Feedstock and Biodiesel Characteristics Report

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1 Executive Summary

The goals of this project were to produce biodiesel from a wide variety of feedstocks and to provide the characteristics of both the feedstock and biodiesel. The project is unique because it encompasses an extensive range of feedstocks and all feedstocks were pretreated, esterified, and transesterified using the same procedures and conditions allowing for uniform comparisons of critical fuel properties.

In this report, 36 feedstocks were evaluated and biodiesel was produced from 34 of them. These feedstocks varied from traditional fats and oils to novel feedstocks from around the world. The feedstocks used in the study were: algae (2 samples), babassu, beef tallow, borage, camelina, canola, castor, choice white grease, coconut, coffee, distiller's corn, *Cuphea viscosissima*, evening primrose, fish, hemp, high IV and low IV hepar, jatropha, jojoba, karanja, *Lesquerella fendleri*, linseed, *Moringa oleifera*, mustard, neem, palm, perilla seed, poultry fat, rice bran, soybean, stillingia, sunflower, tung, used cooking oil, and yellow grease. Jojoba and karanja were tested for feedstock quality but not made into biodiesel.

Each feedstock was tested for the following characteristics: moisture, free fatty acid, kinematic viscosity, FAC color, saponification value, moisture and volatile matter, insoluble impurities, unsaponifiable matter, MIU, oxidation stability, sulfur, phosphorous, calcium, and magnesium. If a feedstock exceeded 10 ppm phosphorous, 5 ppm calcium and magnesium, it was pretreated using the phosphoric acid procedure and dried. Feedstocks having free fatty acid in excess of 0.5 wt % were esterified using Amberlyst BD 20. The feedstocks were transesterified using identical reaction conditions and production protocols. Each biodiesel was characterized according to the American Society for Testing and Materials (ASTM) D6751 and other properties. These characteristics were: cloud point, cold filter plugging point, cold soak filtration, fatty acid profile, relative density, kinematic viscosity, sulfated ash, carbon residue, water and sediment, visual inspection, free and total glycerin, flash point, copper corrosion, phosphorous, calcium, magnesium, total acid number, moisture, sulfur, oxidation stability, and FTIR.

Acknowledgements

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2 Disclaimer

This report contains guidelines, procedures and protocols for performing experiments and testing that includes biodiesel, fats, oils, and chemicals. The authors in no way imply that these procedures are described in complete detail or are safe to reproduce. When performing chemical testing or analyzing products, there is no substitute for good judgment and thorough background research on hazards and toxicities.

A list of possible hazards and hazardous environments when synthesizing and testing products described in the report include, but are not limited to: mechanical failure, high pressures, high temperature, high voltage, chemical toxicity, chemical reactivity, chemical explosion, acid burns, and toxic vapors.

The authors assume no responsibility for any incident that occurs when reproducing procedures similar to or the same as described in this report.

3 Feedstock Sources

Sources of feedstocks are described in this chapter. For supplier contact information, see Chapter 9.

Algae Oil

Two diverse samples of crude algal oil were obtained from Solazyme, Inc.

Babassu Oil

Babassu oil was purchased from Jedwards International, Inc. Babassu oil is extracted from the seeds of the babassu palm tree, *Attalea speciosa*. The tree is common in Brazil, Mexico, and Honduras; it grows well in areas typically cultivated for coconut or palm. The kernels contain 60-70% oil.[1]

Beef Tallow

Crude beef tallow was obtained from a commercially available source. Animal tissue is converted to tallow using rendering; a process by which lipid material is separated from meat tissue and water under heat and pressure.[2]

Borage Oil

Borage oil, gamma linolenic acid (GLA) content of 20%, was purchased from Jedwards International, Inc. Borage oil comes from the plant, *Borago officinalis*, also known as starflower. It has the highest value of γ-linolenic acid in any readily available specialty oil.[3]

Camelina Oil

Camelina oil comes from the plant, *Camelina sativa*. It is an annual flowering plant that grows well in temperate climates and is also known as gold-of-pleasure and false flax. Some varieties of camelina contain 38-40 % oil. Camelina can be grown in arid conditions and does not require significant amounts of fertilizer.[4]

Canola Oil

Crude degummed canola oil was obtained from a commercially available source. Canola is the seed of the species *Brassica napus* or *Brassica campestris*; the oil component contains less than two percent erucic acid and the solid component contains less than 30 micromoles per gram of glucosinolates.[5]

Castor Oil

Castor was United States Pharmacopeia (USP) grade, from Jedwards International, Inc. Castor oil comes from the castor bean *Ricinus communis*. Castor is grown in tropical and subtropical regions and prefers a dry climate. The seeds contain about 45-50% oil. Triglycerides of ricinoleic acid constitute 84-90%.[1]

Choice White Grease

Crude choice white grease (CWG) was obtained from a commercially available source. Choice white grease is a specific grade of mostly pork fat defined by hardness, color, fatty acid content, moisture, insolubles, unsaponifiables and free fatty acids.[6]

Coconut Oil

Refined, bleached, deodorized (RBD) coconut oil was purchased from Jedwards International, Inc.

Coffee Oil

Refined coffee oil was purchased from Oils by Nature, Inc. Coffee oil comes from spent coffee grounds; the grounds can contain as much as 11 to 20 percent oil. Currently coffee grounds are disposed of or used as compost. After oil extraction, the grounds could still be used as compost and the oil could be used to make biodiesel.[7]

Corn Oil, Distiller's

Crude, dry distiller's grain (DDG) extracted corn oil was obtained from a commercially available source. The extracted corn oil comes from the DDG stream of the ethanol production process.

Cuphea viscosissima Oil

RBD *Cuphea* oil was donated by the National Center for Agricultural Utilization Research. *Cuphea viscosissima* is also known as blue waxweed, an annual crop. The seeds contain 25-43% oil.[1]

Evening Primrose Oil

Evening primrose oil, GLA 9%, was purchased from Jedwards International, Inc. Evening primrose is a wildflower native to North America.

Fish Oil

Fish oil was obtained from a commercially available source in Peru.

Hemp Oil

Hemp seed oil was purchased from Jedwards International, Inc. The oil is derived from the plant *Cannabis sativa* and contains significant amounts of α-linolenic acid and γ-linolenic acid.[8] Hemp is legally grown in Canada as a niche crop and is used mainly in the health food market. Hemp seeds have an oil content of 33 percent.[9]

Hepar, High Iodine Value and Low Iodine Value (IV)

Crude, high IV hepar and crude, low IV hepar were obtained from a commercially available source. Hepar is a byproduct of the heparin manufacturing process. Pharmaceutical grade heparin is derived from the mucosal tissues of animals, such as pig intestines or cow lungs.[10]

Jatropha Oil

Crude jatropha oil was obtained from a commercially available source. Jatropha oil comes from the shrub *Jatropha curcas,* also known as physic nut. The plant is native to Mexico, Central America, Brazil, Bolivia, Peru, Argentina, and Paraguay.[11]

Jojoba Oil

Golden jojoba oil was purchased from Jedwards International, Inc. Jojoba (*Simmondsia chinensis)* is an evergreen perennial shrub grown in Arizona, Mexico, and neighboring areas. The dehulled seeds of jojoba contain 44% of liquid wax, which is not a triglyceride.[1]

Karanja Oil

Pure, cold pressed karanja oil was purchased from The Ahimsa Alternative, Inc. Karanja (*Pongamia pinnata)* is a medium sized evergreen tree that grows in India. The seed contains 27-39% oil. The oil is reddish brown and rich in unsaponifiable matter and oleic acid.[1]

Lesquerella fendleri Oil

RBD *Lesquerella* oil was purchased from Technology Crops International. *Lesquerella fendleri* is also known as Fendler's bladderpod. *Lesquerella* seeds contain 20-28% oil with around 62% lesquerolic acid. *Lesquerella* oil is a source of hydroxy unsaturated fatty acids, and can be used similarly to castor oil.[1]

Linseed Oil

Crude linseed oil was purchased from Botanic Oil Innovations, Inc. Linseed has been traditionally used as a drying oil. It grows in Argentina, India, and Canada. It is an annual herb and contains 37-42% oil. The crude oil contains 0.25% phosphatides, a small amount of crystalline wax, and a water-soluble resinous matter with antioxidant properties.[1]

Moringa oleifera Oil

Crude *Moringa* oil was obtained from a commercially available source. *Moringa oleifera* is a tree that ranges in height from 5 to 10 meters, and is native to India, Africa, Arabia, Southeast Asia, the Pacific and Caribbean islands, South America, and the Philippines. *Moringa* seeds contain between 33 and 41 % oil. It is also known as ben oil, due to its content of behenic (docosanoic) acid.[12]

Mustard Oil

Refined mustard oil was obtained from a commercially available source.

Neem Oil

Pure, cold pressed neem oil was purchased from The Ahimsa Alternative, Inc. Neem (*Azadirachta indica*) is a large evergreen tree, 12 to 18 m tall, found in India, Pakistan, Sri Lanka, Burma, Malaya, Indonesia, Japan, and the tropical regions of Australia. The kernels contain 40-50% of an acrid green to brown colored oil.[1]

Palm Oil

Palm oil was obtained from a commercially available source.

Perilla Seed Oil

Perilla seed oil was purchased from Jedwards International, Inc. Perilla oil comes from the plant *Perilla Ocymoides*, the seeds of which contain 35-45 percent oil. Perilla oil has been cultivated in China, Korea, Japan, and India.[13]

Poultry Fat

Crude poultry fat was obtained from a commercially available source.

Rice Bran Oil

Refined, bleached, deodorized, winterized (RBDW) rice bran oil was purchased from Jedwards International, Inc. Rice bran oil is a non-edible vegetable oil which is greatly available in rice cultivating countries. Rice bran is a co-product of rice milling, containing about 15-23% oil.[14]

Soybean Oil

Refined soybean oil was obtained from a commercially available source.

Stillingia Oil

Stillingia oil was donated by SPESS, LSU AgCenter. Stillingia oil comes from the Chinese tallow tree (*Triadica sebifera*). The tree has been used to prevent soil erosion. The tree can be grown on marginal land, and is native to eastern Asia. The seeds contain 45-60 percent oil.[15]

Sunflower Oil

Sunflower oil was purchased from Jedwards, International, Inc.

Tung Oil

Tung oil was purchased from Sigma-Aldrich Co.

Used Cooking Oil

Crude used cooking oil was obtained from a commercially available source.

Yellow Grease

Crude yellow grease was purchased from Wildlife Sciences. Yellow grease is made up of restaurant greases, which are fats and oils left over from cooking. It can also be from rendering plants producing different quality greases.[2]

4 Feedstock Testing

4.1 Moisture

Moisture is a minor component found in all feedstocks tested. Moisture can react with the catalyst during transesterification which can lead to soap formation and emulsions. [16,17] For this study, if the feedstock moisture was above 0.050 wt %, the feedstock was dried using heat and vacuum to reduce the moisture before further conversion to minimize effects from emulsions during transesterification.

Materials and Methods

The feedstock moisture was measured in accordance with ASTM E203, Standard Test Method for Water Using Volumetric Karl Fischer Titration.[17] The moisture was measured on a volumetric Titrando manufactured by Metrohm, Inc.

Results and Discussion

Table 4.1-1

Feedstock	Moisture (wt %)	Feedstock	Moisture (wt %)
Algae 1	0.021	Jatropha	0.073
Algae 2	0.014	Jojoba	0.026
Babassu	0.057	Karanja	0.118
Beef Tallow	0.051	*Lesquerella fendleri*	0.030
Borage	0.023	Linseed	0.099
Camelina	0.051	*Moringa oleifera*	0.065
Canola	0.085	Mustard	0.039
Castor	0.179	Neem	0.098
Choice White Grease	0.218	Palm	0.049
Coconut	0.027	Perilla Seed	0.025
Coffee	0.033	Poultry Fat	0.065
Corn, Distiller's	0.153	Rice Bran	0.021
Cuphea viscosissima	0.091	Soybean	0.029
Evening Primrose	0.019	Stillingia	0.052
Fish	0.106	Sunflower	0.020
Hemp	0.017	Tung	0.093
Hepar, High IV	0.497	Used Cooking Oil	0.242
Hepar, Low IV	0.146	Yellow Grease	0.485

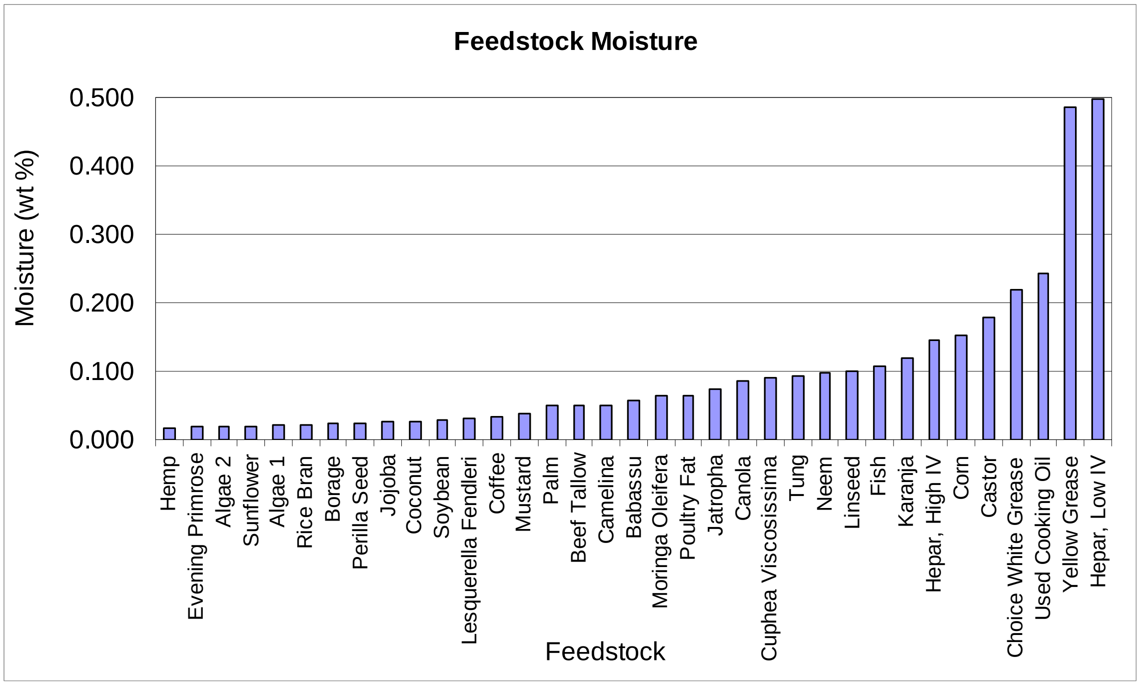


Fig. 4.1-1

For the feedstocks with a moisture content of above 0.05 wt %, the application of heat and vacuum successfully lowered the moisture content.

4.2 Free Fatty Acid (FFA)

The interaction of FFA in the feedstock and sodium methoxide catalyst may form emulsions which make separation of the biodiesel more difficult; possibly leading to yield loss. Emulsions can also increase cost by introducing extra cleaning steps and replacement of filters. To minimize the generation of soaps during the reaction, the target reduction for FFA in the feedstock was 0.5 wt % or less.[16]

Materials and Methods

The FFA determination was performed following two methods. ASTM D664, Standard Test Method for Acid Number of Petroleum Products by Potentiometric Titration, Method A, was first used to determine TAN in the samples, after this, the FFA values were calculated using the mathematical formulas found in the American Oil Chemists' Society (AOCS) Method Ca 5a-40.[18,19]

An 836 Titrando (Metrohm, Inc.) instrument and a Dosino dispensing unit were used. Titration solvent, 0.1 N KOH in isopropanol was purchased from Fisher Scientific Inc.

Results and Discussion

Table 4.2-1

Feedstock	FFA (wt %)	Feedstock	FFA (wt %)
Algae 1	0.45	Jatropha	1.17
Algae 2	1.75	Jojoba	0.20
Babassu*	0.04	Karanja	8.27
Beef Tallow	1.61	*Lesquerella fendleri*	0.16
Borage	0.11	Linseed	0.66
Camelina	0.49	*Moringa oleifera*	0.21
Canola	0.34	Mustard	0.30
Castor	0.54	Neem	2.14
Choice White Grease	0.61	Palm**	0.54
Coconut*	0.07	Perilla Seed	0.43
Coffee	0.29	Poultry Fat	1.70
Corn, Distiller's	12.22	Rice Bran	0.05
Cuphea viscosissima	Not enough sample	Soybean	0.07
Evening Primrose	0.36	Stillingia	5.30
Fish	1.37	Sunflower	0.04
Hemp	0.31	Tung	2.02
Hepar, High IV	3.63	Used Cooking Oil	2.72
Hepar, Low IV	1.27	Yellow Grease	7.38

*FFA is reported as lauric acid for coconut oil and babassu oil
**FFA is reported as palmitic acid for palm oil.

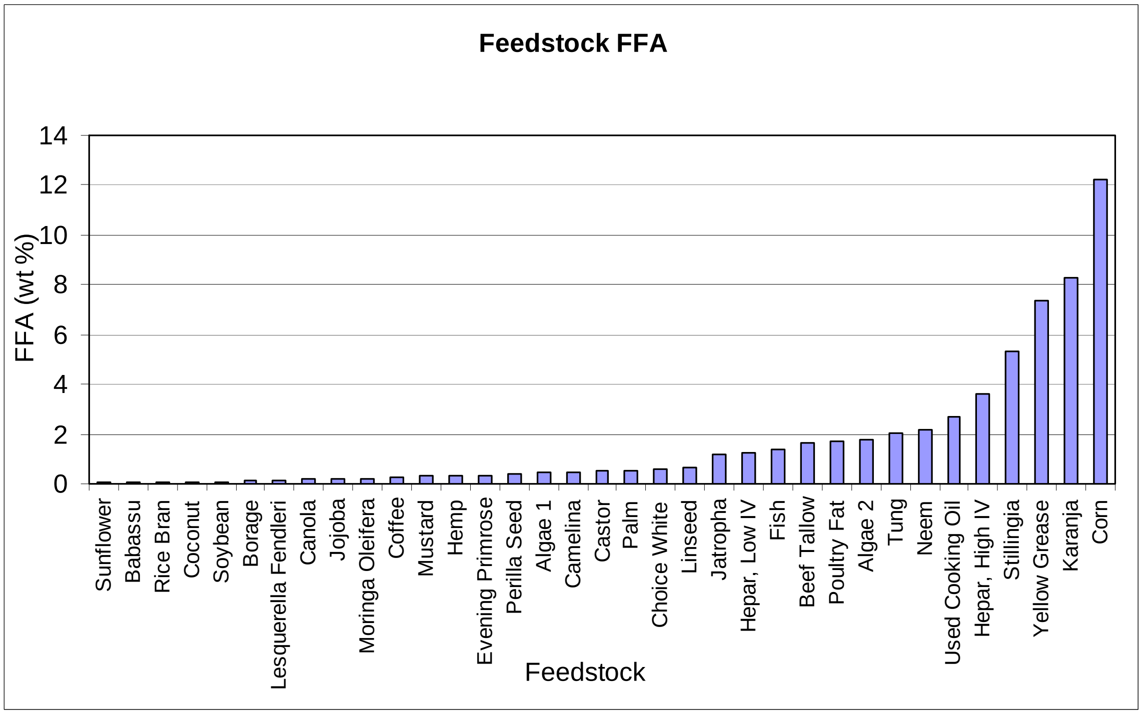


Fig. 4.2-1

From Fig. 4.2-1, it can be seen that many feedstocks as received had FFA values that were above 0.5 wt %. These feedstocks were esterified by a method described in Chapter 6 of this report; using methanol and a special catalyst prior the transesterification step. Except for karanja oil, the FFA content was successfully lowered to below 0.5 wt %.

4.3 Kinematic Viscosity

Viscosity is defined as the resistance to shear or flow; it is highly dependent on temperature and it describes the behavior of a liquid in motion near a solid boundary like the walls of a pipe. The presence of strong or weak interactions at the molecular level can greatly affect the way the molecules of an oil or fat slide pass each other, therefore, affecting their resistance to flow.

The kinematic viscosity test calls for a glass capillary viscometer with a calibration constant (c) given in mm^2/s^2. The kinematic viscosity determination requires the measurement of the time (t) the fluid takes to go from point A to point B inside the viscometer. The kinematic viscosity (ν) is calculated by means of the following equation[20]: $\nu = c \cdot t$

Materials and Methods

ASTM D445, Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity) was used. The units of kinematic viscosity are centistokes (cSt) or mm^2/s.[20] A K23700 kinematic viscosity bath manufactured by Koehler Instrument Company, Inc. was utilized.

Results and Discussion

Table 4.3-1

Feedstock	**Kinematic Viscosity (mm^2/s at 40°C)**	**Feedstock**	**Kinematic Viscosity (mm^2/s at 40°C)**
Algae 1	10.99	Jatropha	33.90
Algae 2	35.41	Jojoba	24.85
Babassu	28.45	Karanja	43.61
Beef Tallow	45.34	*Lesquerella fendleri*	126.80
Borage	29.92	Linseed	25.75
Camelina	30.90	*Moringa oleifera*	43.20
Canola	34.72	Mustard	Not enough sample
Castor	251.20	Neem	50.30
Choice White Grease	40.96	Palm	44.79
Coconut	27.26	Perilla Seed	24.11
Coffee	40.97	Poultry Fat	36.63
Corn, Distiller's	30.75	Rice Bran	36.68
Cuphea viscosissima	Not enough sample	Soybean	28.87
Evening Primrose	29.44	Stillingia	Not enough sample
Fish	24.31	Sunflower	35.84
Hemp	27.60	Tung	110.00
Hepar, High IV	38.62	Used Cooking Oil	27.00
Hepar, Low IV	40.60	Yellow Grease	132.10

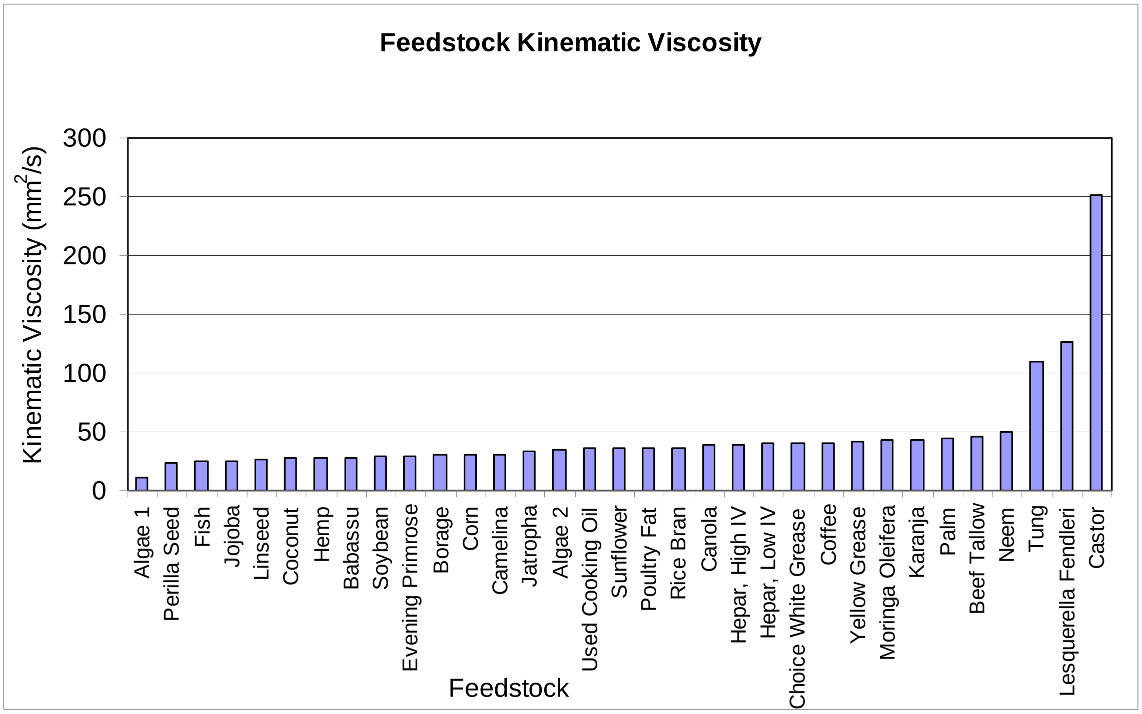


Fig. 4.3-1

Castor and *Lesquerella* oil presented the highest kinematic viscosities among the feedstocks studied. One possible reason for this observation is these two oils contain high concentrations of hydroxy containing fatty acids (ricinoleic and lesquerolic acid) that are capable of forming hydrogen bonding.[21] Investigation into causation was not conducted.

Tung oil contains high concentrations of α-eleostearic acid,[21] an acid with naturally occurring conjugated double bonds that can interact with the double bond of adjacent fatty chains via Van der Waals interactions of the pi cloud. This phenomenon however, is not as strong as hydrogen bonding. It is hypothesized that this difference in bonding results in tung oil having considerably lower viscosity than castor and *Lesquerella*.

4.4 FAC Color

The Fat Analysis Committee (FAC) color method determines the color of oils and fats by comparing them with color standards.

Materials and Methods

This test uses AOCS Method Cc 13a-43, Color, FAC Standard Color.[22] A Lovibond AF229 FAC Color Comparator was used to measure the FAC color of the feedstocks. It was purchased from Wilkens-Anderson Company of Chicago, Illinois.

Results and Discussion

Table 4.4 -1

Feedstock	FAC Color	Feedstock	FAC Color
Algae 1	3	Jatropha	19
Algae 2	13	Jojoba	21
Babassu	<13	Karanja	0
Beef Tallow	11A	*Lesquerella fendleri*	13
Borage	13	Linseed	23
Camelina	23	*Moringa oleifera*	21
Canola	1	Mustard	Not enough sample
Castor	<13	Neem	11A
Choice White Grease	<13	Palm	13
Coconut	13	Perilla Seed	13
Coffee	15	Poultry Fat	11B
Corn, Distiller's	33	Rice Bran	13
Cuphea viscosissima	Not enough sample	Soybean	0
Evening Primrose	15	Stillingia	Not enough sample
Fish	5	Sunflower	<13
Hemp	<13	Tung	0
Hepar, High IV	17	Used Cooking Oil	11B
Hepar, Low IV	<13	Yellow Grease	11B

The FAC standard color set is shown in Table 4.4-2. The lightest color on the wheel is a 13, but most of the oils and fats that received a 13 or <13 as a result would not be considered a dark fat.

Table 4.4 -2, FAC standard color set

Light colored fats	Predominantly yellow fats	Dark fats (red cast)	Very dark fats (predominantly green)	Very dark fats (predominantly red)
1	11	13	21	31
3	11A	15	23	33
5	11B	17	25	35
7	11C	19	27	37
9	-	-	29	39
-	-	-	-	41
-	-	-	-	43
-	-	-	-	45

4.5 Saponification Value

The saponification value is defined as the amount of potassium hydroxide (KOH) in milligrams required to saponify one gram of fat or oil under the conditions specified.[23] Based on the length of the fatty acids present in the triacylglycerol molecule, the weight of the triacylglycerol molecule changes which in turn affects the amount of KOH required to saponify the molecule. Hence, saponification value is a measure of the average molecular weight or the chain length of the fatty acids present. As most of the mass of a triglyceride is in the three fatty acids, it allows for comparison of the average fatty acid chain length.

Materials and Methods

AOCS Method Cd 3-25 was used to determine the saponification value of the feedstocks.[23] The method includes refluxing the known amount of fat or oil with a fixed but excess amount of alcoholic KOH. The amount of KOH remaining after hydrolysis was determined by back titrating with standardized 0.5 N HCl and the amount of KOH consumed during saponification was calculated. Hydrochloric acid solution, potassium hydroxide, and phenolphthalein were purchased from Fisher Scientific Inc.

Results and Discussion

Table 4.5 -1

Feedstock	**Saponification Value (mg KOH/g)**	**Feedstock**	**Saponification Value (mg KOH/g)**
Algae 1	160.60	Jatropha	200.80
Algae 2	185.82	Jojoba	105.99
Babassu	258.49	Karanja	188.50
Beef Tallow	198.00	*Lesquerella fendleri*	173.94
Borage	202.57	Linseed	187.63
Camelina	190.70	*Moringa oleifera*	194.96
Canola	189.80	Mustard	Not enough sample
Castor	191.08	Neem	209.66
Choice White Grease	202.45	Palm	208.62
Coconut	267.56	Perilla Seed	205.77
Coffee	195.65	Poultry Fat	188.08
Corn, Distiller's	183.06	Rice Bran	201.27
Cuphea viscosissima	Not enough sample	Soybean	195.30
Evening Primrose	189.03	Stillingia	Not enough sample
Fish	205.67	Sunflower	193.14
Hemp	203.86	Tung	189.53
Hepar, High IV	205.35	Used Cooking Oil	198.50
Hepar, Low IV	207.41	Yellow Grease	198.36

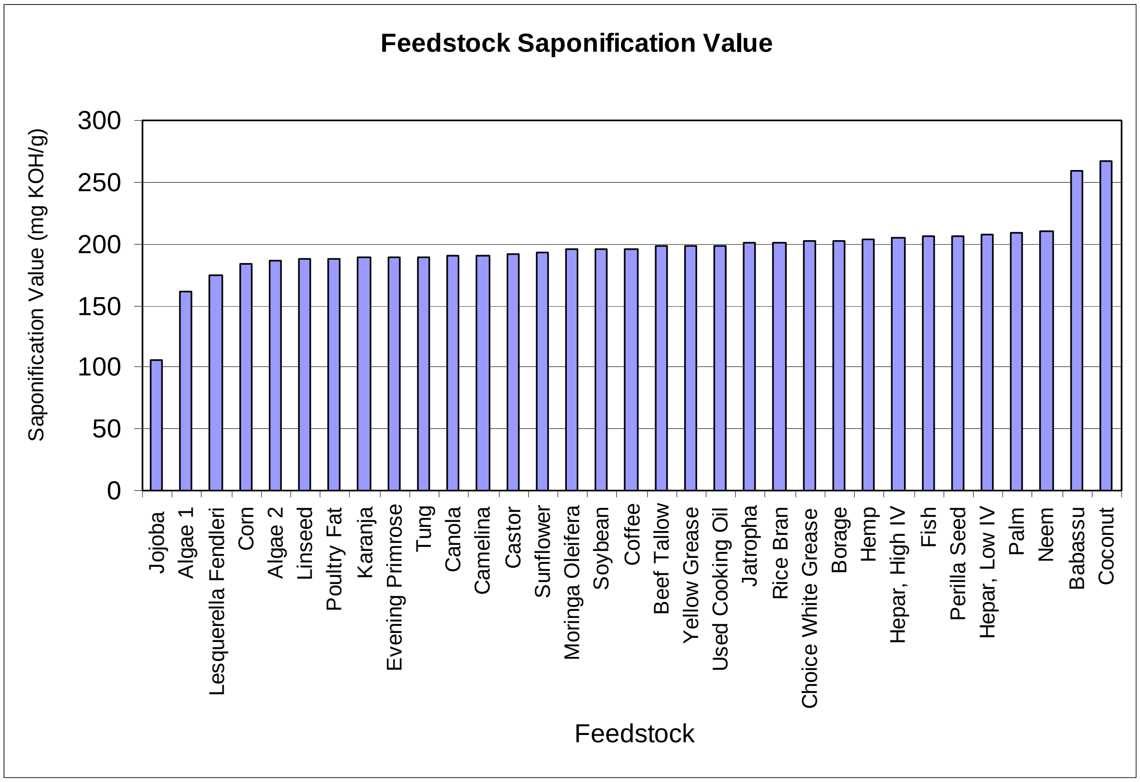


Fig. 4.5 -1

As seen from Table 4.5-1, the saponification value for the majority of the feedstocks are in the range of 185 to 210 mg KOH/g. This range is typical for feedstocks having predominately fatty acids with a chain length between C16 and C18.[16]

Babassu and coconut oil have a relatively higher saponification value of 258.5 and 267.6 mg KOH/g, respectively. Higher saponification values may indicate the presence of shorter chain lengths. As seen in Table 8.4-1, the babassu and coconut oil have a higher fraction of C12 and C14 fatty acids.

