.gov.uk/publications/biofuels-events-calendar/products-residues-wastes-uk-palm-oil-supply.pdf

aspects are considered wastes or residues. The palm oil supply chain was chosen as an example to test the practical application of RTFO/RED principles in feedstock classification because palm oil materials have diverse applications, significant traded volumes, and varying economic values. The four guiding principles include:

1. The main process should not have been deliberately modified to produce a larger quantity or another quality of the material, at the expense of the main product(s); *(based on EC guidance/definitions)*
2. The primary aim of the process is the material(s) to which the process normally is optimized. Such materials should be regarded as main product or co-product, and the remaining materials are residues (or waste); *(based on EC guidance/definitions)*
3. Primary technology choice for a process should not be determining. Instead the optimization and management of the existing process should be determining;
4. If a material from a process represents/constitutes an essential/considerable outcome of the process (amount and economical value) and this material has uses other than energy production, it should be regarded as a coproduct, even where the process is not optimized for this material.

The presentation maps the palm oil supply chain and lists all the associated materials, their main current uses, and approximate market value (summarized in Figure 2-2 below).

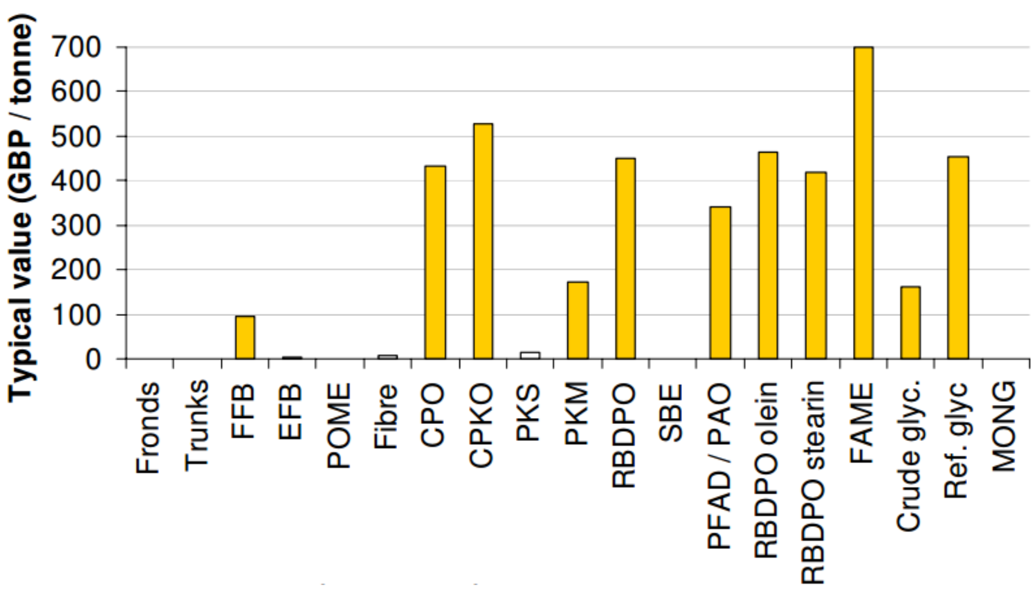

Figure 2-2. Typical market value of palm materials

PFAD arises from the crude palm oil refining step and its main uses include the soap industry, animal feed, and oleo chemical industry. According to this analysis, PFAD is traded at about 75% of the main product in £/tonne, therefore it is considered a co-product, not a residue/waste.

Joint Research Centre-EUCAR-CONCAWE (JEC) Well to Wheels Report[54] and Joint Research Centre (JRC)

The JEC report uses the concept of co-products. LCA methodology is based on a stand-alone analysis, where all energy and emissions generated by a process are allocated to the main or desired product of that process. The co-products generate substitution emissions credits equal to the energy and emissions saved by not producing the material that the co-products are most likely to displace.[55]

The report warns against the potential incentives from the use of substitution emissions. In the case of substitution-credits for electricity exports, use of the substitution method in legislation can give rise to a "perverse incentive" to produce more co-product and less biofuel. The report recommends that a practical way to avoid these effects in legislation is to use some sort of allocation, even though this is not scientifically rigorous. For example, the Renewable Energy Directive requires emissions allocation between co-products according to their energy-content.

The JEC Report lacks a cohesive definition of waste that spans all fuels. The report looks at wastes separately by feedstock type and end fuel. The report uses the concept of waste materials for cooking oils and tallow. While cooking oil is considered zero energy and footprint (the JEC state that the material has to be collected anyway), tallow is considered to have a zero footprint in production, but to have small but significant energy and GHG cost associated with collection and the rendering process. Within this concept, waste material production would have an energy and GHG footprint of zero; however, the material would have an energy and emissions footprint associated with any pre-treatment.

For the JEC report, authors utilized energy allocation in most instances because it is required in the RED. For pathways developed by JRC, they utilize economic allocation, no matter how small or large the economic values. Utilizing this method takes care of co-product, by-product, and waste/residual analysis and the question of whether to allocated emissions and how. As highlighted here, the use of mass or energy allocation is more conducive to LCAs for regulatory purposes and economic allocation for research.[56]

AEA Energy & Environment Tallow Biodiesel Report to the UK Department of Transport[57]

This project examined the concern that tallow being used for biodiesel will cause adverse effects on the other industries that currently use tallow as a feedstock, and addressed the question of whether the UK government should reconsider if changes need to be made to the design of the RTFO. The report drew its conclusions after examining the UK tallow market, assessing the impact of tallow use for biodiesel on tallow price, assessing the impact of the RTFO on the UK oleochemicals, speciality chemicals and

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[54] http://iet.jrc.ec.europa.eu/about-jec/sites/iet.jrc.ec.europa.eu.about-jec/files/documents/wtw_report_v4a_march_2014_final.pdf

[55] Ibid, pg 15.

[56] Personal communication with Robert Edwards, Scientist, Joint Research Centre (JRC) of the European Commission

[57] AEA Energy & Environment, "Advice on the Economic and Environmental Impacts of Government Support for Biodiesel Production from Tallow," report to UK Department of Transport, April 4th, 2008, Report ED05914.

cleaning product industries, and lastly assessing whether the diversion of tallow into biodiesel from other industries will have a beneficial or harmful GHG impact.

The report found the UK tallow is a limited resource dependent on the size of the livestock industry and is difficult to import due to high import costs. All tallow is used for an economic purpose in the UK with the main alternative feedstocks being fuel oil in stationary source applications and palm oil in the oleochemical and soap industry. The price of low quality tallow used in stationary source applications tracks with fuel oil prices and higher quality tallow is linked to the lowest equivalent virgin plant oil (minus transport costs and tariffs). The report demonstrates that the RTFO makes the production of biodiesel from tallow attractive and increases the biodiesel producers' willingness to pay for tallow. The report also concludes that "for feedstocks such as tallow that already have existing applications the RTFO should take into account the effect of substitution on the overall sustainability of switching to biofuels production, particularly on GHG emissions."[58]

To estimate the GHG emission impact of using tallow for biodiesel, the report creates two scenarios that meet the same oleochemical, soap and biodiesel demands:

- Scenario 1: tallow is used in oleochemical and soap manufacturing and boiler fuel in rendering plants and palm oil is used for biodiesel production
- Scenario 2: all inedible tallow is used for biodiesel manufacturing, palm oil is used of oleochemical and soap manufacturing and fuel oil is used for boiler fuel.

The AEA methodology found an increase 974 kgCO_2e/tonne of tallow (approximately 25 gCO_2e/MJ tallow biodiesel) when tallow is converted to a biodiesel feedstock (i.e., the difference between Scenario 2 and Scenario 1). The report assumes no indirect land use change from palm oil production and only fuel oil replacing tallow as boiler fuel. Both of these assumptions likely overestimate the results of the analysis.

The AEA differential methodology varies from conventional LCA modeling. The latter quantifies the absolute or incremental gallon of biodiesel to be produced, as opposed to the AEA methodology, which maintains a consistent production of biodiesel while switching feedstocks. A conventional LCA would have looked at the biodiesel production from tallow in Scenario 2 (including non-tallow for rendering fuel) and, if deemed appropriate would have performed a displacement analysis with palm oil or other oleochemical/soap feedstock. If fuel oil is assumed to replace tallow as a boiler fuel and palm oil to replace tallow in oleochemicals/soap, the AEA methodology likely underestimates the indirect effects of tallow as a biofuel feedstock in the UK.

[58] Ibid

3 Biofuel LCA and Feedstock Definitions

The literature review in the previous section summarizes previous and current thought around categorizing biofuel feedstocks and how they should be handled in an LCA. After reviewing these resources, ICF developed the following biofuel feedstock category definitions, which are consistent with many of the principles in the reviewed resources. Section 3.1 defines general biofuel LCA terms that will be discussed within the definitions of the feedstock categories in Section 3.2. These terms are not always used consistently across the industry and are explicitly defined here to limit any misunderstanding of the rules and guidelines. The rules and guidelines for the analysis used to categorize the feedstocks and perform the emissions analyses are discussed in Section 4.

3.1 Biofuel LCA Definitions

Allocation

Allocation is the quantification and assignment of direct process and/or upstream emissions to products. Allocation can be done by various methods including mass, energy and economic value. If there is one primary product, allocation is straightforward with all emissions being allocated to the primary product (i.e., corn farming to corn grain). Allocation between products occurs when there are multiple primary co-products of a process. For example, soy oil and soy meal are primary co-products of the soybean farming and soy oil extraction processes. Under the California LCFS, the emissions from soybean farming, transportation, and soy oil extraction are allocated between these two products based upon mass, which is the normal convention for agricultural products and how the emission are treated in GREET. Soy oil is approximately 20% of the product mass after oil extraction and is allocated 20% of the upstream and process emissions and soy meal is allocated the remaining 80%. A market value based approach for allocating soy oil and meal upstream emissions would result in approximately 47% of the emissions allocated to soy oil and 53% to soy meal.[59] For secondary products, allocation can occur for the specific processes in which they are produced even though they are not allocated any upstream emissions. For example, within a meat processing facility GREET and the LCFS allocate only the emissions from the raw animal waste rendering process between tallow and meat and bone meal. Another example is that GREET and the LCFS allocate only emissions from corn oil pressing of DGS within the ethanol production facility to corn oil. All of the emissions from corn oil pressing of DGS are allocated to corn oil since it is the singular additive product from the process with DGS being the feedstock and a modified form of DGS a product of the process.

Diversion

Diversion emissions are the emissions (either positive or negative) attributed to a biofuel feedstock or pathway from diverting waste or residual material from disposal to utilization as a useful biofuel feedstock. For example, the diversion of municipal solid waste (MSW) from a landfill to renewable natural gas production from anaerobic digestion would receive an emission credit for the associated biogenic carbon dioxide emission and methane emission reduction. Even landfills with methane capture

[59] GREET model version GREET1_2015; BioOil tab cells B225 and B226.

systems only achieve approximately 75% capture efficiency with remaining methane either oxidized in the soil cap or vented to the atmosphere as methane, in addition to methane leaks prior to capping and gas collection.[60] The use of food and green waste as a feedstock for renewable natural gas (RNG) production from anaerobic digestion diverts the landfill disposal of these feedstocks to biofuel production. Anaerobic digestion captures the entirety of the methane produced and during RNG consumption converts the methane to carbon dioxide. The food and green waste anaerobic digestion pathway receives an emissions reduction credit for the reducing vented methane emissions relative to landfilling.

