Chapter

Biofuels: Production and Properties as Substitute Fuels

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Abstract

Renewable sources include plants and animal fats, which are the main components of biofuels. Biofuels are free from sulfur, aromatics, metals, and crude oil residues. Since biofuels are more lubricating than petroleum diesel fuel, they are nonflammable and extend the life of diesel engines. As a result of this study, the main chemical and physical properties of biofuels were investigated, including their lubricity, viscosity, calorific value, and cetane number, which indicate the quality of renewable fuels, and compared with the other. We examined and compared the combustion characteristics of various types of biofuels as an alternative fuel, as well as their emissions characteristics. Biodiesel and biodiesel blends are compared to mineral diesel, as well as their performance in CI engines in this study's review. With modified combustion equipment, biodiesel fuels can potentially reduce air pollution in diesel engines and are a very good substitute for fossil fuels. There is a need for more research and technological development in order for biofuels to become economically viable. Biofuel/biodiesel research should therefore be supported with policies that make their prices competitive with other conventional sources of energy. In the current state of affairs, biofuels are more effective when used alongside other sources of energy.

Keywords: biodiesel, alternative fuel, physical and chemical properties, emission, compression ignition engine

1. Introduction

World Energy Resources 2013 reported that 82% of electricity in 2013 was generated from fossil fuels, 13% from renewables, and the rest from nuclear sources [1]. Hydroelectric, wind, and solar power generate large amounts of power, but oil reserves are diminishing and could disappear within a century [2], making it essential to find replacements for petroleum-based fuels. A large portion of petroleum-based products are consumed by the transportation sector, which demands approximately 38% [3]. Scientists are also searching for alternative fuel sources due to the high price of fossil fuels, harmful greenhouse gas emissions, and the diversity of energy production. However, diesel engines still contribute significantly to greenhouse gas emissions and adverse effects on human health, despite better fuel economy and lower car taxes. There has been some research into solar cars as a solution to this issue, but their high cost and inconsistency make them unsuitable for daily use. Fuel and lubricant alternatives have been sought as a result [4]. Alternative sources of energy, such as solar, can still be utilized in a variety of ways. During photosynthesis, solar rays are converted into stored energy within plant tissue, which helps the plant live and reproduce through seed production. A biofuel can be produced using this energy change phenomenon. For compression ignition engines, biofuel produced from renewable sources is considered the best alternative to mineral diesel fuel.

The transportation industry contributes significantly to a country's socioeconomic growth and development. Individuals' quality of life is measured by the ease of moving goods and services. Transportation services are affordably and safely provided by governments across jurisdictions. Over 90% of the fossil fuel products are consumed in the transportation sector [5, 6]. By 2030, on-road transport will consume 50% of total energy, and by 2050, 80% [7]. Transport sector energy consumption in 2015 included passenger vehicles (cars and bikes), buses, air, passenger rail, and airline freight and heavy trucks, light trucks, and marine transport consume 35% of the energy used in the transportation sector. By 2050, liquid biofuel consumption will increase to 652 billion liters, and biodiesel consumption in the transport sector will rise to 180 billion liters [8]. By 2035, there will be more than 2 billion cars on the road, and this number will rise to 2.5 billion by 2050 [9, 10]. Environmental consequences and costs will be unimaginable if these cars run on fossil fuels. Low-carbon transport systems include biofuels, hydrogen, and electric vehicles (EVs). The use of ICEs will remain important in most developing countries for some time to come, despite the fact that hydrogen and electric vehicles avoid land use and impact air quality [11].

Most of investigations have been done based on use of the fuels in the diesel engine without any modification. Based on the so many literatures and studies of previous researchers, the authors have attempted to review important research on biodiesel production processes, biodiesel physical and chemical properties, and its performance and emission characteristics as compression ignition engine's fuels.

Because of global warming and increasing air pollution, alternative fuels are increasingly being used in IC engines. Among the alternatives, biodiesel fuels seem remarkably interesting. They will be produced during a renewable way and possess certain advantageous properties that give them the potential to lower pollutants and CO_2 emissions from IC engines.

The review deals with the status of biodiesel fuels and tries to elaborate the future direction for more wider utilization and the possible roles of biodiesel fuels in attaining the far-reaching goal of low-carbon economy using sustainable energy resources.

2. Biodiesel production

There are several options for biomass-derived fuels production involving chemical, biological, and thermochemical processes. An extensive map for these pathways can be seen in **Figure 1** [12]. Two of the most promising fuels appear to be biodiesel or synthetic fuels such, as Fischer-Tropsch diesel [13]. This is because other potential fuels, such as Ethanol, Methanol, and LPG, do not perform as well in modern engines. Within IC engines, there are biofuel options for Gasoline (SI) and Diesel (CI) engines.

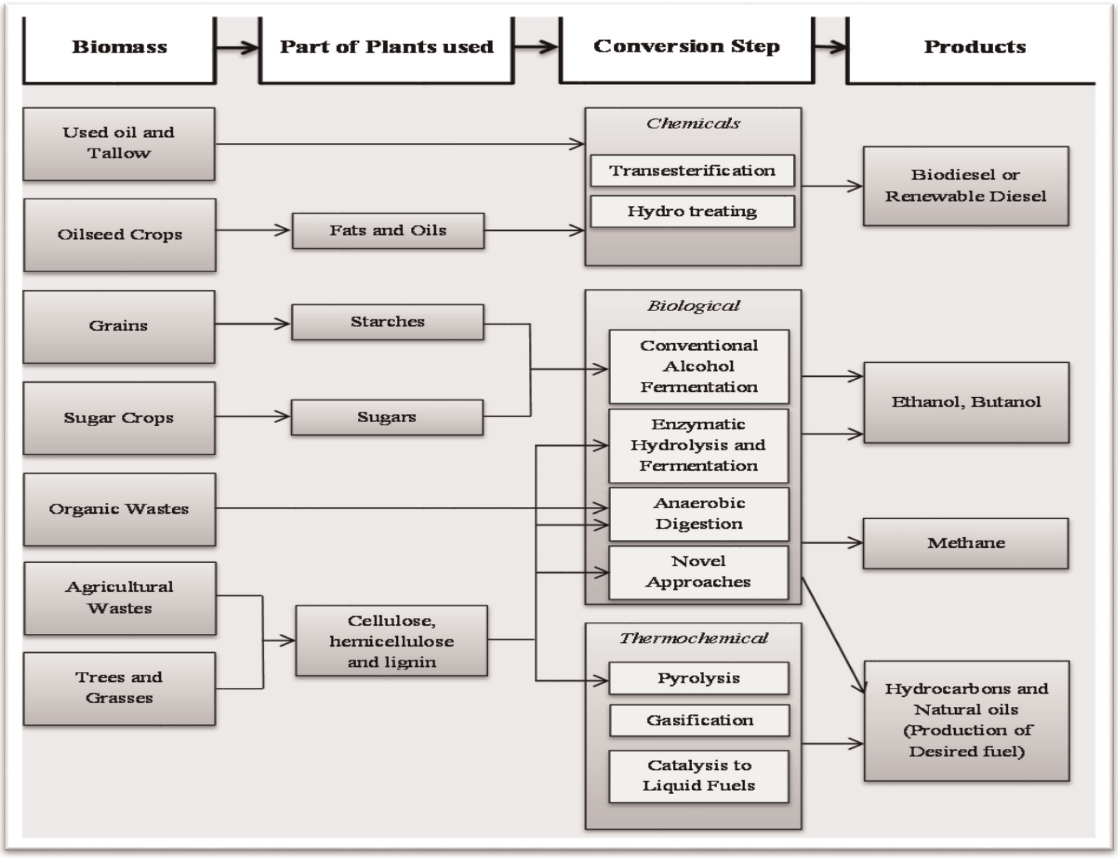

Figure 1.
An image showing biofuel pathways from feedstock to products [12].