Jojoba and *Lesquerella* oil have lower than average saponification values of 106 and 173.9 mg KOH/g, respectively. For *Lesquerella* this indicates the presence of fatty acids with a longer chain length than C18. Table 8.4-1 confirms that *Lesquerella* has a higher C20 and C22 fraction. Jojoba is a long chain ester;[24] of which the alcohol portion is a long chain alcohol and accounts for nearly as much weight in the molecule as the fatty acid portion of the ester. This added weight effectively dilutes the fatty acid leading to a lower saponification value.

4.6 Moisture and Volatile Matter

The test for moisture and volatile matter from the fats and oils industry may be included in fat and oil specifications. The method involves heating a known amount of feedstock to a certain temperature and recording the weight loss. The presence of volatile matter in a feedstock may lead to fatty acid methyl ester yield loss by reacting with the catalyst or by diluting the feedstock.

Materials and Methods

The moisture and volatile matter was run in accordance with AOCS Method Ca 2b-38, Moisture and Volatile Matter Hot Plate Method.[25] The temperature of the feedstock was measured with a Scotchtrak Heat Tracer IR-1000 (3M™).

Results and Discussion

Table 4.6 -1

Feedstock	**Moisture and Volatile Matter (wt %)**	**Feedstock**	**Moisture and Volatile Matter (wt %)**
Algae 1	Not tested	Jatropha	0.0589
Algae 2	Not tested	Jojoba	0.0059
Babassu	0.0260	Karanja	0.3126
Beef Tallow	0.3101	*Lesquerella fendleri*	0.0490
Borage	<0.001	Linseed	0.0410
Camelina	0.0336	*Moringa oleifera*	0.0376
Canola	<0.001	Mustard	Not enough sample
Castor	0.1301	Neem	0.5344
Choice White Grease	0.0415	Palm	0.0039
Coconut	2.5371	Perilla Seed	<0.001
Coffee	<0.001	Poultry Fat	0.0219
Corn, Distiller's	0.4310	Rice Bran	1.7400
Cuphea viscosissima	Not enough sample	Soybean	0.4091
Evening Primrose	<0.001	Stillingia	Not enough sample
Fish	1.1570	Sunflower	<0.001
Hemp	<0.001	Tung	0.0825
Hepar, High IV	0.4854	Used Cooking Oil	0.7598
Hepar, Low IV	0.0635	Yellow Grease	0.1629

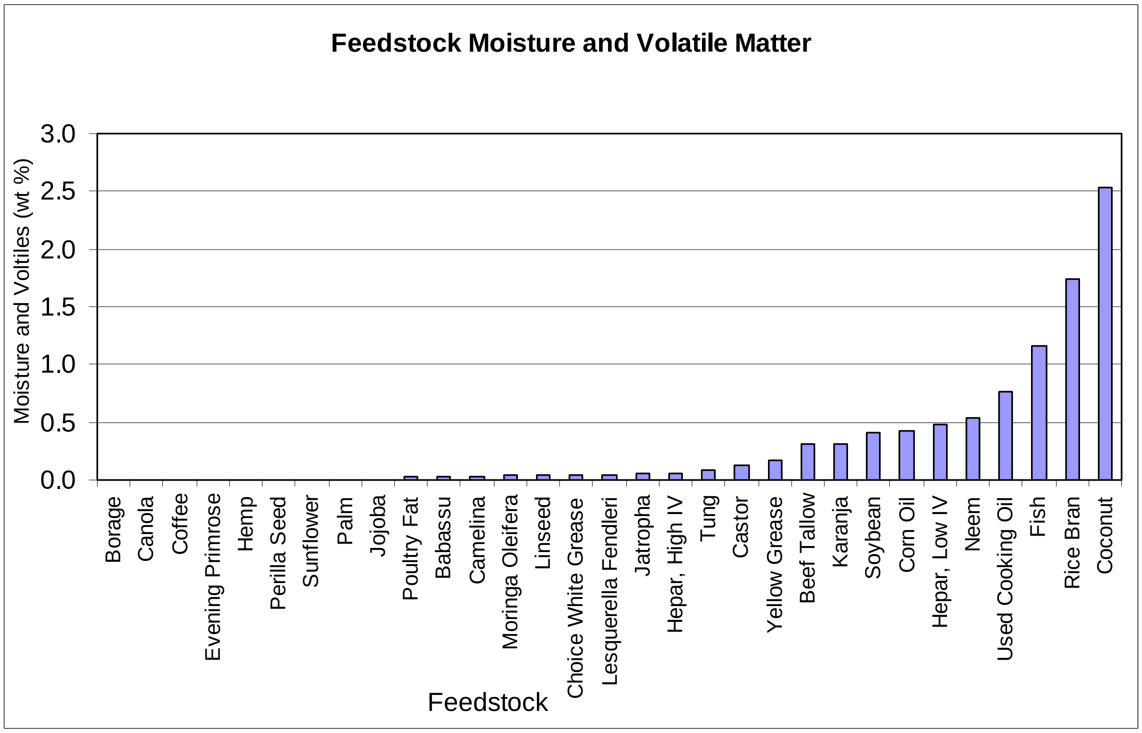


Fig. 4.6-1

The fish oil, rice bran oil, and coconut oil received for this study were suspected to have significant amounts of volatile components because the respective moisture contents of these oils are much lower than the moisture and volatile matter results. AOCS states that Method Ca 2b-38 is not applicable to solvent extracted fats and oils which may contain residues from solvents.[25] Algal oil was not tested because there may have been residual solvent in the crude oil.

A possible drawback of the AOCS moisture and volatile method is the precision. The data in Table 4.6-1 has a standard deviation of 0.142 with 2 degrees of freedom. If the feedstock needs to be less than 0.50 wt % moisture, this method may not be able to measure moisture at or below 0.50 wt %.

4.7 Insoluble Impurities

The insoluble impurities test measures the amount of solids that are insoluble in kerosene and petroleum ether. These solids may consist of sand, dirt, and seed fragments in the case of vegetable oil and small particles of bones and gums in the case of animal fats or used cooking oil.[26]

Materials and Methods

The determination of insoluble impurities in feedstocks performed in this study was done following the instructions of AOCS Method Ca 3a-46.[27] This procedure consists of dissolving the residue from the moisture and volatile matter experiment in kerosene and petroleum ether to allow all the nonpolar substances to dissolve, leaving behind all the small insoluble particles. Kerosene and petroleum ether were obtained from Fisher Scientific Inc.

Results and Discussion

Table 4.7-1

Feedstock	**Insoluble Impurities (wt %)**	**Feedstock**	**Insoluble Impurities (wt %)**
Algae 1	0.1279	Jatropha	0.0240
Algae 2	0.4743	Jojoba	<0.001
Babassu	0.0120	Karanja	0.2730
Beef Tallow	0.1431	*Lesquerella fendleri*	0.0137
Borage	0.3999	Linseed	0.0800
Camelina	0.0139	*Moringa oleifera*	0.0079
Canola	<0.001	Mustard	Not enough sample
Castor	0.1439	Neem	1.1136
Choice White Grease	0.2962	Palm	0.0059
Coconut	<0.001	Perilla Seed	0.0059
Coffee	0.0079	Poultry Fat	0.1055
Corn, Distiller's	0.2545	Rice Bran	0.0059
Cuphea viscosissima	Not enough sample	Soybean	0.0098
Evening Primrose	0.0039	Stillingia	Not enough sample
Fish	0.0277	Sunflower	0.0057
Hemp	<0.001	Tung	0.0137
Hepar, High IV	0.0099	Used Cooking Oil	0.0401
Hepar, Low IV	0.0098	Yellow Grease	0.1728

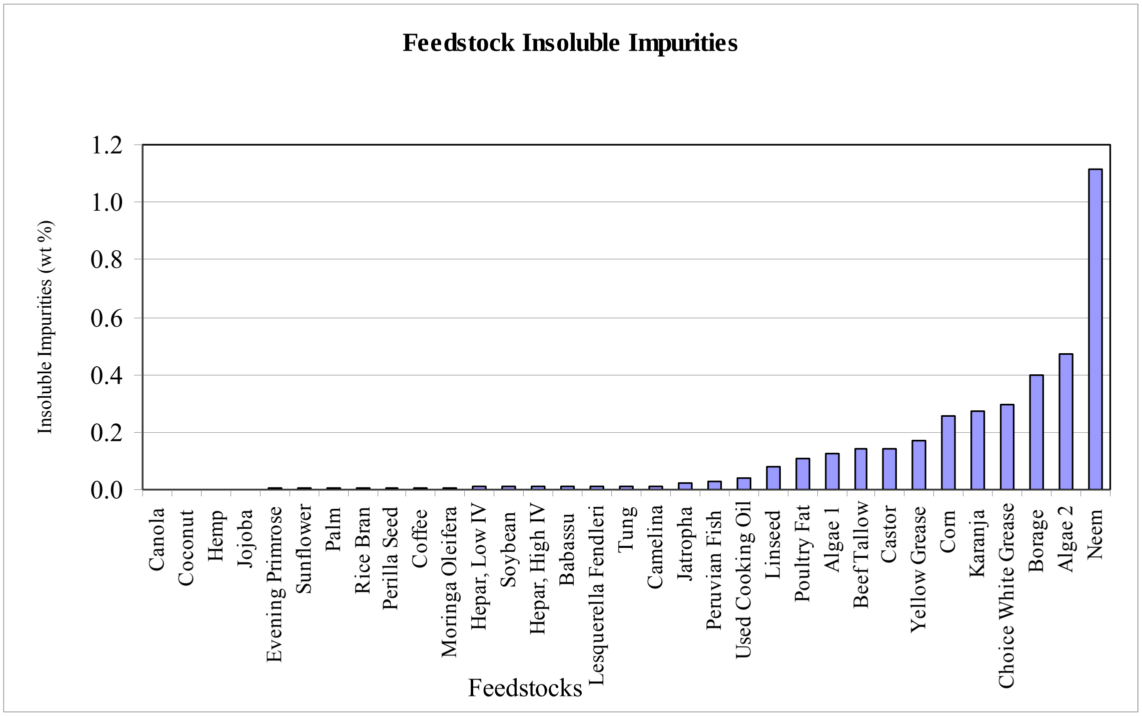


Fig. 4.7-1

The amount of insoluble impurities in oils and fats is primarily related to the extraction and purification methods utilized and therefore, a particular trend was not found that linked insoluble impurities with other oil and fat characteristics.

4.8 Unsaponifiable Matter

Unsaponifiable matter consists of organics which do not react with base to form soaps. These include sterols, higher molecular weight alcohols, pigments, waxes, and hydrocarbons.[28] Since these components are very nonpolar there may be a possibility that they remain in the biodiesel after the transesterification reaction.

Materials and Methods

The determinations of unsaponifiable matter were run in accordance with AOCS Method Ca 6a-40.[28] Potassium hydroxide pellets, ethyl alcohol 95%, petroleum ether, and phenolphthalein were purchased from Fisher Scientific Inc.

Results and Discussion

Table 4.8-1

Feedstock	**Unsaponifiable Matter (wt %)**	**Feedstock**	**Unsaponifiable Matter (wt %)**
Algae 1	0.44	Jatropha	0.08
Algae 2	0.60	Jojoba	Not applicable
Babassu	0.09	Karanja	0.13
Beef Tallow	0.39	*Lesquerella fendleri*	0.78
Borage	0.30	Linseed	0.52
Camelina	0.49	*Moringa oleifera*	0.25
Canola	0.85	Mustard	Not enough sample
Castor	0.14	Neem	0.51
Choice White Grease	0.02	Palm	0.02
Coconut	0.20	Perilla Seed	0.26
Coffee	1.06	Poultry Fat	0.17
Corn, Distiller's	1.67	Rice Bran	0.99
Cuphea viscosissima	Not enough sample	Soybean	0.35
Evening Primrose	1.10	Stillingia	Not enough sample
Fish	0.78	Sunflower	0.64
Hemp	0.22	Tung	0.32
Hepar, High IV	0.55	Used Cooking Oil	0.05
Hepar, Low IV	0.36	Yellow Grease	0.34

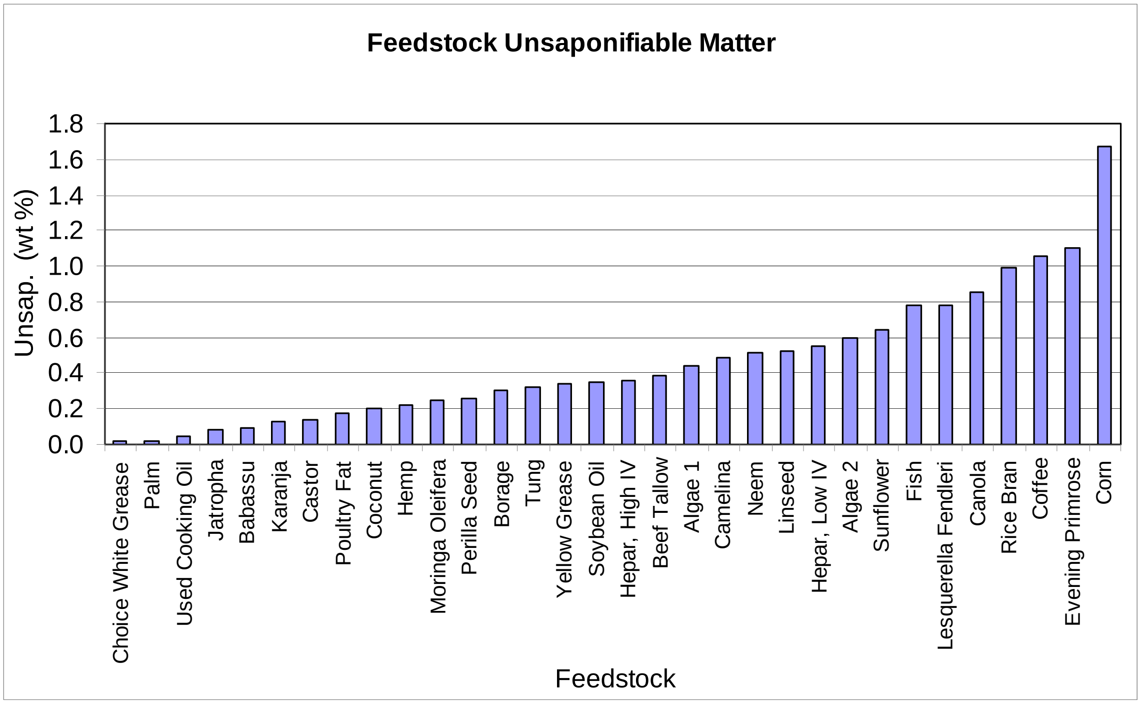

Feedstock Unsaponifiable Matter
Unsap. (wt %)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Choice White Grease
Palm
Used Cooking Oil
Jatropha
Babassu
Karanja
Castor
Poultry Fat
Coconut
Hemp
Moringa Oleifera
Perilla Seed
Borage
Tung
Yellow Grease
Soybean Oil
Hepar, High IV
Beef Tallow
Algae 1
Camelina
Neem
Linseed
Hepar, Low IV
Algae 2
Sunflower
Fish
Lesquerella Fendleri
Canola
Rice Bran
Coffee
Evening Primrose
Corn
Feedstock

Fig.4.8-1

4.9 Moisture, Insolubles, and Unsaponifiables (MIU)

MIU is shorthand for moisture, insolubles and unsaponifiables. It is the calculated sum of the moisture wt %, the insoluble impurities wt % and the unsaponifiable matter wt %. MIU represents materials in the oil or fat which cannot be converted to mono alkyl fatty esters by esterification or transesterification.

Materials and Methods

MIU is the sum of the moisture and volatile wt %, the insoluble impurities wt % and the unsaponifiable matter wt %, results of which can be found in Sections 4.6, 4.7, and 4.8.

Results and Discussion

Table 4.9-1

Feedstock	**MIU (wt %)**	**Feedstock**	**MIU (wt %)**
Algae 1	Not calculated	Jatropha	0.16
Algae 2	Not calculated	Jojoba	Not calculated
Babassu	0.13	Karanja	0.72
Beef Tallow	0.84	*Lesquerella fendleri*	0.84
Borage	0.70	Linseed	0.64
Camelina	0.54	*Moringa oleifera*	0.30
Canola	0.85	Mustard	Not enough sample
Castor	0.41	Neem	2.16
Choice White Grease	0.36	Palm	0.03
Coconut	2.74	Perilla Seed	0.27
Coffee	1.07	Poultry Fat	0.30
Corn, Distiller's	2.36	Rice Bran	2.74
Cuphea viscosissima	Not enough sample	Soybean	0.77
Evening Primrose	1.10	Stillingia	Not enough sample
Fish	1.96	Sunflower	0.65
Hemp	0.22	Tung	0.42
Hepar, High IV	1.05	Used Cooking Oil	0.85
Hepar, Low IV	0.43	Yellow Grease	0.68

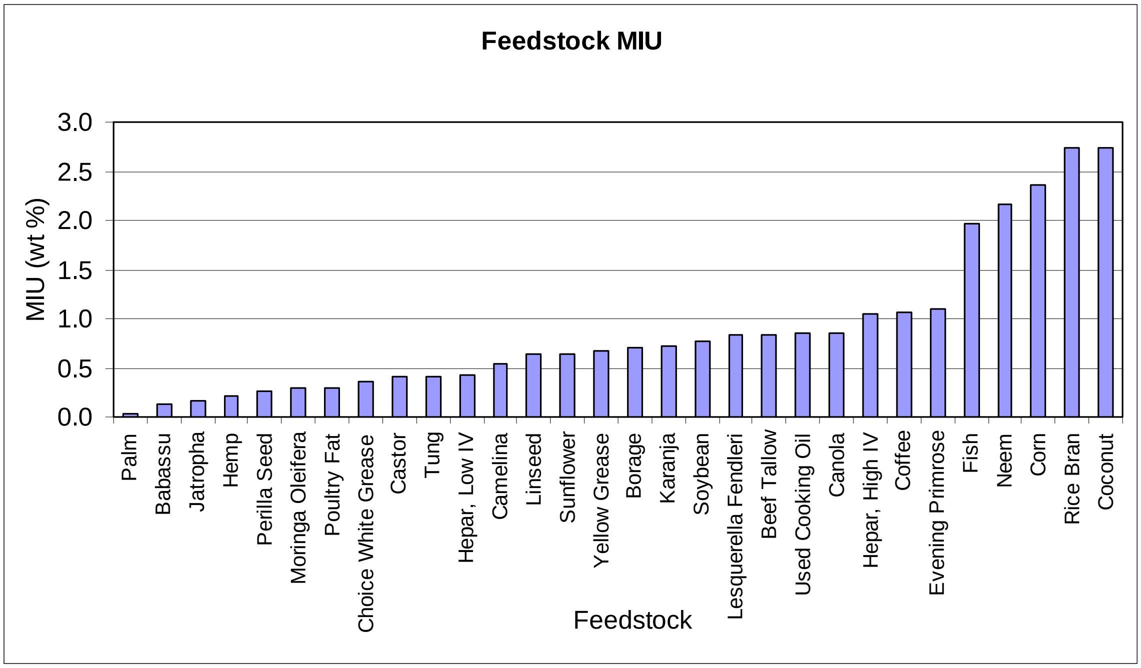

Feedstock MIU
MIU (wt %)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Palm
Babassu
Jatropha
Hemp
Perilla Seed
Moringa Oleifera
Poultry Fat
Choice White Grease
Castor
Tung
Hepar, Low IV
Camelina
Linseed
Sunflower
Yellow Grease
Borage
Karanja
Soybean
Lesquerella Fendleri
Beef Tallow
Used Cooking Oil
Canola
Hepar, High IV
Coffee
Evening Primrose
Fish
Neem
Corn
Rice Bran
Coconut
Feedstock

Fig. 4.9-1

4.10 Oxidation Stability

Feedstock oxidation stability may be indicative of the age or prior storage conditions of the oil or fat and can predict if the feedstock is capable of meeting the minimum requirements for biodiesel oxidation stability as specified by ASTM D6751. The result of the test is expressed in time and the higher the value, the more resistant the oil or fat is towards oxidation.

Oxidation stability in oils and fats is primarily influenced by two aspects. The first aspect is the presence of hydrogen atoms next to carbon-carbon double bonds, which act as points where oxidation can occur.[29] The second aspect is the presence of naturally occurring antioxidants in the feedstock that can prevent oxidation of the triglyceride molecules.[30]

Materials and Methods

The determination of the oxidation stability was performed following EN 14112, Determination of Oxidation Stability, using a 743 Rancimat manufactured by Metrohm, Inc.[31]

Table 4.10-1

Feedstock	**Oxidation Stability (h)**	**Feedstock**	**Oxidation Stability (h)**
Algae 1	51.3	Jatropha	15.6
Algae 2	31.4	Jojoba	56.9
Babassu	85.5	Karanja	28.0
Beef Tallow	23.1	*Lesquerella fendleri*	9.9
Borage	2.3	Linseed	0.2
Camelina	1.7	*Moringa oleifera*	90.8
Canola	14.1	Mustard	6.9
Castor	88.2	Neem	12.4
Choice White Grease	0.8	Palm	2.7
Coconut	92.3	Perilla Seed	1.1
Coffee	8.1	Poultry Fat	4.6
Corn, Distiller's	8.6	Rice Bran	7.8
Cuphea viscosissima	13.3	Soybean	5.3
Evening Primrose	2.8	Stillingia	0.9
Fish	0.4	Sunflower	10.1
Hemp	2.6	Tung	1.0
Hepar, High IV	4.9	Used Cooking Oil	2.8
Hepar, Low IV	12.2	Yellow Grease	104.9

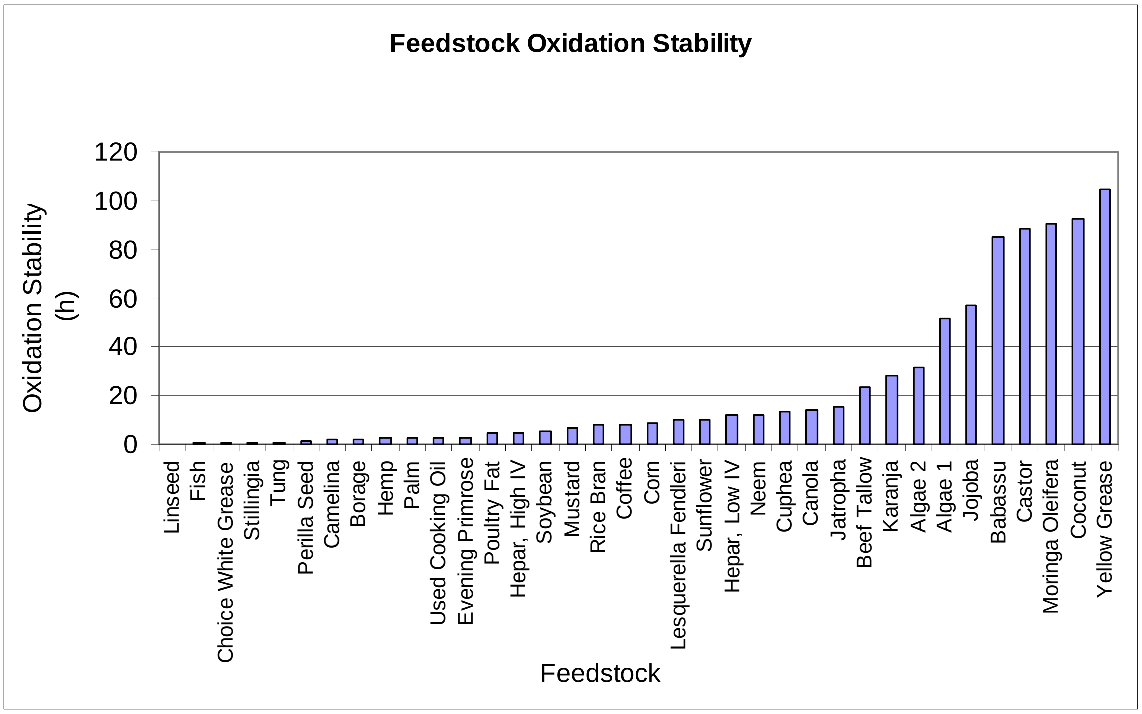


Fig. 4.10-1

Coconut and babassu oil are types of feedstocks that are high in saturated fatty acids making them particularly stable towards oxidation. Some feedstocks, such as linseed, fish, and tung, present low oxidation stabilities since they contain high amounts of polyunsaturated fatty acids which are extremely susceptible to oxidation.

4.11 Sulfur

Sulfur content in biodiesel is limited to 15 ppm maximum by ASTM D6751. Therefore, it is important to know the original feedstock sulfur content since it can contribute to biodiesel sulfur content.

Materials and Methods

The determination of sulfur in the feedstocks was done using ASTM D7039, Standard Test Method for Sulfur in Gasoline and Diesel Fuel by Monochromatic Wavelength Dispersive X-ray Fluorescence Spectrometry.[32] A Sindie Bio Bench Top sulfur analyzer manufactured by X-Ray Optical Systems Inc. was used to measure the amount of sulfur.

Although ASTM D7039 was designed for gasoline and diesel fuel testing, due to equipment availability this method was also used to determine the sulfur content of the feedstock.

Table 4.11-1

Feedstock	Sulfur (ppm)	Feedstock	Sulfur (ppm)
Algae 1	28.1	Jatropha	3.5
Algae 2	15.4	Jojoba	0.3
Babassu	2.3	Karanja	9.7
Beef Tallow	25.2	*Lesquerella fendleri*	158.8
Borage	1.7	Linseed	23.7
Camelina	3.6	*Moringa oleifera*	31.4
Canola	5.7	Mustard	4.8
Castor	1.4	Neem	1990.0
Choice White Grease	7.7	Palm	1.0
Coconut	2.7	Perilla Seed	1.0
Coffee	10.5	Poultry Fat	27.2
Corn, Distiller's	10.5	Rice Bran	4.0
Cuphea viscosissima	Not enough sample	Soybean	0.8
Evening Primrose	0.1	Stillingia	Not enough sample
Fish	24.5	Sunflower	0.1
Hemp	0.3	Tung	8.4
Hepar, High IV	8.3	Used Cooking Oil	3.4
Hepar, Low IV	5.6	Yellow Grease	30.7

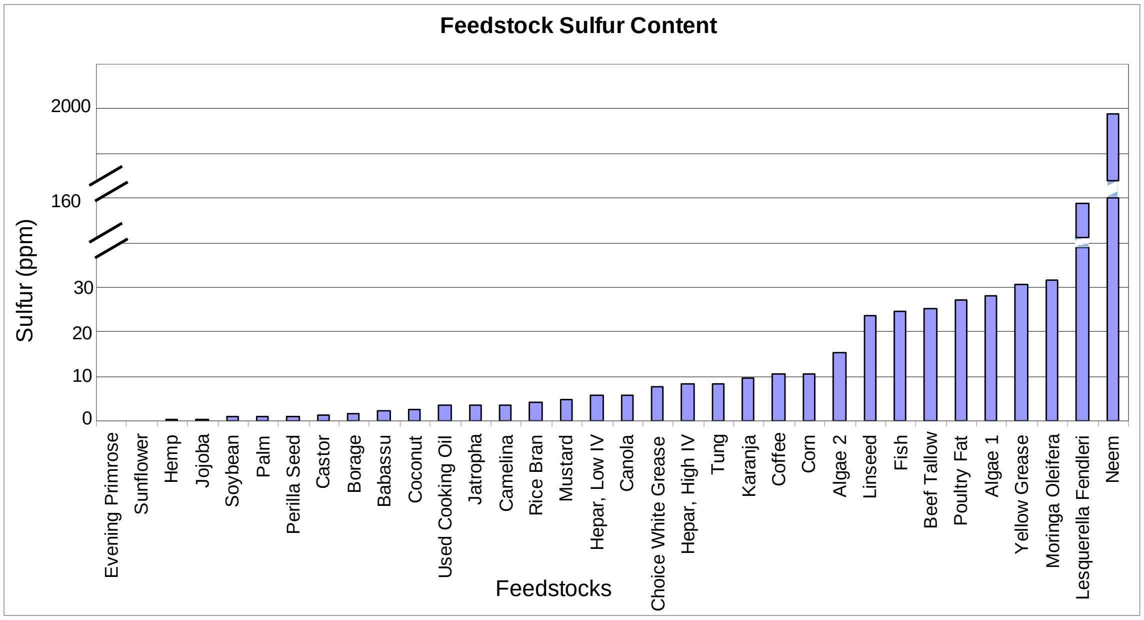


Fig. 4.11-1

Removal of high levels of sulfur, such as in *Lesquerella* and neem, may require additional handling to meet the ASTM D6751 specification. The rest of the feedstocks should be able to pass the ASTM D6751 specification using the pretreatment and transesterification procedures described in Chapters 5 and 6.

4.12 Phosphorous, Calcium, and Magnesium

ASTM D6751 requires phosphorous in biodiesel be limited to 10 ppm (0.001 % mass maximum) and the combined amount of calcium and magnesium to be less than 5 ppm. Phosphorous, calcium, and magnesium are minor components typically associated with phospholipids and gums that may act as emulsifiers[33,34] or cause sediment, lowering yields during the transesterification process.[35]

Feedstocks were tested for metals using an Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES). If the phosphorous was higher than 10 ppm, the feedstock was pretreated and if either the calcium or magnesium were higher than 5 ppm, the feedstock was also pretreated.

Materials and Methods

Phosphorous, calcium, and magnesium levels were determined using ASTM D4951, Standard Test Method for Determination of Additive Elements in Lubricating Oils by Inductively Coupled Plasma Atomic Emission Spectrometry.[36] The feedstocks were run on a PerkinElmer Inc. Optima 7000 dual view ICP-OES with a cyclonic spray chamber. Cobalt was used as the internal standard and deodorized kerosene was used as the base oil.