Displacement

When an economically valuable feedstock is removed from the market in order to be used for biofuel production, another feedstock will need to replace it. Displacement emissions are the indirect emissions from producing and utilizing the replacement feedstock when an economically valuable feedstock is removed from the market. Displacement emissions would be additional to the direct biofuel pathway emissions. It is important to consider whether the feedstock is contained within an existing biofuel pathway and whether similar handling of the displacement emissions should take place in the existing pathway for consistency. An example is corn oil which is contained within the existing corn ethanol pathway.

Indirect Land Use Change (iLUC)

iLUC emissions are the indirect emissions caused by diverting arable land to biofuel production. The emissions are from land conversion (some modeling frameworks also include other associated emissions e.g., increased or decreased livestock emissions) to compensate for the crops now used for biofuel production. iLUC emissions are modeled utilizing complex partial or fully equilibrium economic models.[61] This analysis is limited to crop based biofuel feedstocks where the production of the biofuel is a primary or co-primary product. This includes corn and sorghum for ethanol production and soybeans, canola and palm for biodiesel or renewable diesel production. ARB performs the iLUC analyses for the LCFS.

Substitution

Substitution emissions are the emissions credited to the primary or co-primary product biofuel feedstock or pathway from the substitution of secondary products into the market. For example, corn starch is the primary product of the corn farming and ethanol process and DGS is a secondary product. DGS is sold as an animal feed and is assumed to displace corn based animal feed. The corn ethanol pathway receives a substitution credit for the amount of reduced corn animal feed that is substituted by the DGS. The credit includes reduced emissions from farming, harvesting and producing animal feed.

Elasticity

Supply elasticity is the responsiveness of the supply of a biofuel feedstock to demand or price. A biofuel feedstock supply is inelastic with demand when, as demand changes for the feedstock, whether up or

[60] http://www.arb.ca.gov/fuels/lcfs/121514hsad.pdf

[61] EPA uses a combination of the FASOM and FAPRI models and ARB uses the GTAP model.

down, there is little to no response in supply. When a biofuel feedstock supply is elastic with demand, changes in price result in changes in supply. An increase in demand (i.e., price) will result in an increase in supply and vice versa.

3.2 Biofuel Feedstock Categories

Primary Product

A primary product is a biofuel feedstock that is the singular main product of the production process and has elastic supply with demand. Primary products are allocated all of the upstream emissions including indirect emissions such as iLUC and emissions credits from substitution. For example, corn grain for ethanol production is the primary product of corn farming and is allocated all of the corn farming emissions including fertilizer production and use and iLUC. In existing LCA modeling frameworks such as GREET, corn ethanol receives a displacement credit for DGS production.

Primary Co-Product

A primary co-product is a biofuel feedstock that is one of multiple co-products of a production process with elastic supply with demand. Primary co-products are allocated a proportion of the upstream and process emissions based on mass, energy, or economic value. For crop-based biofuels, iLUC is determined through models on an emissions basis per quantity of fuel and therefore iLUC emissions are fully allocated to the biofuel feedstock. With soy oil, the iLUC models take into account the increased production of soy meal and the effects increased soy meal supply would have on the market.

Secondary Product

A secondary product is a non-primary product of the process where its supply is inelastic with demand. This means that if the demand (e.g., price) of the feedstock were to increase, there would be little to no increase in supply because it is not a primary product of the original process. For example, DGS is a by-product of the corn ethanol process. While valuable as a by-product, increased demand for animal feed (the main market for DGS) would not result in producers increasing ethanol production to make more DGS because if feed demand increased without a corresponding increase in ethanol demand, it would be more rational to supply corn directly to the feed market without fermentation.

By-Products

By-products are a subcategory of secondary products that have significant economic value in the marketplace where they are prominently bought and sold while having an inelastic supply with demand. In existing LCA modeling frameworks (such as GREET), and recommended in this report, by-products are not allocated upstream energy and emissions but can be allocated emissions for the specific process in which they are produced. Emissions necessary to convert the by-product to a usable biofuel feedstock will be allocated to the final biofuel. For by-products that are used as biofuel feedstocks, indirect emissions could be attributed to the feedstock from displacement. DGS are a by-product with some economic value and currently contained within the corn ethanol pathway. If DGS were a biofuel feedstock, they would not be allocated upstream or process emissions since they are produced during the ethanol process and all of the emissions are allocated to corn ethanol. In existing LCA framework and regulations including GREET and the LCFS, DGS are contained within the corn ethanol pathway where corn ethanol receives a substitution credit for reducing corn animal feed production. If choosing to maintain consistency with these existing ethanol pathways, DGS as a biofuel feedstock would be allocated indirect emissions from displacement equal to the corn animal feed needed to replace it in the market.

Wastes and Residuals

Wastes and residuals are the other subcategory of secondary products. They have little to no economic value and their current primary use is usually disposal and/or incineration/combustion. Crop residues left in the field provide some economic value as a soil amendment. The literature review was inconclusive on a specific value to delineate between by-products, and wastes and residuals, and this report does not recommend such a value. Wastes and residuals are not allocated upstream or process emissions and, if their primary use other than biofuel/bioenergy is disposal or combustion/incineration, there are no indirect emissions from displacement. This is consistent with the thinking of EPA[62] and ARB.[63] If the primary use is something other than disposal, combustion/incineration or biofuel/energy, an analysis should be performed to determine if displacement emissions should be added to the pathway. In addition to potential displacement, diversion emission credits should be calculated for those feedstocks that are diverted from waste disposal and incineration to a viable product. An example is MSW that is diverted from disposal at a landfill to produce renewable natural gas. The reduced methane emissions that would have been emitted during natural anaerobic digestion in the landfill, even with a landfill gas capture system in place, should be credited to the pathway.

[62] See EPA literature review and expert interview.

[63] http://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/030714lcfsconceptpaper.pdf

4 Rules and Guidelines for Categorizing Feedstocks and Quantifying LCA Emissions

The previous section defined the feedstock categories. This section discusses these analyses in more detail, rules and guidelines for categorizing the feedstocks, and how they will be handled in a LCA. Figure 4-1 shows the feedstock categorization flow diagram that will be discussed in detail in the following section. In the context of the California LCFS, it is our recommendation the analyses should first be conducted by the applicant (except iLUC quantification), and then reviewed by ARB, minimizing the resources required by ARB to review and approve a new feedstock and fuel pathway.

4.1 Feedstock Economic and Supply Chain Analysis

The proposed first step is a feedstock economic and supply chain analysis when a new biofuel feedstock is proposed to ARB. The purpose of the economic analysis is to understand relative value of the biofuel feedstock to other products in the production process and determine if the feedstock is a primary product or a secondary product, and the elasticity of its supply. This requires a detailed understanding of the process and product values. ICF recommends 10 years' worth of product value data should be presented to minimize annual fluctuations and show any potential trends in product value.

The results of the economic analysis will determine whether the feedstock is categorized as a primary or secondary product and whether multiple products of the process are primary co-products, or if it is a singular primary product. The qualitative and quantitative understanding of the supply elasticity (i.e., responsiveness of the supply of a biofuel feedstock to demand or price) and value of the biofuel feedstock compared to the other products allows the biofuel feedstock to be categorized as either a primary product or a secondary product of the process to produce them. The initial plan was to develop quantitative feedstock value thresholds to distinguish the categories, but as the analysis progressed it became apparent that specific value thresholds were arbitrary to market dynamics at the point when an application was submitted and could potentially lead to manipulation. ICF chose to recommend the qualitative, and potentially more market research intensive, approach of supply elasticity to separate primary from secondary products.

Primary product or co-products are the dominant value product(s) of the process with elastic supply with demand. Examples of singular primary products that are biofuel feedstocks include corn starch for ethanol production, and palm oil for renewable diesel production. Soy oil for biodiesel production is an example of a primary co-product (with soy meal) of soybean farming and oil extraction.

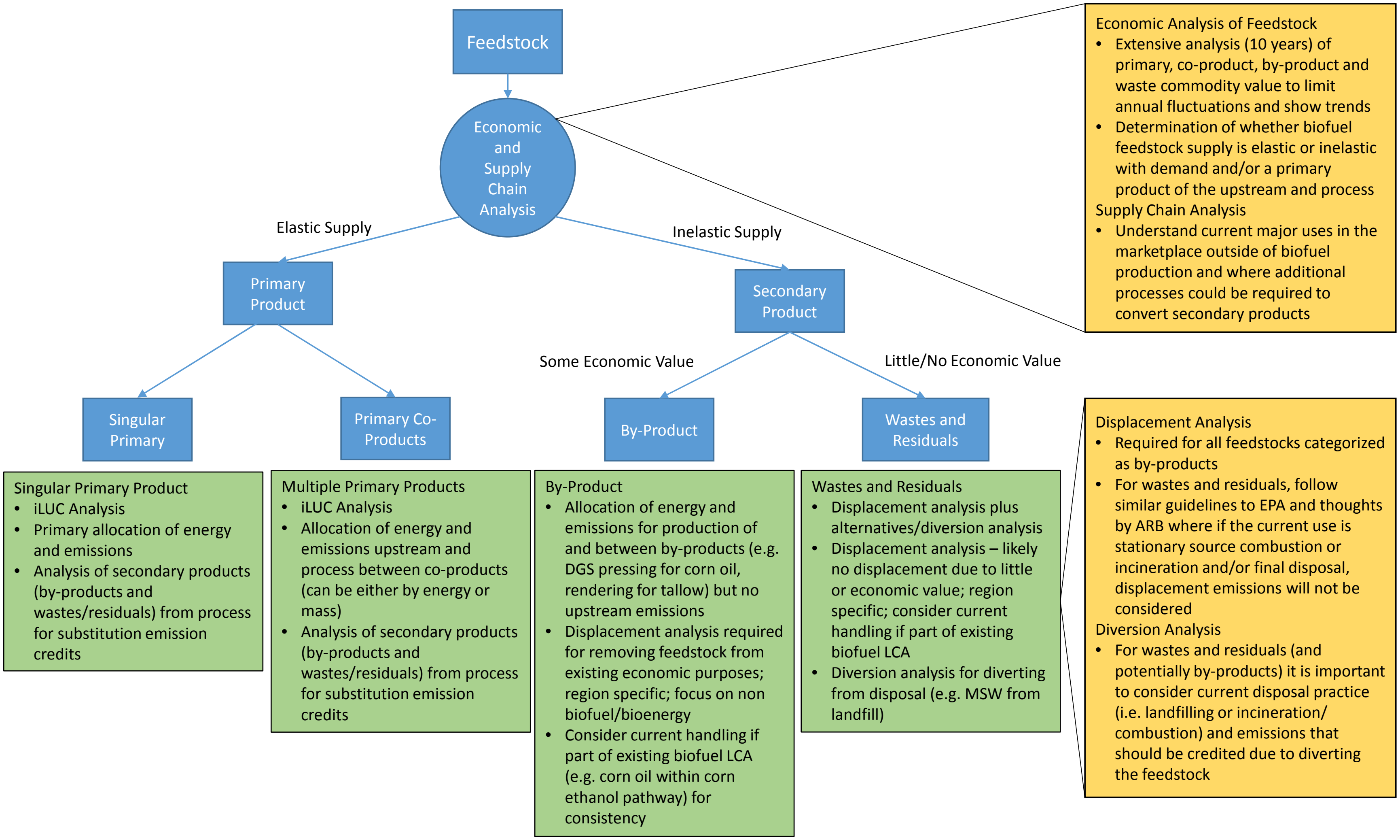

Figure 4-1. Feedstock Categorization Flow Diagram

Secondary products are the products of a process that have inelastic supply with demand, i.e., even if the market value of a secondary product increases you would not expect more of it to be produced from the use of that process. The economic value of secondary products is the determining factor between the two subcategories: by-products, and wastes and residuals. By-products are secondary products with significant economic value and wastes and residuals are secondary products with little or no value. The supply chain analysis would require the applicant to describe and demonstrate the current supply chain for the feedstock from source to final product (or products if there are multiple end uses). The supply chain analysis will show what the major current uses for the feedstock are and help determine whether displacement or diversion emissions should be considered. For example, DGS is a by-product of the corn ethanol process since it has inelastic supply with demand (e.g., if demand for animal feed increases, ethanol production to produce DGS will not increase) and has economic value as an animal feed. The supply chain analysis would start with corn production, continue through ethanol and DGS production, and culminate with DGS used as animal feed. If DGS were used as a feedstock for biofuel production, displacement emissions from the animal feed market would need to be included and attributed to DGS.