Biogas and primary alcohols are the main fuels for SI engine. Ethanol from sugarcane was a key player in Brazil in the 1970s following the oil crisis, unfortunately the recent low petrol prices have undermined the green transport program decreasing the advantages. The government has overhauled their economic policy to ensure that the mandatory mix of ethanol in petrol is increased by 2.5% and have reinstated a levy on fossil fuels. A lot of current research is aimed toward diesel alternatives, as CI engines boast better fuel economy and lower car tax than petrol engines. An extensive map of pathways for the creation of all biofuels can be seen below in **Figure 1** taken from IRENE Transport sector summary charts, 2014 [12].

As shown in **Figure 1**, vegetable oils are a source of biomass, which has the advantages over other energy sources of not exhausting the soil or damaging the environment [6]. Crude vegetable oils can be run through modern engines though their viscosity, calorific value, and freezing point are inferior to diesel fuel.

In literature, there are many examples of fuel properties for biodiesel created by transesterification, which involves removing the glycerides and combining oil esters of vegetable oil with alcohol. This creates fuels made up of alkyl esters of long chain fatty acids, usually found to be fatty acid methyl esters (FAMEs). The major cost in its production is the enzymatic reaction, which, due to the environment-friendly and less energy-intensive nature, prefers enzymes over chemical catalysts [14]. Hwang et al. found that producing biodiesel from Waste Cooking Oil (WCO) through transesterification with methanol and a Sodium Methoxide (NaOCH3) catalyst actually reduced the production of Carbon Monoxide (CO), Hydrocarbons (HC), and Particulate Matter (PM) at low loads, compared to diesel at conventional operating conditions [15]. A more recent development in transesterification and hydrogenation is to create biofuels from algae lipids. Alga is interesting due to its high production rates, lipid content, and rapid growth cycles [16]. They also do not compete for land growth and have the ability to grow anywhere in water [17]. However, Viêgas et al. found that oxidative stability was lower than that of soybean biodiesel; though by working on Palladium and Nickel catalysts, an optimized final product was produced [18]. Another technique of producing fuel to be examined from **Figure 1** is Pyrolysis. The thermochemical reaction takes place at high temperatures in the absence of oxygen. One way to do this of present interest in Literature is by microwave heating, as this process of warming through radiation decreases the energy lost, increasing efficiency and economy, when compared to conventional heating methods [19]. Krutof et al., looked at pyrolysis oils and fish oils and the possibilities within blending, which they found increased their fuels' calorific value [20].

To be able to synchronize biomass-derived fuels with applications for which they would be suited, the fuels must first be characterized. This is due to the high potential of differentiation between the chemical products, with different methods of creation and a huge range variable affecting the composition immensely. To start you may organize the feedstocks for biofuels into four main categories [7] as seen in **Tables 1 and 2**. To further categorize biofuels, they can be organized according technology of their production, on which they are greatly dependent. These are enlisted in **Table 3**. First-generation biofuels are potentially required to be focused on food production commodities and as a result may not be sustainable [3, 7]. FAME (Fatty Acid Methyl Ester), the most common biofuel in Europe, from vegetable oil, is considered a first-generation biofuel as it is exclusively produced using transesterification technology [21]. However, second-generation advanced biofuels, produced from Fischer-Tropsch synthesis, in addition to hydrothermal, pyrolysis liquefaction, and alternative catalytic procedures, maybe sustainable for future societies with their advantages as eco-friendly fuels [3, 7, 23]. These aim to overcome the limitations of first-generation biofuels [21], but they are still deeply reliant on the price of feedstock. Previous

Category	Edible vegetable oil	Non-edible vegetable oil	Waste or recycled oil	Animal fats
Examples	Canola, soybean, peanut, sunflower, palm and coconut oil	Jatropha curcas, Calophyllum inophyllum, Moringa oleifera and Croton megalocarpus	Waste or recycled oils both edible and nonedible	Chicken fat, pork lard, beef tallow and poultry fat

Table 1.
A table showing categories of biofuel feedstocks [7].

First generation	Second generation	Third generation	Fourth generation
Feedstock: sugar, starch, vegetable oils or animal fats	**Feedstock:** non-food crops, wheat straw, corn, wood, solid waste, and energy crop.	**Feedstock:** algae	**Feedstock:** genetically modified algae (Cyanobacteria)
Examples: bio-alcohols, vegetable oil, biodiesel, bio-syngas and biogas	**Examples:** bio alcohols, bio-oil, DMF, biohydrogen and bio-Fischer-Tropsch diesel	**Example:** biodiesel	**Example:** Biodiesel

Table 2.
A table showing biofuel classification on different generation technologies [3].

Advantage	Explanation
Biodiesel contains more energy than diesel	Biodiesel carries 4.5 units of energy against each unit of fossil fuels [3]. Also, plants can be harvested completely by modern technology and the tops could be burned in the high efficiency distilleries or boilers, which can be used for gasification and could increase the total energy return up to 40% [7]
Biodiesel decreases the reliance on petroleum [3]	Biodiesel provides and alternative which means when oil runs out we will not be solely dependent on it which will positively impact on the transportation market [3]
Biodiesel can be produce locally from renewable sources	Biodiesel is possible to manufactured using edible, non-edible, waste oils, fats and oil seeds [3, 7, 11, 21]
Biodiesel is biodegradable, non-toxic and non-flammable [3, 9, 13, 22]	Bio-diesel degrades four times faster than diesel [9]. The higher flash point makes the storage safer [9]
Biodiesel can be used in Compression Ignitions engines without need for modification [9, 11, 13, 14].	Biodiesel will give and efficient performance in existing diesel engines [14] with no substantial modifications to the engine [9]
Biodiesel is environmentally friendly by emitting less pollutants [11, 22]	Biodiesel has the potential to be a carbon neutral fuel [9, 21], due to balance between the amount of CO2 emissions and the amount of CO2 absorbed by the plants producing vegetable oil being equal [9]. Also in general it has reduced greenhouse gas (GHGs) emissions [14] by 78% when compared to petroleum diesel [13]. Biodiesel contains no sulfur [9, 13] and negligible aromatic content [13]. However, with a high concentration of oxygen, the fuel produces significant reductions of sulfur dioxide (SO2), soot, carbon monoxide (CO) and unburned hydrocarbons (UHC) [13].
Biodiesel is safer	The above characteristics of biodiesel make it non-toxic and therefore safer to breathe [4]. Also biodiesel gives a 90% reduction in cancer risks, according to Ames mutagenicity tests [9].