Results and Discussion

Table 4.12-1, Phosphorous

Feedstock	Phosphorous (ppm)	Feedstock	Phosphorous (ppm)
Algae 1	339.7	Jatropha	322.9
Algae 2	286.2	Jojoba	4.8
Babassu	3.6	Karanja	44.2
Beef Tallow	270.8	*Lesquerella fendleri*	<0.1
Borage	0.5	Linseed	12.0
Camelina	43.7	*Moringa oleifera*	7.3
Canola	17.9	Mustard	57.1
Castor	<0.1	Neem	47.6
Choice White Grease	42.5	Palm	7.3
Coconut	2.0	Perilla Seed	<0.1
Coffee	5.0	Poultry Fat	209.3
Corn, Distiller's	<0.1	Rice Bran	0.9
Cuphea viscosissima	<0.1	Soybean	3.7
Evening Primrose	0.1	Stillingia	73.1
Fish	49.0	Sunflower	<0.1
Hemp	<0.1	Tung	32.9
Hepar, High IV	46.0	Used Cooking Oil	27.0
Hepar, Low IV	38.5	Yellow Grease	132.1

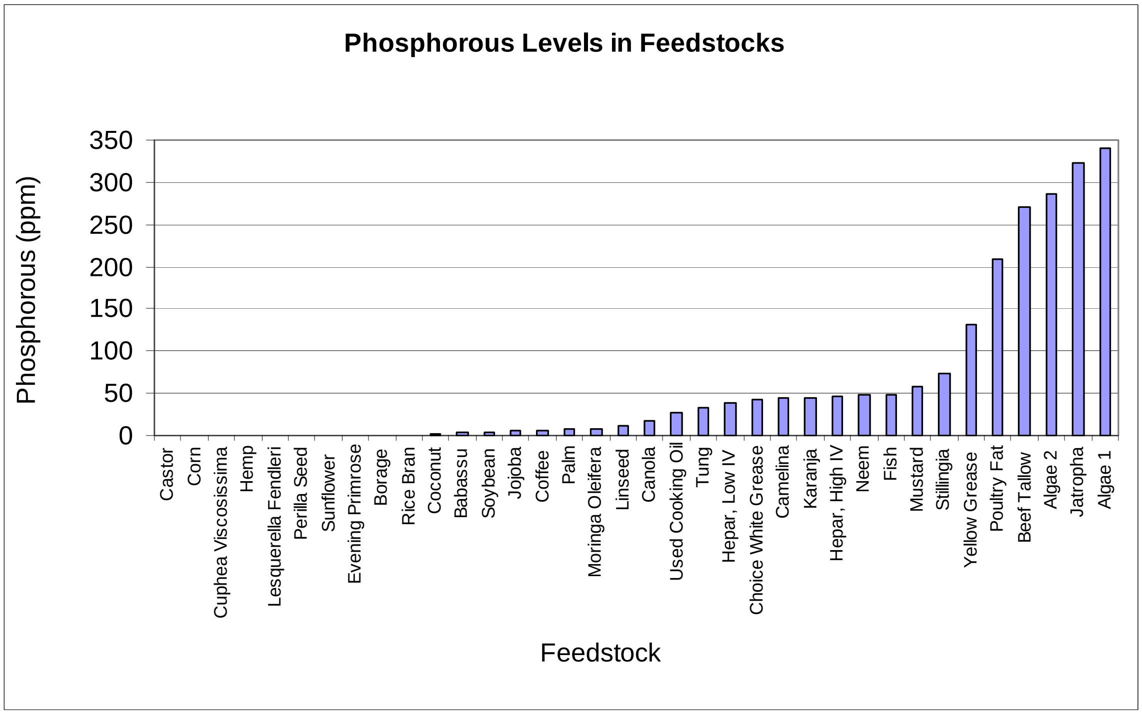


Fig. 4.12-1, Phosphorous

Table 4.12-2, Calcium

Feedstock	**Calcium (ppm)**	**Feedstock**	**Calcium (ppm)**
Algae 1	<0.1	Jatropha	121.5
Algae 2	1.3	Jojoba	4.0
Babassu	0.4	Karanja	11.2
Beef Tallow	97.3	*Lesquerella fendleri*	<0.1
Borage	5.6	Linseed	13.5
Camelina	15.8	*Moringa oleifera*	5.7
Canola	4.6	Mustard	9.1
Castor	<0.1	Neem	25.9
Choice White Grease	0.7	Palm	1.1
Coconut	<0.1	Perilla Seed	0.8
Coffee	3.3	Poultry Fat	35.5
Corn, Distiller's	<0.1	Rice Bran	0.6
Cuphea viscosissima	<0.1	Soybean	0.1
Evening Primrose	0.8	Stillingia	45.9
Fish	5.2	Sunflower	<0.1
Hemp	0.2	Tung	13.4
Hepar, High IV	6.7	Used Cooking Oil	0.1
Hepar, Low IV	3.8	Yellow Grease	38.9

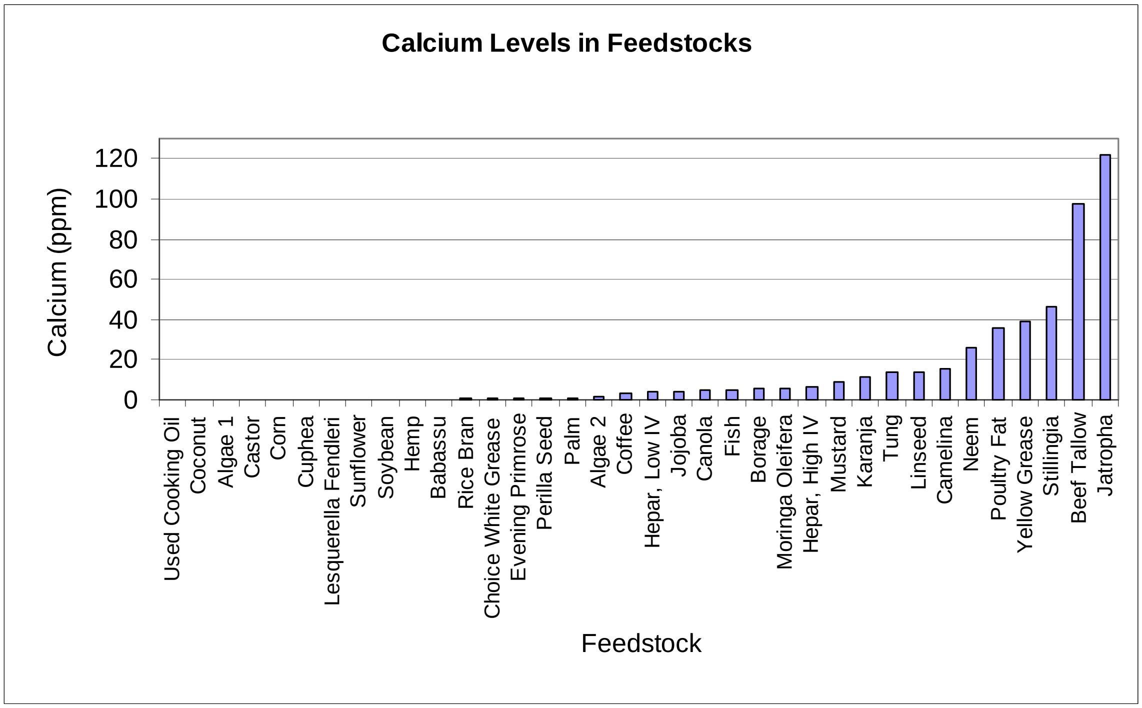


Fig. 4.12-2, Calcium

Table 4.12-3, Magnesium

Feedstock	**Magnesium (ppm)**	**Feedstock**	**Magnesium (ppm)**
Algae 1	0.2	Jatropha	104.1
Algae 2	19.0	Jojoba	2.4
Babassu	0.3	Karanja	4.9
Beef Tallow	16.1	*Lesquerella fendleri*	0.7
Borage	0.6	Linseed	5.8
Camelina	10.0	*Moringa oleifera*	4.3
Canola	4.9	Mustard	4.6
Castor	0.8	Neem	21.3
Choice White Grease	1.5	Palm	0.5
Coconut	0.1	Perilla Seed	0.2
Coffee	2.0	Poultry Fat	8.2
Corn, Distiller's	<0.1	Rice Bran	0.9
Cuphea viscosissima	0.2	Soybean	0.3
Evening Primrose	0.3	Stillingia	14.6
Fish	3.3	Sunflower	0.1
Hemp	0.2	Tung	13.5
Hepar, High IV	4.2	Used Cooking Oil	0.8
Hepar, Low IV	2.7	Yellow Grease	10.5

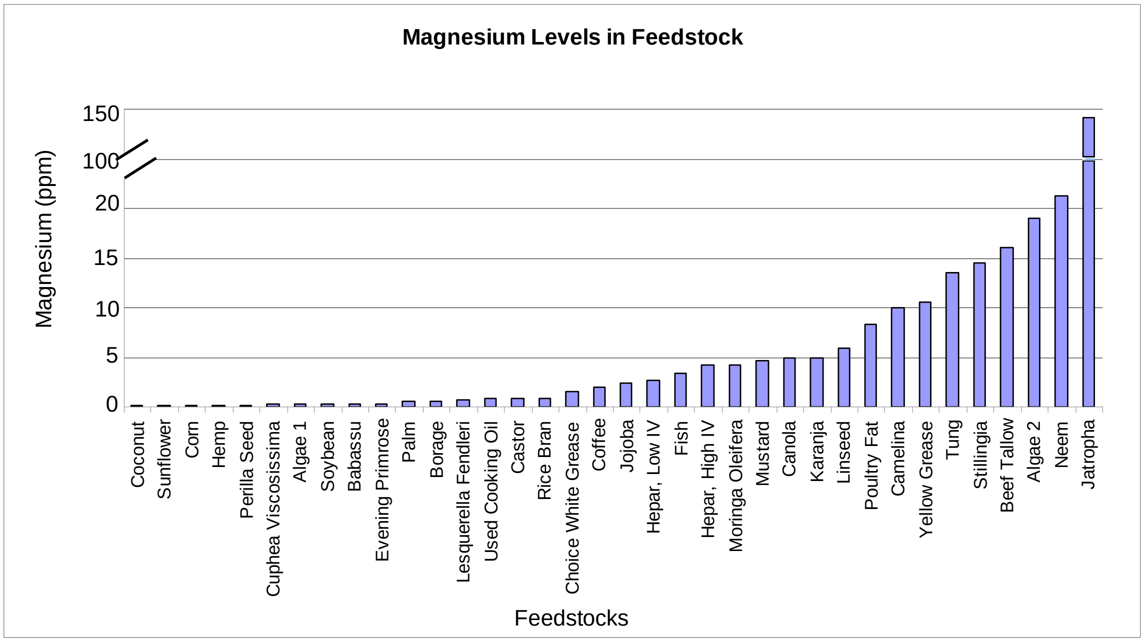


Fig. 4.12-3, Magnesium

5 Phosphoric Acid Pretreatment of Fats and Oils

Oils and fats contain a number of constituents such as phospholipids, fatty acids, pigments and odoriferous compounds that may need to be removed before conversion to biodiesel. In this project, all feedstocks with levels of phosphorous, calcium and magnesium above 10 ppm, 5 ppm and 5 ppm respectively were pretreated using the phosphoric acid procedure described below.

Materials and Methods

Fig. 5.1 shows the block flow diagram of the phosphoric acid pretreatment process. A feedstock mass of 1780 g (about 2 liters) was added to a 4L flask; it was then heated to 80ºC and transferred to a blender. Phosphoric acid, 85%, was added directly to the feedstock at a ratio of 0.09 % by weight of feedstock. The mixture was blended at the highest speed setting on the blender (about 2000 rpm) for 2 minutes to ensure high shear mixing of the acid with the feedstock. After two minutes of blending, 58 g of 0.5N sodium hydroxide was added and blended for 2-4 seconds. The mixture was then transferred to a two liter flask and heated to 85ºC with stirring for 30 minutes. After neutralization, the mixture was centrifuged at 1800 rpm for 10 minutes at 80ºC to separate the water and gums from the treated feedstock. The top oil or fat layer in the centrifuge tube was removed. Pretreatment chemicals were all purchased from Fisher Scientific Inc.

Silica and diatomaceous earth were added to the centrifuged oil or fat at 1 wt % and 3 wt % respectively and slurried for 20 minutes at 80ºC to bleach the oil. After 20 minutes of mixing, the oil or fat was dried at 85ºC for 30 minutes under a vacuum of 25 in Hg. The dried and bleached feedstock was then filtered through a 20 µm filter using a Buchner funnel.

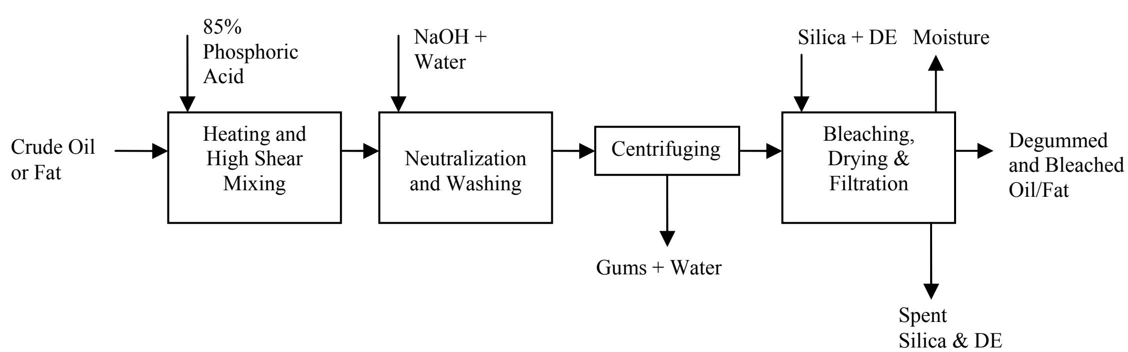


Fig. 5.1, Block flow diagram of phosphoric acid pretreatment

Results and Discussion

Pretreatment was found to be effective in degumming the feedstocks. Of the oils and fats pretreated, all but one of them were processed without anomaly. However, while processing tung oil, the oil emulsified during the caustic neutralization and water washing step. Acidulation with sulfuric acid and centrifugation of the emulsified oil to break the emulsion and remove water and gums was not effective. To break the emulsion, water was removed by drying under heat and vacuum. The dried, unemulsified oil was then centrifuged and bleached before continuing to the esterification process.

6 Esterification of Free Fatty Acid with Amberlyst BD 20

Feedstocks with FFA levels below 0.5 wt % do not require FFA reduction before transesterification.[16] Feedstocks with FFA content greater than 0.5 wt % were esterified to lower the FFA prior to transesterification. The FFA was reduced in the feedstocks by esterification catalyzed by Amberlyst BD 20. For the FFA to be esterified, the feedstock should have a Karl Fischer moisture of < 0.05 wt %, calcium < 5 ppm, magnesium < 5 ppm and phosphorous < 10 ppm. If these conditions were not met, the feedstock was processed by the pretreatment procedure in Chapter 5. The results are summarized in Table 6.1.

Materials and Methods

Amberlyst BD 20 (Rohm and Haas Co., Philadelphia) catalyst is activated by washing the solid particles with an equal volume of dry methanol (Fisher Scientific Inc.) and filtering by gravity six times. To a 5 liter, 4 necked, round bottom flask equipped with magnetic stirring, a 400 mL distillation receiver, Friedrichs condenser, a thermocouple probe, and heated by a heating mantle with digital controller, is added 316 g of activated Amberlyst BD 20 (16 % by weight of methanol and feedstock), 1620 g of feedstock and 355.5 g (20 % by volume of feedstock) of dry methanol. The mixture is heated to reflux. After one hour the methanol is removed by a vacuum of 21-24 inches Hg. Complete removal of methanol is assumed when the system reached 80-85°C. The FFA is then measured. If the FFA is less than 0.50 wt % the feedstock is removed from the catalyst by a siphon. If the FFA is more than 0.50 wt % another 355.5 g (20 % by volume of feedstock) of methanol is added, the mixture is refluxed for another hour, the methanol removed and the FFA checked. After the feedstock is removed from the catalyst, the Amberlyst BD 20 is washed with four volumes of dry methanol and stored under methanol until the next use.

Results and Discussion

Table 6.1, Summary of Reaction Conditions with Amberlyst BD 20

Feedstock	Stage	Feedstock FFA %	Esterified Feedstock FFA %
Algae 2, refined	1	1.60	0.24
Beef Tallow, refined	1	1.90	0.23
Camelina, refined	1	2.00	0.26
Castor	1	1.10	0.36
Choice White Grease, refined	1	1.80	0.19
Corn, refined	1	12.20	1.40
Corn, refined	2	1.40	0.47
Fish Oil, refined	1	2.90	0.20
Hepar, High IV, refined	1	3.70	0.32
Hepar, Low IV, refined	1	1.33	0.11
Jatropha, refined	1	2.70	0.69
Jatropha, refined	2	0.68	0.28
Karanja, refined	1	8.20	2.73
Karanja, refined	2	2.73	1.80
Karanja, refined	3	1.80	1.10
Karanja, refined	4	1.10	0.85
Karanja, refined	5*	0.85	0.87
Karanja, refined	6	0.87	0.57
Karanja, refined	7	0.57	0.71
Linseed, refined	1	0.67	0.11
Moringa, refined	1	2.90	0.24
Neem, refined	1	5.80	1.00
Neem, refined	2	1.00	0.47
Palm	1	0.83	0.17
Poultry Fat, refined	1	8.80	1.20
Poultry Fat, refined	2	1.20	0.29
Stillingia, refined	1	5.30	0.85
Stillingia, refined	2	0.85	0.29
Tung, refined	1	1.70	0.17
Used Cooking Oil, refined	1	2.80	0.27
Yellow Grease, refined	1	6.70	1.10
Yellow Grease, refined	2	1.10	0.37
*Catalyst washed with four volumes of methanol			

During the esterification reaction, changes in the feedstock were observed in addition to a reduction of FFA. All fats and oils appeared to shift in color toward red and the odor was modified for selected feedstocks. This was especially noticed for yellow grease, poultry fat, and used cooking oil.

Between feedstocks, the catalyst was washed with four volumes of methanol and reused. This enabled one batch of Amberlyst BD 20 to be used for a number of reactions and as many as 17 reactions were run with the same batch of catalyst without substantial reduction in the rate of conversion.

With the exception of refined karanja oil, Amberlyst BD 20 successfully reduced the FFA to below 0.5 wt %. In refined karanja oil the conversion of FFA to methyl ester was hindered and the FFA could not be reduced to below 0.5 wt %. Refined karanja oil not only inhibited the reaction; it appeared to have reached an equilibrium between 1.0 and 0.5 wt %. The reasons for this inhibition of the esterification were not pursued.

7 Transesterification of Feedstocks

In order for a feedstock to be transesterified for this project, the feedstock must have a moisture content of less than 0.05 wt %, a free fatty acid content of less than 0.5 wt %, phosphorous content of less than 10 ppm, and a combined calcium and magnesium content of less than 5 ppm.

Each feedstock was transesterified using the same production procedure. Two 700 g batches were made for each feedstock in order to have enough biodiesel for ASTM testing. For *Cuphea*, mustard, and stillingia, one batch was made due to limited feedstock quantity.

Materials and methods

Transesterification was carried out in a 1000 mL EZE-Seal stirred reactor from Autoclave Engineers. Certified ACS Grade Methanol was purchased from Fisher Scientific Inc. Sodium methoxide solution was purchased from Sigma-Aldrich Co. (25 wt % in methanol). A 0.2 N hydrochloric acid solution was made using 36.5-38.0 % HCl purchased from Fisher Scientific Inc. (Mallinckrodt Baker NF/FCC/ACS grade) and deionized water.

Standard Transesterification Procedure

To the reactor are added: 700 grams feedstock; methanol, 17.6 wt % of feedstock; and sodium methoxide, 2.64 wt % of feedstock. The reactor temperature is set to 65°C and remains at 65°C until the methyl ester is removed from the reactor. The mixer is turned on and set to 1200 rpm for 15 minutes for the first reaction.

After 15 minutes in the first reaction, the mixer is turned off and the methyl esters and glycerin settle for 15 minutes. The glycerin is removed and 4.4 wt % of methanol and 0.66 wt % of sodium methoxide are added for the second reaction. The mixer is set to 600 rpm for 15 minutes for the second reaction.

After 15 minutes in the second reaction, the mixer is turned off and 0.2 N hydrochloric acid solution (13 wt % of feedstock) is added. The mixer is turned back on and neutralization occurs for two minutes. After the two minutes, the methyl esters settle for 15 minutes. The hydrochloric acid layer is removed from the reaction vessel and then the methyl esters are removed.

When two batches of methyl ester are made, they are combined together into the same flask before proceeding to the next step.

The methyl esters are transferred into a flask which is heated to 70°C with stirring and the use of a vacuum pump. The methyl esters are placed under vacuum for 30 minutes to remove the methanol. After the methanol has been removed, the methyl esters are poured into a separatory funnel. Deionized water, 10 wt %, at 70°C is added to the separatory funnel and the mixture is shaken vigorously for two minutes.

The methyl esters are then settled for 15 minutes at room temperature. After 15 minutes, the water phase is removed. The methyl esters are then transferred to a flask to be dried.

The methyl esters are dried using a hotplate and a vacuum pump. The methyl esters are heated to 110°C under vacuum for one hour.

After the methyl esters have been dried and cooled back down to room temperature, diatomaceous earth (5 wt % of methyl ester) is added to the methyl ester. The methyl esters and diatomaceous earth are stirred and chilled at 15°C for 30 minutes.

The slurry is removed and filtered through a filter press equipped with a 0.7 µm filter paper. The filtered methyl esters are then filtered again through a 0.7 µm glass fiber filter paper to remove all the diatomaceous earth.

Variations to the Standard Transesterification Procedure

Beef Tallow

The filtration of the beef tallow methyl esters resulted in some gelling when the methyl esters were chilled and passed through the filter press. A small amount of methyl ester remained in the filter cake with the diatomaceous earth. It is believed the beef tallow gelled in the filtration step because it was chilled (15°C) below the cloud point of the biodiesel (16°C). In order to improve the yield for beef tallow biodiesel, a filtration temperature of 18°C is recommended.

Castor

The castor methyl esters plugged the filter press filter paper. Therefore the filter paper was replaced four times to limit the yield loss. While the biodiesel was filtered through the filter press, the rest of the castor methyl esters were kept at 15°C in the water bath so it would all be filtered at the same temperature.

Cuphea viscosissima

Due to the limited amount of *Cuphea* methyl ester remaining after drying, the methyl esters were not chilled and filtered.

Evening Primrose

In the water wash step, an emulsion formed in the separatory funnel. After 15 minutes, there was no visible water separation at the bottom of the funnel. Hydrochloric acid was added 10 grams at a time (40 grams total) until the methyl ester and water phase separated.

Jojoba

Jojoba was characterized for its feedstock properties but not made into biodiesel because the procedure described in this chapter would not be applicable to a wax ester. The purpose of this project was to transesterify all the feedstocks using the same procedure and if jojoba was done differently, comparisons could not be made with jojoba methyl esters. Jojoba can be transesterified and used as a fuel using a different process.[37]

Karanja

Esterification was only able to reduce the FFA of the oil to 0.7 wt %. Since 0.5 wt % was the maximum amount of FFA allowed in the feedstock, karanja was not made into biodiesel using the standard procedure. A small scale experiment was performed to see what would happen to the karanja when it was transesterified. A 20 gram sample of karanja oil was used, along with the standard ratios of chemicals as in the other feedstocks for the project. After the water wash step, the karanja formed an emulsion with the water and the phases would not separate. No further refining experiments were done to make karanja suitable for transesterification.

Lesquerella fendleri

In the first batch of *Lesquerella* biodiesel, the methyl ester became very dark after the second reaction in comparison to the original oil color. Therefore the batches were not mixed together after the second reaction and were water washed separately. There was an extra layer in the water in batch 1 after the water wash step. Also, the color of the methyl ester in batch 1 was noticeably darker than in batch 2. The batches were combined before the drying step.

Palm

The palm methyl esters were filtered at 18°C because the methyl esters became gel-like in the water bath at 15°C during the filtration step.

Tung

The tung methyl esters took a longer time than other methyl esters to filter through the diatomaceous earth and filter paper during the final filtration step.

8 Biodiesel Characteristics

8.1 Cloud Point (CP)

Low temperature operability of biodiesel fuel is an important aspect from the engine performance standpoint in cold weather conditions.[16] There are several tests that are commonly used to determine the low temperature operability of biodiesel. Cloud point is one of these tests and is included as a standard in ASTM D6751. The cloud point is the temperature at which crystals first appear in the fuel when cooled. ASTM D6751 requires the producer to report the cloud point of the biodiesel sold, but it does not set a range as the desired cloud point is determined by the intended use of the fuel.[33]

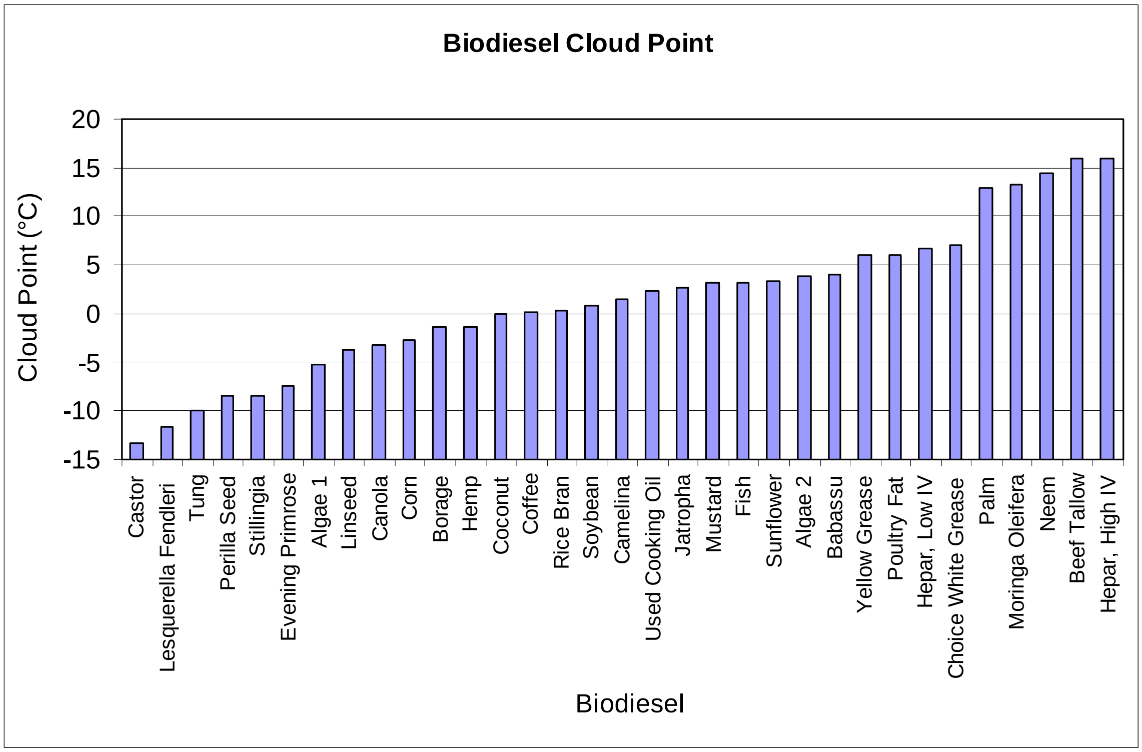
Materials and Methods

Cloud point was determined using ASTM D2500, Standard Test Method for Cloud Point of Petroleum Products.[38] An automatic cloud point analyzer was used from PAC L.P., model number CPP 5GS.

Results and Discussion

Table 8.1-1

Biodiesel	Cloud Point (°C)	Biodiesel	Cloud Point (°C)
Algae 1	-5.2	Hepar, Low IV	6.7
Algae 2	3.9	Jatropha	2.7
Babassu	4.0	*Lesquerella fendleri*	-11.6
Beef Tallow	16.0	Linseed	-3.8
Borage	-1.3	*Moringa oleifera*	13.3
Camelina	1.5	Mustard	3.2
Canola	-3.3	Neem	14.4
Castor	-13.4	Palm	13.0
Choice White Grease	7.0	Perilla Seed	-8.5
Coconut	0.0	Poultry Fat	6.1
Coffee	0.2	Rice Bran	0.3
Corn, Distiller's	-2.8	Soybean	0.9
Cuphea viscosissima	Not enough sample	Stillingia	-8.5
Evening Primrose	-7.5	Sunflower	3.4
Fish	3.2	Tung	-10.0
Hemp	-1.3	Used Cooking Oil	2.4
Hepar, High IV	16.0	Yellow Grease	6.0



<u>Fig, 8.1-1</u>

The cloud point of biodiesel varies significantly with feedstock. Of the feedstocks evaluated, castor biodiesel has the lowest cloud point of -13.4ºC whereas beef tallow biodiesel and high IV hepar biodiesel have the highest cloud points of 16.0ºC. The fatty acid distribution of the feedstock has an effect on the cloud point. Table 8.4-1 shows the fatty acid distribution of various fats and oils. Biodiesel made from feedstocks such as stillingia, tung, perilla, hemp, evening primrose, linseed, corn, borage, and soybean have a cloud point below or close to 0ºC because of the lower fraction of saturated fatty acids like palmitic and stearic. Biodiesel made from feedstocks such as beef tallow, yellow grease, and poultry fat, have a higher fraction of saturated fatty acids and therefore have higher cloud points. Biodiesel made from *Lesquerella* and castor oil have cloud points of -11.6ºC and -13.4ºC, which may be due to the low amount of saturated fatty acids. The interaction of viscosity in determination of cloud point was not evaluated.

8.2 Cold Filter Plugging Point (CFPP)

Cold filter plugging point refers to the temperature at which the test filter starts to plug due to fuel components that have started to gel or crystallize. The CFPP is a commonly used indicator of low temperature operability of fuels. As with other low temperature properties, the CFPP of biodiesel also depends on the feedstock used for production of methyl esters. ASTM D6751 does not include the CFPP test as a standard.

Materials and Methods

CFPP was measured using ASTM D6371, Standard Test Method for Cold Filter Plugging Point of Diesel and Heating Fuels.[39] An FPP 5GS automated cold filter plugging point analyzer was used from PAC L.P.