4.2 Direct Emission Analysis

The direct emissions are those emissions from directly producing the biofuel feedstock and any emissions directly reduced by diverting the feedstock from its conventional disposal method. Direct emissions for producing corn as a feedstock for ethanol include those from corn farming, fertilizer production and application, corn harvesting, and corn transport. The emissions sources include fuel combustion (i.e., diesel, natural gas) and soil carbon and nitrous oxide emissions from fertilizer application. Direct emissions reduced by diverting MSW from a landfill include reduced methane emissions. The following subsections discuss the rules and guidelines for allocation of direct emissions and determining diversion emissions.

4.2.1 Allocation

Allocation, as defined in Section 3.1, is the division of direct emissions between products and can be done on the basis of mass, energy or economic value. The quantification of direct emissions is relatively straightforward where the energy resources (and upstream emissions to produce the energy sources) are included plus any emissions required to produce other inputs such as fertilizer or process chemicals. The decision of the allocation basis between mass, energy or economic values can be the most difficult part. Each method for allocation has significant drawbacks. Mass-based allocation is not applicable for all cases (such as co-produced electricity) and it potentially over-allocates emissions to heavy products. Energy allocation (allocation by heating value) is preferred within European regulatory LCA for biofuels, but just as mass allocation may over-allocated to heavy products, energy allocation could under-allocate to valuable materials with limited energetic content. Market value based allocations are more closely aligned to the value assigned to each material by the market, but are therefore subject to market variability and price fluctuations. For agricultural products, the main convention in existing LCA modeling and regulatory frameworks, such as GREET and the LCFS, is to use a mass based approach (e.g., soy oil and soy meal). The applicant should apply the appropriate GREET modeling framework allocation methodology since the LCFS LCA model is based on the GREET model.

Direct process and upstream emissions should be allocated to the primary product or products of a process, and secondary products should not be allocated primary process and upstream emissions. For primary product biofuel feedstocks, the handling of secondary products via substitution is discussed in the indirect emissions section. Secondary products can be allocated direct emissions from processes that convert the raw secondary product into the actual biofuel feedstock or processing to specifically extract the biofuel feedstock. For example, the emissions from processing animal waste at rendering plants should be allocated between the primary co-products of tallow (a by-product biofuel feedstock of livestock and meat production), grease and bone meal.

4.2.2 Diversion

Diversion emissions (either positive or negative) are the direct emissions from diverting the biofuel feedstock from final disposal including landfilling and incineration/combustion (without energy recovery). Diversion emissions are only applicable to biofuel feedstocks that are categorized as a waste or residual in the case that the feedstock is primarily disposed of. The supply chain analysis will identify the primary disposal method and in-depth research will be required by the applicant to quantify the emissions that are being diverted. For example, ARB has detailed the expected diverted landfill methane emissions from utilizing organic food and green waste as a feedstock for renewable natural gas.[64] A detailed analysis would be required from the applicant, and the principle of conservativeness should be applied to the allocation of diversion emissions to avoid over-crediting.

4.3 Indirect Emission Analysis

Indirect emissions are the increased emissions associated with producing an economic product to replace a biofuel feedstock when it is removed from another market (i.e., displacement and indirect land use change), or the decreased emissions due to a secondary non-biofuel product substituting for an existing economic product (i.e., substitution). These are referred to as indirect emissions because they are not direct results of the production of the biofuel and its feedstock(s). Assessing indirect emissions requires significant analysis and will be dependent on assumptions about the response of the market to changing availability of the feedstock material. The following subsections discuss the rules and guidelines for quantification of substitution, displacement, and indirect land use change emissions.

4.3.1 Indirect Land Use Change

ARB is solely responsible in the LCFS for the quantification of iLUC emissions from primary crop products using the modified GTAP model. The applicant may be called upon to assist in the sourcing of data to be used as inputs to the GTAP model. The applicant is not responsible for having in-depth knowledge of or actually running the GTAP model. ARB has to-date quantified the iLUC emissions for the following primary products and their resultant biofuels[65]:

[64] http://www.arb.ca.gov/fuels/lcfs/121514hsad.pdf

[65] http://www.arb.ca.gov/regact/2015/lcfs2015/lcfsfinalregorder.pdf

- Corn ethanol
- Sugarcane ethanol
- Soy biodiesel
- Canola biodiesel
- Sorghum ethanol
- Palm biodiesel

Any new crop based biofuel feedstock not listed could require an iLUC analysis.

4.3.2 Substitution

Substitution emissions are the reduced emissions, or emission credits, from secondary products substituting or displacing existing economic products in the market. These emissions are quantified for primary product feedstocks where their production processes result in secondary products with economic value. For example DGS is a by-product of the corn ethanol production process. Within GREET and the LCFS, corn ethanol receives an emissions credit equal to the emissions required to produce the quantity of animal feed displaced by the DGS produced. Quantification of substitution emissions will require detailed research and information about the primary economic sectors that use secondary products, what potential main feedstocks the secondary products could displace, and what are the emissions required to produce the displaced feedstocks. It is also important to consider the region where the substitution is occurring because a secondary product may displace different economic products by region.

4.3.3 Displacement

Displacement emissions are the additional emissions to produce a replacement material when an economically valuable feedstock is used for biofuel production. These emissions are quantified for by-products used to produce biofuels that have economic value and will require another feedstock to replace them in their current use. Quantification of displacement emissions, similar to substitution emissions, requires a detailed understanding of the displaced product sector, what are the main feedstocks that could replace the biofuel feedstock, and what are the emissions to produce the replacement feedstocks. It is important to consider whether the feedstock is contained within an existing biofuel pathway and whether similar handling of the displacement emissions to the substitution emissions should take place for consistency.

There are two issues that need to be considered when quantifying displacement emissions where the main alternative use of a biofuel feedstock is in biofuel or bioenergy applications: effective prioritization of the existing bioenergy use over transportation fuels and a circular effect when identifying the feedstock that is being displaced. It is not the intent of the LCFS to make a determination about which bioenergy application is preferable between heat, power, or transport fuels. The addition of displacement emissions based upon this alternative use and potential replacement with a fossil fuel would effectively prioritize the current use over transportation fuels. One solution to avoid the prioritization is to quantify the displacement emissions based upon a non-energy feedstock use. For the limited cases where feedstocks are used exclusively in biofuel and bioenergy applications, no displacement emissions will be quantified. But, even if a lesser percentage of a biofuel feedstock is used in non-energy applications (and the remaining in energy applications), then displacement emissions should be quantified for the non-energy feedstock use.

There can be a circular effect of displacement emission calculations when the biofuel feedstock's alternative use is in biofuel or bioenergy applications. The biofuel feedstock could be replaced by another inelastic feedstock which would require quantification of its own displacement emission, and many times that same inelastic feedstock has the potential to be a biofuel feedstock. It is recommended that the identified replacement feedstock has elastic supply with demand to eliminate circular quantification of displacement emissions.

Regional difference can occur for the main alternative use of a biofuel feedstock. For example, the main uses for edible or inedible tallow are different in the United States and United Kingdom and the sourced tallow from each region could have different displacement emissions. Table 4-1 shows the main uses of inedible tallow in the US and UK.

Table 4-1. Main Uses of Inedible Tallow

	United States[66]	United Kingdom[67]
Existing Uses for Tallow	Animal feed Oleochemicals Biodiesel	Heating Fuel - 49% Oleochemicals – 21% Biodiesel – 12% Pet Food – 10%

These regional differences could be due to regulatory policy (e.g., existing environmental policies) or market factors (e.g., constrained exports or local dominant markets). Utilizing the recommendation for quantifying displacement emissions based upon non-bioenergy/biofuel uses, displacement emissions for inedible tallow sourced from the US would likely be based upon animal feed while tallow from the UK based upon oleochemicals.

Current EPA[68] and ARB[69] thinking is stationary source combustion/incineration as the current use should be excluded from displacement emissions calculations for wastes and residuals that have little or no economic value or when there is no other main economic purpose for the feedstock. If there is a prominent alternative fate to disposal, combustion/incineration or biofuel/energy for a categorized waste and residual feedstock, an analysis should be performed to determine if displacement emissions

[66] See Section 5.1

[67] Brander et. al., "Methodology and Evidence Base on the Indirect Greenhouse Gas Effects of Using Wastes, Residues, and By-products for Biofuels and Bioenergy," Report to the Report to the Renewable Fuels Agency and the Department for Energy and Climate Change, 30 November 2009, report: PR-091007-A, Appendix 7

[68] See EPA literature review and expert interview.

[69] http://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/030714lcfsconceptpaper.pdf

should be added to the pathway. It should be noted that in the rare cases where no prominent alternative fate to biofuel/bioenergy exists resulting in no displacement emissions being quantified, a fossil fuel could replace the biofuel feedstock in the previous energy use application. In carbon-regulated markets like California this is less likely to occur, but fossil fuel use could replace the biofuel feedstock when the biofuel feedstock is taken from markets that are not carbon-regulated.

4.4 Summary

These definitions in Section 3 and rules for categorization in Section 4 attempt to place biofuel feedstock as separate categories and identify what emissions should be included. Table 4-2 summarizes the feedstock definitions and the emissions that should be included.

Table 4-2. Feedstock Categories and Emissions

Feedstock Category	Definition	Direct Emissions	Indirect Emissions
Primary (Co-Primary) Product(s)	Main product(s) of the production process with elastic supply	Allocation of upstream and process emissions	iLUC, substitution from secondary products
By-Products	Secondary product with inelastic supply and some economic value	Allocation of process emissions to directly produce the feedstock; no upstream emissions	Displacement Method
Wastes and Residuals	Secondary product with inelastic supply and little to no economic value	No upstream emissions; credits for Diversion	Displacement Method, if necessary

Since supply elasticity and value are two main metrics for the categories, in the future feedstocks have the potential to move between categories. For example, the organic material from MSW maybe become valuable enough that it is diverted from landfills and used for another industrial purpose. At that point it could be re-categorized as a by-product and require a displacement emission analysis and removal of previously quantified diversion credits. Adjustments to the quantification of displacement emissions could also occur for the limited feedstocks used exclusively in bioenergy and biofuel applications. At the point where the feedstock begins to be used in non-energy applications, even at a lesser percentage than the energy application, then displacement emissions should be quantified for the non-energy feedstock use.