Table 3.
A table showing the advantages of biodiesel in literature.

studies show that the feedstock cost embodies 75–80% of the total production cost [8]. In addition, the sources of the feedstock vary country to country and according to environmental conditions. For example, soybean for North America, sunflower and rapeseed for Europe, palm for Southeast Asia, coconut for tropic and sub-tropic areas, etc. [4]. Therefore, choosing the source with the highest oil yield is detrimental to success of producing low-cost biodiesel [8].

2.1 Fischer-Tropsch synthesis

Chemical, biological, and thermochemical processes can be used to produce biomass-derived fuels. Biodiesel and synthetic fuels such as Fischer-Tropsch diesel appear to be the most promising fuels [13, 24]. Modern engines do not perform well with other potential fuels, such as ethanol, methanol, and LPG. Furthermore, biomass will play an important role soon as one of the most important renewable energy sources. Another significant research area in the field of renewable energy includes the use of hydrogen [25, 26]. Using Fischer-Tropsch as a substitute for liquid fossil fuels is considered a good solution for the abovementioned issue [27–29].

$$n(CO + 2H_2) \rightarrow (CH_2)_n + n(H_2O) \quad (1)$$

During FTS, CO and H_2 react on the catalyst surface, resulting in a surface polymerization reaction. The process is described as the formation of a carbide layer on the surface of catalysts, discovered nine decades ago by Fischer and Tropsch [30–33]. Hydrocarbon molecules that are released from catalyst surfaces and reabsorbed undergo two further reactions. The reaction shown in Eqs. (2) and (3) is the reaction of methane formation (as an unwanted product in FTS); it is considered irreversible. FTS is also characterized by the water-gas shift reaction, which produces water as a coproduct; this reaction plays a significant role in reactors where the reaction occurs over cobalt catalysts and produces carbon dioxide [26, 31, 33, 34].

$$(CO + 3H_2) \rightarrow (CH_4) + (H_2O) \quad (2)$$

$$(CO + H_2O) \leftrightarrow (CO_2) + (H_2) \quad (3)$$

Fischer-Tropsch is an alternative catalytic procedure involved in the Biomass to Liquid (BTL) fuel route, which results from the FT-synthesis technology pioneered by the Germans in the 1920s [21]. The original scheme utilized coal in the place of biomass, as required during WWII. Another FT route is the Gas to Liquid path by way of converting Natural gas. The modern process is a set of chemical reactions of synthesizing hydrocarbons from a mixture of carbon monoxide and hydrogen [15], otherwise referred to as syngas, which was produced through a gasification process at the previous stage. An overview of the Fischer-Tropsch process is outline in the flow chart in **Figure 2** [35].

2.2 Vegetable oils and animal fats

Other biodiesel production techniques include ultrasonic cavitation, hydrodynamic cavitation, microwave irradiation, response surface technology, two-step reaction process, etc. [36]. Vegetable oil or animal fats are another alternative energy source, which appear to be an excellent substitute for transportation fuel. This is due to the ease of their production, utilization, storage, and the significant reduction achievable in pollutant emissions, mainly carbon dioxide (CO_2) [13]. Some examples of types of oilseed crop whose produce can be applicable are Canola, Palm, Corn, Cotton, Crambe, Linseed, Peanut, Rapeseed, Safflower, Sesame, Soya bean, Sunflower, Palm, Babassu, and Karanja, which are all examined in this paper. The main problems of using crude

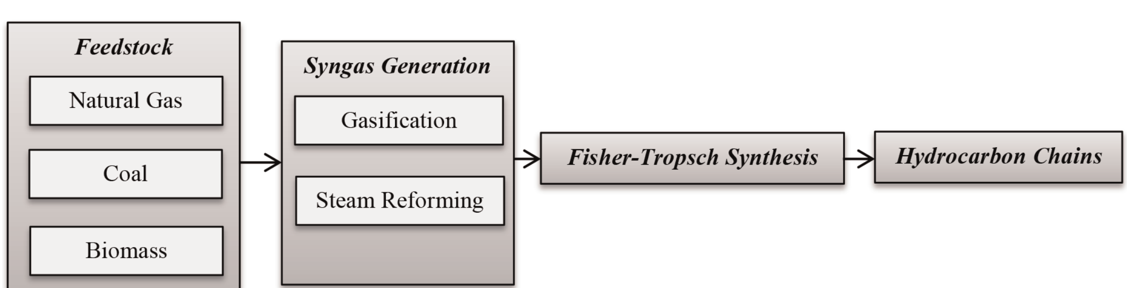

Figure 2.
An overview of Fischer-Tropsch process.

vegetable oils, which make it inferior as a fuel, are their viscosity, heating value, freezing point, etc. [4]. Chemical treatment such as alkali-catalyzed transesterification can be used to improve properties and produce biodiesel [4, 22]. Biodiesel is made up of alkyl esters of long-chain fatty acids with the major cost in its production being in the enzymatic reaction, which, due to the environment friendly and less energy-intensive nature, prefers enzymes over chemical catalysts [14].

2.3 Advantages of biofuels

Biomass is constantly being converted into energy by ways of natural processes such as aerobic digestion, fermentation, and composting. For example, by merely consuming vegetables and plant life, we in turn are converting biomass into the energy we require to live. By taking this primal concept and applying it literally to the creation of biofuels, it could be possible to devise a new mainstream renewable energy solution. Vegetable oils have the advantages of being available across the globe. They are renewable, as they produce oil seeds that can be planted to further the biofuel cycle and are "greener" as they seldom contain sulfur. Using these oils to then create biodiesel implements dependencies such as the viability of the fuel. This will rely on such factors as availability of the raw material in commercial quantity, ease of oil extraction, the oil content (yield) of the plant seeds as well as the quality of their product, which will need to meet the basic fuel characteristics for diesel fuels [22]. Extensive advantages of biodiesel are discussed in **Table 1** and were discovered through research.

2.4 Disadvantages of biofuels

There are several drawbacks to using crude vegetable oil, and these can be seen below and were taken from Gandure et al., [22]. These problems contribute to the reasoning behind chemically modifying the oils to biodiesel through transesterification. This is because the transesterification process involves removing the glycerides and combining oil esters of vegetable oil with alcohol, and in doing this viscosity reduces to a value that is compatible with diesel.