Results and Discussion

Table 8.2-1

Biodiesel	CFPP (°C)	Biodiesel	CFPP (°C)
Algae 1	-7	Hepar, Low IV	6
Algae 2	2	Jatropha	0
Babassu	10	*Lesquerella fendleri*	-6
Beef Tallow	14	Linseed	-8
Borage	-4	*Moringa oleifera*	13
Camelina	-1	Mustard	-5
Canola	-13	Neem	11
Castor	7	Palm	12
Choice White Grease	6	Perilla Seed	-11
Coconut	-4	Poultry Fat	2
Coffee	-4	Rice Bran	-3
Corn, Distiller's	-3	Soybean	-4
Cuphea viscosissima	Not enough sample	Stillingia	-12
Evening Primrose	-10	Sunflower	-3
Fish	0	Tung	-11
Hemp	-6	Used Cooking Oil	-2
Hepar, High IV	13	Yellow Grease	2

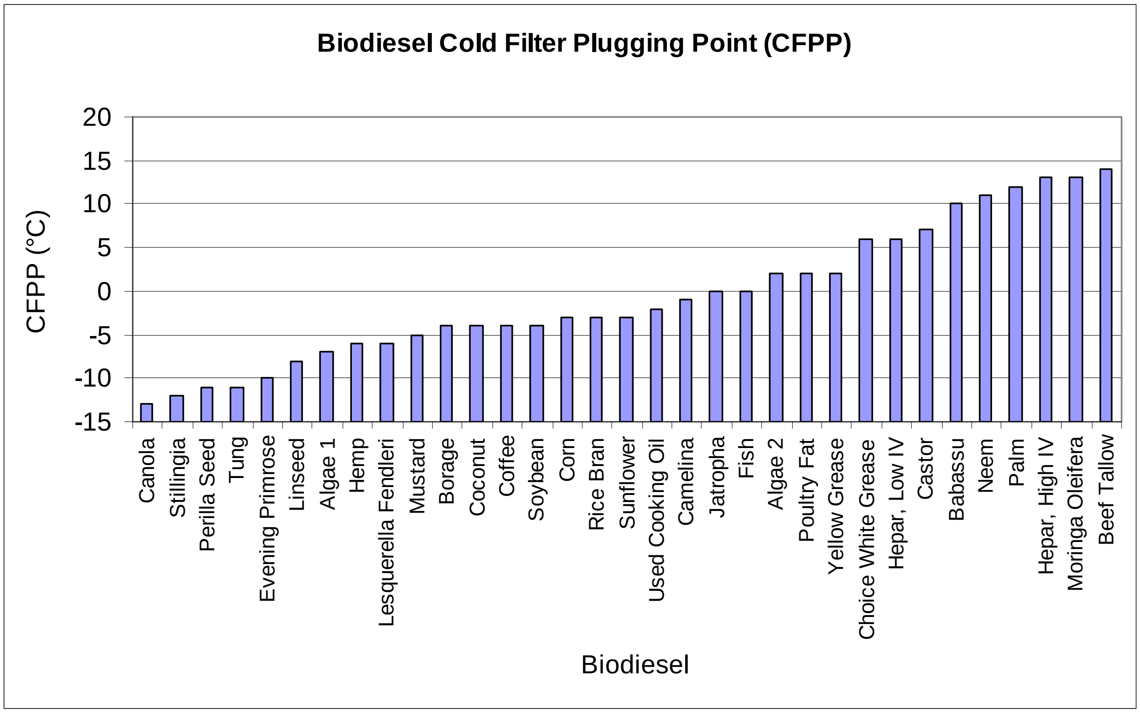


Fig. 8.2-1

Similar to cloud point, the CFPP of biodiesel also varies with the fatty acid distribution; with a lower fraction of saturated fatty acids resulting in a lower CFPP, and a higher fraction of saturated fatty acids resulting in a higher CFPP. Usually, the CFPP of a fuel is lower than its cloud point.[16] However, in the case of biodiesel made from castor and *Lesquerella*, the CFPP is higher than the cloud point. To determine the CFPP of the biodiesel by ASTM D6371, the biodiesel passes through a 45 micron filtration device under a vacuum of 2 kPa. The biodiesel is cooled at 1°C intervals, and the temperature at which the fuel fails to pass through the test filter under the test conditions in a specified length of time is reported as its CFPP.[39] In the case of biodiesel made from castor and *Lesquerella* oils, the reason for test filter plugging at temperatures higher than the cloud point could be due to the high viscosity of the biodiesel and not due to the crystallization of biodiesel molecules. Babassu also has a cloud point lower than the CFPP, reasons of which have not been investigated.

8.3 Cold Soak Filtration

Cold soak filtration is the newest biodiesel requirement set in ASTM D6751.[33] The cold soak filtration test is done to determine if crystals form at low temperatures and do not redissolve when the biodiesel returns to a higher temperature.

Materials and Methods

The ASTM D6751 procedure involves chilling 300 mL of biodiesel for 16 hours at 40°F, removing the sample and letting the sample warm back up to room temperature. When the sample has warmed back up to 20-22°C, it is filtered through a 0.7 µm filter paper. The sample is timed as it passes through the filter paper and when all 300 mL passes through the paper, the result is reported (in seconds). The maximum allowable test result for cold soak filtration is 360 seconds.[33]

A Thermo Scientific refrigerator model number 3556 was used to chill all of the samples to the specified 40°F. A Hydrosol stainless steel filter holder from Millipore Corp. with a filter diameter of 47 mm was used for all of the biodiesel samples. The filter paper used was Grade GF/F glass fiber from Whatman Ltd. If the biodiesel did not pass through the filter in 720 seconds, the test was aborted and the result was reported as >720 s, and the volume of biodiesel that did not pass through the filter paper was measured in mL.

Results and Discussion

Table 8.3-1

Biodiesel	Cold Soak Filtration (s) (mL Remaining)	Biodiesel	Cold Soak Filtration (s) (mL Remaining)
Algae 1	85	Hepar, Low IV	77
Algae 2	84	Jatropha	286
Babassu	310	*Lesquerella fendleri*	>720 (190 mL)
Beef Tallow	76	Linseed	64
Borage	74	*Moringa oleifera*	78
Camelina	223	Mustard	Not enough sample
Canola	113	Neem	>720 (170 mL)
Castor	>720 (216 mL)	Palm	88
Choice White Grease	72	Perilla Seed	200
Coconut	49	Poultry Fat	>720 (239 mL)
Coffee	203	Rice Bran	111
Corn, Distiller's	131	Soybean	67
Cuphea viscosissima	Not enough sample	Stillingia	Not enough sample
Evening Primrose	269	Sunflower	107
Fish	68	Tung	>720 (69 mL)
Hemp	66	Used Cooking Oil	81
Hepar, High IV	87	Yellow Grease	95

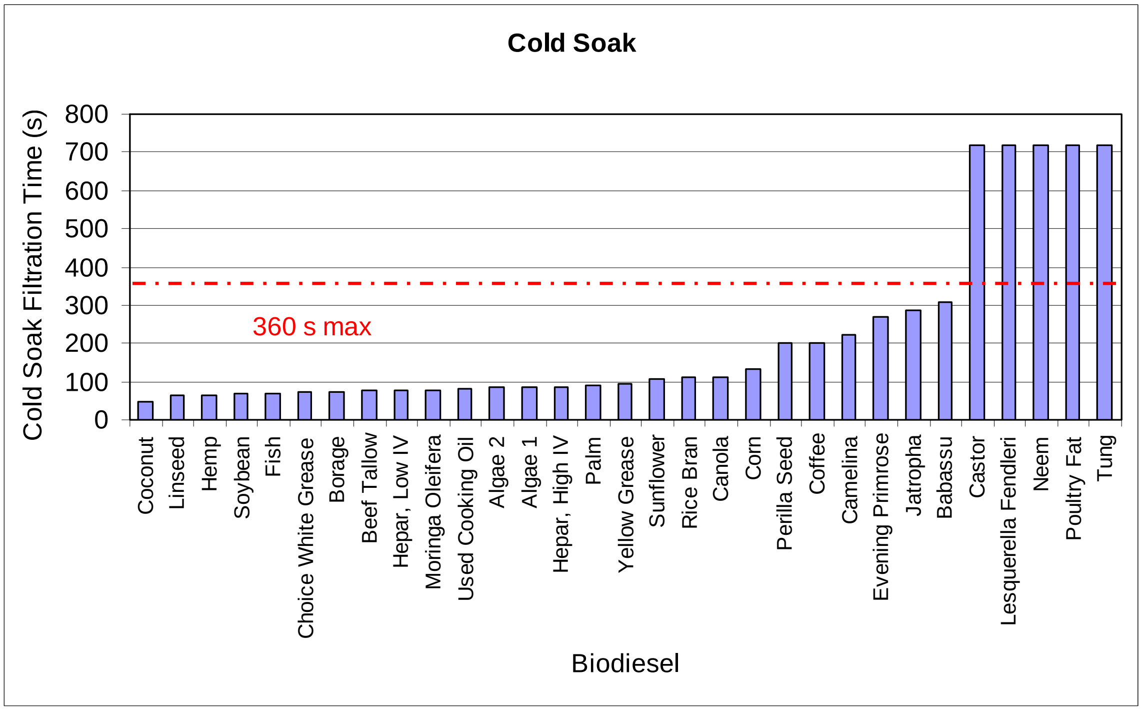


Fig. 8.3-1

Five biodiesel samples did not pass the ASTM specification of 360 seconds, all of which had filtration times longer than 720 seconds.

8.4 Fatty Acid Profile

Biodiesel is defined by ASTM D6751 as a mixture of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats.[33] These mono-alkyl esters are the predominant chemical species present in B100 biodiesel. About ninety percent of the structure of mono-alkyl esters in biodiesel is made of long chain fatty acids. The structure and composition of these long chain fatty acid components have been associated with trends in cetane number, heat of combustion, cold flow properties, oxidation stability, viscosity, and lubricity.[16,40,41] The fatty acid profile (FAP) is a list of fatty acids and their amounts in biodiesel.

Materials and Methods

The determination of the fatty acid profile was based on AOCS Method Ce 1c-89 using a PerkinElmer Inc. Clarus 600 GC-FID equipped with a Supelco SP 2340 fused silica column (Sigma-Aldrich Co.), 60 m, 0.25 µm ID, 0.2 µm film thickness. The GC oven was heated to 150°C, ramped to 200°C at 1.3°C/min and held at 200°C for 20 minutes. A total volume of 1.0 µL was injected and split at a 100:1 ratio, the helium flow was 2.0 ml/min at 1.6 psi and the FID temperature was 210°C. The biodiesel was diluted to a 1 % solution in heptane before injection.

Results and Discussion

The FAP of the biodiesel are summarized in Table 8.4-1. For castor biodiesel and *Lesquerella* biodiesel, the hydroxy acid peaks for ricinoleic acid and lesquerolic acid do not appear on the chromatograms. In this study the amount of these hydroxy acids was estimated from the hydroxyl value with the assumption that all the hydroxyl value was from the predominate hydroxy acid found in the feedstock.

For fish oil there are large quantities of unknown peaks. These peaks are observed in the >C20 region of the chromatogram. They are believed to be from >C20 unsaturated fatty acids present in fish oils.[21]

When determining FAP by methods developed for common oils and animal fats to other novel oils and fats; the possibility for missing peaks and unknown peaks exists. Quantification of the FAP in these biodiesels may require modification to the GC/FID procedure such as sample preparation and calibration with new standards. In some cases other techniques may be required to identify and measure the fatty acids.

The fatty acid profile for algae 2 is proprietary data and publication is withheld by the supplier.

Table 8.4-1, Fatty acid profiles for selected fats and oils

Feedstock	C8:0	C10:0	C12:0	C14:0	C15:0	C16:0	C16:1	C17:0	C17:1	C18:0	C18:1	C18:1n-9(OH)	C18:2	C18:3	C18:3 9c,11t,13t	C20:0	C20:1	C20:1n-n(OH)	C20:2	C20:5	C22:0	C22:1	C24:0	C24:1	UNKNOWNS
Algae 1				0.6		6.9	0.2			3.0	75.2		12.4	1.2		0.4					0.1				
Babassu	0.5	3.8	48.8	17.2		9.7				4.0	14.2		1.8												
Beef Tallow			0.2	2.9	0.6	24.3	2.1	1.2	0.4	22.8	40.2		3.3	0.7		0.2	0.6								0.5
Borage						9.3				3.8	17.1		38.7	26.1							0.2	2.5		1.5	0.8
Camelina Oil						5.0				2.2	17.7		18.0	37.9		1.4	9.8		1.6		0.4	4.5	0.3	0.2	1.0
Canola Oil						3.8	0.3			1.9	63.9		19.0	9.7		0.6					0.4		0.2	0.2	
Castor[a]						0.9				1.1	3.1	90.3	4.0	0.6											
Choice White Grease				1.3		21.6	2.8	0.2	0.3	9.0	50.4		12.2	1.0		0.2	0.5					0.3			0.2
Coconut	6.3	6.0	49.2	18.5		9.1				2.7	6.5		1.7												
Coffee						11.0	0.5			3.4	70.0		12.7	0.8		0.6	0.1				0.2		0.1		0.6
Corn						12.1	0.1		0.1	1.8	27.2		56.2	1.3		0.4					0.2				0.6
Cuphea Viscosissima				4.7		18.2				3.5	46.9		22.8	2.3		0.6					0.4		0.6		
Evening Primrose						6.0				1.8	6.6		76.3	9.0		0.3									
Fish			0.2	7.7		18.8	9.3	0.3	0.3	3.9	15.0		4.6	0.3		0.2	1.4			25.1	0.7	1.3		0.4	10.5
Hemp						5.2				2.4	13.1		57.1	20.0		0.7					0.5		0.3		0.7
Hepar, High IV			0.2	1.0		20.7	2.7	0.3	0.3	8.9	46.7		15.6	0.5		0.2	0.8		1.3		0.2	0.4		0.1	0.1
Hepar, Low IV		0.1	0.1	1.5		28.0	1.9	0.3	0.2	20.2	36.1		9.7	0.3		0.2	0.7		0.4			0.3			
Jatropha						12.7	0.7			5.5	39.1		41.6	0.2		0.2									
Lesquerella Fendleri[a]				0.1		0.9	0.3			1.7	13.0		5.8	10.6		0.7		66.5						0.4	
Linseed						4.4				3.8	20.7		15.9	54.6		0.2					0.3		0.1		
Moringa Oleifera						5.5	1.2			5.8	76.3		0.7			3.1	2.0				4.2		0.4		0.8
Mustard						2.6	0.2			1.2	20.6		20.6	13.3		0.9	10.7		1.0		0.5	25.6	0.2	1.5	1.1
Neem						14.9	0.1			20.6	43.9		17.9	0.4		1.6					0.3		0.3		
Palm			0.2	0.5		43.4	0.1			4.6	41.9		8.6	0.3		0.3					0.1				
Perilla Seed						5.3	0.1			2.2	16.6		13.7	62.1											
Poultry Fat			0.1	1.0		19.6	3.2	0.3	0.2	7.5	36.8		28.4	2.0		0.1			0.1		0.3	0.4			
Rice Bran				0.3		12.5				2.1	47.5		35.4	1.1		0.6					0.3		0.2		
Soybean						9.4				4.1	22.0		55.3	8.9							0.3				
Stillingia			0.4	0.1		7.5				2.3	16.7		31.5	41.5											
Sunflower						4.2				3.3	63.6		27.6	0.2							0.7		0.4		
Tung						1.8				2.1	5.3		6.8	0.7	72.2	0.2			0.1				10.4		0.4
Used Cooking Oil			0.1	0.1		11.8	0.4	0.1	0.1	4.4	25.3		49.5	7.1		0.3					0.4	0.3	0.1		
Yellow Grease			0.1	0.5		14.3	1.1	0.3	0.2	8.0	35.6		35.0	4.0		0.3					0.3	0.2		0.1	

[a] In the GC/FID chromatogram the hydroxy ester peaks were missing. The quantity of the hydroxy ester peaks was estimated from the hydroxyl value with the assumption that all the hydroxy value was the primary hydroxy acid in the sample.

8.5 Relative Density

Relative density is the density of the component compared to the density of water. Relative density is a measure of weight per unit volume. The relative density of biodiesel is needed to make mass to volume conversions, calculate flow and viscosity properties, and is used to judge the homogeneity of biodiesel tanks.

Materials and Methods

Relative density was measured with a hydrometer in accordance with ASTM D1298, Standard Test Method for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method.[42] A Haake C10-K10 refrigerated bath was used from Thermo Fisher Scientific Inc.

Results and Discussion

Table 8.5-1

Biodiesel	**Relative Density**	**Biodiesel**	**Relative Density**
Algae 1	0.8780	Hepar, Low IV	0.8755
Algae 2	0.8780	Jatropha	0.8795
Babassu	0.8760	*Lesquerella fendleri*	0.9110
Beef Tallow	0.8740	Linseed	0.8925
Borage	0.8865	*Moringa oleifera*	0.8770
Camelina	0.8880	Mustard	Not enough sample
Canola	0.8820	Neem	0.8845
Castor	0.8990	Palm	0.8760
Choice White Grease	0.8770	Perilla Seed	0.8990
Coconut	0.8073	Poultry Fat	0.8805
Coffee	0.8815	Rice Bran	0.8855
Corn, Distiller's	0.8850	Soybean	0.8840
Cuphea viscosissima	Not enough sample	Stillingia	Not enough sample
Evening Primrose	0.8885	Sunflower	0.8800
Fish	0.8955	Tung	0.9030
Hemp	0.8885	Used Cooking Oil	0.8555
Hepar, High IV	0.8755	Yellow Grease	0.8825

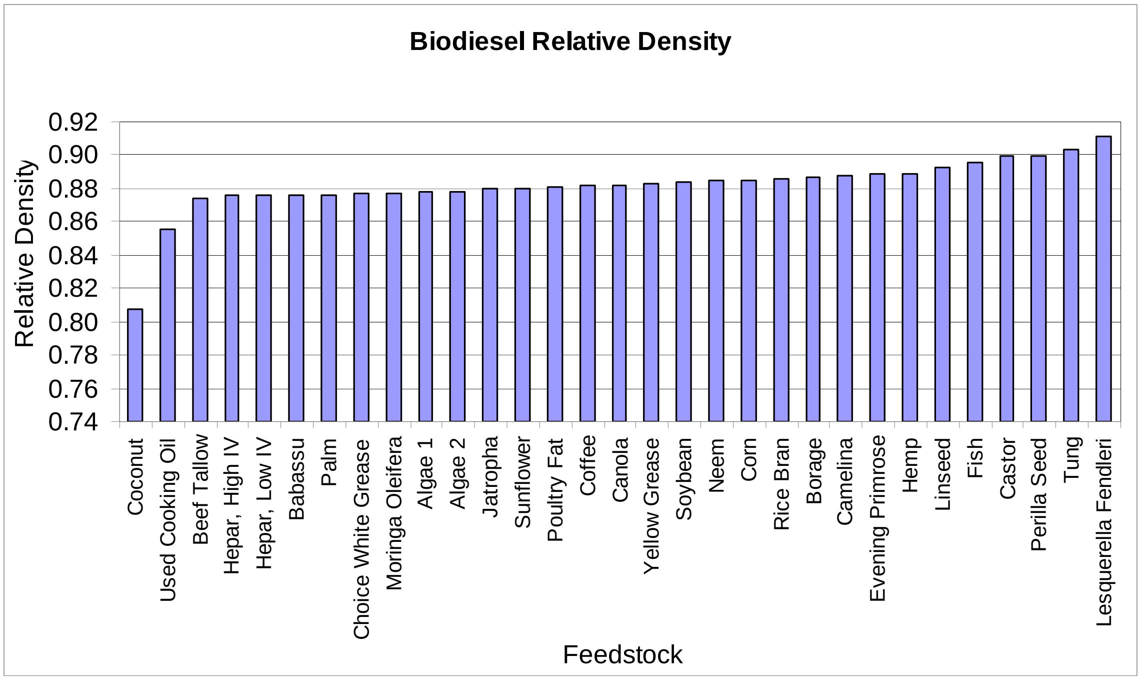


Fig. 8.5-1

For twenty seven of the thirty one biodiesels, the relative density falls in the range 0.8600 to 0.9000. The most notable outlier is coconut biodiesel with a relative density of 0.8073. Since babassu biodiesel which has a similar fatty acid profile has a relative density of 0.8760, the reason for the low relative density in coconut biodiesel is unclear and was not investigated further. *Lesquerella* biodiesel (0.9110) and tung biodiesel (0.9030) have densities higher than 0.9 and may not pass EN Standard 14214, which specifies the density at 15°C to be 860-900 kg/m^3.[43] This would be equivalent to a relative density range of 0.86 to 0.90. Since castor biodiesel has a similar relative density to *Lesquerella* biodiesel, and both castor biodiesel and *Lesquerella* biodiesel are the only biodiesels in the study high in hydroxy esters,[21] the presence of high amounts of hydroxy esters may be associated with higher density.

In the top ten highest relative densities, there is biodiesel from borage (0.8865), camelina (0.8880), evening primrose (0.8885), hemp (0.8885), linseed (0.8925), perilla (0.8990) and fish (0.8955). All these biodiesels have a similar structural component that is significantly different than the other biodiesels in the study. These biodiesels are rich in unsaturated esters with more than two double bonds. The presence of more than 25 wt % of unsaturated esters with more than two double bonds appears to be associated with an increase in relative density.

Of the 13 lowest relative densities, 11 are from biodiesels with 1.0 wt % or less unsaturated esters with more than two double bonds. This further strengthens the association of high levels of unsaturated ester with more than two double bonds to increased relative density.

8.6 Kinematic Viscosity

Materials and Methods

Kinematic viscosity in biodiesel was determined using ASTM D445, Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity).[20] A K23700 kinematic viscosity bath manufactured by Koehler Instrument Company, Inc. was used.

Results and Discussion

Table 8.6-1

Biodiesel	**Kinematic Viscosity (mm^2/s)**	**Biodiesel**	**Kinematic Viscosity (mm^2/s)**
Algae 1	4.519	Hepar, Low IV	4.643
Algae 2	4.624	Jatropha	4.253
Babassu	3.239	*Lesquerella fendleri*	10.020
Beef Tallow	4.824	Linseed	3.752
Borage	4.083	*Moringa oleifera*	5.008
Camelina	4.365	Mustard	Not enough sample
Canola	4.439	Neem	5.213
Castor	15.250	Palm	4.570
Choice White Grease	4.536	Perilla Seed	3.937
Coconut	2.726	Poultry Fat	4.496
Coffee	4.852	Rice Bran	4.958
Corn, Distiller's	4.382	Soybean	4.039
Cuphea viscosissima	Not enough sample	Stillingia	Not enough sample
Evening Primrose	4.112	Sunflower	4.439
Fish	3.777	Tung	7.530
Hemp	3.874	Used Cooking Oil	4.332
Hepar, High IV	4.422	Yellow Grease	4.552

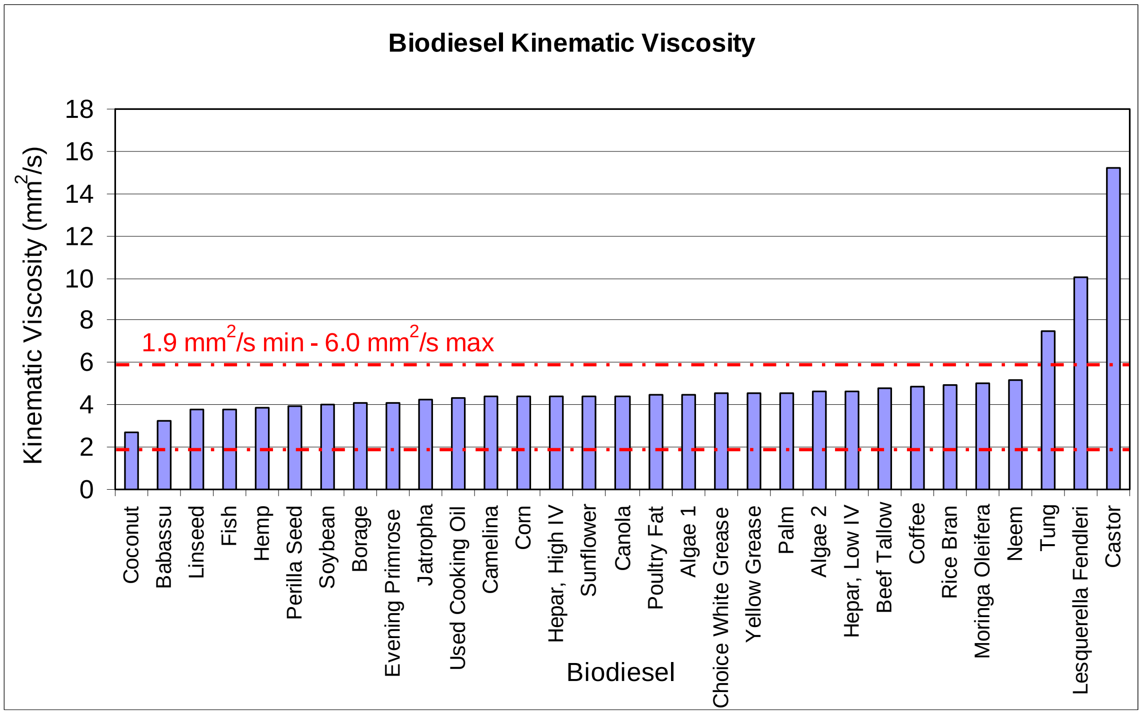


Fig. 8.6-1

Biodiesel kinematic viscosities are all lower that those presented by their respective oils or fats. This is an expected finding since biodiesel molecules are single, long chain fatty esters with higher mobility than the bigger and bulkier triglyceride molecules. The same trends found for kinematic viscosity in the feedstocks are found in the biodiesels.

Castor, *Lesquerella*, and tung biodiesel present the highest kinematic viscosities among the biodiesel of this study; the reasons are the same explained previously in the kinematic viscosity of feedstocks chapter. They did not pass the ASTM D6751 specification of 1.9 mm^2/s to 6.0 mm^2/s.

8.7 Sulfated Ash

ASTM D874 measures sulfated ash that may come from abrasive solids, soluble metallic soaps, and unremoved catalysts.[33] The biodiesel is ignited and burned and then treated with sulfuric acid to determine the percentage of sulfated ash present in the biodiesel.[44]

Materials and Methods

The sulfated ash determination of biodiesel samples in this study was done following ASTM D874, Standard Test Method for Sulfated Ash from Lubricating Oils and Additives.[44] A muffle furnace, model FB1415M, from Thermo Scientific Inc. was used.

Results and Discussion

Table 8.7-1

Biodiesel	**Sulfated Ash (% mass)**	**Biodiesel**	**Sulfated Ash (% mass)**
Algae 1	<0.005	Hepar, Low IV	<0.005
Algae 2	<0.005	Jatropha	0.009
Babassu	<0.005	*Lesquerella fendleri*	0.010
Beef Tallow	<0.005	Linseed	<0.005
Borage	<0.005	*Moringa oleifera*	<0.005
Camelina	<0.005	Mustard	Not enough sample
Canola	<0.005	Neem	<0.005
Castor	0.034	Palm	<0.005
Choice White Grease	<0.005	Perilla Seed	<0.005
Coconut	0.006	Poultry Fat	<0.005
Coffee	<0.005	Rice Bran	<0.005
Corn, Distiller's	<0.005	Soybean	<0.005
Cuphea viscosissima	Not enough sample	Stillingia	Not enough sample
Evening Primrose	0.038	Sunflower	<0.005
Fish	<0.005	Tung	<0.005
Hemp	<0.005	Used Cooking Oil	<0.005
Hepar, High IV	<0.005	Yellow Grease	<0.005

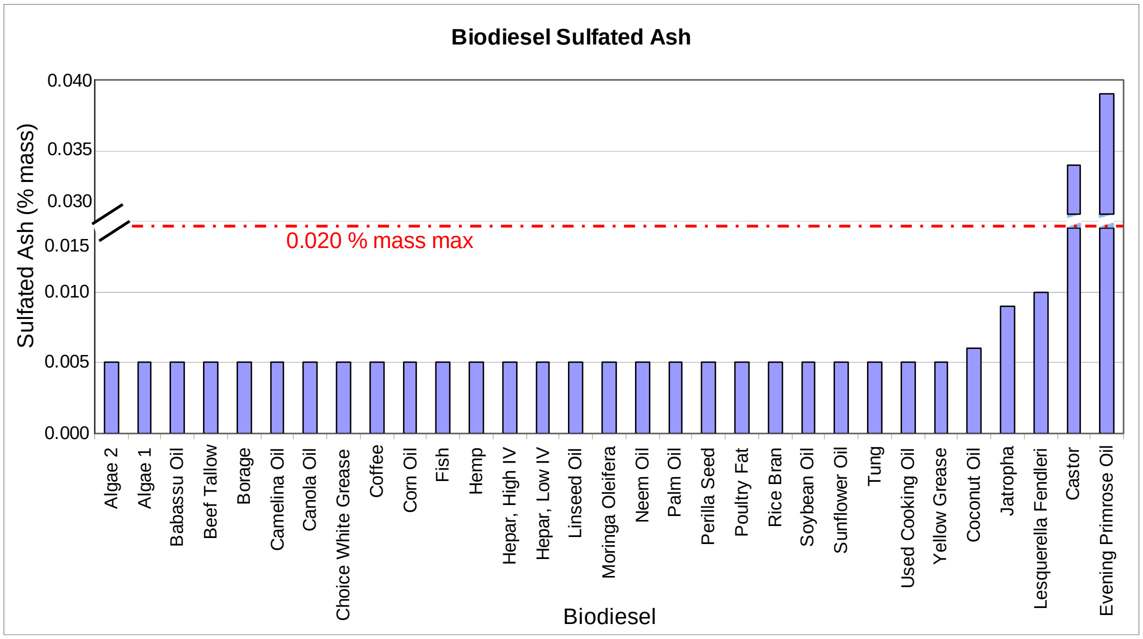


Fig. 8.7-1

The maximum ASTM limit for sulfated ash is 0.020 % mass and the majority of the evaluated biodiesels fell under the maximum limit with the exceptions of castor and evening primrose biodiesels.[33] These biodiesels do not present high concentrations of calcium, magnesium, phosphorous or sulfur which are some common elements that compose sulfated ash, therefore, the source for these high sulfated ash results is unknown.

8.8 Carbon Residue

The carbon residue test indicates the extent of deposits that result from the combustion of a fuel. Carbon residue which is formed by decomposition and subsequent pyrolysis of the fuel components can clog the fuel injectors. ASTM D6751 includes carbon residue as a standard for biodiesel. The maximum allowable carbon residue for biodiesel is 0.050 % by mass.[33]

Materials and Methods

The carbon residue for biodiesel was measured according to ASTM D524, Standard Test Method for Ramsbottom Carbon Residue of Petroleum Products.[45] The samples were tested using a Ramsbottom carbon residue tester manufactured by Koehler Instrument Company, Inc.