From a regulatory perspective re-categorization would need to be handled with a degree of delicacy in order to maintain regulatory certainty. Often significant infrastructure investment would have been made based on the environmental attributes of the current categorization. Re-categorization, or even the potential for re-categorization, could cause uncertainty in the market and investment community. A potential solution is to grandfather approved pathways and their associated facilities with the feedstock categorization at the time of approval, so that if a feedstock is re-categorized, only new facilities would be required to utilize the new categorization. This would allow for certainty in the market that the relative credit generating potential will not be fundamentally altered after the investment is made.

5 Case Studies for Categorizing Feedstocks

The following four case studies utilize the recommended rules and guidelines for categorizing tallow, corn oil, PFAD and used cooking oil as biofuel feedstocks. Each case study includes a general description of the biofuel feedstock, an economic and supply chain analysis, and categorization and indirect effects determination.

5.1 Case Study 1: U.S. Tallow

General Description

Tallow is animal fat extracted primarily from beef, characterized by hardness, moisture, insolubility, unsaponifiables, free fatty acids, fatty acid content, and color. The animal tissue containing fats are converted to tallow by a process called rendering in which lipid materials are separated from meat tissue and water under the influence of heat and pressure. The sources of raw materials are:

- Packinghouse by-products, such as organ fats, offal, bones, and blood.
- Boning house materials which consist of bones and meat trimmings.
- Meat market trimmings including adipose and intermuscular fats, bone, cartilage, and meat trimmings.
- Fallen animals.

The national Renderers Association distinguishes two major types of tallows in the U.S.: edible tallow and inedible tallow.[70] Edible Beef Tallow, made exclusively from the highest quality edible beef fat, is processed for human consumption (e.g., margarine, cooking oil, and baking products) and pet food. Inedible or Industrial Tallow is processed to serve livestock feed, oleo-chemical, and biofuel uses. Edible rendering processes are normally operated in conjunction with meat packing operations. Inedible rendering processes are operated as independent or integrated rendering operations.

In recent years, in addition to traditional markets, tallow and other animal fats have been used as a biodiesel feedstock in the U.S. Tallow has contributed around 19% of the rendered fat/grease used in Biodiesel production between 2009 and 2013 as shown in Figure 5-1[71] and Figure 5-2[72]. Because edible fats are likely to attract a higher price in the food industry than inedible rendering products, inedible tallow is expected to be more likely to be used for biodiesel production.

[70] The American Fats and Oils Association provides specifications for a variety of different types of tallow and grease, including edible tallow, lard (edible), top white tallow, all beef packer tallow, extra fancy tallow, fancy tallow, bleachable fancy tallow, prime tallow, choice white grease, and yellow grease. The specifications include such characteristics as the melting point, color, density, moisture content, insoluble impurities, and others".

[71] Source of data: Centrec Consulting Group based on Census Bureau and Renderer Magazine data. Available online at http://biodiesel.org/docs/default-source/news---supporting-files/animal-fats-and-tallow-bd-demand-impact-report.pdf?sfvrsn=2

[72] Source of data: National Renderers Association based on U.S. Energy Information Administration data. Available online at https://fatsandoils.org/wp-content/uploads/2014/10/Kent-Swisher.pdf

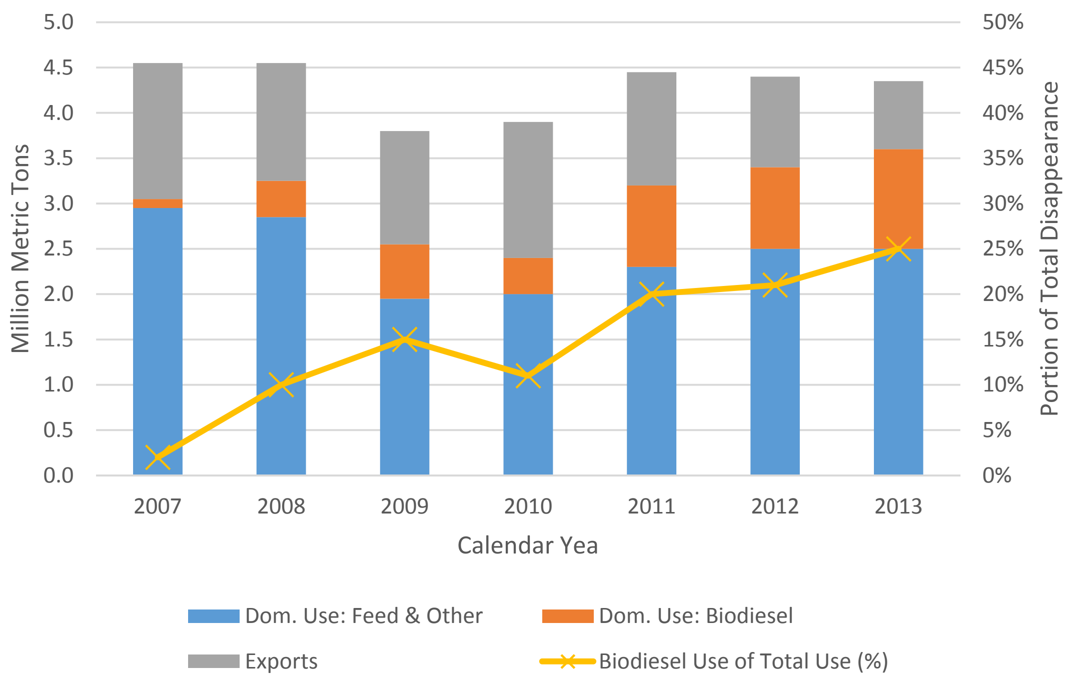

Figure 5-1. U.S. Animal Fats and Tallow Disappearance

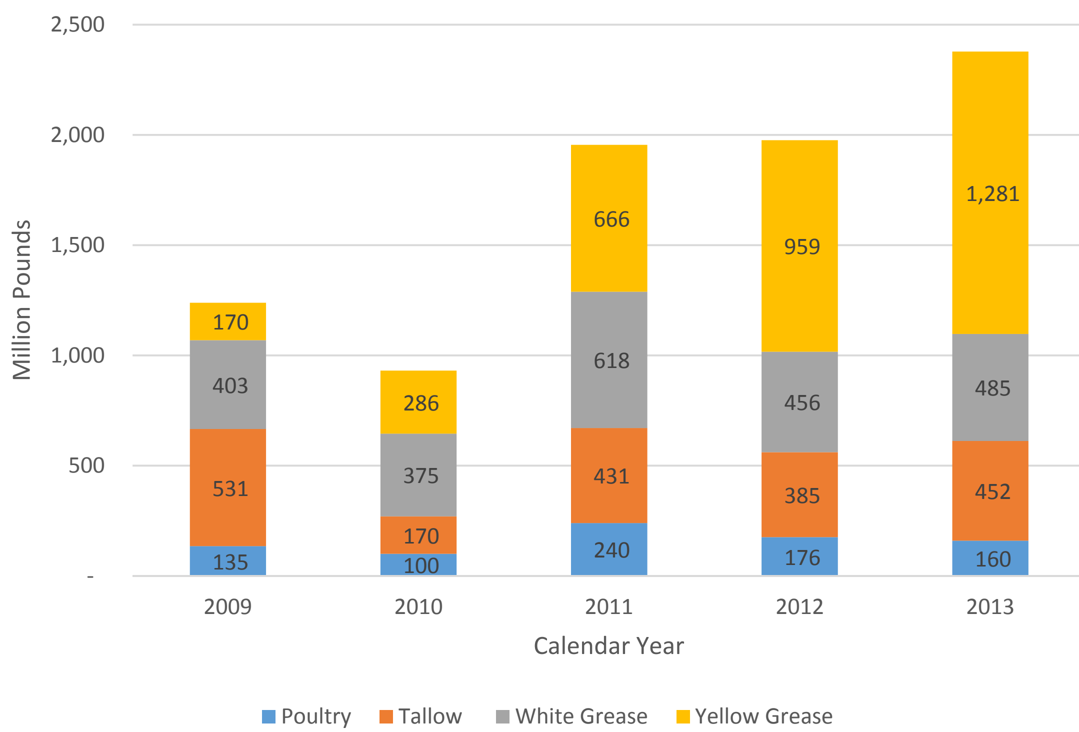

Figure 5-2. Rendered Fat/Grease Used in Biodiesel/ Renewable Diesel Production (2009 – 2013)

Beef Tallow Supply Chain and Economic Analysis

Tallow's supply chain can be simplified by focusing on four major economic activities within the meat industry (i.e., livestock, meat processing, rendering, and the end final use of the feedstock or feedstock's value-added processing) and the materials flow among those activities as illustrated in Figure 5-3.

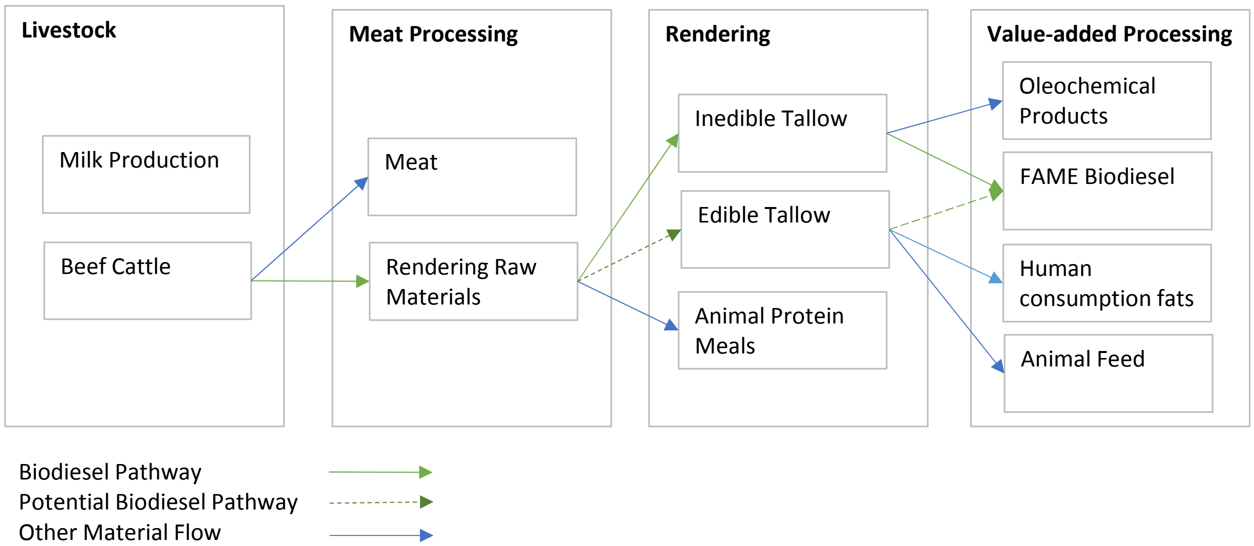

Figure 5-3. Representation of Tallow's Supply Chain as Biodiesel Feedstock in Terms of Major Meat Industry Economic Activities and Flow Materials