- Vegetable oil has significantly dissimilar injection, atomization, and combustion characteristics to diesel fuel
- Vegetable oil has high viscosity, which interferes with the injection process and leads to poor fuel atomization, low volatility both of which cause bad combustion in CI engines
- Vegetable oil, when inefficiently mixed with air, can contribute to incomplete combustion and therefore heavy smoke emissions
- Vegetable oil has high cloud and pour points, which can cause problem during cold weather
- Further problems incurred by using vegetable oil are lube oil dilution, high carbon deposits, ring sticking, scuffing of the engine liner, and injection nozzle failure

Despite the promise of an alternative fuel, biodiesel does claim some drawbacks. A full record of these disadvantages, created through literature research, can be seen in

Disadvantages	Explanation
Biodiesel from biomass has a several ecological issues	Biomass creation is land intensive and requires rich agricultural land for growth of feedstock. This limits ground for growing food [3]. Biomass requires pesticides and fertilizer which can pollute nearby water resources [3].
Biodiesel is expensive [3, 7, 9]	Biodiesel is dependent on the production of vegetable oil which is a lot less making biodiesel more expensive [7, 9]
Biodiesels chemical properties are affected by cold weather	Biodiesel has weak cold flow properties [3] due to the increase in its density at low temperatures [7, 9]. Also the higher surface tension and viscosity deteriorate the cold start stability [9].
Biodiesel as a fuel may have higher NOx emissions [9]	Biodiesel running in an engine has a negative effect on the injection system (injector coking, fuel lines clogging, etc.), on combustion (poor atomization, carbon deposits, etc.) and on the hardware (piston ring sticking). Due to Biodiesels effect on ignition delay and some of the above listed effects, the vaporization process is negatively inclined, so that incomplete combustion is induced during the engine start and also an increase of NOx emissions can be noticed [9].

Table 4.
A table showing the disadvantages of biodiesel in literature.

Table 4. To overcome the many failings of biodiesel, there is the option of blending the fuels with petroleum diesel. By doing this, there is an opportunity to use the fuel in sub-freezing conditions [7, 9]. Another way to improve its low temperature properties, which is currently being researched, is by applying cold filter clogging [37]. Further reasons for blending include significantly improving GHG emissions and increasing engine efficiency [14].

3. Key chemical and physical properties of biofuels

The performance, combustion, and emission characteristics of fuels depend on their properties. Many researchers state that the most important characteristics for fuel application are density, viscosity, lubricity, heating value, cetane number, flash and fire points, cloud and pour points due to their strong control over emissions characteristics and engine efficiency, ultimately indicating the quality of the fuel [3]. Before using any fuel in a compression ignition engine, its properties must measure as specified by standards. This section presents the main fuel properties that affect the quality of fuel [38–40].

3.1 Flash and fire point

The flash point is the temperature at which the liquid vapors ignite under normal pressure. The flash point is measured according to ASTM-D93 [41].

3.2 Density

Density is the mass per unit volume, and for diesel, fuel is normally determined at 15°C [21]. The composition of the fuel controls the density as diesel/biodiesel fuels are made up of a wide range of different hydrocarbon compounds of various densities and molecular weights. Density affects engine power, emissions, and fuel consumption particularly in contact injection systems [21]. There are strong correlations between viscosity, cetane number, and aromatics content, higher density increases energy concentration of fuel and minimizes fuel leakage, as well as encouraging the fuel optimization efficiency [4]. However, higher density does also incur higher viscosity, which consequently decreases engine performance and worsens emissions. For these reasons, the density must be meticulously regulated to be within a relatively narrow range [4, 21].

3.3 Lubricity

Lubricity has come to be a vital quality, mainly for biodiesel, because of better pressures in new diesel gas injection (DFI) generation, which needs higher lubrication from the gas [5, 38]. Lubricity is surely the capacity of the gas to lessen friction among shifting elements inside the engine to assist it run smoothly. Up to 30% of mechanical strength is fed on through friction, making it key to attaining the goal of growing engine performance through decreasing losses [42, 43]. A "dry gas" is a gas that is not made of a good enough quantity of lubricating components inflicting it to be not able to lubricate additives such as gas transport and injection system, cylinder liners, etc. Tribological assessments may be executed to evaluate lubricity, and on this record High-Frequency Reciprocating Rig (HFRR) system might be used as a different technique, which includes Scuffing Load Ball-on-Cylinder Lubricity Evaluator (SLBOCLE) having now no longer been used a lot in view in 2005 and a literature assessment of consequences is desired [44]. Diesel refiners now no longer impart a lubricity price in any respect of their specs for wholesalers, and the reality that the ASTM recommendations best installed a fashionable lubricity requirement in 2005 [45]. Supposedly, as a lot as 30% of mechanical strength is fed on through friction [23, 42, 43]. This makes gas lubrication essential to lessen scarring of additives within the engine. Biodiesel gas blends provide considerably better lubricity than traditional diesel, for instance, B2 can offer as much as a 65% development in lubricity [46].

3.4 Cloud and pour point

The pour point of a liquid is the lowest temperature at which liquid can flow when it is cooled. The pour point is measured according to ASTM-D97. The cloud point is the temperature at which the solid crystals or wax is formed in cloudy color when it is cooled. The cloud point is measured according to ASTM-D2500 [41].

3.5 Viscosity

Viscosity is a measure of "thickness" of a fluid and its resistance to deformation. Kinematic viscosity is the ratio of dynamic viscosity to density. Viscosity is dependent on fuel composition and so is replicated in the distillation parameters, density, and cold flow properties. A low viscosity is preferred as a very high viscosity may cause fuel pump distortion, which encourages the production of engine deposits and delays combustion [10]. In addition, there is a proven negative correlation between increasing temperature and the viscosity of a fuel [11]. It is the most important property of fuel when aiming to preserve the performance of a diesel operation engine [11]. A higher viscosity means the greater the affinity of the fuel to induce the formation of engine deposits [38], incurring poor fuel spray [3], atomization, and also insufficient fuel flow. It also delays combustion [11]. Furthermore, a very high viscosity may cause fuel pump distortion [21]. In these respects, lower viscosity is desired [3].

3.6 Heating value, gross calorific value

A fuel's heating value, calorific value of combustion are a gauge of the quantity of thermal strength it releases for the duration of its burning and is an influential component within the gasoline economic system and energy deliverability [5, 22]. There are several values to consider when concentration on the available energy within a fuel, the lower heating value (LHV) and the higher heating value (HHV) included. These differ, as the lower HV does not include energy in the combustion of water vapor, whereas the higher does. It is known that higher moisture contents in the fuel have a negative correlation with both LHV and HHV as the water takes up volume, which could have been fuel and must vaporized before the fuel can ignite. The net heating value is the appropriate quantity for comparing fuels as the engine exhaust water in gas phase [21]. A diesel engine fuel is of better calorific value as it allows the heat launch for the duration of combustion and improves engine's overall performance for the duration of combustion [4, 11]. The three fundamental elements that influence automobile gasoline economic system, torque, and horsepower are the performance of the engine turning strength within the gasoline into usable work, kind of engine (fuel or diesel), and the gasoline's volumetric strength content material or heating value [5, 21, 23].