Results and Discussion

Table 8.8-1

Biodiesel	**Carbon Residue (% mass)**	**Biodiesel**	**Carbon Residue (% mass)**
Algae 1	0.007	Hepar, Low IV	0.025
Algae 2	0.042	Jatropha	0.026
Babassu	0.050	*Lesquerella fendleri*	0.109
Beef Tallow	0.028	Linseed	0.035
Borage	0.008	*Moringa oleifera*	0.033
Camelina	0.075	Mustard	Not enough sample
Canola	0.030	Neem	0.105
Castor	0.110	Palm	0.010
Choice White Grease	0.034	Perilla Seed	0.037
Coconut	0.010	Poultry Fat	0.025
Coffee	0.004	Rice Bran	0.047
Corn, Distiller's	0.020	Soybean	0.038
Cuphea viscosissima	Not enough sample	Stillingia	Not enough sample
Evening Primrose	0.051	Sunflower	0.035
Fish	0.078	Tung	0.116
Hemp	0.019	Used Cooking Oil	0.040
Hepar, High IV	0.041	Yellow Grease	0.026

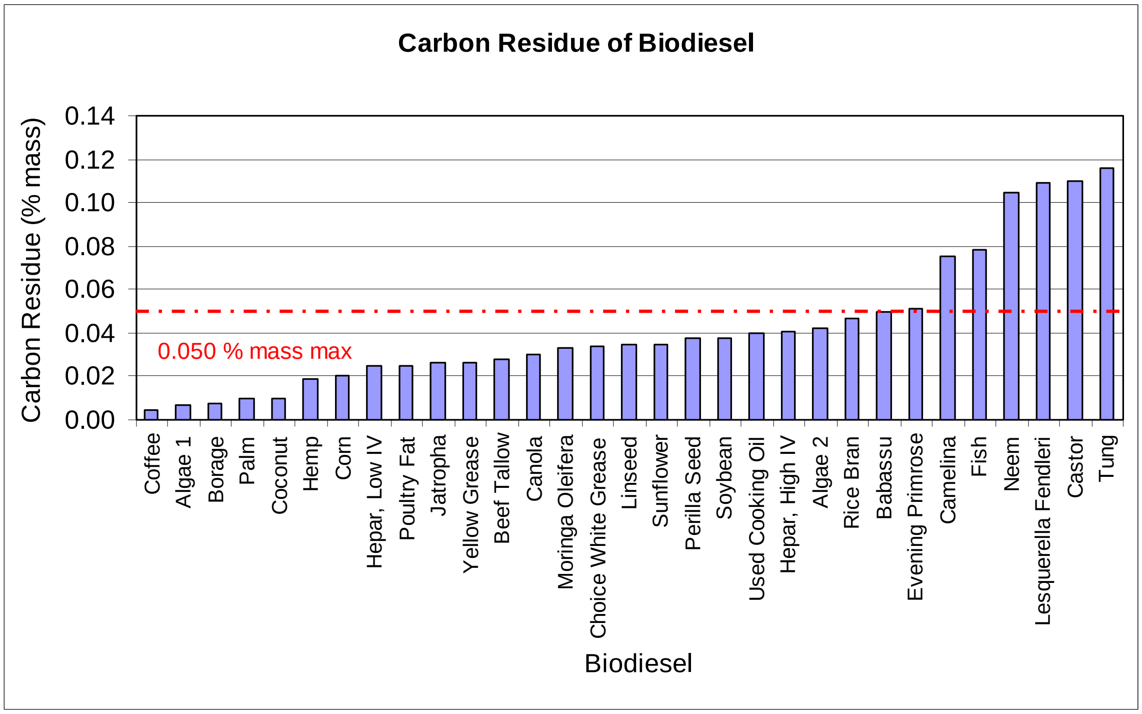


Fig. 8.8-1

As shown in Fig. 8.8-1, biodiesel made from the majority of feedstocks had a carbon residue below the ASTM limit except those made from babassu, evening primrose, camelina, fish, neem, *Lesquerella*, castor, and tung.

8.9 Water and Sediment

Water and sediment testing is done using 100 mL of biodiesel and centrifuging it at 1870 rpm for 11 minutes. If the water and sediment level is below 0.005 % volume (vol), the result is reported as <0.005 % vol.[46]

Materials and Methods

Water and sediment tests were done as per ASTM D2709 Standard Test Method for Water and Sediment in Middle Distillate Fuels by Centrifuge.[46] Samples were centrifuged using an L-K Industries, Inc. Benchmark 2000 centrifuge.

Table 8.9-1

Biodiesel	Water and Sediment (% Volume)	Biodiesel	Water and Sediment (% Volume)
Algae 1	< 0.005	Hepar, Low IV	< 0.005
Algae 2	< 0.005	Jatropha	< 0.005
Babassu	< 0.005	*Lesquerella fendleri*	0.075
Beef Tallow	< 0.005	Linseed	< 0.005
Borage	< 0.005	*Moringa oleifera*	< 0.005
Camelina	< 0.005	Mustard	Not enough sample
Canola	< 0.005	Neem	< 0.005
Castor	< 0.005	Palm	< 0.005
Choice White Grease	< 0.005	Perilla Seed	< 0.005
Coconut	< 0.005	Poultry Fat	< 0.005
Coffee	< 0.005	Rice Bran	< 0.005
Corn, Distiller's	< 0.005	Soybean	< 0.005
Cuphea viscosissima	Not enough sample	Stillingia	Not enough sample
Evening Primrose	< 0.005	Sunflower	< 0.005
Fish	< 0.005	Tung	< 0.005
Hemp	< 0.005	Used Cooking Oil	< 0.005
Hepar, High IV	< 0.005	Yellow Grease	< 0.005

Most of the biodiesel samples generated during this study presented <0.005 % volume as many samples had undetectable levels of water and sediment. A water layer was never observed. The *Lesquerella* biodiesel presented a green colored, gel-like sediment. *Lesquerella* biodiesel had a relatively high moisture level (0.073 wt %) and the biodiesel also appeared hazy.

8.10 Visual Inspection

The visual inspection test is a visual comparison method used to determine the presence of water and particulates in biodiesel. It is measured as a haze value by placing a line chart behind a clear jar of biodiesel and referencing how the lines compare to six different pictures with haze ratings from 1 to 6, with 1 being the least amount of particulates and 6 being the highest. A haze rating of 1 is the clearest; while a haze rating of 6 means that the biodiesel is very cloudy.

Materials and Methods

Visual inspection of biodiesel is determined by ASTM D4176, Standard Test Method for Free Water and Particulate Contamination in Distillate Fuels (Visual Inspection Procedures), Procedure 2.[47]

Results and Discussion

Table 8.10-1

Biodiesel	**Visual Inspection**	**Biodiesel**	**Visual Inspection**
Algae 1	1	Hepar, Low IV	1
Algae 2	1	Jatropha	1
Babassu	1	*Lesquerella fendleri*	2
Beef Tallow	1	Linseed	1
Borage	1	*Moringa oleifera*	1
Camelina	1	Mustard	Not enough sample
Canola	1	Neem	3
Castor	1	Palm	1
Choice White Grease	1	Perilla Seed	1
Coconut	1	Poultry Fat	1
Coffee	2	Rice Bran	1
Corn, Distiller's	1	Soybean	1
Cuphea viscosissima	Not enough sample	Stillingia	Not enough sample
Evening Primrose	1	Sunflower	1
Fish	1	Tung	1
Hemp	1	Used Cooking Oil	1
Hepar, High IV	1	Yellow Grease	1

Neem had the highest haze rating of 3. Neem had a low moisture content of 0.036 wt %, and no suspended water particles were seen in the neem biodiesel. Neem also had a low water and sediment result, of <0.005 % volume. One possible reason that the neem biodiesel has a high haze rating is that the neem oil has a high level of insoluble impurities. The insoluble impurities in neem oil were higher than any of the other feedstocks at 1.11 wt %.

Lesquerella fendleri biodiesel appeared to have moisture in it, which was verified by the Karl Fischer moisture result of 0.073 wt %. The *Lesquerella fendleri* biodiesel had the most moisture of any of the biodiesels that were tested and may have been related to the performance on the visual inspection test.

Coffee biodiesel did not appear to have moisture in it and had a low Karl Fischer moisture content of 0.030 wt %. The coffee biodiesel appeared to have a high level of particulates, but other biodiesel and feedstock test results were not indicative of a cause for the haze particles.

8.11 Free and Total Glycerin

Free and total glycerin is a measurement of how much triglyceride remains unconverted into methyl esters. Total glycerin is calculated from the amount of free glycerin, monoglycerides, diglycerides, and triglycerides.

Materials and Methods

Free and total glycerin was run in accordance with ASTM D6584, Standard Test Method for Determination of Free and Total Glycerin in B100 Biodiesel Methyl Esters by Gas Chromatography.[48] A PerkinElmer Inc. Clarus 600 gas chromatograph equipped with a Restek MXT-Biodiesel TG Column, 14 m, 0.53 mm ID, 0.16 µm film thickness with 2 m Integra-Gap was used. Calibration standards were purchased from Sigma-Aldrich Co.

Results and Discussion

Table 8.11-1, Free Glycerin

Biodiesel	**Free Glycerin (mass %)**	**Biodiesel**	**Free Glycerin (mass %)**
Algae 1	0.009	Hepar, Low IV	0.002
Algae 2	0.014	Jatropha	0.006
Babassu	0.008	*Lesquerella fendleri*	0.055
Beef Tallow	0.008	Linseed	0.001
Borage	0.001	*Moringa oleifera*	0.001
Camelina	0.002	Mustard	0.004
Canola	0.006	Neem	0.000
Castor	0.367	Palm	0.003
Choice White Grease	0.012	Perilla Seed	0.000
Coconut	0.025	Poultry Fat	0.002
Coffee	0.001	Rice Bran	0.001
Corn, Distiller's	0.001	Soybean	0.012
Cuphea viscosissima	0.002	Stillingia	0.000
Evening Primrose	0.005	Sunflower	0.007
Fish	0.006	Tung	0.015
Hemp	0.001	Used Cooking Oil	0.012
Hepar, High IV	0.002	Yellow Grease	0.009

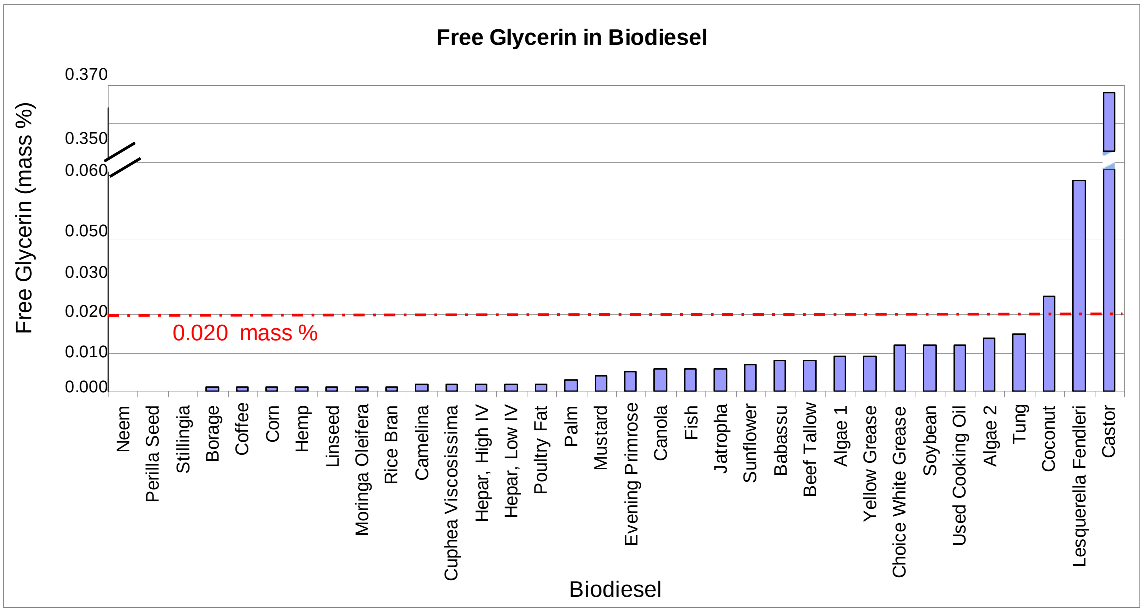


Fig. 8.11-1

Table 8.11-2, Monoglycerides

Biodiesel	**Monoglycerides (mass %)**	**Biodiesel**	**Monoglycerides (mass %)**
Algae 1	0.265	Hepar, Low IV	0.282
Algae 2	0.292	Jatropha	0.291
Babassu	0.341	*Lesquerella fendleri*	0.559
Beef Tallow	0.223	Linseed	0.392
Borage	0.250	*Moringa oleifera*	0.208
Camelina	0.222	Mustard	0.195
Canola	0.363	Neem	0.338
Castor	0.258	Palm	0.196
Choice White Grease	0.265	Perilla Seed	0.308
Coconut	0.130	Poultry Fat	0.244
Coffee	0.575	Rice Bran	0.281
Corn, Distiller's	0.197	Soybean	0.473
Cuphea viscosissima	0.780	Stillingia	0.359
Evening Primrose	0.386	Sunflower	0.387
Fish	0.118	Tung	0.120
Hemp	0.513	Used Cooking Oil	0.411
Hepar, High IV	0.227	Yellow Grease	0.300

Table 8.11-3, Diglycerides

Biodiesel	Diglycerides (mass %)	Biodiesel	Diglycerides (mass %)
Algae 1	0.078	Hepar, Low IV	0.072
Algae 2	0.070	Jatropha	0.104
Babassu	0.231	*Lesquerella fendleri*	0.710
Beef Tallow	0.063	Linseed	0.112
Borage	0.066	*Moringa oleifera*	0.070
Camelina	0.125	Mustard	0.040
Canola	0.127	Neem	0.474
Castor	0.479	Palm	0.095
Choice White Grease	0.089	Perilla Seed	0.075
Coconut	0.040	Poultry Fat	0.079
Coffee	0.175	Rice Bran	0.059
Corn, Distiller's	0.080	Soybean	0.088
Cuphea viscosissima	0.089	Stillingia	0.423
Evening Primrose	0.134	Sunflower	0.092
Fish	0.019	Tung	0.161
Hemp	0.101	Used Cooking Oil	0.161
Hepar, High IV	0.065	Yellow Grease	0.130

Table 8.11-4, Triglycerides

Biodiesel	Triglycerides (mass %)	Biodiesel	Triglycerides (mass %)
Algae 1	0.020	Hepar, Low IV	0.022
Algae 2	0.019	Jatropha	0.022
Babassu	0.038	*Lesquerella fendleri*	0.023
Beef Tallow	0.000	Linseed	0.000
Borage	0.000	*Moringa oleifera*	0.021
Camelina	0.022	Mustard	0.019
Canola	0.000	Neem	0.000
Castor	0.023	Palm	0.000
Choice White Grease	0.019	Perilla Seed	0.000
Coconut	0.000	Poultry Fat	0.020
Coffee	0.022	Rice Bran	0.000
Corn, Distiller's	0.021	Soybean	0.019
Cuphea viscosissima	0.000	Stillingia	0.000
Evening Primrose	0.035	Sunflower	0.000
Fish	0.000	Tung	0.000
Hemp	0.022	Used Cooking Oil	0.000
Hepar, High IV	0.000	Yellow Grease	0.019

Table 8.11-5, Total Glycerin

Biodiesel	Total Glycerin (mass %)	Biodiesel	Total Glycerin (mass %)
Algae 1	0.091	Hepar, Low IV	0.088
Algae 2	0.102	Jatropha	0.100
Babassu	0.135	*Lesquerella fendleri*	0.307
Beef Tallow	0.076	Linseed	0.120
Borage	0.076	*Moringa oleifera*	0.067
Camelina	0.080	Mustard	0.062
Canola	0.114	Neem	0.158
Castor	0.507	Palm	0.068
Choice White Grease	0.095	Perilla Seed	0.091
Coconut	0.065	Poultry Fat	0.079
Coffee	0.178	Rice Bran	0.083
Corn, Distiller's	0.066	Soybean	0.149
Cuphea viscosissima	0.218	Stillingia	0.156
Evening Primrose	0.128	Sunflower	0.121
Fish	0.040	Tung	0.070
Hemp	0.151	Used Cooking Oil	0.143
Hepar, High IV	0.070	Yellow Grease	0.108

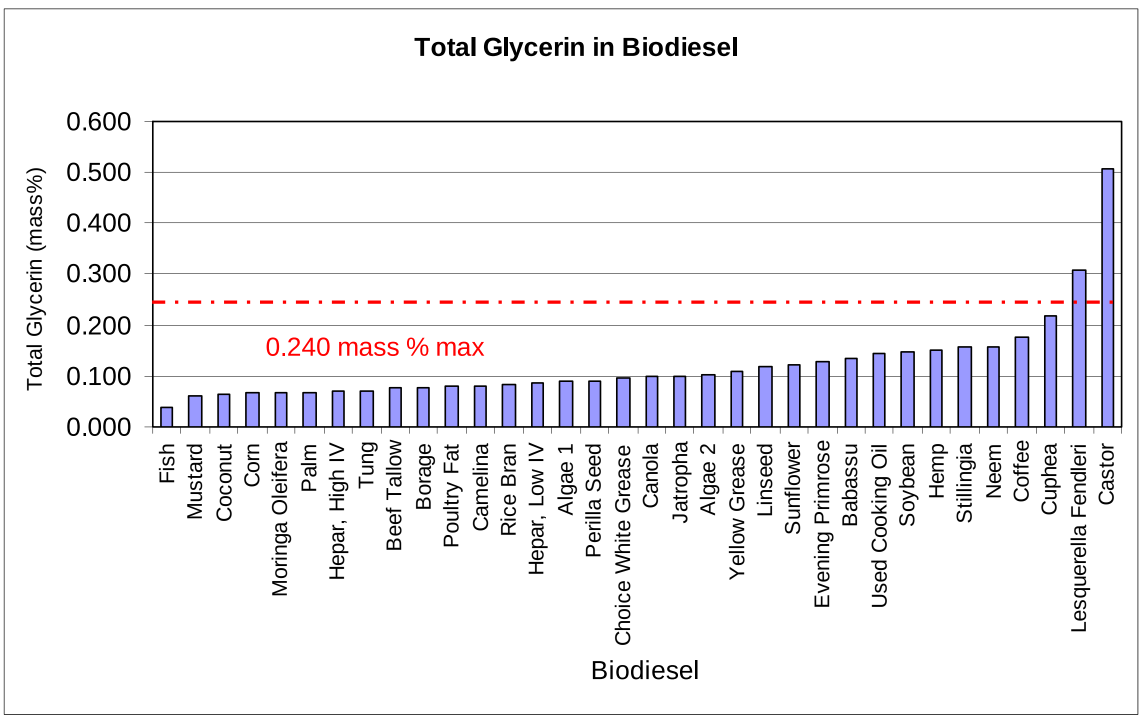


Fig. 8.11-2

ASTM D6751 specifies that the free glycerin must be under 0.020 mass % and that the total glycerin must be under 0.240 mass %.[33] Coconut, *Lesquerella*, and castor biodiesel failed the specification for free glycerin. *Lesquerella* and castor biodiesel failed the specification for total glycerin. It is hypothesized that additional water washes or longer settling times would reduce the levels of free and total glycerin in the finished product.

8.12 Flash Point

The flash point is the lowest temperature at which fuel emits enough vapors to ignite.[49] Biodiesel has a high flash point; usually more than 150°C, while conventional diesel fuel has a flash point of 55-66°C.[16] If methanol, with its flash point of 12°C is present in the biodiesel the flash point can be lowered considerably.[50] To ensure that the methanol has been adequately stripped from the biodiesel, the Pensky-Martens closed cup flash point test was adopted.

Materials and Methods

The flash points were measured with a Pensky-Martens closed cup tester (Koehler Instrument Company, Inc. K16200) using ASTM D93, Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester.[49] The apparatus and method consist of the controlled heating of the biodiesel in a closed cup, introducing an ignition source, and observing if the heated biodiesel flashes. The temperature at which the biodiesel flashes is recorded as the flash point. For biodiesel, a flash point of below 93°C is considered to be out of specification.[33] If the biodiesel has not flashed at 160°C, the test is finished and the result is reported as >160°C.[49]

Results and Discussion

Table 8.12-1

Biodiesel	**Flash Point (°C)**	**Biodiesel**	**Flash Point (°C)**
Algae 1	>160	Hepar, Low IV	>160
Algae 2	>160	Jatropha	>160
Babassu	135	*Lesquerella fendleri*	>160
Beef Tallow	>160	Linseed	>160
Borage	>160	*Moringa oleifera*	>160
Camelina	>160	Mustard	Not enough sample
Canola	>160	Neem	>160
Castor	>160	Palm	>160
Choice White Grease	>160	Perilla Seed	>160
Coconut	115	Poultry Fat	>160
Coffee	>160	Rice Bran	>160
Corn, Distiller's	>160	Soybean	>160
Cuphea viscosissima	Not enough sample	Stillingia	Not enough sample
Evening Primrose	>160	Sunflower	>160
Fish	>160	Tung	>160
Hemp	>160	Used Cooking Oil	>160
Hepar, High IV	>160	Yellow Grease	>160

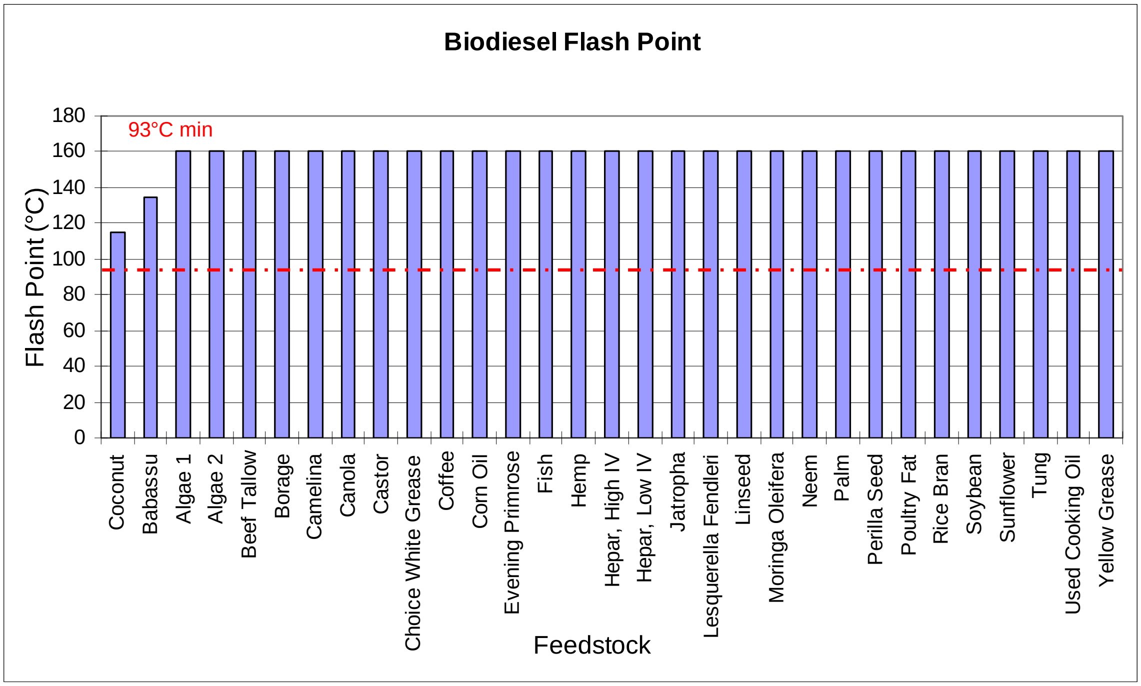


Fig. 8.12-1

None of the measured flash points are less than 93°C and almost all the flash points are above 160°C, indicating very low methanol levels in the biodiesel. The exceptions are babassu biodiesel with a flash point of 135°C, and coconut biodiesel with a flash point of 115°C. These flash points are probably not due to the methanol content since the methanol was stripped from them in a similar manner as the other biodiesel samples. The lower flash points in babassu and coconut biodiesel are more likely due to the presence of methyl esters with a chain length of less than 12 carbons. Methyl esters with these chain lengths have lower flash points than the C16 and C18 carbon chain lengths which predominate in biodiesel. The Pensky-Martens closed cup flash point of C10 methyl ester, methyl caprate, is 93.3 to 97.8°C.[51] The Pensky-Martens closed cup flash point of C8 methyl ester, methyl caprylate, is 74°C.[52] The babassu biodiesel contains 0.5 % methyl caprylate and 3.8 % methyl caprate while the coconut biodiesel contained 6.3 % methyl caprylate and 6.0 % methyl caprate.

8.13 Copper Corrosion

The copper corrosion test measures corrosion forming tendencies of fuel when used with copper, brass, or bronze parts. The presence of acids or sulfur can tarnish copper.[33]

Materials and Methods

Copper corrosion is tested using ASTM D130; Standard Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test.[53] A polished copper strip is immersed in biodiesel and allowed to heat in a 50°C water bath for 3 hours. After 3 hours, the strip is removed, examined, and compared with a set of copper strip corrosion standards furnished by ASTM. A Koehler Instrument Company, Inc. copper strip corrosion test tube bath was used, model K25330.

Results and Discussion

Table 8.13-1

Biodiesel	**Copper Corrosion**	**Biodiesel**	**Copper Corrosion**
Algae 1	1a	Hepar, Low IV	1a
Algae 2	1a	Jatropha	1a
Babassu	1a	*Lesquerella fendleri*	1a
Beef Tallow	1a	Linseed	1a
Borage	1a	*Moringa oleifera*	1a
Camelina	1a	Mustard	Not enough sample
Canola	1a	Neem	1b
Castor	1a	Palm	1a
Choice White Grease	1a	Perilla Seed	1a
Coconut	1b	Poultry Fat	1a
Coffee	1a	Rice Bran	1a
Corn, Distiller's	1a	Soybean	1a
Cuphea viscosissima	Not enough sample	Stillingia	Not enough sample
Evening Primrose	1a	Sunflower	1a
Fish	1a	Tung	1a
Hemp	1a	Used Cooking Oil	1a
Hepar, High IV	1a	Yellow Grease	1a

The ASTM D6751 limit for copper corrosion is number 3.[33] All of the biodiesel passed ASTM specifications. Coconut and neem biodiesel have a rating of 1b, which is slightly more orange colored and tarnished than 1a; however the strips did not show any major degradation or discoloration.

8.14 Phosphorous, Calcium, and Magnesium

The specifications from ASTM D6751 state that in biodiesel, the phosphorous must be less than 10 ppm, and calcium and magnesium combined must be less than 5 ppm.[33]

Materials and Methods

Phosphorous was determined using ASTM D4951, Standard Test Method for Determination of Additive Elements in Lubricating Oils by Inductively Coupled Plasma Atomic Emission Spectrometry.[36] Calcium and Magnesium were determined using EN Standard 14538, Fat and Oil Derivatives – Fatty Acid Methyl Ester (FAME) - Determination of Ca, K, Mg, and Na content by optical emission spectral analysis with inductively coupled plasma (ICP OES).[54]

The biodiesel samples were run on a PerkinElmer Inc. Optima 7000 dual view ICP-OES with a cyclonic spray chamber. Cobalt was used as the internal standard, and PremiSolv (a light hydrotreated distillate, manufactured by Conostan) was used as the base oil.

Results and Discussion:

Table 8.14-1

Biodiesel	**Phosphorous (ppm)**	**Biodiesel**	**Phosphorous (ppm)**
Algae 1	<0.1	Hepar, Low IV	<0.1
Algae 2	<0.1	Jatropha	<0.1
Babassu	<0.1	*Lesquerella fendleri*	<0.1
Beef Tallow	<0.1	Linseed	<0.1
Borage	<0.1	*Moringa oleifera*	<0.1
Camelina	<0.1	Mustard	<0.1
Canola	<0.1	Neem	<0.1
Castor	<0.1	Palm	<0.1
Choice White Grease	<0.1	Perilla Seed	<0.1
Coconut	<0.1	Poultry Fat	<0.1
Coffee	<0.1	Rice Bran	<0.1
Corn, Distiller's	<0.1	Soybean	<0.1
Cuphea viscosissima	<0.1	Stillingia	<0.1
Evening Primrose	<0.1	Sunflower	<0.1
Fish	<0.1	Tung	0.9
Hemp	<0.1	Used Cooking Oil	<0.1
Hepar, High IV	<0.1	Yellow Grease	<0.1

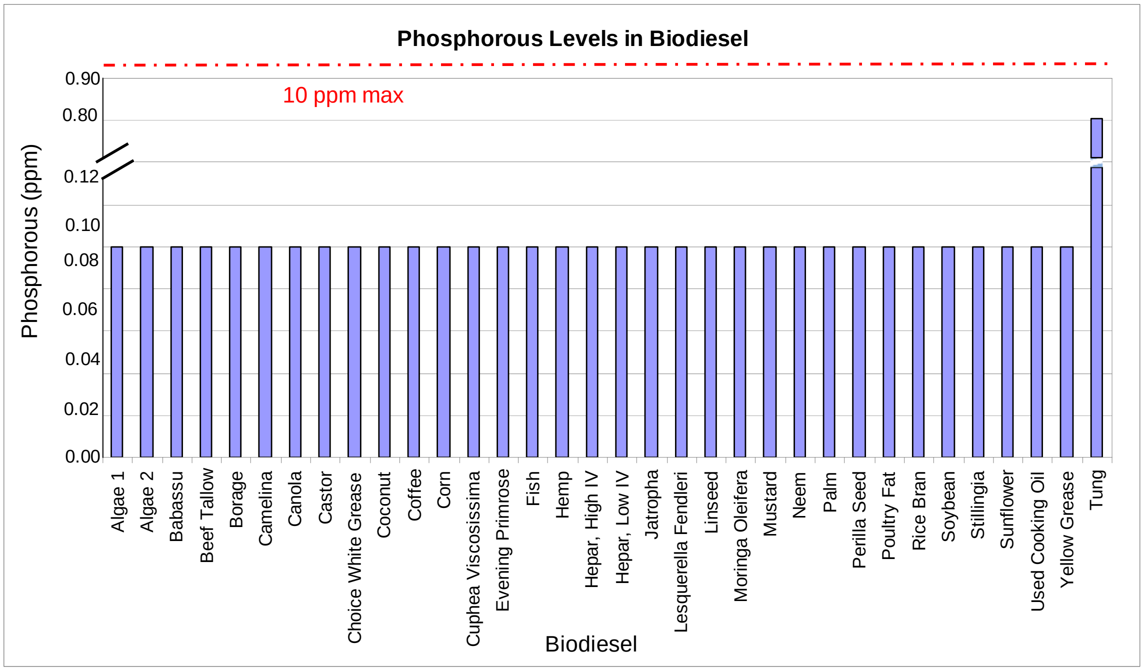


Fig. 8.14-1

The phosphorous for the biodiesel samples was undetectable for all of the samples except for tung biodiesel. Tung biodiesel was measured at 0.9 ppm, which is well below the specification of 10 ppm.