Beef cattle are raised for meat production (independent from dairy production). Within the livestock and meat processing economic activities, meat demand defines beef cattle production. Demand for rendering raw materials derived from the processing of cattle does not drive the meat market direction. Between 2005 and 2015 beef prices have consistently increased[73]. Beef price ranged from $2,500 – $5,000/ton and increased consistently with cattle prices that ranged from $1,500 – 5,900 /ton. These prices are significantly larger than the price for rendering raw materials estimated to be $64.49/ton. Using a 60% average dressing percentage[74] for 2010-2015[75], an approximated revenue can be estimated to be $1,500-3,000/ton of beef cattle due to beef market, and $25.6/ton of beef cattle due to rendering raw material market. This represents a ratio between 0.008 and 0.017 of the market value of rendering

[73] http://www.ers.usda.gov/data-products/meat-price-spreads.aspx
http://www.ers.usda.gov/topics/animal-products/cattle-beef/statistics-information.aspx

[74] The dressing percentage is calculated by dividing the warm carcass weight by the shrunk live weight of the animal and expressing the result as a percentage. Represents the meat and skeletal portion of an animal compared to its live weight. Notice this is an approximated indicator for production; carcasses still contain quantities of fat and bones that varies with the animal (e.g., Dutch/Holstein Friesian may have 17% bone, 68% muscle, and 15% fatty tissue) that can be processed further.

[75] Value estimated based on historical Livestock and poultry live and dressed weights federally inspected data. http://www.ers.usda.gov/data-products/livestock-meat-domestic-data.aspx

raw materials to the total marketable value of the beef cattle (actual ratio can be slightly higher as dressing percentage includes some rendering raw materials).

There are multiple processes for rendering the raw materials. In the case of inedible tallow, currently only the "dry rendering" process is used in the U.S. The dry rendering process is a batch or continuous process that dehydrates raw material in order to release fat. Following dehydration in batch or continuous cookers, the melted fat and protein solids are separated which allows to obtain two type of products: fats and animal protein meals. Each type of product has their own market, and the demand of one type of product does not impact the production of the other. Production is defined by the composition of the raw material (share of tallow/grease, protein solids, and moisture in a mass basis) specific to the type of animal used. Within the fats products, they are different product qualities (e.g., edible tallow, industrial tallow, yellow grease, feed grade fats, fats used as fuel). Similarly, within the animal protein meals they are a variety of products (e.g., meat-and-bone-meal, meat meal, hydrolyzed feather meal, poultry by-product meal, low ash poultry meal, blood meal, specialized protein blends). Using an average composition of cattle as dead stock of 12%wt tallow, 25%wt protein solids, and 63%wt moisture, and price ranges of $887-946/ton of tallow and $421 – 1,118/ton of protein meals, an approximated revenue can be estimated to be $106-114/ton of wet raw material due to fat/tallow market, and $105-280/ ton of wet raw material due to protein meals market. This represents a 0.29 to 0.50 ratio of the market value of tallow to the total marketable value of rendering raw materials.

Biofuel Feedstock Categorization and Indirect Effects

In general, the rendering raw materials are used to produce tallow and animal protein meals. The rendering raw materials result from upstream livestock and meat processing economic activities. The supply of rendering raw materials is inelastic with demand since tallow demand does not result in a change in the livestock industry. Using the proposed biofuel categorization and indirect effects guidelines, rendering raw materials can be categorized as secondary products from the livestock and meat processing economic activities. Price information indicates that the materials contribute around 1.7% of total marketable value of the beef cattle. Within the secondary products category, rendering raw materials can be classified as by-products as they have value within these economic activities.

In the rendering process, production of fats and animal protein meals is defined by the composition of the raw material. Price information indicates that fats and protein meals can equally contribute to revenue of the rendering process. The products at this level of analysis can be categorized and classified as primary co-products within the rendering economic activity. At the biodiesel feedstock supply chain level, tallow can be categorized as a secondary product. In addition, tallow can be classified as a by-product because it has some economic value (2.8% of total marketable value of the beef cattle; this reflects a higher value of tallow compared to the value of rendering raw materials).

Table 5-1. Livestock and Animal Rendering Processes Product Values and Categorization

Economic Activity	Product	Approximate revenue/contribution to market value	Feedstock Category
Livestock and Meat Processing	Beef	$3,000/ton beef	Primary, Singular Primary Product
	Rendering raw material	$25.6/ton beef	Secondary, By-product
Rendering	Tallow	$114/ton of wet rendering raw material	Co-primary product
	Protein meals market	$280/ ton of wet rendering raw material	Co-primary product

In the LCA of the feedstock, this categorization indicate that upstream energy use and emissions associated with livestock and meat processing are not allocated to rendering raw materials and rendering process products, including tallow. At the rendering process level, energy and emissions are allocated among co-products including tallow and bone and meat meal (i.e., feed grade fats and animal protein meals[76]). As a by-product, a displacement emissions analysis is performed to determine the replacement feedstock for the existing economic purposes in the specific region of the current /actual market.

Inedible tallow in the U.S. is directed to animal feed and industry uses (Fatty Acid Chemical Industry), and competes in the animal fats and greases' global market. The rendered animal fat competes with the growing and stable vegetable oils market. For example, in 2004 the increase in production of competing vegetable oils resulted in large supplies that had the effect of depressing prices for animal fats; as a result, tallow lost its competitiveness, becoming a price taker. Considering the two major economic activities in which inedible tallow is used, the use of inedible tallow for biodiesel production would likely result in additional production of elastic supply of grains within livestock energy rations. Tallow is considered a source of fat in animal feed. Sources of fat for beef cows include alfalfa, corn, whole soybeans, tallow, megalac. In the US, corn is the main energy ingredient in livestock feed and palm oil is the major competitor to tallow for industrial uses within the oleo-chemical industry. Displacement emissions analysis associated with corn farming or palm oil supply is required for tallow.

[76] Animal protein meals derived from rendering process includes: Meat-and-bone-meal, Meat meal, Hydrolyzed feather meal, Poultry by-product meal, Low ash poultry meal, Blood meal, specialized protein blends.

5.2 Case Study 2: U.S. Corn Oil

General Description

Corn oil is the oil extracted from the germ of corn. There are two corn oil production processes: corn wet milling and corn dry milling. The corn wet milling process separates the corn kernel into its components (i.e., starch (61%), protein (8%), fiber (11%), oil components (4%), and moisture (16%)) through several physical and thermal processes. In the dry milling process, the entire corn kernel is processed without separating out the various component parts of the grain, and the material is sent to a fermentation process for the production of ethanol. After fermentation, the ethanol is separated from the remaining "stillage", and the stillage is further treated into saleable DGS products. DGS has corn oil content that can subsequently be extracted in the recovering process of the DGS[77]. It is expected that the majority of U.S. dry mill ethanol plants are extracting corn oil[78]. This case study focused on oil extraction linked to ethanol production; thus, the case study is focused on the corn dry milling process[79]. They are two major types of corn oil products (crude corn oil and refined corn oil) that can be sold into three primary markets: domestic biofuel, domestic feed market, and export market (for both feed and biofuel markets). Virtually all refined corn oil is utilized in foods.

Corn Oil Supply Chain and Economic Analysis

Corn oil's supply chain analysis as biodiesel feedstock can be simplified by focusing on three major economic activities within the corn farming and processing industry (i.e., Farming, Milling, and the end final use of the feedstock or feedstock's Value-added Processing) and the materials flow among those activities as illustrated in Figure 5-4.

[77] "A relative small number of dry grind ethanol plants implemented "front-end" fractionation technologies to separate the starch rich fraction from the non-fermentable fractions … because of poor long-term economic viability of using these technologies, very few U.S. dry grind ethanol plants are using "front-end" fractionation technologies Today" DDGS User Handbook. Third edition. http://www.grains.org/buyingselling/ddgs

[78] http://farmindustrynews.com/biofuel/biodiesel-industry-turns-corn-oil

[79] "Wet mills represent a significant, but smaller proportion of the U.S. ethanol industry, and produce corn gluten feed, corn gluten meal, and corn germ meal as main products." DDGS User Handbook. Third edition. http://www.grains.org/buyingselling/ddgs.

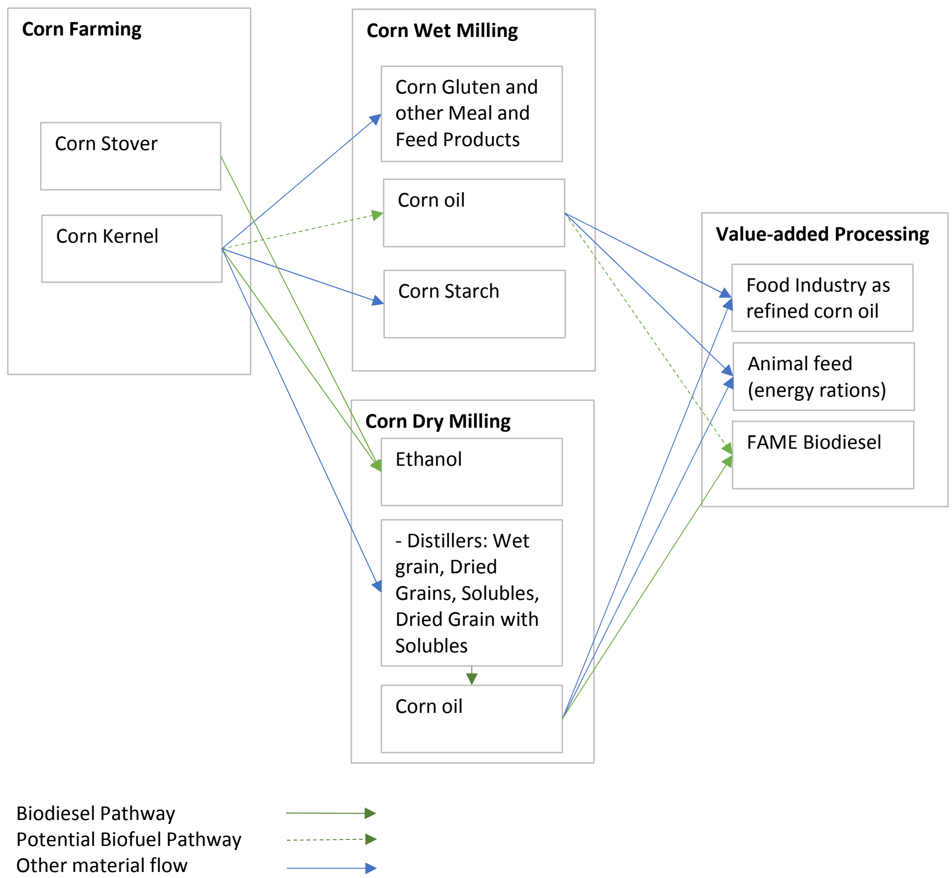

Figure 5-4. Representation of Corn Oil's Supply Chain as Biodiesel Feedstock in Terms of Major Corn Industry Economic Activities and Flow Materials

Farming is conducted for the production of corn. Corn demand changes farming activity, and demand for corn stover[80] does not change the corn market direction. Corn prices have oscillated but consistently increased between 2009 and 2015[81]. Corn weighted-average farm price ranged from $2.00 – $6.89/bushel ($6.89/bushel was a peak value in 2012/13). In 2014, the weighted-average farm price was estimated to be $3.70/bushel. These prices are significantly larger than the estimated cost for corn stover around $72/ton based on feed value[82]. Assuming a production yield of 0.006 dry ton of corn stover per bushel of corn grain[83], an approximated revenue can be estimated to be $3.70/bushel due to corn market, and $0.44/bushel due to corn stover material market. This represents a 0.80 ratio of the market value of corn to the total marketable value of the corn farming.