3.7 Cetane number

In terms of Spark Ignition and Compression ignition engine types, each requires opposite abilities with regard to speed of combustion. For example, gasoline (SI) engine prefers a high octane rating as it will then be able to withstand more compression before igniting. The opposing diesel (CI) engine favors low octane ratings, as fuel is injected once air has already been compressed. The cetane number is the inverse of octane number and therefore is defined as ease of combustion in a compression setting so a lower one is required for SI and higher ratings for CI engines. The cetane number is also a prime indicator of the quality of fuel used [4] and directly affects its combustion quality [11]. As there is a negative correlation between cetane number and ignition delay time, a shorter delay causes a higher cetane rating [3, 4, 11, 21], which is desired by a CI engine for smooth operation, with nice cold start behavior at low noise, and additionally provides greater fuel economy and power [3, 7, 21].

4. Properties of crude vegetable oil

Research was gathered on the above key physicochemical properties for vegetable oils before they have been altered to biodiesel. The data can be seen in **Table 5** below along with the average values for diesel gathered from several sources.

The density is presented in **Table 5** and shows the variety of oils to not be far from diesel, with percentage differences of all the oils being in the range of about 8.04–13.23% above diesel. However as stated earlier, there is narrows gap acceptable for density, so engine testing would have to be done to see if this was suitable and also as previously specified, a high density will lead to a high viscosity, which is not desired. This can be seen to be true in **Table 5**, as it can be seen that all the unprocessed vegetable oils have a very high viscosity with the maximum gathered being for crambe oil, which is almost 15 times higher than that of diesel. The minimum viscosity of vegetable oils is for linseed, which is still seven and a half times as much a diesel. The large molecular mass of these oils is what causes the elated viscosity. The molecular weight of the oils is in the range of 600–900, which is about 20 times higher than that of diesel fuel [9]. High viscosity in a fuel can cause fuel flow and ignition problems in unmodified CI engines and also decreases in power output [48].

The best and highest calorific value, in terms of mass, which can be seen in **Table 5**, is for diesel. The vegetable oils are between 9 and 12% lower than its value of 44.651 MJ/kg due to the presence of chemically bound oxygen, which lowers their heating values by this percent [9]. The best vegetable oils are beef tallow and crambe, which both have a heating value of 40.5 MJ/kg. However, the fuel with the most superior cetane number is not diesel, but palm oil has a value of 52 compared to diesel's 50.1. All other vegetable oils are inferior to diesel in this regard, and linseed has the lowest number, which is 15.5 less than diesel.

Another interesting calorific value for fuels is MJ/l as this factor is in density. It is worked out by multiplying the calorific value (MJ/kg) by density (kg/l). These were determined from the data gathered from literature and are presented in the fourth

Fuel	Density (kg/m^3)	Calorific value (MJ/kg)	Kinematic viscosity at 40°C (mm^2/s)	Lubricity (μm)	Cetane number	References
Canola	910	39.78	37.7	—	41.5	[3]
Palm	925	39.3	38.25	—	52	[3]
Beef tallow	920	40.5	NA	—	NA	[3]
Corn	909.5	39.5	34.9	—	37.6	[9]
Cotton seed	914.8	39.5	33.5	—	41.8	[9]
Crambe	904.8	40.5	53.6	—	44.6	[9]
Linseed	923.6	39.3	27.2	—	34.6	[9]
Peanut	902.6	39.8	39.6	—	41.8	[9]
Rapeseed	911.5	39.7	37	—	37.6	[9]
Safflower	914.4	39.5	31.3	—	41.3	[9]
Sesame	913.3	39.3	35.5	—	40.2	[9]
Soya bean	913.8	39.6	32.6	—	37.9	[9]
Sunflower	916.1	39.6	33.9	—	37.1	[9]
Palm	918	NA	39.6	—	42	[9]
Babassu	946	NA	30.3	—	38	[9]
Karanja	NA	34	27.84	—	NA	[9]
Diesel	800-845	35	1.9-6	300	51	[3, 4, 8, 9, 11, 21, 22, 42, 47]

Table 5.
Important physiochemical properties of vegetable oils and diesel.

column of **Table 5**. It can be seen that the calorific values shift significantly closer to diesel. This is represented by the range going from 9 to 12% lower, in kilograms terms, to a range of just 0.04–3.1% lower, in liter terms, than that of diesel. This is a significant drop in percentage error. Diesel's calorific value actually drops by incorporating the density, though it still claims the highest value in the table. In terms of aiding combustion by increasing heat release and therefore performance, diesel is the best fuel shown in the table. Linseed's shorter ignition delay makes it valuable, even though it fails in all respects. Further processing is required to improve the properties of vegetable oil and bring them closer to that of diesel so they can be immediately implemented in CI engines. The transesterification process produces more favorable physicochemical parameter fuels, which have wider applications than their corresponding vegetable oil counterparts [49]. The methyl esters of Canola, Palm, and Beef Tallow shown in **Table 5** are examined in the following section.

5. Properties of biodiesel

Literature was investigated to find key physicochemical properties for biodiesel and synthetic diesel produced by either transesterification or Fischer-Tropsch Synthesis. The data can be seen in **Table 6** below along with the average values for diesel. All transesterification-produced biodiesels in the table are methyl esters.

Firstly by looking at the first three rows of data in **Table 6**, which were taken from McCarthy et al. [48] and Arbab et al. [4] for canola, palm, and tallow, it can be processed that the goal of transesterification to reduce the viscosity of vegetable oil is

Fuel	Density (kg/m^3)	Kinematic Viscosity at 40°C (mm^2/s)	Calorific Value (MJ/Kg)	Lubricity (μm)	Cetane number	References
Diesel Standard Min/Max	800–845	1.9–6	35	300	51	[3, 4, 8, 9, 11, 21, 22]
Canola—(methyl ester)	887.5	4	40.07	—	41.5	[3]
Palm oil—(methyl ester)	866.75	4.6175	40.3225	—	58.5	[3, 4]
Tallow—(methyl ester)	877	4.6	39.9	184.5	58	[3, 42]
Jatropha	852	4.3233333	40.8333	—	50.5	[3, 4, 11, 22]
Coconut	887	3.355	36.55	—	55.5	[3, 4]
Cotton seed	879.5	4.45	40.64	—	51.725	[3, 4, 11]
Sunflower	879.5	5.2	40.13	—	50.5	[3, 4]
Soybeen	890	4.525	39.035	193	46.5	[3, 4, 42]
Rapeseed	861.5	4.35	38.525	205	50.95	[3, 4, 50]
Marula oil	813	3.74	42.2	—	—	[22]
Marma bean (Tylosema esculentum)	846	3.5	42	—	—	[22]