Table 8.14-2

Biodiesel	Calcium (ppm)	Biodiesel	Calcium (ppm)
Algae 1	<0.1	Hepar, Low IV	0.2
Algae 2	0.7	Jatropha	<0.1
Babassu	0.5	*Lesquerella fendleri*	0.2
Beef Tallow	<0.1	Linseed	<0.1
Borage	1.2	*Moringa oleifera*	<0.1
Camelina	0.8	Mustard	<0.1
Canola	0.4	Neem	0.3
Castor	0.1	Palm	<0.1
Choice White Grease	<0.1	Perilla Seed	<0.1
Coconut	<0.1	Poultry Fat	<0.1
Coffee	<0.1	Rice Bran	0.4
Corn, Distiller's	0.6	Soybean	<0.1
Cuphea viscosissima	7.2	Stillingia	0.5
Evening Primrose	<0.1	Sunflower	<0.1
Fish	<0.1	Tung	0.2
Hemp	<0.1	Used Cooking Oil	0.6
Hepar, High IV	<0.1	Yellow Grease	<0.1

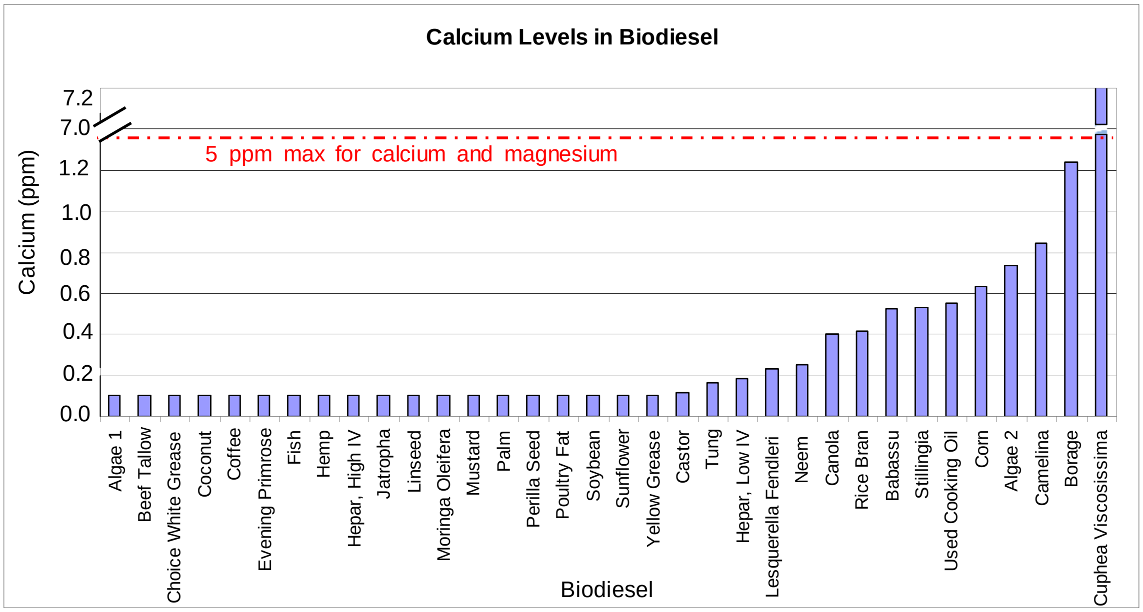


Fig. 8.14-2

All but one of the biodiesel samples had very small amounts of calcium present. The *Cuphea* biodiesel had a larger amount of calcium than in the oil. The oil was found to contain less than 0.1 ppm of calcium and it is unknown why the result for calcium in biodiesel was more than the result for the oil.

Table 8.14-3

Biodiesel	**Magnesium (ppm)**	**Biodiesel**	**Magnesium (ppm)**
Algae 1	0.3	Hepar, Low IV	1.6
Algae 2	1.1	Jatropha	0.3
Babassu	0.4	*Lesquerella fendleri*	0.4
Beef Tallow	0.3	Linseed	0.3
Borage	0.4	*Moringa oleifera*	0.3
Camelina	1.1	Mustard	0.5
Canola	0.5	Neem	0.9
Castor	0.1	Palm	0.3
Choice White Grease	0.3	Perilla Seed	0.3
Coconut	0.3	Poultry Fat	0.3
Coffee	0.3	Rice Bran	1.1
Corn, Distiller's	1.0	Soybean	0.3
Cuphea viscosissima	1.1	Stillingia	0.4
Evening Primrose	0.3	Sunflower	0.3
Fish	0.3	Tung	0.4
Hemp	0.3	Used Cooking Oil	1.1
Hepar, High IV	0.3	Yellow Grease	0.4

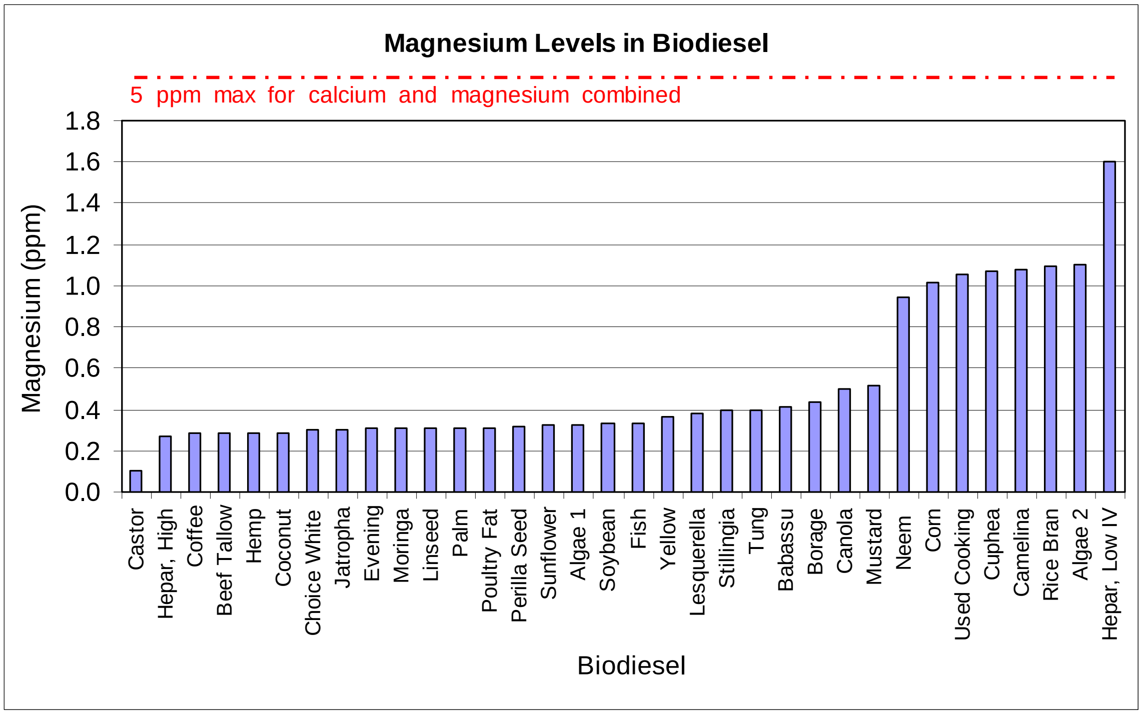


Fig. 8.14-3

All of the magnesium results show that the magnesium was effectively reduced during pretreatment and transesterification.

8.15 Total Acid Number (TAN)

The TAN determination is an important test to assess the quality of a particular biodiesel. It can indicate the degree of hydrolysis of the methyl ester, a particularly important aspect when considering storage and transportation as large quantities of free fatty acids can cause corrosion in tanks.[55]

Materials and Methods

The TAN determination in the biodiesel samples was performed following ASTM D664 Standard Test Method for Acid Number of Petroleum Products by Potentiometric Titration, Method A.[18] The tests were performed on an 836 Titrando titrator, manufactured by Metrohm Inc., and a Dosino dispensing unit.

Results and Discussion

Table 8.15-1

Biodiesel	**Total Acid Number (mg KOH/g)**	**Biodiesel**	**Total Acid Number (mg KOH/g)**
Algae 1	0.022	Hepar, Low IV	0.165
Algae 2	0.003	Jatropha	0.156
Babassu	0.431	*Lesquerella fendleri*	0.630
Beef Tallow	0.147	Linseed	0.058
Borage	0.138	*Moringa oleifera*	0.185
Camelina	0.338	Mustard	0.037
Canola	0.010	Neem	0.649
Castor	0.996	Palm	0.046
Choice White Grease	0.021	Perilla Seed	0.293
Coconut	0.106	Poultry Fat	0.044
Coffee	0.076	Rice Bran	0.586
Corn, Distiller's	0.283	Soybean	0.266
Cuphea viscosissima	2.141	Stillingia	0.708
Evening Primrose	0.370	Sunflower	0.027
Fish	0.085	Tung	0.001
Hemp	0.097	Used Cooking Oil	0.332
Hepar, High IV	0.062	Yellow Grease	0.073

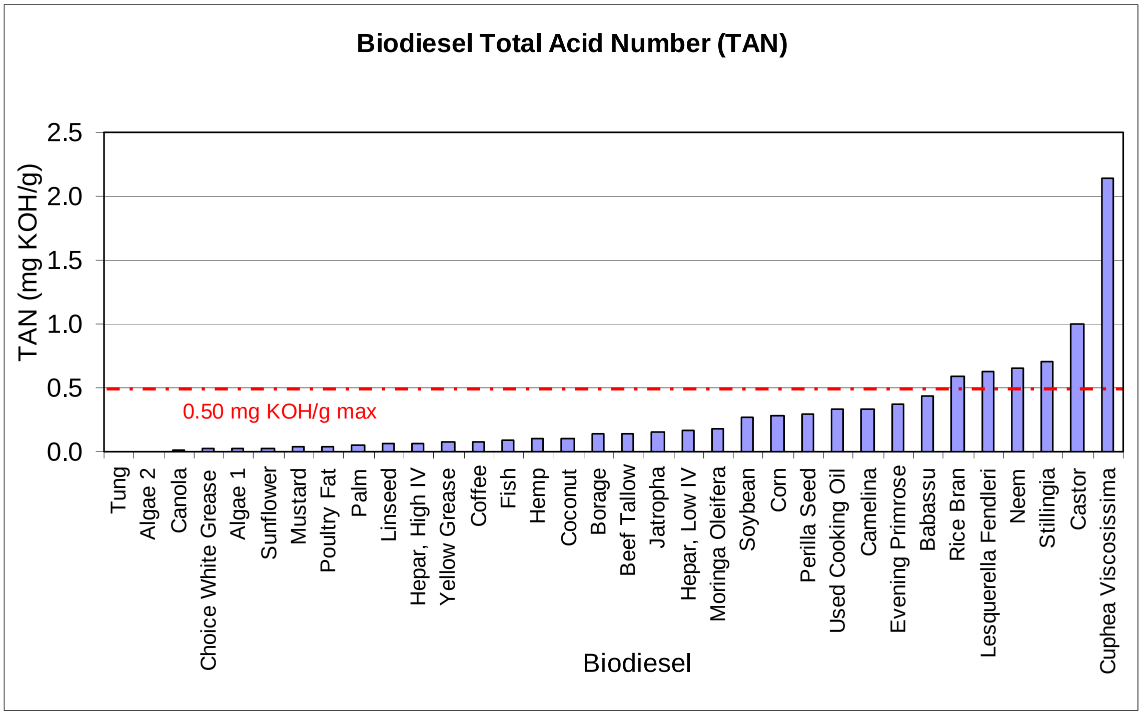


Fig. 8.15-1

Most of the biodiesel are within specification as they fall under the ASTM limit for TAN (0.5 mg KOH/g).[33] Rice bran, *Lesquerella*, neem, stillingia, castor and *Cuphea*, all had values that were higher than 0.5 mg KOH/g. Reasons for high total acid numbers in some biodiesels were not investigated further.

8.16 Moisture

Materials and Methods

The moisture in the biodiesels was measured in accordance with ASTM E203 Standard Test Method for Water Using Volumetric Karl Fischer Titration[17] on a volumetric Titrando manufactured by Metrohm, Inc.

Results and Discussion

Table 8.16-1

Biodiesel	Moisture (wt %)	Biodiesel	Moisture (wt %)
Algae 1	0.037	Hepar, Low IV	0.026
Algae 2	0.026	Jatropha	0.022
Babassu	0.040	*Lesquerella fendleri*	0.073
Beef Tallow	0.038	Linseed	0.042
Borage	0.041	*Moringa oleifera*	0.060
Camelina	0.040	Mustard	0.021
Canola	0.036	Neem	0.036
Castor	0.053	Palm	0.083
Choice White Grease	0.026	Perilla Seed	0.042
Coconut	0.034	Poultry Fat	0.052
Coffee	0.030	Rice Bran	0.015
Corn, Distiller's	0.032	Soybean	0.035
Cuphea viscosissima	0.050	Stillingia	0.052
Evening Primrose	0.031	Sunflower	0.032
Fish	0.056	Tung	0.067
Hemp	0.031	Used Cooking Oil	0.038
Hepar, High IV	0.024	Yellow Grease	0.036

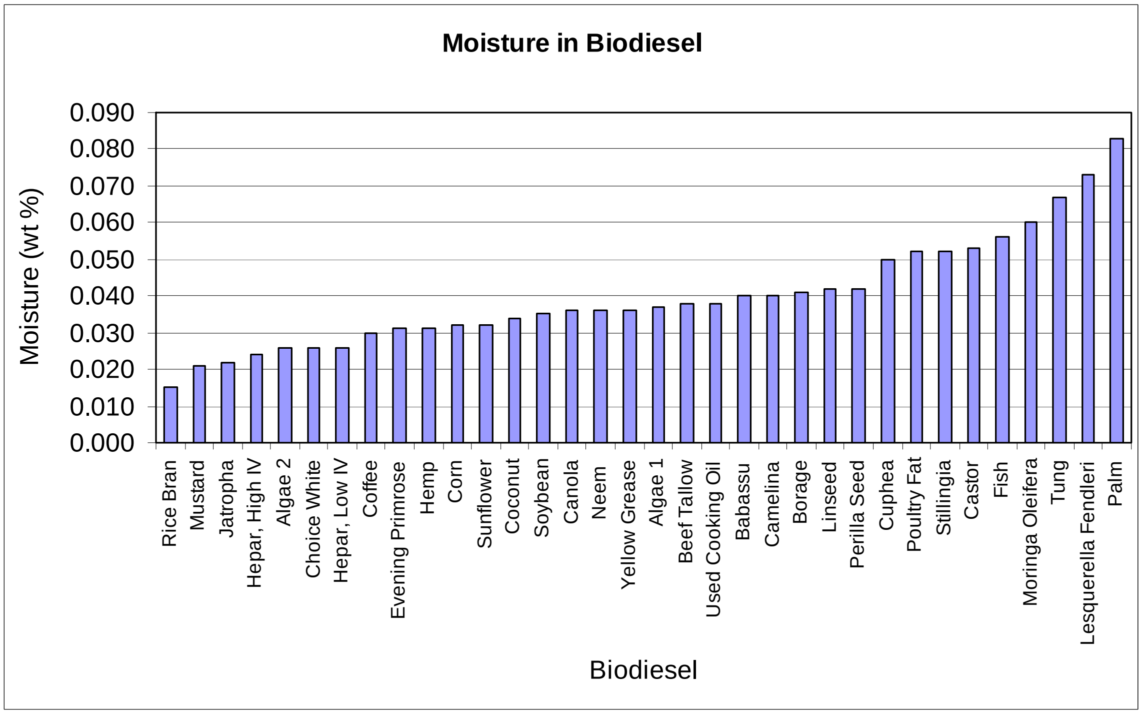


Fig. 8.16-1

Currently there is no ASTM D6751 specification for Karl Fischer moisture. The water specification is ASTM D2709, Standard Test Method for Water and Sediment in Middle Distillate Fuels by Centrifuge.[46] All the biodiesels made in this study are well below the water saturation point in biodiesel (up to 1500 ppm).[16] In Europe, standard EN 14214 has a Karl Fischer moisture specification of 0.050 wt % maximum.[43] As can be seen in Table 8.16-1 and Fig. 8.16-1, 8 of the 34 biodiesels made did not meet the EN specification. To bring biodiesel moisture down to meet the EN specification, further treatment with heat and vacuum or with an absorbent may be tried.

8.17 Sulfur

In 2006, the U.S. Environmental Protection Agency mandated all on-road diesel fuel to have less than 15 ppm of sulfur. Beginning in 2010, off-road, locomotive, and marine fuels will begin to have a specification of less than 15 ppm sulfur for all No.1 and No.2 diesel fuel in the United States, with some rules being implemented over time.[16]

Materials and Methods

Sulfur was measured using ASTM D7039, Standard Test Method for Sulfur in Gasoline and Diesel Fuel by Monochromatic Wavelength Dispersive X-ray Fluorescence Spectrometry.[32] A Sindie Bio Bench Top sulfur analyzer manufactured by X-Ray Optical Systems, Inc. was used to measure the amount of sulfur.

Results and Discussion

Table 8.17-1

Biodiesel	Sulfur (ppm)	Biodiesel	Sulfur (ppm)
Algae 1	5.1	Hepar, Low IV	3.1
Algae 2	0.6	Jatropha	1.2
Babassu	5.3	*Lesquerella fendleri*	180.0
Beef Tallow	7.0	Linseed	1.9
Borage	1.3	*Moringa oleifera*	9.9
Camelina	0.6	Mustard	0.9
Canola	1.4	Neem	473.8
Castor	1.3	Palm	1.2
Choice White Grease	5.4	Perilla Seed	1.5
Coconut	3.2	Poultry Fat	21.1
Coffee	9.7	Rice Bran	6.0
Corn, Distiller's	4.6	Soybean	0.8
Cuphea viscosissima	Not enough sample	Stillingia	1.5
Evening Primrose	1.1	Sunflower	0.2
Fish	9.3	Tung	13.3
Hemp	0.4	Used Cooking Oil	2.4
Hepar, High IV	3.4	Yellow Grease	6.2

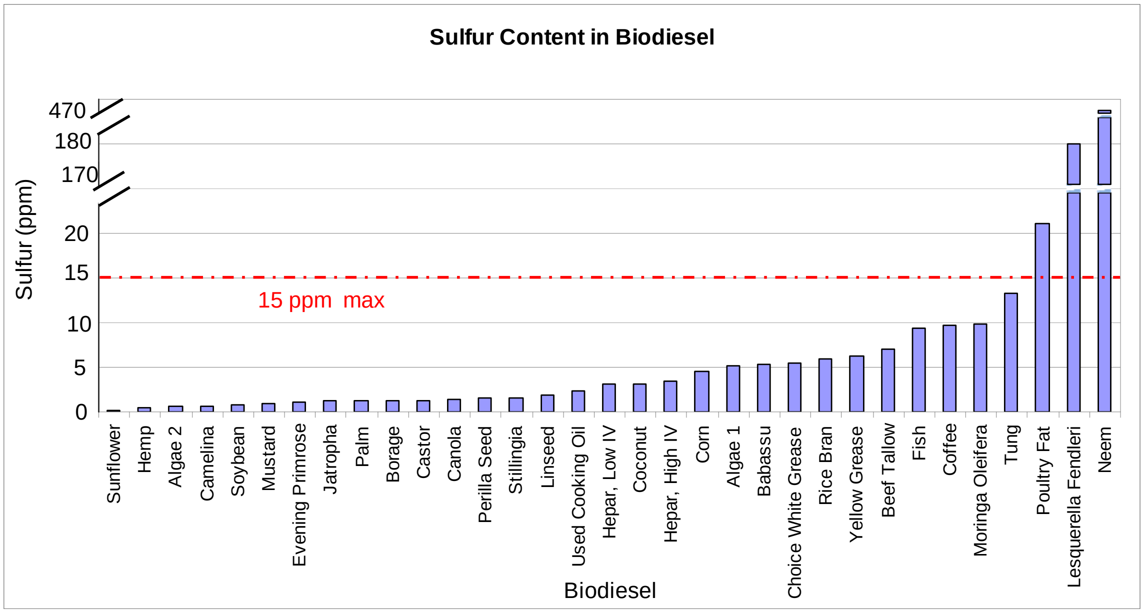


Fig. 8.17-1

As seen from Fig. 8.17-1, the sulfur content of biodiesel is below the ASTM D6751 limit of 15 ppm except for neem, *Lesquerella* and poultry fat biodiesel. Table 8.17-2 also shows the amount of sulfur present in the crude feedstocks used to make the biodiesel.

Pretreatment and transesterification are able to reduce sulfur contents to some extent. For feedstocks such as neem and *Lesquerella*, additional pretreatment may be required to remove the sulfur so the biodiesel passes ASTM D6751.

The sulfur content of some of the biodiesels was higher than their respective feedstock. There are a number of possible explanations including the applicability of ASTM D7039 to crude oil and fat and the higher viscosity of some feedstocks compared with the calibration standards. These explanations were not investigated further.

8.18 Oxidation Stability

Oxidation stability is an important parameter to investigate; it is an indication of the degree of oxidation, potential reactivity with air, and can determine the need for antioxidants.[56]

Materials and Methods

The determination of the oxidation stability for the oils and fats used in this study is performed following EN 14112, Determination of Oxidation Stability, with a 743 Rancimat (Metrohm, Inc.) instrument.[31] Three grams of biodiesel in a test tube is heated to 110°C and connected to an air bubbler until the measurement of conductivity versus time in a water vessel attached to the sample test tube reaches the inflection point. The result is performed in duplicate and expressed as an average in units of time (h). The higher the value the more stable the biodiesel is towards oxidation by air.

Table 8.18-1

Biodiesel	**Oxidation Stability (h)**	**Biodiesel**	**Oxidation Stability (h)**
Algae 1	8.5	Hepar, Low IV	1.2
Algae 2	11.0	Jatropha	2.3
Babassu	15.7	*Lesquerella fendleri*	10.5
Beef Tallow	1.6	Linseed	0.2
Borage	1.8	*Moringa oleifera*	2.3
Camelina	1.3	Mustard	1.1
Canola	7.6	Neem	7.1
Castor	1.1	Palm	0.2
Choice White Grease	0.2	Perilla Seed	0.2
Coconut	35.5	Poultry Fat	11.0
Coffee	8.1	Rice Bran	0.4
Corn, Distiller's	2.2	Soybean	2.1
Cuphea viscosissima	9.6	Stillingia	Unable to Determine
Evening Primrose	0.2	Sunflower	0.9
Fish	0.2	Tung	0.4
Hemp	0.9	Used Cooking Oil	1.0
Hepar, High IV	1.4	Yellow Grease	5.2

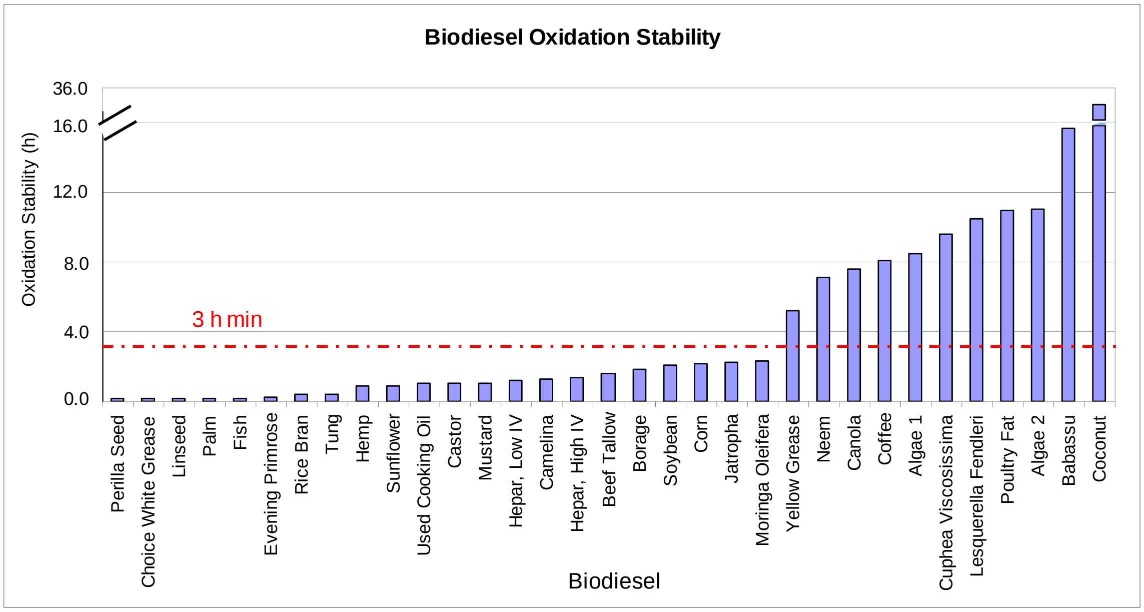


Fig. 8.18-1

Stillingia biodiesel exhibited conductivity higher than the maximum measurable by the Rancimat apparatus and an induction point was never reached. Therefore, an induction period was not calculated.

Some of the biodiesel samples exhibited bubbling to the top of the test tube at the 110°C testing temperature, which may have lead to erroneous results. To limit leakage from the tube, electrical tape was wrapped around the cap and test tube junction.

As a general observation, all the biodiesels in this study, aside from a few exceptions, presented oxidation stabilities lower than the respective oil or fat. Biodiesel made with feedstocks that have high concentrations of saturated fatty acids in general show better stability.

Under laboratory conditions, feedstock and biodiesel have a much greater chance to become oxidized as there are many opportunities for air to enter the system. The ratio of biodiesel to air is much greater when making small, laboratory batches and the laboratory conditions used in the production process exposed the biodiesel to heat and mixing in the presence of air which can increase the oxidation reactions. Therefore, it is the opinion of the authors that these oxidative stability results would not be indicative of the actual oxidative stability obtained in a commercial scale production process.

8.19 FTIR

FTIR (Fourier Transform Infra Red) is used to examine the functional groups of molecules. It does this by measuring the energy associated with the vibration of atoms that are connected together. FTIR has been used to elucidate structures in biodiesel and oleochemicals. AOCS Methods Cd 14-95 (00) and Cd 14d-99 (99) quantify the amount of *trans* acids in fats, oils and oleochemicals by FTIR.[57,58] ASTM D7371 uses FTIR to determine the amount of biodiesel in blended fuels.[59] Material at or less than 1 wt % may not be detectable by FTIR.

Materials and Methods

The FTIR of the finished biodiesel samples were made with a PerkinElmer Inc. 100 spectrometer with attenuated total reflectance (ATR) sampling attachment and a resolution of 4° per cm^{-1}. The spectra were taken at room temperature and in a range of 4000 – 650 cm^{-1}. Air spectrum was used as the background.

Results and Discussion

For biodiesel, the FTIR spectra is characterized by a series of peaks from 3100 cm^{-1} to 2750 cm^{-1}, a strong peak from 1745 cm^{-1} to 1740 cm^{-1}, a series of peaks from 1470 cm^{-1} to 1430 cm^{-1}, a peak at 1360 cm^{-1}, as well as a series of peaks from 1220 cm^{-1} to 1160 cm^{-1}, 1020 cm^{-1} to 970 cm^{-1}, 920 cm^{-1} to 840 cm^{-1}, and a peak at 720 cm^{-1}. These peaks are characteristic of the long chain fatty acid methyl esters which predominate in biodiesel.

Differences in the amount of unsaturation in biodiesel are responsible for variations in smaller peaks in the 1660 cm^{-1} and 1400 cm^{-1} region and for biodiesel high in methyl linoleate in the 790 cm^{-1} region.

The 1745 cm^{-1} to 1740 cm^{-1} peak is due to the carbonyl (C=O) of the ester group. This peak is not symmetrical. It has a series of shoulders at 1740 cm^{-1} to 1730 cm^{-1} associated with monoglycerides and 1720 cm^{-1} to 1710 cm^{-1} associated with free fatty acids.

The major differences seen in the FTIR between the feedstocks are in castor and *Lesquerella* biodiesel. The differences in the FTIR are similar for both of these biodiesels and are due to the presence of hydroxy esters. The presence of hydroxy esters adds a wide absorbance in the 3460 cm^{-1} region, a large absorbance in the 860 cm^{-1} region, and the region between 1100-950 cm^{-1} is different from other fatty acid methyl esters.

The castor biodiesel also has a very unsymmetrical carbonyl absorbance at 1742 cm^{-1}. There is a large shoulder at 1740 cm^{-1}. This shoulder is probably a carbonyl absorbance from an ester other than a methyl ester. It is probably not due to glycerides since it occurs at a higher wave number than is expected for the glycerides. Other biodiesels with similar glyceride contents do not exhibit this shoulder.

The FTIR of tung biodiesel also showed differences with an absorbance at 1585 cm^{-1} as well as at 992 cm^{-1} and 964 cm^{-1}. These absorbances are most likely due to the unique fatty acid methyl ester found in tung biodiesel, methyl α-eleostearate. The absorbances at 992 cm^{-1} and 964 cm^{-1} may be due to the large quantity of *trans* double bonds present in tung biodiesel. The fish oil biodiesel also has a prominent absorbance at 992 cm^{-1}, possibly indicating the presence of *trans* double bonds.

The FTIR of biodiesels from a variety of feedstocks from vegetable and animal origins are very similar. They can be recognized as being fatty acid methyl esters. Differences in unsaturation and the amount of *trans* double bonds are noticeable. The detection of fatty acid methyl ester with other functional groups can be readily discerned. The presence of some minor components can also be detected and sometimes quantified.