[80] Corn stover is the biomass that remains in corn field. It is generally left in place to restore nutrients in soil, or used as animal feed, and considered a biomass source for cellulosic ethanol. It is included here for the purposes of categorizing all farming products, and particularly the corn kernel as biodiesel feedstock.

[81] Table 1. http://www.ers.usda.gov/data-products/feed-grains-database/feed-grains-yearbook-tables.aspx#26766

[82] https://www.extension.iastate.edu/agdm/crops/html/a1-70.html

[83] GREET1_2014

The traditional design of the dry milling process has been oriented to the production of ethanol from corn starch and the recovery of distillers. Recently, additional processes have been incorporated for the extraction of corn oil from the thin stillage portion of the DGS production process. Corn oil extraction from thin stillage occurs after fermentation and distillation, and before the drying to produce Distiller's dried grains with solubles (DDGS). Ethanol and corn oil have their own market. The installation of corn oil extraction equipment in existing ethanol plant facilities does not affect ethanol production volumes. However, due to the recent addition of corn oil extraction to the traditional process, the extraction of oil varies the known characteristics of distiller products and changes their functionality in the animal feed market.

U.S. ethanol retail prices have increased from $2.56 to 3.33/GGE (i.e., $1.96 to 2.56/gallon) between 2009 and 2015. A peak in price of $4.89/GGE (i.e., $3.76/gallon) was observed during this timeframe. The 2015 average corn oil price is estimated to be 34.5 cents per pound for Edible Chicago market. The price has ranged between 32.5 to 60 cents per pound during 2009 to 2015[84]. In the 2014/2015 marketing year, DDGS average price was $158/ton. The price has consistently increased from an annual average price of $113 - $158/ton during 2009 to 2015. Using a production yield of 2.7 gallons of ethanol per bushel, and 18 pounds of DDGS for a conventional dry milling process, and assuming an extraction of 60% of the corn oil present in the distillers (i.e., 60% of the 1.6 pounds of corn oil per bushel estimated for a wet process), an approximated revenue can be estimated to be $5.29 - 6.91 per bushel due to ethanol market, $0.31 - 0.58 per bushel due to corn oil market, and $0.87 - 1.22 per bushel due to DDGS. The ratio of the market value of corn oil to the total marketable value of the dry milling products is ~ 0.048.

Biofuel Feedstock Categorization and Indirect Effects

In general, corn grain/kernel are used to produce starch-derived products, oil, and feed products. Corn grain/kernel results from farming economic activity. The supply of corn grain is elastic and corn farming economic activity changes with changes in market conditions. Using the proposed biofuel categorization and indirect effects guidelines, corn grain/kernel can be categorized as primary product within the farming economic activity. Price information indicates that corn grain has the largest contribution to revenue (80% of the total marketable value of the corn farming); thus, within the primary product category, corn grain can be classified as single product (corn stover can be categorized as a secondary product and due to its economic value as a by-product).

In the milling process, corn oil production is defined by the composition of corn kernel. Price information indicates that in the dry milling production, corn oil contributes 4.8% to the total marketable value of the milling process. This contribution is considered to be small for changes in corn oil market to drive any significant change in the corn milling and corn farming economic activities. Thus, corn oil supply is inelastic as the milling economic activity output is determined by farming production and raw material composition. Corn oil at this level of analysis can be categorized and classified as a secondary and by-product of the milling processes.

[84] http://www.ers.usda.gov/data-products/oil-crops-yearbook.aspx

Table 5-2. Corn and Ethanol Production Product Values and Categorization

Economic Activity	Product	Approximate revenue/contribution to market value	Feedstock Category
Corn Farming	Corn	$3.70/bushel	Singular Primary Product
	Corn Stover	$0.44/bushel	Secondary, By-product
Dry milling	Ethanol	$6.91 per bushel	Singular Primary Product
	Corn Oil	$0.58 per bushel	Secondary, By-product
	DDGS	1.22 per bushel	Secondary, By-product

In the life cycle analysis of the feedstock this categorization indicates that upstream energy use and emissions associated with corn farming economic activity are 100% allocated to corn grain/corn kernel material, and therefore, they are allocated to the primary products of the corn dry milling economic activity (i.e., 100% allocation to ethanol). Similarly, at the corn dry milling economic activity, energy used and emissions associated are allocated 100% to the milling primary products. As a result, there are no upstream or onsite energy use and/or emissions attributed to by-products such as corn oil except for emissions associated with pressing dry mill DGS to produce corn oil. At the overall supply chain, energy use and emissions associated with the use of corn oil as biodiesel feedstock are analyzed through a displacement analysis of removing the feedstock from existing economic purposes in the specific region of current /actual market.

Basis for indirect emission analysis (i.e., displacement analysis)

In the dry milling ethanol production, corn oil's existing economic purpose is as a contributing material to the energy content in distiller grains products. Distiller grains are widely used as feed for livestock. It is marketed as dried distillers' grains with solubles (DDGS), modified distillers grains with solubles (MDGS) or wet distillers' grains with solubles (WDGS). Condensed distillers solubles (CDS or corn syrup) also are marketed from some plants. The removing of corn oil from distillers result in a product of lower fat content known as reduced-oil DDGS. The displacement analysis of emissions should consider any effects that the variation in composition in the distiller grains may have in the current market it is used. For example, DGS are a source of energy and protein for beef cattle diets in all phases of production. It has 102% to 127% the energy value of dry-rolled corn, and it can be fed up to 40% of ration dry-matter intake for finishing cattle. One study shows that WDGS energy value is reduced by 1.3% for each 1% reduction in oil content. The study found that reduced-oil WDGS with a 6.7% crude fat content (as opposed to 12.9%) has an energy value equal to corn and is still an appropriate energy source for beef feedlot cattle, but that beef cattle fed reduced-oil as opposed to normal-fat WDGS had reduced final body weight[85]. This suggests that there may be a reduction in nutritional value to beef cattle of DGS due to corn oil extraction from DGS. In this case, the displacement effect of removing corn oil would be greater than the effect of simply reducing DGS mass output. A full assessment of the displacement impact of corn oil extraction for biodiesel would therefore require identifying both the feed that would compensate for reduced overall DGS production, and the response in the market to any marginal reduction in cattle productivity due to reduced energy content in DGS. The direct replacement to reduced overall DGS production is likely to be increased feed corn use. The response to reduced nutritive value of DGS in beef cattle could be a reduction in cattle productivity and hence marginal increase in head of cattle, and hence a further increase primarily in corn feed demand. It could also be an additional adjustment to feed rations to compensate for the lost energy value. In this latter case, a full displacement analysis would require an assessment of what the additional dietary supplement might be (e.g., additional feed corn or alternative fatty supplements such as vegetable oil).

While the predominant use of DDGS in the US is beef livestock feed, it is important to consider that other regions have other dominant uses for DDGS. DDGS can also be used in dairy cattle and poultry diets. Studies have shown that in dairy cattle diets, use of reduced-oil DDGS with a 3.5% crude fat content to replace soybean meal shows some positive effects with no negative effects on lactation performance of dairy cows[86]. It is, however, unclear from this study what the direct comparison is between the value of reduced-oil and normal fat DGS for dairy cattle feed. It has been reported that nutritionists are concerned that the high fat content in normal fat DGS could suppress the fat content of milk.[87] However, the same survey of nutritionists found that on average nutritionists felt that the price of reduced-oil DGS should be reduced by 24%, which is even greater than the reduction in energy content. This suggests that nutritionists feel that oil extraction could have a disproportionate impact on the feed value of DGS. A full displacement analysis would therefore need to determine whether the displacement impact in dairy cattle of corn oil extraction is proportional to the reduction in overall produced DGS mass, overall DGS energy content, or could fall outside that range either way. As for beef cattle, it would also be necessary to identify a reliable and cost-effective replacement feed, which could be corn feed, soy meal, vegetable oil as a feed supplement, or some combination.

Finally, typical DDGS in poultry diets provides 85% of the energy value of corn for poultry[88]. However, it has been estimated that corn oil extraction from DDGS could reduce metabolizable energy to poultry by 23%, despite only representing a total energy content reduction of 5.5%. This results suggest that for DGS fed in poultry rations, corn oil extraction may have a negative impact on feed value disproportionate to the reduction in both total DGS mass and total DGS energy output[89]. An emissions displacement analysis in this case would consider usual current use of DDGS as a poultry feed ingredient, determining the DDGS main use (i.e., determine an equivalent system unit of analysis as energy or as

[85] DDGS User Handbook. Third edition. http://www.grains.org/buyingselling/ddgs

[86] Ibid

[87] Ibid

[88] Ibid

[89] Ibid

protein supplement), and identifying the grain or/and other by-products of the edible oil refining industry that can also be a reliable and cost-effective feed ingredient.

The variation and complexity in these results across different animals and dietary assumptions emphasizes that great care must be taken when undertaking these displacement analyses.

Basis for direct emission analysis

Dry milling in the U.S. has focused on the production of ethanol and recovery of fermented material as distiller grains for feed animal purposes. Currently, most U.S. dry milling plants have added technology to the process to recover corn oil from the distiller grains, and obtain a higher marketable value from their production. Initially, the LCFS did not consider the extraction of corn oil as part of the corn ethanol dry mill pathway (corn oil is included in the wet milling ethanol pathway)[90]. Therefore, in the existing corn ethanol pathway, it is not clear if energy and emissions savings due to corn oil extraction are already accounted for[91]. For example, California Air Resources Board produced a memorandum of information in which it is recognized that default energy value for the DGS-drying system in the ethanol pathway can be considered a reasonable approximation; however, specific process conditions should be determined. Applicants should provide plant-specific operational information that will allow among identification of whether there has been a reduction in ethanol plant thermal energy use compared to the original pathway, and to determine if such a reduction may be due to reduced DGS dryer energy consumption[92]. In that case, the displacement analysis for corn oil should be extended and include an analysis of direct energy use/savings and emissions associated with dry milling distiller grains pressing/oil extraction that were not considered in the initial pathway, and award of an associated credit or deficit to the corn oil pathway. If the corn ethanol pathways were to be re-evaluated, the energy savings and emissions associated with dry milling distiller grains should be accounted for in the primary corn-ethanol production pathway (i.e., 100% allocation to ethanol and no emission credits applied to corn oil).