Fuel	Density (kg/m^3)	Kinematic Viscosity at 40°C (mm^2/s)	Calorific Value (MJ/Kg)	Lubricity (μm)	Cetane number	References
Mongongo (Manketti oil)	817	3.86	41.7	—	—	[22]
Karanja	883	8.2925	36.56	—	55	[9, 11]
Polanga	899.3	4.67	40.275	—	57.3	[11]
Mohu	910	4.89	39.655	—	51.5	[11]
Rubber seed oil	870.5	5.885	38.735	—	43	[11]
Jojoba oil	864.5	22.3	45.017	—	63.5	[11]
Tobacco oil	874.25	3.865	39.12	—	50.30	[11]
Neem	938.5	34.5	36.6	—	51	[11]
Linseed oil	907.5	26.4	38.35	—	31.5	[11]
FT diesel	773.5	2.7925	45.505	211	77	[5, 13, 21, 47]
Diesel	800-845	1.9-6	35	300	51	[3, 4, 8, 9, 11, 21, 22, 42, 47]

Table 6.
Important physiochemical properties of biodiesels and diesel.

achieved. The values for both palm and canola are reduced by about 33.7 mm^2/s. This makes the biodiesels more suitable for CI engines. The three fuels all have reduced density than that of their vegetable oil counterparts with improvements between about 2.5 and 6.3%, but still have higher density than diesel, which would result in higher fuel consumption [48]. The calorific values of canola and palm also see a slight increase where tallow sees a minor decrease, though they still do not obtain the value of 44.651 MJ/kg for diesel. This means that the biodiesel may incur high fuel consumption and less power in a diesel engine, with tallow performing the worst. The power reduction can be between 5% and 10% depending on the biodiesel, engine speed, and load [48]. The cetane numbers of palm and tallow, however, rise well above diesel by 16.8% and 15.8%, respectively. It would be true to say for the three mentioned methyl esters that palm is the better source, as if used as engine fuel it would be more efficient. Among the various types of oils, there are differentiations in the types of fatty acids in their chain making them either, saturated, monounsaturated, or polyunsaturated. Biodiesel properties can be affected by these ranges of chain saturation levels [48].

5.1 Density

Overall, from **Table 6** and **Figure 3**, it can be said that the biodiesels usually have a higher density than diesel, with only SB100, SR100, and FT diesel failing outside of that rule. However, it also can be seen that Jatropha, SB100, SR100, and TE100 have the closest density to diesel all coming in under 3% difference. Neem biodiesel has the highest density with an average of 938.5 kg/m^3 compared to diesels at 835.126/m^3. Then Fischer-Tropsch diesel has the lowest density of all the fuels at 773.5 kg/m^3, which is a 7.076% variation from diesel. When looking at B100 fuel, pure biodiesels, and

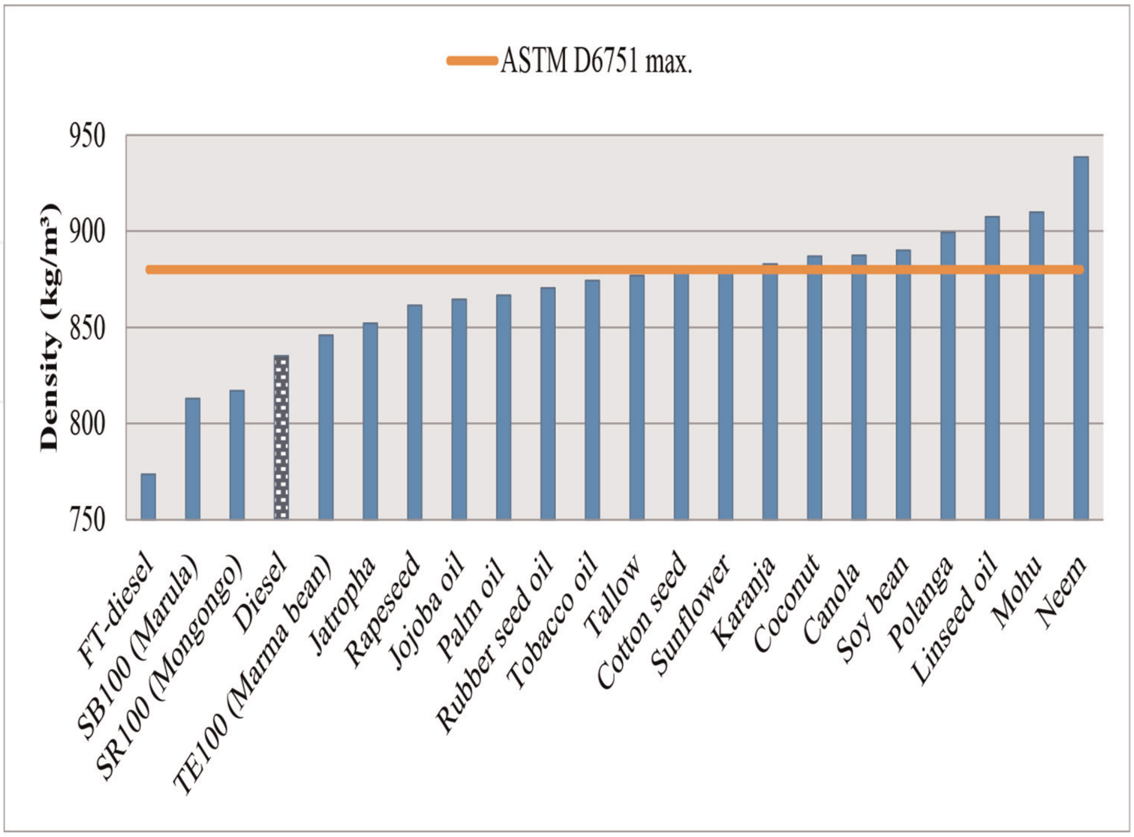

Figure 3.
Density comparison of various kinds of biodiesels.

petroleum diesel, ASTM D6751 standards must be followed. According to Ali et al. [8], the density for these pure fuels should not exceed 880 kg/m^3, a graph is presented in **Figure 3**, which shows the density of the evaluated fuels with the ASTM limit visible. Only FT-diesel, SB100 (Marula), SR100 (Mongongo), TE100 (Marma bean), Jatropha, Rapeseed, Jojoba oil, Palm oil, Rubber seed oil, Tobacco oil, Tallow, Cotton seed, and Sunflower remain within this specification making them the most suitable fuels for use in this instance.

5.2 Viscosity

In **Table 6**, the examined biofuels can be seen to have viscosities ranging from 2.79 to 34.5 mm^2/s, with FT diesel at the bottom end and Neem biodiesel at the top end of this range. It is stated in ASTM D6751 standards. For B100 and diesel fuels, that viscosity should not be below 1.9 or above 6 mm^2/s. **Figure 4** contains a graph with the viscosities of the fuels except Jojoba, Linseed, and Neem biodiesel, which are incredibly vicious, and compares them to the maximum value of ASTM D6751 limitations, as non-fall below 1.9 mm^2/s minimum. It can be seen that Karanja biodiesel also does not meet the specification requirements and exceeds the limit by 2.2925 mm^2/s. All other biodiesels as shown in t **Figure 4** are acceptable and could be effectively used in diesel engines since they largely satisfy the fluidity requirements of alternative biodiesel fuel [20]. However, with the aim of a low-viscosity FT, diesel proves to be the best fuel, though coconut and TE100 also improve on diesel with lower values and therefore would give enhanced combustion and atomization [4, 11].