9 Feedstock Supplier Information

Botanic Oil Innovations, Inc.
1540 South River Street
Spooner, WI 54801
Phone: (715) 635-7513
Fax: (715) 635-7519
Homepage: www.botanicoil.com

Jedwards International, Inc.
39 Broad Street
Quincy, MA 02169
Phone: (617) 472-9300
Fax: (617) 472-9359
Homepage: www.bulknaturaloils.com

National Center for Agricultural Utilization Research (NCAUR)
Steven C. Cermak
New Crops and Processing Technology Research Unit
1815 N. University
Peoria, IL 61604

Oils by Nature, Inc.
30300 Solon Industrial Parkway, Suite E
Solon, Ohio 44139
Phone: (440) 498-1180
Fax: (440) 498-0574
Homepage: www.oilsbynature.com

School of Plant, Environmental, and Soil Sciences (SPESS)
Louisiana State University AgCenter
Gary Breitenbeck
314 M. B. Sturgis
Baton Rouge, LA 70803
Phone: (225) 578-1362

Sigma-Aldrich Corp.
3050 Spruce Street
St. Louis, MO 63103
Phone: (314) 771-5765
Homepage: www.sigmaaldrich.com/united-states.html

Solazyme, Inc.
561 Eccles Ave.
South San Francisco, CA 94080
Phone: (650) 780-4777
Fax: (650) 989-6700

Technology Crops International
PO Box 11925
Winston-Salem, NC 27116
Toll free: (877) 780-5882
Fax: (336) 759-9406

The Ahimsa Alternative, Inc.
15 Timberglade Rd.
Bloomington, MN 55437
Phone: (877)-873-6336
Fax: (866) 211-5460
Homepage: www.neemresource.com

Wildlife Sciences
David Pichotta
4268 Norex Dr.
Chaska, MN 55318
Phone: (888) 316-2473
Fax: (952) 368-4234
Homepage: www.suetplus.com

10 Biodiesel Certificates of Analysis

10.1 Algae 1

Biodiesel Certificate of Analysis

Feedstock: Algae 1	Product Type: B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	-5.2 *(22.64)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	-7	N/A	**°C**	D 6371
Free Glycerin:	0.009	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.091	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.265	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.078	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.020	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.022	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8780	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	8.5	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	> 160	93 min.	**°C**	D 93
Moisture[5]:	0.037	N/A	**% Mass**	E 203
Cold Soak Filtration:	85	360	**seconds**	D 6751 Annex
Sulfur:	5.1	15	**ppm**	D 7039
Calcium:	<0.1	5 max. Ca+Mg	**ppm (ug/g)**	EN 14538
Magnesium:	0.3	5 max. Ca+Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.007	0.050 max.	**% Mass**	D 524
Sulfated Ash:	<0.005	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	4.519	1.9-6.0	**mm²/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric		%	AOCS Ce1c-89
C14:0	Myristic	0.6	%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	6.9	%	AOCS Ce1c-89
C16:1	Palmitoleic	0.2	%	AOCS Ce1c-89
C17:0	Margaric		%	AOCS Ce1c-89
C17:1	Margaroleic		%	AOCS Ce1c-89
C18:0	Stearic	3.0	%	AOCS Ce1c-89
C18:1	Oleic	75.2	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	12.4	%	AOCS Ce1c-89
C18:3	Linolenic	1.2	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic	0.4	%	AOCS Ce1c-89
C20:1	Gadoleic		%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic		%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic	0.1	%	AOCS Ce1c-89
C22:1	Erucic		%	AOCS Ce1c-89
C24:0	Lignoceric		%	AOCS Ce1c-89
C24:1	Nervonic		%	AOCS Ce1c-89
UNKNOWNS			%	AOCS Ce1c-89

10.2 Algae 2

Biodiesel Certificate of Analysis

Feedstock: Algae 2 **Product Type:** B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	3.9 *(39.02)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	2	N/A	**°C**	D 6371
Free Glycerin:	0.014	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.102	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.292	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.070	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.019	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.003	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8780	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	11.0	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	> 160	93 min.	**°C**	D 93
Moisture[5]:	0.026	N/A	**% Mass**	E 203
Cold Soak Filtration:	84	360	**seconds**	D 6751 Annex
Sulfur:	0.6	15	**ppm**	D 7039
Calcium:	0.7	5 max. Ca+Mg	**ppm (ug/g)**	EN 14538
Magnesium:	1.1	5 max. Ca+Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.042	0.050 max.	**% Mass**	D 524
Sulfated Ash:	<0.005	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	4.624	1.9-6.0	**mm²/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

The fatty acid profile for algae 2 is proprietary data and publication is withheld by the supplier.

10.3 Babassu

Biodiesel Certificate of Analysis

Feedstock: Babassu	Product Type: B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	4.0 *(39.2)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	10	N/A	**°C**	D 6371
Free Glycerin:	0.008	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.135	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.341	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.231	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.038	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.431	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8760	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	15.7	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	134.7	93 min.	**°C**	D 93
Moisture[5]:	0.040	N/A	**% Mass**	E 203
Cold Soak Filtration:	310	360	**seconds**	D 6751 Annex
Sulfur:	5.3	15	**ppm**	D 7039
Calcium:	0.5	5 max. Ca+Mg	**ppm (ug/g)**	EN 14538
Magnesium:	0.4	5 max. Ca+Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.050	0.050 max.	**% Mass**	D 524
Sulfated Ash:	<0.005	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	3.239	1.9-6.0	**mm²/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic	0.5	%	AOCS Ce1c-89
C10:0	Capric	3.8	%	AOCS Ce1c-89
C12:0	Lauric	48.8	%	AOCS Ce1c-89
C14:0	Myristic	17.2	%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	9.7	%	AOCS Ce1c-89
C16:1	Palmitoleic		%	AOCS Ce1c-89
C17:0	Margaric		%	AOCS Ce1c-89
C17:1	Margaroleic		%	AOCS Ce1c-89
C18:0	Stearic	4.0	%	AOCS Ce1c-89
C18:1	Oleic	14.2	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	1.8	%	AOCS Ce1c-89
C18:3	Linolenic		%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic		%	AOCS Ce1c-89
C20:1	Gadoleic		%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic		%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic		%	AOCS Ce1c-89
C22:1	Erucic		%	AOCS Ce1c-89
C24:0	Lignoceric		%	AOCS Ce1c-89
C24:1	Nervonic		%	AOCS Ce1c-89
UNKNOWNS			%	AOCS Ce1c-89

10.4 Beef Tallow

Biodiesel Certificate of Analysis

Feedstock: Beef Tallow | **Product Type:** B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	16.0 *(60.8)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	14	N/A	**°C**	D 6371
Free Glycerin:	0.008	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.076	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.223	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.063	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.000	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.147	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8740	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	1.6	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	>160	93 min.	**°C**	D 93
Moisture[5]:	0.038	N/A	**% Mass**	E 203
Cold Soak Filtration:	76	360	**seconds**	D 6751 Annex
Sulfur:	7	15	**ppm**	D 7039
Calcium:	<0.1	5 max. Ca+Mg	**ppm (ug/g)**	EN 14538
Magnesium:	0.3	5 max. Ca+Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.028	0.050 max.	**% Mass**	D 524
Sulfated Ash:	<0.005	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	4.824	1.9-6.0	**mm²/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric	0.2	%	AOCS Ce1c-89
C14:0	Myristic	2.9	%	AOCS Ce1c-89
C15:0	Pentadecanoic	0.6	%	AOCS Ce1c-89
C16:0	Palmitic	24.3	%	AOCS Ce1c-89
C16:1	Palmitoleic	2.1	%	AOCS Ce1c-89
C17:0	Margaric	1.2	%	AOCS Ce1c-89
C17:1	Margaroleic	0.4	%	AOCS Ce1c-89
C18:0	Stearic	22.8	%	AOCS Ce1c-89
C18:1	Oleic	40.2	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	3.3	%	AOCS Ce1c-89
C18:3	Linolenic	0.7	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic	0.2	%	AOCS Ce1c-89
C20:1	Gadoleic	0.6	%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic		%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic		%	AOCS Ce1c-89
C22:1	Erucic		%	AOCS Ce1c-89
C24:0	Lignoceric		%	AOCS Ce1c-89
C24:1	Nervonic		%	AOCS Ce1c-89
UNKNOWNS		0.5	%	AOCS Ce1c-89

10.5 Borage

Biodiesel Certificate of Analysis

Feedstock: Borage | **Product Type:** B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	-1.3 *(29.66)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	-4	N/A	**°C**	D 6371
Free Glycerin:	0.001	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.076	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.250	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.066	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.000	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.138	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8865	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	1.8	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	>160	93 min.	**°C**	D 93
Moisture[5]:	0.041	N/A	**% Mass**	E 203
Cold Soak Filtration:	74	360	**seconds**	D 6751 Annex
Sulfur:	1.3	15	**ppm**	D 7039
Calcium:	1.2	5 max. Ca+Mg	**ppm (ug/g)**	EN 14538
Magnesium:	0.4	5 max. Ca+Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.008	0.050 max.	**% Mass**	D 524
Sulfated Ash:	<0.005	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	4.083	1.9-6.0	**mm²/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric		%	AOCS Ce1c-89
C14:0	Myristic		%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	9.3	%	AOCS Ce1c-89
C16:1	Palmitoleic		%	AOCS Ce1c-89
C17:0	Margaric		%	AOCS Ce1c-89
C17:1	Margaroleic		%	AOCS Ce1c-89
C18:0	Stearic	3.8	%	AOCS Ce1c-89
C18:1	Oleic	17.1	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	38.7	%	AOCS Ce1c-89
C18:3	Linolenic	26.1	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic		%	AOCS Ce1c-89
C20:1	Gadoleic		%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic		%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic	0.2	%	AOCS Ce1c-89
C22:1	Erucic	2.5	%	AOCS Ce1c-89
C24:0	Lignoceric		%	AOCS Ce1c-89
C24:1	Nervonic	1.5	%	AOCS Ce1c-89
UNKNOWNS		0.8	%	AOCS Ce1c-89

10.6 Camelina

Biodiesel Certificate of Analysis				
Feedstock: Camelina			**Product Type:** B100	
ASTM D 6751 Analysis of Biodiesel				
Test Parameter	**Result**	**ASTM Limit**	**Units**	**Test Method (current revision)**
Cloud point:	1.5 *(34.7)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	-1	N/A	**°C**	D 6371
Free Glycerin:	0.002	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.080	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.222	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.125	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.022	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.338	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8880	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	1.3	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	>160	93 min.	**°C**	D 93
Moisture[5]:	0.040	N/A	**% Mass**	E 203
Cold Soak Filtration:	223	360	**seconds**	D 6751 Annex
Sulfur:	0.6	15	**ppm**	D 7039
Calcium:	0.8	5 max. Ca+Mg	**ppm (ug/g)**	EN 14538
Magnesium:	1.1	5 max. Ca+Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.075	0.050 max.	**% Mass**	D 524
Sulfated Ash:	<0.005	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	4.365	1.9-6.0	**mm²/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel				
Test Parameter	**Name**	**Result**	**Units**	**Test Method**
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric		%	AOCS Ce1c-89
C14:0	Myristic		%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	5.0	%	AOCS Ce1c-89
C16:1	Palmitoleic		%	AOCS Ce1c-89
C17:0	Margaric		%	AOCS Ce1c-89
C17:1	Margaroleic		%	AOCS Ce1c-89
C18:0	Stearic	2.2	%	AOCS Ce1c-89
C18:1	Oleic	17.7	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	18	%	AOCS Ce1c-89
C18:3	Linolenic	37.9	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic	1.4	%	AOCS Ce1c-89
C20:1	Gadoleic	9.8	%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic	1.6	%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic	0.4	%	AOCS Ce1c-89
C22:1	Erucic	4.5	%	AOCS Ce1c-89
C24:0	Lignoceric	0.3	%	AOCS Ce1c-89
C24:1	Nervonic	0.2	%	AOCS Ce1c-89
UNKNOWNS		1.0	%	AOCS Ce1c-89

10.7 Canola

Biodiesel Certificate of Analysis

Feedstock: Canola | **Product Type:** B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	-3.3 *(26.06)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	-13	N/A	**°C**	D 6371
Free Glycerin:	0.006	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.098	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.301	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.078	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.020	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.010	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8820	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	7.6	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	>160	93 min.	**°C**	D 93
Moisture[5]:	0.036	N/A	**% Mass**	E 203
Cold Soak Filtration:	113	360	**seconds**	D 6751 Annex
Sulfur:	1.4	15	**ppm**	D 7039
Calcium:	0.4	5 max. Ca+Mg	**ppm (ug/g)**	EN 14538
Magnesium:	0.5	5 max. Ca+Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.030	0.050 max.	**% Mass**	D 524
Sulfated Ash:	<0.005	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	4.439	1.9-6.0	**mm²/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric		%	AOCS Ce1c-89
C14:0	Myristic		%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	3.8	%	AOCS Ce1c-89
C16:1	Palmitoleic	0.3	%	AOCS Ce1c-89
C17:0	Margaric		%	AOCS Ce1c-89
C17:1	Margaroleic		%	AOCS Ce1c-89
C18:0	Stearic	1.9	%	AOCS Ce1c-89
C18:1	Oleic	63.9	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	19.0	%	AOCS Ce1c-89
C18:3	Linolenic	9.7	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic	0.6	%	AOCS Ce1c-89
C20:1	Gadoleic		%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic		%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic	0.4	%	AOCS Ce1c-89
C22:1	Erucic		%	AOCS Ce1c-89
C24:0	Lignoceric	0.2	%	AOCS Ce1c-89
C24:1	Nervonic	0.2	%	AOCS Ce1c-89
UNKNOWNS			%	AOCS Ce1c-89

10.8 Castor

Biodiesel Certificate of Analysis

Feedstock: Castor	Product Type: B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	-13.4 *(7.88)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	7	N/A	**°C**	D 6371
Free Glycerin:	0.367	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.507	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.258	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.479	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.023	N/A	**% Mass**	D 6584
Water & Sediment:	<0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.996	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8990	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	1.1	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	>160	93 min.	**°C**	D 93
Moisture[5]:	0.053	N/A	**% Mass**	E 203
Cold Soak Filtration:	84 mL in 720 sec	360	**seconds**	D 6751 Annex
Sulfur:	1.3	15	**ppm**	D 7039
Calcium:	0.1	5 max.	**ppm (ug/g)**	EN 14538
Magnesium:	<0.1	5 max.	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.110	0.050 max.	**% Mass**	D 524
Sulfated Ash:	0.034	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	15.25	1.9-6.0	**mm^2/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric		%	AOCS Ce1c-89
C14:0	Myristic		%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	0.9	%	AOCS Ce1c-89
C16:1	Palmitoleic		%	AOCS Ce1c-89
C17:0	Margaric		%	AOCS Ce1c-89
C17:1	Margaroleic		%	AOCS Ce1c-89
C18:0	Stearic	1.1	%	AOCS Ce1c-89
C18:1	Oleic	3.1	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic	90.3	%	AOCS Ce1c-89
C18:2	Linoleic	4	%	AOCS Ce1c-89
C18:3	Linolenic	0.6	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic		%	AOCS Ce1c-89
C20:1	Gadoleic		%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic		%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic		%	AOCS Ce1c-89
C22:1	Erucic		%	AOCS Ce1c-89
C24:0	Lignoceric		%	AOCS Ce1c-89
C24:1	Nervonic		%	AOCS Ce1c-89
UNKNOWNS			%	AOCS Ce1c-89

10.9 Choice White Grease

Biodiesel Certificate of Analysis

Feedstock: Choice White Grease | **Product Type:** B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	7.0 *(44.6)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	6	N/A	**°C**	D 6371
Free Glycerin:	0.012	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.095	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.265	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.089	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.019	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.021	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8770	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	0.2	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	>160	93 min.	**°C**	D 93
Moisture[5]:	0.026	N/A	**% Mass**	E 203
Cold Soak Filtration:	72	360	**seconds**	D 6751 Annex
Sulfur:	5.4	15	**ppm**	D 7039
Calcium:	<0.1	5 max. Ca+Mg	**ppm (ug/g)**	EN 14538
Magnesium:	0.3	5 max. Ca+Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.034	0.050 max.	**% Mass**	D 524
Sulfated Ash:	<0.005	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	4.536	1.9-6.0	**mm²/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric		%	AOCS Ce1c-89
C14:0	Myristic	1.3	%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	21.6	%	AOCS Ce1c-89
C16:1	Palmitoleic	2.8	%	AOCS Ce1c-89
C17:0	Margaric	0.2	%	AOCS Ce1c-89
C17:1	Margaroleic	0.3	%	AOCS Ce1c-89
C18:0	Stearic	9.0	%	AOCS Ce1c-89
C18:1	Oleic	50.4	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	12.2	%	AOCS Ce1c-89
C18:3	Linolenic	1	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic	0.2	%	AOCS Ce1c-89
C20:1	Gadoleic	0.5	%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic		%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic		%	AOCS Ce1c-89
C22:1	Erucic	0.3	%	AOCS Ce1c-89
C24:0	Lignoceric		%	AOCS Ce1c-89
C24:1	Nervonic		%	AOCS Ce1c-89
UNKNOWNS		0.2	%	AOCS Ce1c-89

10.10 Coconut

Biodiesel Certificate of Analysis

Feedstock: Coconut	**Product Type:** B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	0.0 *(32)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	-4	N/A	**°C**	D 6371
Free Glycerin:	0.025	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.065	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.130	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.040	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.000	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.106	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8073	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	35.5	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	114.8	93 min.	**°C**	D 93
Moisture[5]:	0.034	N/A	**% Mass**	E 203
Cold Soak Filtration:	49	360	**seconds**	D 6751 Annex
Sulfur:	3.2	15	**ppm**	D 7039
Calcium:	<0.1	5 max.	**ppm (ug/g)**	EN 14538
Magnesium:	0.3	5 max.	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.010	0.050 max.	**% Mass**	D 524
Sulfated Ash:	0.006	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	2.726	1.9-6.0	**mm^2/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1b	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic	6.3	%	AOCS Ce1c-89
C10:0	Capric	6	%	AOCS Ce1c-89
C12:0	Lauric	49.2	%	AOCS Ce1c-89
C14:0	Myristic	18.5	%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	9.1	%	AOCS Ce1c-89
C16:1	Palmitoleic		%	AOCS Ce1c-89
C17:0	Margaric		%	AOCS Ce1c-89
C17:1	Margaroleic		%	AOCS Ce1c-89
C18:0	Stearic	2.7	%	AOCS Ce1c-89
C18:1	Oleic	6.5	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	1.7	%	AOCS Ce1c-89
C18:3	Linolenic		%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic		%	AOCS Ce1c-89
C20:1	Gadoleic		%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic		%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic		%	AOCS Ce1c-89
C22:1	Erucic		%	AOCS Ce1c-89
C24:0	Lignoceric		%	AOCS Ce1c-89
C24:1	Nervonic		%	AOCS Ce1c-89
UNKNOWNS			%	AOCS Ce1c-89

10.11 Coffee

Biodiesel Certificate of Analysis

Feedstock: Coffee | **Product Type:** B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	0.2 *(32.36)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	-4	N/A	**°C**	D 6371
Free Glycerin:	0.001	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.178	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.575	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.175	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.022	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.076	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	2	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8815	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	8.1	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	>160	93 min.	**°C**	D 93
Moisture[5]:	0.030	N/A	**% Mass**	E 203
Cold Soak Filtration:	203	360	**seconds**	D 6751 Annex
Sulfur:	9.7	15	**ppm**	D 7039
Calcium:	<0.1	5 max. Ca+Mg	**ppm (ug/g)**	EN 14538
Magnesium:	0.3	5 max. Ca+Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.004	0.050 max.	**% Mass**	D 524
Sulfated Ash:	<0.005	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	4.852	1.9-6.0	**mm^2/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric		%	AOCS Ce1c-89
C14:0	Myristic		%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	11.0	%	AOCS Ce1c-89
C16:1	Palmitoleic	0.5	%	AOCS Ce1c-89
C17:0	Margaric		%	AOCS Ce1c-89
C17:1	Margaroleic		%	AOCS Ce1c-89
C18:0	Stearic	3.4	%	AOCS Ce1c-89
C18:1	Oleic	70	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	12.7	%	AOCS Ce1c-89
C18:3	Linolenic	0.8	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic	0.6	%	AOCS Ce1c-89
C20:1	Gadoleic	0.1	%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic		%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic	0.2	%	AOCS Ce1c-89
C22:1	Erucic		%	AOCS Ce1c-89
C24:0	Lignoceric	0.1	%	AOCS Ce1c-89
C24:1	Nervonic		%	AOCS Ce1c-89
UNKNOWNS		0.6	%	AOCS Ce1c-89

10.12 Corn, Distiller's

Biodiesel Certificate of Analysis

Feedstock: Corn	Product Type: B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	-2.8 *(26.96)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	-3	N/A	**°C**	D 6371
Free Glycerin:	0.001	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.066	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.197	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.080	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.021	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.283	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8850	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	2.2	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	> 160	93 min.	**°C**	D 93
Moisture[5]:	0.032	N/A	**% Mass**	E 203
Cold Soak Filtration:	131	360	**seconds**	D 6751 Annex
Sulfur:	4.6	15	**ppm**	D 7039
Calcium:	0.6	5 max. Ca+Mg	**ppm (ug/g)**	EN 14538
Magnesium:	1.0	5 max. Ca+Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.020	0.050 max.	**% Mass**	D 524
Sulfated Ash:	<0.005	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	4.382	1.9-6.0	**mm²/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric		%	AOCS Ce1c-89
C14:0	Myristic		%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	12.1	%	AOCS Ce1c-89
C16:1	Palmitoleic	0.1	%	AOCS Ce1c-89
C17:0	Margaric		%	AOCS Ce1c-89
C17:1	Margaroleic	0.1	%	AOCS Ce1c-89
C18:0	Stearic	1.8	%	AOCS Ce1c-89
C18:1	Oleic	27.2	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	56.2	%	AOCS Ce1c-89
C18:3	Linolenic	1.3	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic	0.4	%	AOCS Ce1c-89
C20:1	Gadoleic		%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic		%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic	0.2	%	AOCS Ce1c-89
C22:1	Erucic		%	AOCS Ce1c-89
C24:0	Lignoceric		%	AOCS Ce1c-89
C24:1	Nervonic		%	AOCS Ce1c-89
UNKNOWNS		0.6	%	AOCS Ce1c-89

10.13 *Cuphea viscosissima*

Biodiesel Certificate of Analysis

Feedstock: Cuphea Viscosissima | **Product Type:** B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	Not Tested	Report	**°C** *(°F)*	D 2500
CFPP[1]:	Not Tested	N/A	**°C**	D 6371
Free Glycerin:	0.002	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.218	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.780	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.089	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.000	N/A	**% Mass**	D 6584
Water & Sediment:	Not Tested	0.050 max.	**% Volume**	D 2709
Acid Number:	2.141	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	Not Tested	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	Not Tested	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	9.6	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	Not Tested	93 min.	**°C**	D 93
Moisture[5]:	0.050	N/A	**% Mass**	E 203
Cold Soak Filtration:	Not Tested	360	**seconds**	D 6751 Annex
Sulfur:	Not Tested	15	**ppm**	D 7039
Calcium:	7.2	5 max. Ca+Mg	**ppm (ug/g)**	EN 14538
Magnesium:	0.2	5 max. Ca+Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	Not Tested	0.050 max.	**% Mass**	D 524
Sulfated Ash:	Not Tested	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	Not Tested	1.9-6.0	**mm²/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	Not Tested	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric		%	AOCS Ce1c-89
C14:0	Myristic	4.7	%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	18.2	%	AOCS Ce1c-89
C16:1	Palmitoleic		%	AOCS Ce1c-89
C17:0	Margaric		%	AOCS Ce1c-89
C17:1	Margaroleic		%	AOCS Ce1c-89
C18:0	Stearic	3.5	%	AOCS Ce1c-89
C18:1	Oleic	46.9	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	22.8	%	AOCS Ce1c-89
C18:3	Linolenic	2.3	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic	0.6	%	AOCS Ce1c-89
C20:1	Gadoleic		%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic		%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic	0.4	%	AOCS Ce1c-89
C22:1	Erucic		%	AOCS Ce1c-89
C24:0	Lignoceric	0.6	%	AOCS Ce1c-89
C24:1	Nervonic		%	AOCS Ce1c-89
UNKNOWNS			%	AOCS Ce1c-89

10.14 Evening Primrose

Biodiesel Certificate of Analysis

Feedstock: Evening Primrose | **Product Type:** B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	-7.5 *(18.5)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	-10	N/A	**°C**	D 6371
Free Glycerin:	0.005	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.128	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.386	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.134	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.035	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.370	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8885	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	0.2	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	>160	93 min.	**°C**	D 93
Moisture[5]:	0.031	N/A	**% Mass**	E 203
Cold Soak Filtration:	269	360	**seconds**	D 6751 Annex
Sulfur:	1.1	15	**ppm**	D 7039
Calcium:	<0.1	5 max.	**ppm (ug/g)**	EN 14538
Magnesium:	0.3	5 max.	**ppm (ug/g)**	EN 14538
Phosphorus:	<.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.051	0.050 max.	**% Mass**	D 524
Sulfated Ash:	0.038	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	4.112	1.9-6.0	**mm^2/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric		%	AOCS Ce1c-89
C14:0	Myristic		%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	6.0	%	AOCS Ce1c-89
C16:1	Palmitoleic		%	AOCS Ce1c-89
C17:0	Margaric		%	AOCS Ce1c-89
C17:1	Margaroleic		%	AOCS Ce1c-89
C18:0	Stearic	1.8	%	AOCS Ce1c-89
C18:1	Oleic	6.6	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	76.3	%	AOCS Ce1c-89
C18:3	Linolenic	9	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic	0.3	%	AOCS Ce1c-89
C20:1	Gadoleic		%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic		%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic		%	AOCS Ce1c-89
C22:1	Erucic		%	AOCS Ce1c-89
C24:0	Lignoceric		%	AOCS Ce1c-89
C24:1	Nervonic		%	AOCS Ce1c-89
UNKNOWNS			%	AOCS Ce1c-89

10.15 Fish

Biodiesel Certificate of Analysis

Feedstock: Fish | **Product Type:** B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	3.2 *(37.76)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	0	N/A	**°C**	D 6371
Free Glycerin:	0.006	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.040	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.118	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.019	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.000	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.085	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8955	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	0.2	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	>160	93 min.	**°C**	D 93
Moisture[5]:	0.056	N/A	**% Mass**	E 203
Cold Soak Filtration:	68	360	**seconds**	D 6751 Annex
Sulfur:	9.3	15	**ppm**	D 7039
Calcium:	<0.1	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Magnesium:	0.3	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.078	0.050 max.	**% Mass**	D 524
Sulfated Ash:	<0.005	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	3.777	1.9-6.0	**mm²/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric	0.2	%	AOCS Ce1c-89
C14:0	Myristic	7.7	%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	18.8	%	AOCS Ce1c-89
C16:1	Palmitoleic	9.3	%	AOCS Ce1c-89
C17:0	Margaric	0.3	%	AOCS Ce1c-89
C17:1	Margaroleic	0.3	%	AOCS Ce1c-89
C18:0	Stearic	3.9	%	AOCS Ce1c-89
C18:1	Oleic	15	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	4.6	%	AOCS Ce1c-89
C18:3	Linolenic	0.3	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic	0.2	%	AOCS Ce1c-89
C20:1	Gadoleic	1.4	%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic		%	AOCS Ce1c-89
C20:5	Timnodonic	25.1	%	AOCS Ce1c-89
C22:0	Behenic	0.7	%	AOCS Ce1c-89
C22:1	Erucic	1.28	%	AOCS Ce1c-89
C24:0	Lignoceric		%	AOCS Ce1c-89
C24:1	Nervonic	0.4	%	AOCS Ce1c-89
UNKNOWNS		10.52	%	AOCS Ce1c-89

10.16 Hemp

Biodiesel Certificate of Analysis

Feedstock: Hemp | **Product Type:** B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	-1.3 *(29.66)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	-6	N/A	**°C**	D 6371
Free Glycerin:	0.001	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.151	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.513	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.101	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.022	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.097	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8885	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	0.9	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	>160	93 min.	**°C**	D 93
Moisture[5]:	0.031	N/A	**% Mass**	E 203
Cold Soak Filtration:	66	360	**seconds**	D 6751 Annex
Sulfur:	0.4	15	**ppm**	D 7039
Calcium:	<0.1	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Magnesium:	0.3	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.019	0.050 max.	**% Mass**	D 524
Sulfated Ash:	<0.005	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	3.874	1.9-6.0	**mm^2/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric		%	AOCS Ce1c-89
C14:0	Myristic		%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	5.2	%	AOCS Ce1c-89
C16:1	Palmitoleic		%	AOCS Ce1c-89
C17:0	Margaric		%	AOCS Ce1c-89
C17:1	Margaroleic		%	AOCS Ce1c-89
C18:0	Stearic	2.4	%	AOCS Ce1c-89
C18:1	Oleic	13.1	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	57.1	%	AOCS Ce1c-89
C18:3	Linolenic	20	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic	0.7	%	AOCS Ce1c-89
C20:1	Gadoleic		%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic		%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic	0.5	%	AOCS Ce1c-89
C22:1	Erucic		%	AOCS Ce1c-89
C24:0	Lignoceric	0.3	%	AOCS Ce1c-89
C24:1	Nervonic		%	AOCS Ce1c-89
UNKNOWNS		0.7	%	AOCS Ce1c-89

10.17 Hepar, High IV

Biodiesel Certificate of Analysis

Feedstock: Hepar, High IV | **Product Type:** B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	16.0 *(60.8)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	13	N/A	**°C**	D 6371
Free Glycerin:	0.002	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.070	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.227	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.065	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.000	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.062	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8755	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	1.4	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	>160	93 min.	**°C**	D 93
Moisture[5]:	0.024	N/A	**% Mass**	E 203
Cold Soak Filtration:	87	360	**seconds**	D 6751 Annex
Sulfur:	3.4	15	**ppm**	D 7039
Calcium:	<0.1	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Magnesium:	0.3	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.041	0.050 max.	**% Mass**	D 524
Sulfated Ash:	<0.005	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	4.422	1.9-6.0	**mm²/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric	0.1	%	AOCS Ce1c-89
C12:0	Lauric	0.1	%	AOCS Ce1c-89
C14:0	Myristic	1.5	%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	28.0	%	AOCS Ce1c-89
C16:1	Palmitoleic	1.9	%	AOCS Ce1c-89
C17:0	Margaric	0.3	%	AOCS Ce1c-89
C17:1	Margaroleic	0.2	%	AOCS Ce1c-89
C18:0	Stearic	20.2	%	AOCS Ce1c-89
C18:1	Oleic	36.1	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	9.7	%	AOCS Ce1c-89
C18:3	Linolenic	0.3	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic	0.2	%	AOCS Ce1c-89
C20:1	Gadoleic	0.7	%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic	0.4	%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic		%	AOCS Ce1c-89
C22:1	Erucic	0.3	%	AOCS Ce1c-89
C24:0	Lignoceric		%	AOCS Ce1c-89
C24:1	Nervonic		%	AOCS Ce1c-89
UNKNOWNS			%	AOCS Ce1c-89

10.18 Hepar, Low IV

Biodiesel Certificate of Analysis

Feedstock: Hepar, Low IV | **Product Type:** B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	6.7 *(44.06)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	6	N/A	**°C**	D 6371
Free Glycerin:	0.002	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.088	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.282	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.072	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.022	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.165	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8755	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	1.2	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	> 160	93 min.	**°C**	D 93
Moisture[5]:	0.026	N/A	**% Mass**	E 203
Cold Soak Filtration:	77	360	**seconds**	D 6751 Annex
Sulfur:	3.1	15	**ppm**	D 7039
Calcium:	0.2	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Magnesium:	1.6	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.025	0.050 max.	**% Mass**	D 524
Sulfated Ash:	<0.005	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	4.643	1.9-6.0	**mm²/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric	0.2	%	AOCS Ce1c-89
C14:0	Myristic	1	%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	20.7	%	AOCS Ce1c-89
C16:1	Palmitoleic	2.7	%	AOCS Ce1c-89
C17:0	Margaric	0.3	%	AOCS Ce1c-89
C17:1	Margaroleic	0.3	%	AOCS Ce1c-89
C18:0	Stearic	8.9	%	AOCS Ce1c-89
C18:1	Oleic	46.7	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	15.6	%	AOCS Ce1c-89
C18:3	Linolenic	0.5	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic	0.2	%	AOCS Ce1c-89
C20:1	Gadoleic	0.8	%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic	1.3	%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic	0.2	%	AOCS Ce1c-89
C22:1	Erucic	0.4	%	AOCS Ce1c-89
C24:0	Lignoceric		%	AOCS Ce1c-89
C24:1	Nervonic	0.1	%	AOCS Ce1c-89
UNKNOWNS		0.1	%	AOCS Ce1c-89