5.3 Case Study 3: Southeast Asia PFAD

General Description

PFAD (palm fatty acid distillate) is a product of physical refining of crude palm oil products. PFAD is comprised mainly of free fatty acids (range of 85-93% content), glycerides (added to the free fatty acids

[90] ARB (2009). Detailed Modified –California GREET Pathway for Corn Ethanol. February 27, 2009. http://www.arb.ca.gov/fuels/lcfs/workgroups/workgroups.htm#pathways

[91] "*Significant energy savings result from the installation of Corn Oil Extraction at ethanol plants in the DGS dry process. The main sources are: 1) Improved heat transfer efficiency in the evaporators as a result of removal of oil and its insulating characteristics; 2) Increased drying efficiency resulting from a lower mass flow through the dryers; 3) Improved flow characteristics of DGS after corn oil removal, which results in less drying time*". CARB, 2010. California modified GREET Pathway for the Production of Biodiesel from Corn Oil AT Dry Mill Ethanol Plants.

[92] http://www.arb.ca.gov/fuels/lcfs/2a2b/co-products-memo-010814.pdf

composing around 96% of PFAD content)[93], and other minor bioactive components such as squalene, vitamin E, and sterols. The product results from the need to reduce free fatty acids in palm oil products to acceptable low levels for human consumption. Free fatty acids can also be reduced through chemical alkali refining, in which case a different product is produced and is known as palm acid oil, with soapstock as a by-product.

PFAD Supply Chain and Economic Analysis

PFAD's supply chain as a biodiesel feedstock can be simplified by focusing on four major economic activities within the palm industry (i.e., plantation, milling, refining, and the end final use of the feedstock or feedstock's value-added processing) and the materials flow among those activities as illustrated in Figure 5-5:

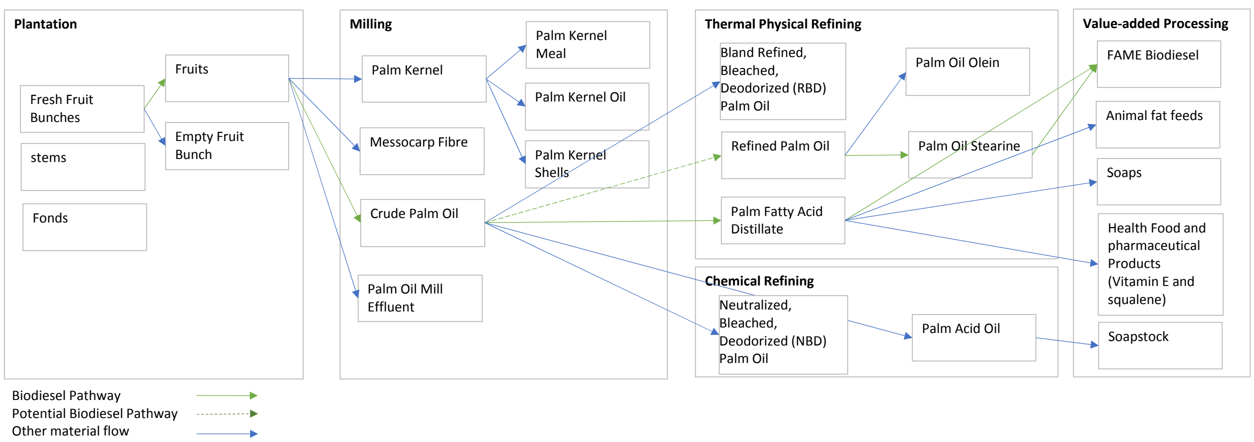

Figure 5-5. Representation of Palm Fatty Acid Distillate's Supply Chain as Biodiesel Feedstock in Terms of Major Palm Industry Economic Activities and Flow Materials

Palm plantations are developed for palm oil production. Within the plantation and milling economic activities, palm oil demand defines production. Demand for palm kernel and main products derived from the processing of palm fruits does not change the palm oil market direction. Other materials identified within the plantation and milling economic activities are used and disposed within the processes as residuals-wastes: palm stems and fronds are used as fertilizer and nutrition recycling in plantation; empty fruit bunch, messocarp fibre, kernel shells, and mill effluent are used as fertilizer or as an energy source. During 2010 to 2015, CIF Rotterdam (Malaysia) palm oil prices have consistently decreased, and ranged from $1,230 – $544/ton [94]. In 2015, Malaysian Palm Oil Board (MPOB) average local price for crude palm oil is estimated at $507/ton (i.e., 2,111 RM/ton). This price and price behavior are comparable with the price and price behavior for palm kernel and palm kernel derived products. During

[93] Estiasih et al. Bioactive Compounds of Palm Fatty Acid Distillate (PFAD) from Several Palm Oil Refineries. Advance Journal of Food Science and Technology. September 5, 2013.

[94] http://www.indexmundi.com/commodities/?commodity=palm-oil&months=60

2010 to 2015, CIF Rotterdam (Malaysia) palm kernel oil prices decreased as well and ranged from $2,240 – $875/ton[95]. In 2015, MPOB average prices for palm kernel and palm kernel oil are estimated at $398/ton and $828/ton (1,657 and 3,448 RM/ton) respectively. Using production yields of 76% crude palm oil, 8% palm kernel or 4% palm kernel oil, an approximated revenue can be estimated to be $413-935/ton fruit due to crude palm oil, $70-179/ ton of fruit due to palm kernel oil (used as approximated revenue from palm kernel that is expected to be slightly lower than its oil). This represents a ratio between 0.84 and 0.86 of the market value of crude palm oil to the total marketable value of the palm fruit.

Crude palm oil can be refined through different processes. Within the refining economic activity, refined palm oil demand defines production. Demand for PFDA (or palm acid oil in the case of chemical refining) does not change the refined palm oil market direction; in fact, PFDA is extracted to achieve Refined/Blanched/Deodorized palm oil (RBD) market specifications. MPOB average annual export prices for RBD and PFAD consistently increased between 2008 and 2011, and then decreased until 2015 to a lower price than the average price reported for 2008. The prices ranged from $FOB592– 1,117/ton for RBD and $FOB 501 to 814/ton for FDA [96]. During this time, PFAD increased its value compared to RBD. In 2008, average export price for PFAD represented 62% of price for RBD. By 2015, the price of PFAD increased up to 86% of the price for RBD. In 2015, MPOB average export price for refined palm oil is estimated at $FOB 591/ton. Similarly, 2015 MPOB average export price for PFAD is estimated at $FOB 506/ton.[97] Assuming a 4% free acid content in crude palm oil and full recovery as PFAD, an approximated revenue can be estimated to be $568/ton of crude palm oil due to RBD and $20/ ton of crude palm oil due to PFAD. This represents a 0.034 ratio of the market value of PFAD to the total marketable value of the crude palm oil.

Biofuel Feedstock Categorization and Indirect Effects

Palm plantation and milling economic activities are driven by the production of palm crude oil. Palm crude oil represents around 85% of the marketable value of palm fruit. As a result, crude palm oil supply is elastic, and market conditions defined it. Price information indicates comparable prices between crude palm oil and palm kernel. However, the contribution of palm kernel to marketable value of palm fruit is limited. The supply of palm kernel is defined by the raw material composition, and therefore it is inelastic to changes in the market. Using the proposed biofuel categorization and indirect effects guidelines, crude palm oil can be categorized as a primary product, palm kernel and/or derivate palm kernel products can be categorized as secondary products (secondary and by-products due to their economic value). Crude palm oil can be classified as a singular primary product from the palm plantation and milling economic activities.

Refining economic activities are driven by the production of refined palm oil. Refined palm oil represents around 97% of the marketable value of the crude palm oil. The contribution of PFAD to marketable

[95] http://www.indexmundi.com/commodities/?commodity=palm-kernel-oil&months=60

[96] http://www.indexmundi.com/commodities/?commodity=palm-oil&months=60

[97] http://bepi.mpob.gov.my/index.php/statistics/price/monthly.html

value of crude palm oil is limited (3%) due to raw material composition. PFAD supply is inelastic to changes in the market. Using the proposed biofuel categorization and indirect effects guidelines, PFAD can be categorized as a secondary product and as a by-product within the refining economic activity.

Table 5-3. Palm Production and Refining Product Values and Categorization

Economic Activity	Product	Approximate revenue/contribution to market value	Feedstock Category
Palm Plantation and Milling	Crude palm oil	935/ton fruit	Singular Primary Product
	Palm kernel oil	$179/ ton of fruit	Secondary, By-product
Refining	Refined/Blanched/Deodorized palm oil (RBD)	$568/ton of crude palm oil	Singular Primary Product
	Palm Fatty Acid Distillate (PFAD)	$20/ ton of crude palm	Secondary, By-product

In the life cycle analysis of the feedstock this categorization indicates that upstream energy use and emissions associated with plantation and milling economic activities are 100% allocated to crude palm oil material and therefore these energy use and emissions are allocated to primary products of the refining economic activity (i.e., 100% allocation to refined palm oil, or its derived products). There are not upstream or onsite energy use or emissions attributed to by-products such as PFAD. The energy use and emissions associated with the use of PFAD as a biodiesel feedstock are include a displacement analysis.

PFAD has been used in the soap-making industry, as an animal feed ingredient, and as raw material for the oleochemical industry. "It is used to produce food emulsifiers, foam stabilizers, water repellant, and to extract vitamin E. It is used to produce Calcium Soap for animal feed as a source of calcium and fat. It is also used to produce fatty alcohol and fatty acid esters used in cosmetic industries. Moreover, Fatty acid distillates are generally used to manufacture laundry and toilet grade soap noodles depending on oils blend and ratios in the soap industry"[98]. At the world market, the "Asia-Pacific region is the largest market in terms of consumption followed by Europe. The region has potential for this product due to increasing demand from the end-use industries such as detergents, surfactants, personal care and food additives and others. In addition, growth in end-user industries is anticipated to surge the consumption

[98] http://www.chemtradeasia.com/index.php?r=TblProduct/view&id=911

of PFAD"[99]. Presently, several facilities use emerging technologies focused on obtaining products of high value such as vitamin E to be used within the cosmetic, pharmacy, and healthy food industries.

As an animal feed ingredient, PFAD is known as the "cheapest most reliable source of feed fat and is a source of essential fatty acid as it contains about 10% of linoleic acid (18:2)"[100]. In particular, PFAD is recognized within the market of bypass or "protected" fats"[101] directed to dairy cow feed: "The most widely used and effective method for producing a rumen bypass fat is to react vegetable fatty acids with calcium oxide to form insoluble calcium soaps (Enertia®, ADM; Megalac®*, Church and Dwight Co., Inc.). Within the feed industry, these calcium soaps, or salts, appear on feed labels as "calcium salts of long chain fatty acids." Fatty acids distilled from palm oil processing are most commonly used to make calcium salts, because these fatty acids are produced in the greatest quantity worldwide. By far, calcium salts of palm fatty acids (PFA) are the highest quality and best understood bypass fat for dairy cattle"[102].

In the oleochemical industry, there is little public available information about the use of PFAD compared to the information available for its use as animal feed ingredient. Because there are several uses of PFAD within the oleochemical industry, and most of them are in emerging markets, the displacement analysis could focus on use of PFAD for animal feed. The "Asia-Pacific animal feed additives market is the largest in the world comprising of almost one third of the global animal feed additive market. Improving nutrient availability, digestibility and growth rate of animals throughout Asia-Pacific and particularly in countries such as India, China, Vietnam and Australia have been some of the factors that have promoted to the growth of feed additives in the region. Additionally, consumption of feed additives has also been observed to play an important role in reducing environmental pollution associated with the livestock industry"[103]. However, producers can provide additional specific information that allows to determine the actual market to be displaced.