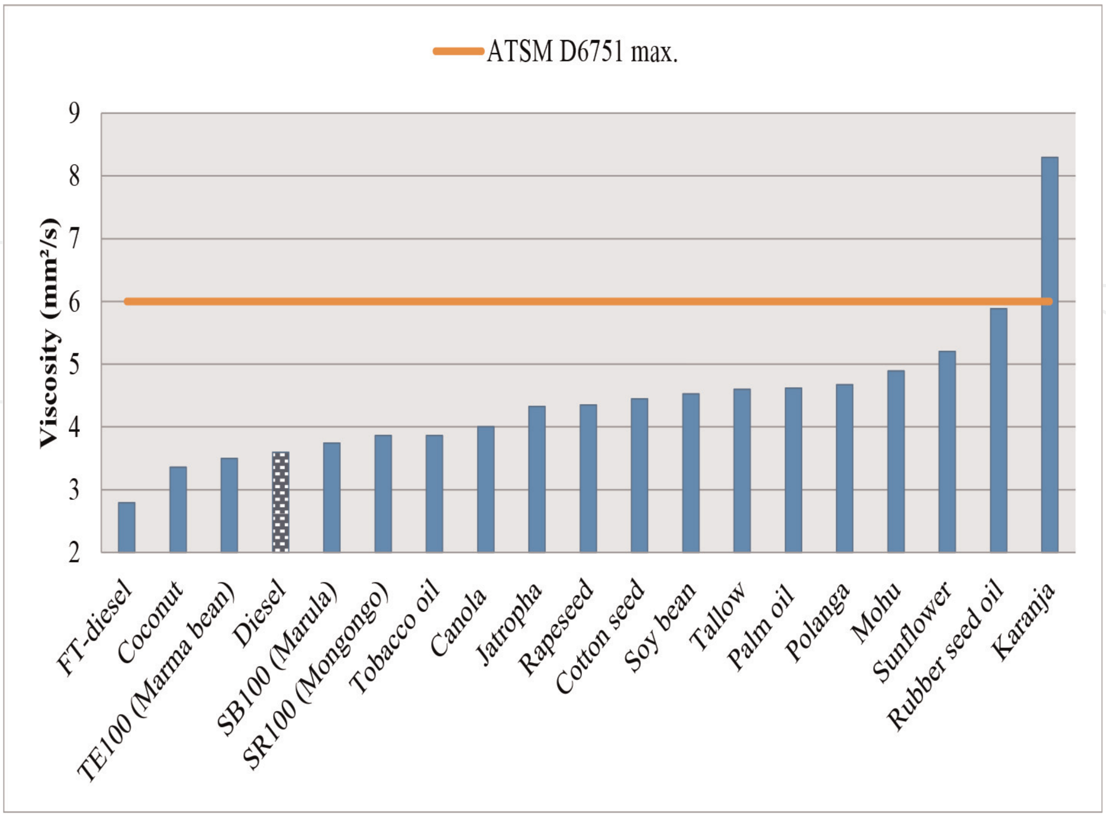

Figure 4.
Viscosity comparison of various kinds of biodiesels.

5.3 Lubricity

Results from literature for this test can been seen in **Table 6** for several alternative diesel fuels. The smaller the wear scare, the better the lubricating properties of the fuel, and they must comply with ASTM maximum value of 300 μm. It can be seen that soybean 20% blend biodiesel forms the smallest wear scar and diesel performs the worst; however, the values of diesel found in text fluctuated a lot so it is difficult to make a comparison here. Therefore, it would be suggested that a control diesel lubricity test should be done every time. Unfortunately, no Biomass-To-Liquid (BTL) Fischer-Tropsch diesel could be found, so Gas-To-Liquid (GTL) from Natural Gas is compared here. It is also suggested that some BTL FT fuel be experimented on for a better comparison. Overall, the biodiesels are seen to improve the lubricity of diesel from **Figure 5**.

5.4 Calorific value

The calorific value of all the biofuels in **Table 6** can be seen to be less than petro-diesel with the exception of Jojoba oil and FT diesel, this is due to its higher oxygen content [11]. As was stated earlier, a high heating value is desired, though a minimum value is not specified in the biodiesel standards ASTM D6751 but is prescribed in EN 14213 at 35 MJ/kg [8]. The biofuels are judged against this standard in **Figure 6** below, and it can be seen that all of the fuels have satisfactory heating values. Coconut-derived biodiesel is the closest to the EN14214 value at 36.55 MJ/kg, which is an 18% decrease from petro-diesel in its calorific value, while FT diesel achieves 1.91%

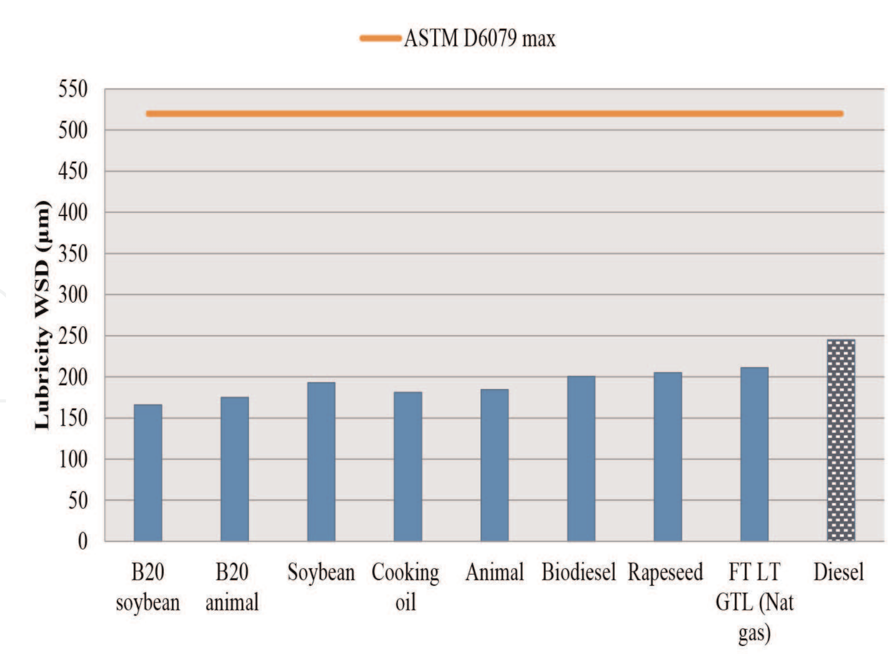

Figure 5.
Lubricity comparison of various kinds of biodiesel blends.