10.19 Jatropha

Biodiesel Certificate of Analysis

Feedstock: Jatropha | **Product Type:** B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	2.7 *(36.86)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	0	N/A	**°C**	D 6371
Free Glycerin:	0.006	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.100	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.291	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.104	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.022	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.156	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8795	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	2.3	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	>160	93 min.	**°C**	D 93
Moisture[5]:	0.022	N/A	**% Mass**	E 203
Cold Soak Filtration:	286	360	**seconds**	D 6751 Annex
Sulfur:	1.2	15	**ppm**	D 7039
Calcium:	<0.1	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Magnesium:	0.3	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.026	0.050 max.	**% Mass**	D 524
Sulfated Ash:	0.009	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	4.253	1.9-6.0	**mm²/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric		%	AOCS Ce1c-89
C14:0	Myristic		%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	12.7	%	AOCS Ce1c-89
C16:1	Palmitoleic	0.7	%	AOCS Ce1c-89
C17:0	Margaric		%	AOCS Ce1c-89
C17:1	Margaroleic		%	AOCS Ce1c-89
C18:0	Stearic	5.5	%	AOCS Ce1c-89
C18:1	Oleic	39.1	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	41.6	%	AOCS Ce1c-89
C18:3	Linolenic	0.2	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic	0.2	%	AOCS Ce1c-89
C20:1	Gadoleic		%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic		%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic		%	AOCS Ce1c-89
C22:1	Erucic		%	AOCS Ce1c-89
C24:0	Lignoceric		%	AOCS Ce1c-89
C24:1	Nervonic		%	AOCS Ce1c-89
UNKNOWNS			%	AOCS Ce1c-89

10.20 *Lesquerella fendleri*

Biodiesel Certificate of Analysis

Feedstock: Lesquerella Fendleri	Product Type: B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	-11.6 *(11.12)*	Report	°C *(°F)*	D 2500
CFPP[1]:	-6	N/A	°C	D 6371
Free Glycerin:	0.055	0.020 max.	% Mass	D 6584
Total Glycerin:	0.307	0.240 max.	% Mass	D 6584
Monoglycerides[2]:	0.559	N/A	% Mass	D 6584
Diglycerides[3]:	0.710	N/A	% Mass	D 6584
Triglycerides[4]:	0.023	N/A	% Mass	D 6584
Water & Sediment:	0.075	0.050 max.	% Volume	D 2709
Acid Number:	0.630	0.50 max.	mg KOH/g	D 664, Test Method A
Visual Inspection:	2	N/A	Haze	D 4176, Procedure 2
Relative Density at 60 °F:	0.9110	N/A	N/A	D 1298
Oxidative Stability (110 °C):	10.5	3 min.	hrs	EN 14110
Flashpoint (closed cup):	>160	93 min.	°C	D 93
Moisture[5]:	0.073	N/A	% Mass	E 203
Cold Soak Filtration:	110 mL in 720 sec	360	seconds	D 6751 Annex
Sulfur:	180	15	ppm	D 7039
Calcium:	0.2	5 max. Ca + Mg	ppm (ug/g)	EN 14538
Magnesium:	0.4	5 max. Ca + Mg	ppm (ug/g)	EN 14538
Phosphorus:	<0.1	0.001 max.	% Mass	D 4951
Carbon Residue:	0.109	0.050 max.	% Mass	D 524
Sulfated Ash:	0.01	0.020 max.	% Mass	D 874
Kinematic Viscosity at 40 °C:	10.02	1.9-6.0	mm²/sec.	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	N/A	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric		%	AOCS Ce1c-89
C14:0	Myristic	0.1	%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	0.9	%	AOCS Ce1c-89
C16:1	Palmitoleic	0.3	%	AOCS Ce1c-89
C17:0	Margaric		%	AOCS Ce1c-89
C17:1	Margaroleic		%	AOCS Ce1c-89
C18:0	Stearic	1.7	%	AOCS Ce1c-89
C18:1	Oleic	13	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	5.8	%	AOCS Ce1c-89
C18:3	Linolenic	10.6	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic	0.7	%	AOCS Ce1c-89
C20:1	Gadoleic		%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic	66.5	%	AOCS Ce1c-89
C20:2	Eicosadienoic		%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic		%	AOCS Ce1c-89
C22:1	Erucic		%	AOCS Ce1c-89
C24:0	Lignoceric		%	AOCS Ce1c-89
C24:1	Nervonic	0.4	%	AOCS Ce1c-89
UNKNOWNS			%	AOCS Ce1c-89

10.21 Linseed

Biodiesel Certificate of Analysis

Feedstock: Linseed | **Product Type:** B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	-3.8 *(25.16)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	-8	N/A	**°C**	D 6371
Free Glycerin:	0.001	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.120	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.392	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.112	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.000	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.058	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8925	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	0.2	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	>160	93 min.	**°C**	D 93
Moisture[5]:	0.042	N/A	**% Mass**	E 203
Cold Soak Filtration:	64	360	**seconds**	D 6751 Annex
Sulfur:	1.9	15	**ppm**	D 7039
Calcium:	<0.1	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Magnesium:	0.3	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.035	0.050 max.	**% Mass**	D 524
Sulfated Ash:	<0.005	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	3.752	1.9-6.0	**mm²/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric		%	AOCS Ce1c-89
C14:0	Myristic		%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	4.4	%	AOCS Ce1c-89
C16:1	Palmitoleic		%	AOCS Ce1c-89
C17:0	Margaric		%	AOCS Ce1c-89
C17:1	Margaroleic		%	AOCS Ce1c-89
C18:0	Stearic	3.8	%	AOCS Ce1c-89
C18:1	Oleic	20.7	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	15.9	%	AOCS Ce1c-89
C18:3	Linolenic	54.6	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic	0.2	%	AOCS Ce1c-89
C20:1	Gadoleic		%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic		%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic	0.3	%	AOCS Ce1c-89
C22:1	Erucic		%	AOCS Ce1c-89
C24:0	Lignoceric	0.1	%	AOCS Ce1c-89
C24:1	Nervonic		%	AOCS Ce1c-89
UNKNOWNS			%	AOCS Ce1c-89

10.22 *Moringa oleifera*

Biodiesel Certificate of Analysis

Feedstock: Moringa Oleifera | **Product Type:** B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	13.3 *(55.94)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	13	N/A	**°C**	D 6371
Free Glycerin:	0.001	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.067	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.208	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.070	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.021	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.185	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8770	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	2.3	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	>160	93 min.	**°C**	D 93
Moisture[5]:	0.060	N/A	**% Mass**	E 203
Cold Soak Filtration:	78	360	**seconds**	D 6751 Annex
Sulfur:	9.9	15	**ppm**	D 7039
Calcium:	<0.1	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Magnesium:	0.3	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.033	0.050 max.	**% Mass**	D 524
Sulfated Ash:	<0.005	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	5.008	1.9-6.0	**mm²/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric		%	AOCS Ce1c-89
C14:0	Myristic		%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	5.5	%	AOCS Ce1c-89
C16:1	Palmitoleic	1.2	%	AOCS Ce1c-89
C17:0	Margaric		%	AOCS Ce1c-89
C17:1	Margaroleic		%	AOCS Ce1c-89
C18:0	Stearic	5.8	%	AOCS Ce1c-89
C18:1	Oleic	76.3	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	0.7	%	AOCS Ce1c-89
C18:3	Linolenic		%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic	3.1	%	AOCS Ce1c-89
C20:1	Gadoleic	2	%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic		%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic	4.2	%	AOCS Ce1c-89
C22:1	Erucic		%	AOCS Ce1c-89
C24:0	Lignoceric	0.4	%	AOCS Ce1c-89
C24:1	Nervonic		%	AOCS Ce1c-89
UNKNOWNS		0.8	%	AOCS Ce1c-89

10.23 Mustard

Biodiesel Certificate of Analysis				
Feedstock: Mustard			**Product Type:** B100	
ASTM D 6751 Analysis of Biodiesel				
Test Parameter	**Result**	**ASTM Limit**	**Units**	**Test Method (current revision)**
Cloud point:	3.2 *(37.76)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	-5	N/A	**°C**	D 6371
Free Glycerin:	0.004	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.062	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.195	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.040	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.019	N/A	**% Mass**	D 6584
Water & Sediment:	Not Tested	0.050 max.	**% Volume**	D 2709
Acid Number:	0.037	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	Not Tested	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	Not Tested	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	1.1	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	Not Tested	93 min.	**°C**	D 93
Moisture[5]:	0.021	N/A	**% Mass**	E 203
Cold Soak Filtration:	Not Tested	360	**seconds**	D 6751 Annex
Sulfur:	0.9	15	**ppm**	D 7039
Calcium:	<0.1	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Magnesium:	0.5	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	Not Tested	0.050 max.	**% Mass**	D 524
Sulfated Ash:	Not Tested	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	Not Tested	1.9-6.0	**mm²/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	Not Tested	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel				
Test Parameter	**Name**	**Result**	**Units**	**Test Method**
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric		%	AOCS Ce1c-89
C14:0	Myristic		%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	2.6	%	AOCS Ce1c-89
C16:1	Palmitoleic	0.2	%	AOCS Ce1c-89
C17:0	Margaric		%	AOCS Ce1c-89
C17:1	Margaroleic		%	AOCS Ce1c-89
C18:0	Stearic	1.2	%	AOCS Ce1c-89
C18:1	Oleic	20.6	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	20.6	%	AOCS Ce1c-89
C18:3	Linolenic	13.3	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic	0.9	%	AOCS Ce1c-89
C20:1	Gadoleic	10.7	%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic	1	%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic	0.5	%	AOCS Ce1c-89
C22:1	Erucic	25.6	%	AOCS Ce1c-89
C24:0	Lignoceric	0.2	%	AOCS Ce1c-89
C24:1	Nervonic	1.5	%	AOCS Ce1c-89
UNKNOWNS		1.1	%	AOCS Ce1c-89

10.24 Neem

Biodiesel Certificate of Analysis

Feedstock: Neem | **Product Type:** B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	14.4 *(57.92)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	11	N/A	**°C**	D 6371
Free Glycerin:	0.000	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.158	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.338	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.474	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.000	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.649	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	3	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8845	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	7.1	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	>160	93 min.	**°C**	D 93
Moisture[5]:	0.036	N/A	**% Mass**	E 203
Cold Soak Filtration:	130 mL in 720 sec	360	**seconds**	D 6751 Annex
Sulfur:	473.8	15	**ppm**	D 7039
Calcium:	0.3	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Magnesium:	0.9	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.105	0.050 max.	**% Mass**	D 524
Sulfated Ash:	<0.005	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	5.213	1.9-6.0	**mm^2/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1b	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric		%	AOCS Ce1c-89
C14:0	Myristic		%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	14.9	%	AOCS Ce1c-89
C16:1	Palmitoleic	0.1	%	AOCS Ce1c-89
C17:0	Margaric		%	AOCS Ce1c-89
C17:1	Margaroleic		%	AOCS Ce1c-89
C18:0	Stearic	20.6	%	AOCS Ce1c-89
C18:1	Oleic	43.9	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	17.9	%	AOCS Ce1c-89
C18:3	Linolenic	0.4	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic	1.6	%	AOCS Ce1c-89
C20:1	Gadoleic		%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic		%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic	0.3	%	AOCS Ce1c-89
C22:1	Erucic		%	AOCS Ce1c-89
C24:0	Lignoceric	0.3	%	AOCS Ce1c-89
C24:1	Nervonic		%	AOCS Ce1c-89
UNKNOWNS			%	AOCS Ce1c-89

10.25 Palm

Biodiesel Certificate of Analysis

Feedstock: Palm | **Product Type:** B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	13.0 *(55.4)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	12	N/A	**°C**	D 6371
Free Glycerin:	0.003	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.068	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.196	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.095	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.000	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.046	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8760	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	0.2	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	>160	93 min.	**°C**	D 93
Moisture[5]:	0.083	N/A	**% Mass**	E 203
Cold Soak Filtration:	88	360	**seconds**	D 6751 Annex
Sulfur:	1.2	15	**ppm**	D 7039
Calcium:	<0.1	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Magnesium:	0.3	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.010	0.050 max.	**% Mass**	D 524
Sulfated Ash:	<0.005	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	4.57	1.9-6.0	**mm²/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric	0.2	%	AOCS Ce1c-89
C14:0	Myristic	0.5	%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	43.4	%	AOCS Ce1c-89
C16:1	Palmitoleic	0.1	%	AOCS Ce1c-89
C17:0	Margaric		%	AOCS Ce1c-89
C17:1	Margaroleic		%	AOCS Ce1c-89
C18:0	Stearic	4.6	%	AOCS Ce1c-89
C18:1	Oleic	41.9	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	8.6	%	AOCS Ce1c-89
C18:3	Linolenic	0.3	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic	0.3	%	AOCS Ce1c-89
C20:1	Gadoleic		%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic		%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic	0.1	%	AOCS Ce1c-89
C22:1	Erucic		%	AOCS Ce1c-89
C24:0	Lignoceric		%	AOCS Ce1c-89
C24:1	Nervonic		%	AOCS Ce1c-89
UNKNOWNS			%	AOCS Ce1c-89

10.26 Perilla

Biodiesel Certificate of Analysis

Feedstock: Perilla Seed | **Product Type:** B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	-8.5 *(16.7)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	-11	N/A	**°C**	D 6371
Free Glycerin:	0.000	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.091	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.308	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.075	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.000	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.293	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8990	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	0.2	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	>160	93 min.	**°C**	D 93
Moisture[5]:	0.042	N/A	**% Mass**	E 203
Cold Soak Filtration:	200	360	**seconds**	D 6751 Annex
Sulfur:	1.5	15	**ppm**	D 7039
Calcium:	<0.1	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Magnesium:	0.3	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.037	0.050 max.	**% Mass**	D 524
Sulfated Ash:	<0.005	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	3.937	1.9-6.0	**mm²/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric		%	AOCS Ce1c-89
C14:0	Myristic		%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	5.3	%	AOCS Ce1c-89
C16:1	Palmitoleic	0.1	%	AOCS Ce1c-89
C17:0	Margaric		%	AOCS Ce1c-89
C17:1	Margaroleic		%	AOCS Ce1c-89
C18:0	Stearic	2.2	%	AOCS Ce1c-89
C18:1	Oleic	16.6	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	13.7	%	AOCS Ce1c-89
C18:3	Linolenic	62.1	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic		%	AOCS Ce1c-89
C20:1	Gadoleic		%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic		%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic		%	AOCS Ce1c-89
C22:1	Erucic		%	AOCS Ce1c-89
C24:0	Lignoceric		%	AOCS Ce1c-89
C24:1	Nervonic		%	AOCS Ce1c-89
UNKNOWNS			%	AOCS Ce1c-89

10.27 Poultry Fat

Biodiesel Certificate of Analysis

Feedstock: Poultry Fat | **Product Type:** B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	6.1 *(42.98)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	2	N/A	**°C**	D 6371
Free Glycerin:	0.002	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.079	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.244	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.079	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.020	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.044	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8805	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	11.0	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	>160	93 min.	**°C**	D 93
Moisture[5]:	0.052	N/A	**% Mass**	E 203
Cold Soak Filtration:	61 mL in 720 sec	360	**seconds**	D 6751 Annex
Sulfur:	21.1	15	**ppm**	D 7039
Calcium:	<0.1	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Magnesium:	0.3	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.025	0.050 max.	**% Mass**	D 524
Sulfated Ash:	<0.005	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	4.496	1.9-6.0	**mm²/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric	0.1	%	AOCS Ce1c-89
C14:0	Myristic	1	%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	19.6	%	AOCS Ce1c-89
C16:1	Palmitoleic	3.2	%	AOCS Ce1c-89
C17:0	Margaric	0.3	%	AOCS Ce1c-89
C17:1	Margaroleic	0.2	%	AOCS Ce1c-89
C18:0	Stearic	7.5	%	AOCS Ce1c-89
C18:1	Oleic	36.8	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	28.4	%	AOCS Ce1c-89
C18:3	Linolenic	2	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic	0.1	%	AOCS Ce1c-89
C20:1	Gadoleic		%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic	0.1	%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic	0.3	%	AOCS Ce1c-89
C22:1	Erucic	0.4	%	AOCS Ce1c-89
C24:0	Lignoceric		%	AOCS Ce1c-89
C24:1	Nervonic		%	AOCS Ce1c-89
UNKNOWNS			%	AOCS Ce1c-89

10.28 Rice Bran

Biodiesel Certificate of Analysis

Feedstock: Rice Bran	Product Type: B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	0.3 *(32.54)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	-3	N/A	**°C**	D 6371
Free Glycerin:	0.001	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.083	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.281	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.059	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.000	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.586	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8855	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	0.4	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	>160	93 min.	**°C**	D 93
Moisture[5]:	0.015	N/A	**% Mass**	E 203
Cold Soak Filtration:	111	360	**seconds**	D 6751 Annex
Sulfur:	6	15	**ppm**	D 7039
Calcium:	0.4	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Magnesium:	1.1	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.047	0.050 max.	**% Mass**	D 524
Sulfated Ash:	<0.005	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	4.958	1.9-6.0	**mm²/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric		%	AOCS Ce1c-89
C14:0	Myristic	0.3	%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	12.5	%	AOCS Ce1c-89
C16:1	Palmitoleic		%	AOCS Ce1c-89
C17:0	Margaric		%	AOCS Ce1c-89
C17:1	Margaroleic		%	AOCS Ce1c-89
C18:0	Stearic	2.1	%	AOCS Ce1c-89
C18:1	Oleic	47.5	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	35.4	%	AOCS Ce1c-89
C18:3	Linolenic	1.1	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic	0.6	%	AOCS Ce1c-89
C20:1	Gadoleic		%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic		%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic	0.3	%	AOCS Ce1c-89
C22:1	Erucic		%	AOCS Ce1c-89
C24:0	Lignoceric	0.2	%	AOCS Ce1c-89
C24:1	Nervonic		%	AOCS Ce1c-89
UNKNOWNS			%	AOCS Ce1c-89

10.29 Soybean

Biodiesel Certificate of Analysis

Feedstock: Soybean | **Product Type:** B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	0.9 *(33.62)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	-4	N/A	**°C**	D 6371
Free Glycerin:	0.012	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.149	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.473	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.088	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.019	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.266	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8840	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	2.1	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	>160	93 min.	**°C**	D 93
Moisture[5]:	0.035	N/A	**% Mass**	E 203
Cold Soak Filtration:	67	360	**seconds**	D 6751 Annex
Sulfur:	0.8	15	**ppm**	D 7039
Calcium:	<0.1	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Magnesium:	0.3	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.038	0.050 max.	**% Mass**	D 524
Sulfated Ash:	<0.005	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	4.039	1.9-6.0	**mm²/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric		%	AOCS Ce1c-89
C14:0	Myristic		%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	9.4	%	AOCS Ce1c-89
C16:1	Palmitoleic		%	AOCS Ce1c-89
C17:0	Margaric		%	AOCS Ce1c-89
C17:1	Margaroleic		%	AOCS Ce1c-89
C18:0	Stearic	4.1	%	AOCS Ce1c-89
C18:1	Oleic	22	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	55.3	%	AOCS Ce1c-89
C18:3	Linolenic	8.9	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic		%	AOCS Ce1c-89
C20:1	Gadoleic		%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic		%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic	0.3	%	AOCS Ce1c-89
C22:1	Erucic		%	AOCS Ce1c-89
C24:0	Lignoceric		%	AOCS Ce1c-89
C24:1	Nervonic		%	AOCS Ce1c-89
UNKNOWNS			%	AOCS Ce1c-89

10.30 Stillingia

Biodiesel Certificate of Analysis

Feedstock: Stillingia	Product Type: B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	-8.5 *(16.7)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	-12	N/A	**°C**	D 6371
Free Glycerin:	0.000	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.156	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.359	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.423	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.000	N/A	**% Mass**	D 6584
Water & Sediment:	Not Tested	0.050 max.	**% Volume**	D 2709
Acid Number:	0.708	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	Not Tested	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	Not Tested	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	Unable to Determine	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	Not Tested	93 min.	**°C**	D 93
Moisture[5]:	0.052	N/A	**% Mass**	E 203
Cold Soak Filtration:	Not Tested	360	**seconds**	D 6751 Annex
Sulfur:	1.5	15	**ppm**	D 7039
Calcium:	0.5	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Magnesium:	0.4	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	Not Tested	0.050 max.	**% Mass**	D 524
Sulfated Ash:	Not Tested	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	Not Tested	1.9-6.0	**mm²/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	Not Tested	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric	0.4	%	AOCS Ce1c-89
C14:0	Myristic	0.1	%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	7.5	%	AOCS Ce1c-89
C16:1	Palmitoleic		%	AOCS Ce1c-89
C17:0	Margaric		%	AOCS Ce1c-89
C17:1	Margaroleic		%	AOCS Ce1c-89
C18:0	Stearic	2.3	%	AOCS Ce1c-89
C18:1	Oleic	16.7	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	31.5	%	AOCS Ce1c-89
C18:3	Linolenic	41.5	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic		%	AOCS Ce1c-89
C20:1	Gadoleic		%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic		%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic		%	AOCS Ce1c-89
C22:1	Erucic		%	AOCS Ce1c-89
C24:0	Lignoceric		%	AOCS Ce1c-89
C24:1	Nervonic		%	AOCS Ce1c-89
UNKNOWNS			%	AOCS Ce1c-89

10.31 Sunflower

Biodiesel Certificate of Analysis

Feedstock: Sunflower	Product Type: B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	3.4 *(38.12)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	-3	N/A	**°C**	D 6371
Free Glycerin:	0.007	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.121	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.387	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.092	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.000	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.027	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8800	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	0.9	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	>160	93 min.	**°C**	D 93
Moisture[5]:	0.032	N/A	**% Mass**	E 203
Cold Soak Filtration:	107	360	**seconds**	D 6751 Annex
Sulfur:	0.2	15	**ppm**	D 7039
Calcium:	<0.1	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Magnesium:	0.3	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.035	0.050 max.	**% Mass**	D 524
Sulfated Ash:	<0.005	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	4.439	1.9-6.0	**mm²/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric		%	AOCS Ce1c-89
C14:0	Myristic		%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	4.2	%	AOCS Ce1c-89
C16:1	Palmitoleic		%	AOCS Ce1c-89
C17:0	Margaric		%	AOCS Ce1c-89
C17:1	Margaroleic		%	AOCS Ce1c-89
C18:0	Stearic	3.3	%	AOCS Ce1c-89
C18:1	Oleic	63.6	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	27.6	%	AOCS Ce1c-89
C18:3	Linolenic	0.2	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic		%	AOCS Ce1c-89
C20:1	Gadoleic		%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic		%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic	0.7	%	AOCS Ce1c-89
C22:1	Erucic		%	AOCS Ce1c-89
C24:0	Lignoceric	0.4	%	AOCS Ce1c-89
C24:1	Nervonic		%	AOCS Ce1c-89
UNKNOWNS			%	AOCS Ce1c-89

10.32 Tung

Biodiesel Certificate of Analysis

Feedstock: Tung	Product Type: B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	-10.0 *(14)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	-11	N/A	**°C**	D 6371
Free Glycerin:	0.015	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.070	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.120	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.161	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.000	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.001	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.9030	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	0.4	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	> 160	93 min.	**°C**	D 93
Moisture[5]:	0.067	N/A	**% Mass**	E 203
Cold Soak Filtration:	231 mL in 720 sec	360	**seconds**	D 6751 Annex
Sulfur:	13.3	15	**ppm**	D 7039
Calcium:	0.2	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Magnesium:	0.4	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	0.9	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.116	0.050 max.	**% Mass**	D 524
Sulfated Ash:	<0.005	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	7.53	1.9-6.0	**mm²/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric		%	AOCS Ce1c-89
C14:0	Myristic		%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	1.8	%	AOCS Ce1c-89
C16:1	Palmitoleic		%	AOCS Ce1c-89
C17:0	Margaric		%	AOCS Ce1c-89
C17:1	Margaroleic		%	AOCS Ce1c-89
C18:0	Stearic	2.1	%	AOCS Ce1c-89
C18:1	Oleic	5.3	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	6.8	%	AOCS Ce1c-89
C18:3	Linolenic	0.7	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic	72.2	%	AOCS Ce1c-89
C20:0	Arachidic	0.2	%	AOCS Ce1c-89
C20:1	Gadoleic		%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic	0.1	%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic		%	AOCS Ce1c-89
C22:1	Erucic		%	AOCS Ce1c-89
C24:0	Lignoceric	10.4	%	AOCS Ce1c-89
C24:1	Nervonic		%	AOCS Ce1c-89
UNKNOWNS		0.4	%	AOCS Ce1c-89

10.33 Used Cooking Oil

Biodiesel Certificate of Analysis

Feedstock: Used Cooking Oil | **Product Type:** B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	2.4 *(36.32)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	-2	N/A	**°C**	D 6371
Free Glycerin:	0.012	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.143	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.411	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.161	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.000	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.332	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8555	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	1.0	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	>160	93 min.	**°C**	D 93
Moisture[5]:	0.038	N/A	**% Mass**	E 203
Cold Soak Filtration:	81	360	**seconds**	D 6751 Annex
Sulfur:	2.4	15	**ppm**	D 7039
Calcium:	0.6	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Magnesium:	1.1	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.040	0.050 max.	**% Mass**	D 524
Sulfated Ash:	<0.005	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	4.332	1.9-6.0	**mm²/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric	0.1	%	AOCS Ce1c-89
C14:0	Myristic	0.1	%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	11.8	%	AOCS Ce1c-89
C16:1	Palmitoleic	0.4	%	AOCS Ce1c-89
C17:0	Margaric	0.1	%	AOCS Ce1c-89
C17:1	Margaroleic	0.1	%	AOCS Ce1c-89
C18:0	Stearic	4.4	%	AOCS Ce1c-89
C18:1	Oleic	25.3	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	49.5	%	AOCS Ce1c-89
C18:3	Linolenic	7.1	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic	0.3	%	AOCS Ce1c-89
C20:1	Gadoleic		%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic		%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic	0.4	%	AOCS Ce1c-89
C22:1	Erucic	0.3	%	AOCS Ce1c-89
C24:0	Lignoceric	0.1	%	AOCS Ce1c-89
C24:1	Nervonic		%	AOCS Ce1c-89
UNKNOWNS			%	AOCS Ce1c-89

10.34 Yellow Grease

Biodiesel Certificate of Analysis

Feedstock: Yellow Grease | **Product Type:** B100

ASTM D 6751 Analysis of Biodiesel

Test Parameter	Result	ASTM Limit	Units	Test Method (current revision)
Cloud point:	6.0 *(42.8)*	Report	**°C** *(°F)*	D 2500
CFPP[1]:	2	N/A	**°C**	D 6371
Free Glycerin:	0.009	0.020 max.	**% Mass**	D 6584
Total Glycerin:	0.108	0.240 max.	**% Mass**	D 6584
Monoglycerides[2]:	0.300	N/A	**% Mass**	D 6584
Diglycerides[3]:	0.130	N/A	**% Mass**	D 6584
Triglycerides[4]:	0.019	N/A	**% Mass**	D 6584
Water & Sediment:	< 0.005	0.050 max.	**% Volume**	D 2709
Acid Number:	0.073	0.50 max.	**mg KOH/g**	D 664, Test Method A
Visual Inspection:	1	N/A	**Haze**	D 4176, Procedure 2
Relative Density at 60 °F:	0.8825	N/A	**N/A**	D 1298
Oxidative Stability (110 °C):	5.2	3 min.	**hrs**	EN 14110
Flashpoint (closed cup):	>160	93 min.	**°C**	D 93
Moisture[5]:	0.036	N/A	**% Mass**	E 203
Cold Soak Filtration:	95	360	**seconds**	D 6751 Annex
Sulfur:	6.2	15	**ppm**	D 7039
Calcium:	<0.1	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Magnesium:	0.4	5 max. Ca + Mg	**ppm (ug/g)**	EN 14538
Phosphorus:	<0.1	0.001 max.	**% Mass**	D 4951
Carbon Residue:	0.026	0.050 max.	**% Mass**	D 524
Sulfated Ash:	<0.005	0.020 max.	**% Mass**	D 874
Kinematic Viscosity at 40 °C:	4.552	1.9-6.0	**mm²/sec.**	D 445
Copper Corrosion (3 hrs at 50 °C):	1a	No. 3 max.	**N/A**	D 130

[1,2,3,4,5] These are not ASTM D 6751 specification requirements.

Fatty Acid Profile Analysis of Biodiesel

Test Parameter	Name	Result	Units	Test Method
C8:0	Caprylic		%	AOCS Ce1c-89
C10:0	Capric		%	AOCS Ce1c-89
C12:0	Lauric	0.1	%	AOCS Ce1c-89
C14:0	Myristic	0.5	%	AOCS Ce1c-89
C15:0	Pentadecanoic		%	AOCS Ce1c-89
C16:0	Palmitic	14.3	%	AOCS Ce1c-89
C16:1	Palmitoleic	1.1	%	AOCS Ce1c-89
C17:0	Margaric	0.3	%	AOCS Ce1c-89
C17:1	Margaroleic	0.2	%	AOCS Ce1c-89
C18:0	Stearic	8.0	%	AOCS Ce1c-89
C18:1	Oleic	35.6	%	AOCS Ce1c-89
C18:1-9c,12(OH)	Ricinoleic		%	AOCS Ce1c-89
C18:2	Linoleic	35	%	AOCS Ce1c-89
C18:3	Linolenic	4	%	AOCS Ce1c-89
C18:3-9c,11t,13t	α-Eleostearic		%	AOCS Ce1c-89
C20:0	Arachidic	0.3	%	AOCS Ce1c-89
C20:1	Gadoleic		%	AOCS Ce1c-89
C20:1-11c,14(OH)	Lesquerolic		%	AOCS Ce1c-89
C20:2	Eicosadienoic		%	AOCS Ce1c-89
C20:5	Timnodonic		%	AOCS Ce1c-89
C22:0	Behenic	0.3	%	AOCS Ce1c-89
C22:1	Erucic	0.2	%	AOCS Ce1c-89
C24:0	Lignoceric		%	AOCS Ce1c-89
C24:1	Nervonic	0.1	%	AOCS Ce1c-89
UNKNOWNS			%	AOCS Ce1c-89

11 Pictures of Feedstock and Biodiesel

Algae 1

Algae 2

Babassu

Beef Tallow

Borage

Camelina

Canola

Castor

Choice White Grease

Coconut

Coffee

Corn

Evening Primrose

Fish

Hemp

Hepar, High IV

Hepar, Low IV

Jatropha

Jojoba

Karanja

Lesquerella fendleri

Linseed

Moringa oleifera

Neem

Palm

Perilla

Poultry Fat

Rice Bran

Soybean

Sunflower

Tung

Used Cooking Oil

Yellow Grease

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