In the global animal feed additive market, PFAD used as biofuel feedstock can be replaced by specific calcium soaps/salts or "protected" fats available in the specific market. Different fat sources including products derived from vegetable oils are available. The forage program (agriculture practices that impact the forage quality), supplemental nutrients, cost, and other factors (e.g., PFAD calcium soap increases milk yield but decreases protein) will define the product to be used. Considering only PFAD volume and price data, soybean oil derived products can be considered a plausible alternative within the "protected fats" market. "Several commercial fat preparations are available and most of them are

[99] http://www.frontresearch.com/reports/oleochemicals/palm-fatty-acid-distillate-pfad-global-market-and-forecast-research/

[100] Ab Gapor Md Top (2010). Production and utilization of palm fatty acid distillate (PFAD). Lipid Technology. January 2010, Vol.22, No.1.

[101] Rumen bypass or "protected" fats are essentially dry fats that are processed to be easily handled and mixed into all animal feeds.

[102] http://www.admani.com/Dairy/Technical%20Bulletins/Dairy%20Rumen%20Bypass%20Fats.htm

[103] http://www.prnewswire.com/news-releases/asia-pacific-animal-feed-additives-market-outlook-to-2018---increasing-demand-for-meat-products-to-steer-growth-300002075.html

marketed as rumen inert sources. These fats fall into two general categories: calcium salts and processed tallow (either hydrolyzed tallow FA or PHT). The calcium salts are made from palm oil (higher in C16:0), soybean oil (higher in C18:2), or blend of fat sources"[104]. "The method that produces the least desirable product for the cow, partial hydrogenation of tallow, is seldom used for dairy rations"[105]. However, as calcium salts of soy are produced from soy fatty acids, a by-product of soy oil refining, the supply of soy-based alternatives to calcium salts of PFADs is likely to be inelastic. It is possible that the net displacement impact of reducing PFAD availability in the market would therefore be reduced supply of primary vegetable oils with more elastic supply, such as palm, soy or canola. The displaced oils could vary by region. Identifying the appropriate elastic substitute to PFAD as animal feed supplement would therefore require additional analysis of the market for fats as livestock feed.

5.4 Case Study 4: U.S. Used Cooking Oil

General Description

Used cooking oils are oils and fats that result from cooking and frying processes in the food processing industry, restaurants, snack shops, and households. Used cooking oil can originate from both vegetable and animal fats and oils and its composition varies widely. Used cooking oils differentiate from waste oils in that they include some level of animal fat naturally derived from the cooking process. Waste oil is generally used to refer to used cooking oils that are primary vegetable oil based and have a minimum or no animal fats from the cooking process.[106]

Used Cooking Oil Supply Chain and Economic Analysis

Used cooking oil's supply chain as biodiesel feedstock analysis can be simplified by focusing on three major economic activities within the food industry (i.e., Vegetable oils and fat supply, Food processing, and the end final use of the feedstock or feedstock's Value-added Processing) and the materials flow among those activities as illustrated in Figure 5-6.

[104] http://dairy.osu.edu/resource/feed/Feeding%20Fat.pdf

[105] http://www.admani.com/Dairy/Technical%20Bulletins/Dairy%20Rumen%20Bypass%20Fats.htm

[106] http://pacaltenergy.com/uco.html

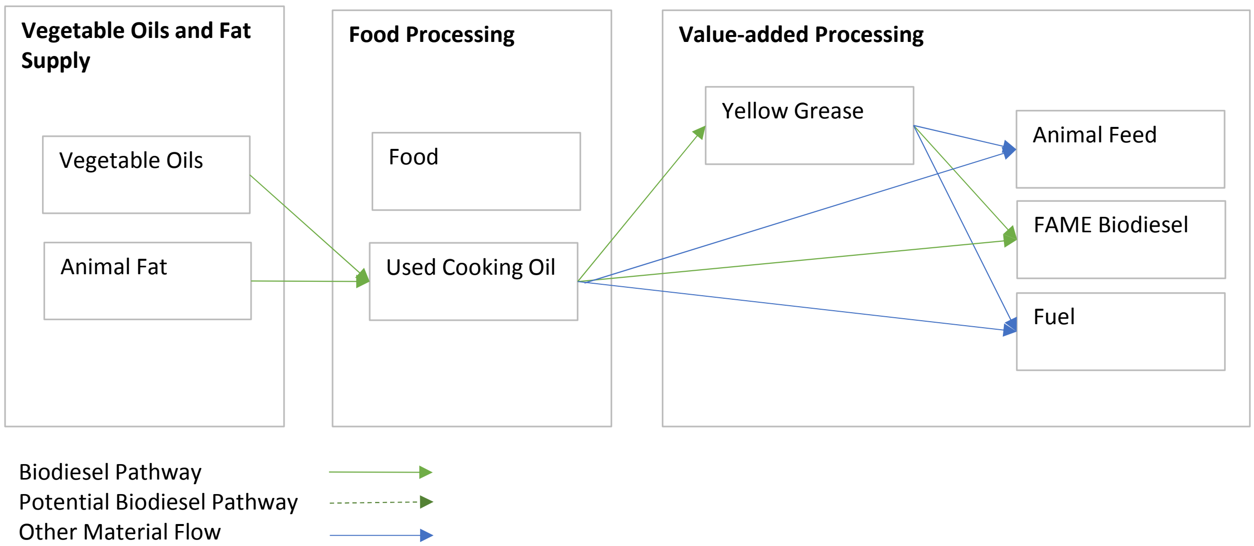

Figure 5-6. Representation of Used Cooking Oil's Supply Chain as Biodiesel Feedstock in Terms of Major Food Industry Economic Activities and Flow Materials

Fats, oils, grease are one of several ingredients used in the food processing industry. U.S. EPA establishes that used fats, oil, and grease materials should not be sent to landfills or disposed in the sanitary sewer system to avoid issues in the performance of public sewer lines and water treatment facilities. The material should be sent to the rendering industry, converted to biofuel, or sent to an anaerobic digester:

- The rendering process transform the used cooking oils into yellow grease, a commodity produced in the rendering industry that typically contain rendered low quality animal fats such as tallow, poultry, or lard. As a fully processed and rendered product, yellow grease is an appropriate animal feed and ingredient (as opposed to the direct use of used cooking oil).
- Used cooking oil can be converted into biodiesel
- Used cooking oil can be sent to anaerobic digesters at wastewater treatment plants to generate renewable energy in the form of biogas[107].

Generally, used cooking oil and yellow grease (used cooking oil added value product) are the lowest priced fats, oils, grease when compared to fresh oils and animal fats (see for example Figure 5-7). In the US some restaurants are required to collect the grease in traps and pay to have it hauled off by a renderer. Nonetheless, the Cooking Oil Recycling industry has grown very strongly over the past five years. While historically viewed as a waste product, used cooking oil has become a valuable commodity over the past decade. The industry is expected to continue to grow strongly over the five years to 2019 as the EPA's Renewable Fuel Standard requirements persist to encourage strong biodiesel production growth, which will increase the demand for used cooking oil"[108]. Used cooking oil has been priced based on crude oil prices (i.e., the price of a barrel of crude oil divided by 133 equals a gallon of clean used

[107] http://www2.epa.gov/sustainable-management-food/industrial-uses-wasted-food#fog
[108] http://www.ibisworld.com/industry/cooking-oil-recycling.html

vegetable oil. For example, at $100 a barrel of crude oil, used cooking oil has been priced at 75 cents a gallon). A floor price has been offered of 25 cents per gallon of used cooking oil at a crude oil price below $33 a barrel, and a ceiling price of $1.00 per gallon of used cooking oil at crude oil price up to or over $133 a barrel[109]. Meanwhile, yellow grease has been priced as twice the price of used cooking oil raw material (e.g., in 2012, the used oil was sold for 15 cents per pound, vs. 5 cents per pound in 2005. Once the product is converted to yellow grease — the commodity version of cooking oil — it was sold for 30 to 40 cents per pound, vs. 25 cents per pound in 2010, according to USDA figures[110]).

	2009	2010	2012	2013	2014
Palm oil, refined, CIF bulk, U.S. ports	33.88	43.93	55.98	41.13	39.86
Soybean oil, crude, tank cars, FOB Decatur	33.01	39.00	54.05	44.98	36.83
Yellow grease, rail, Minneapolis	21.86	28.05	44.16	35.47	30.48

Figure 5-7. Comparison of average monthly wholesale prices for Palm Oil, Soybean Oil and Yellow Grease 2009-2014[111]

Biofuel Feedstock Categorization and Indirect Effects

Food processing focuses on the transformation of raw ingredients, by physical or chemical means into food, or of food into other forms of marketable food products that can be easily prepared and served by the consumer. As an ingredient, use of cooking oils is elastic to food demand; however, the supply of used cooking oil is inelastic to biodiesel market changes. Using the proposed biofuel categorization and indirect effects guidelines, used cooking oil can be categorized as a secondary product. The contribution of used cooking oils or yellow greases to the marketable value of food processing is specific to the food market and product. However, the development of a commodity, the growth of the Cooking Oil Recycling industry, and guidelines from EPA to send used fats, oils, grease to the rendering industry indicates the material has economic value resulting in used cooking oil being classified as a by-product.

[109] http://smartfuelamerica.com/Services_files/paymentandquestions.pdf

[110] http://usatoday30.usatoday.com/money/industries/energy/story/2012-03-10/cnbc-rising-gasoline-prices-cooking-oil/53421936/1

[111] Source: United States Department of Agriculture : http://search.ers.usda.gov/search?utf8=%E2%9C%93&sc=0&query=yellow+grease&m=&affiliate=ers&commit=Search

In the life cycle analysis of the feedstock this categorization indicates that the upstream energy use and emissions associated with vegetable oils and fat supply and food processing activities are 100% allocated to food production. Therefore, there is no energy use and/or emissions to be allocated to used cooking oil. At the overall supply chain, energy use and emissions associated with the use of used cooking oil as biodiesel feedstock are analyzed through displacement analysis.

There are many uses for used cooking oil with 2 primary markets: 1) as biofuel feedstock and 2) the traditional use as blending material into animal feed for cattle and poultry through further processing to yellow grease (only in-spec yellow grease with FFA 15% or below and MIU <2% is accepted in feed markets). Vegetable oil would likely replace yellow grease from used cooking oil in the animal feed market. It is difficult to foresee what vegetable oil may be used instead of yellow grease in the animal feed market due to the nature of the product (i.e., used cooking oil and yellow grease results from the blend of several oil and fat sources, and quality varies widely). However, U.S. domestic disappearance of edible fats and oils data can be used as an indicator. Since 2011, the domestic disappearance of edible fats and oils has been dominated by soybean oil (65% and 51% total disappearance in 2001 and 2014 respectively); corn and canola oils have gained share and represented 10% and 14% of total disappearance in 2014[112].

[112] Table 31. http://www.ers.usda.gov/data-products/oil-crops-yearbook.aspx