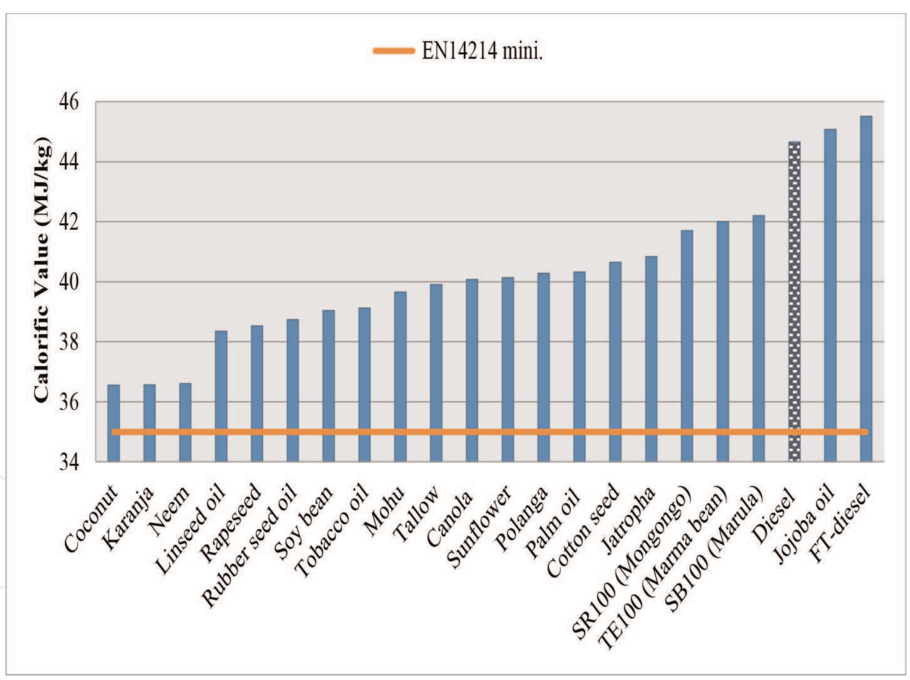

Figure 6.
Calorific value comparison of various kinds of biodiesels.

increase with Jojoba close behind at 0.94% increase. This shows that Jojoba biodiesel and FT diesel would give better engine performance and are attractive diesel substitutes [11, 21]. Though there is variation in the values as is exemplified in **Figure 6**, if it was stated that fuels within 10% of petro-diesels calorific value were comparable, this would encompass Palm oil methyl etser, Jatropha, Cotton seed, SB100 (Marula), TE100 (Marma bean), SR100 (Mongongo), FT diesel, Polanga, and Jojoba oil giving a wide range of alternative fuel options.

5.5 Cetane number

CN of a fuel is a measure of its propensity for auto-ignition. Cetane number has a strong impact on the time interval between the fuel injection and the combustion in the diesel engine. The majority of fuels had a higher cetane number than petro-diesel though Linseed, Canola ethyl ester, Rubber seed, and Soybean do fall below diesel and in fact below the ASTM minimum requirement at 47, making them unsuitable as diesel fuels. A comparison of the cetane number and the specification necessity can be seen in **Figure 7**. FT diesel and Jojoba oil biodiesel are again the fuels with the best and highest values, 77 and 63.5, respectively. This is an increase of 53.69% and 26.75% on petro-diesel, and in this respect these two alternative diesels are better than others, which indicates better auto-ignition quality [21]. The reason the cetane number of biodiesel is usually higher than that of petro-diesel is its longer fatty acid carbon chains and the presence of saturation in molecules. The cetane measurement is dependent on two compounds, namely hexadecane and heptamethyl nonane [11]. Though the fuels with the best cetane number have been highlighted, it should be noted that any of the fuels, which follow the guidelines, are acceptable for use in CI engines.

6. Properties of biodiesel blends

When implementing biomass-derived fuels in modern engines, failure can occur due to high viscosity, density, and deposit build-up. A solution with potential is to blend the mixtures with fossil fuels [35]. This will also aim to solve the fundamental problem associated with growing plants specifically for energy, the trade-off between foods and fuels [51]. Biodiesel blends between are represented in such a way that the number value signifies the percentage of biodiesel contained in the blend; for

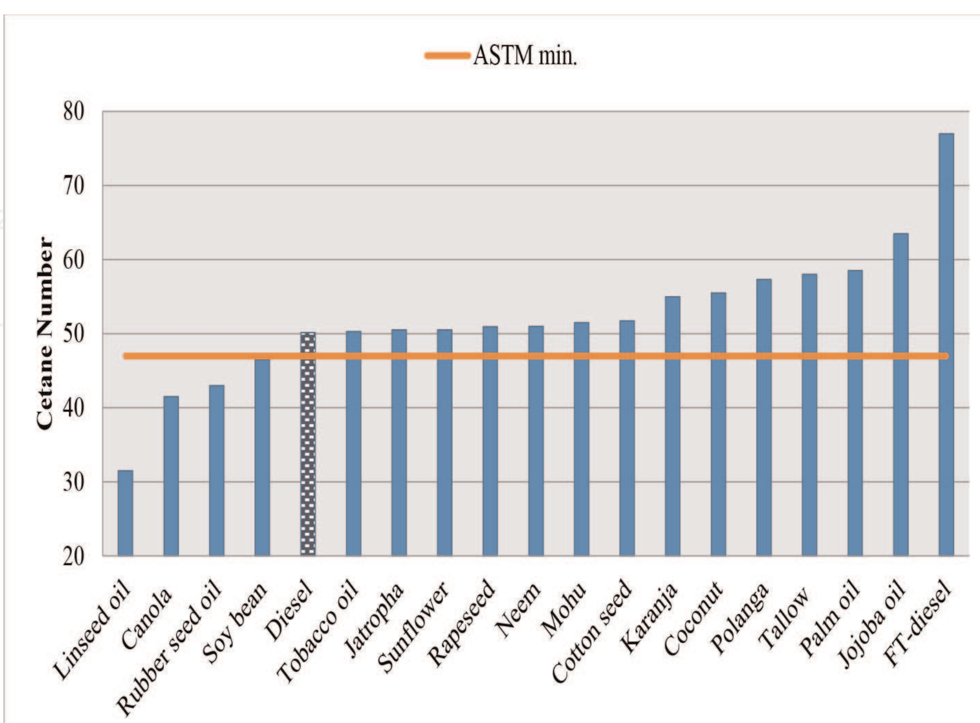

Figure 7.
Cetane number comparison of various kinds of biodiesels.

example, B30 contains 30% biodiesel and 70% petro-diesel. B6 to B20 should follow the specification for ASTM D7467, and the data from several sources for biodiesel blends are presented in **Table 7** below with average values for diesel, gathered from several sources [8, 9, 13]. All of the biodiesels used in the blends are methyl esters.

Fuel	Density (kg/m^3)	Calorific value (MJ/kg)	Kinemtaic viscosity at 40°C (mm^2/s)	Cetane number	References
B10 (palm oil)	850	44.23	3.86	NA	[8]
B20 (palm oil)	853	44.12	3.91	NA	[8]
B30 (palm oil)	857	43.13	3.95	NA	[8]
B40 (palm oil)	860	42.95	3.97	NA	[8]
B50 (palm oil)	863	42.74	4	NA	[8]
B100 (palm oil)	880	38.57	4.61	NA	[8]
B20 (Karanja)	NA	38.28	3.39	NA	[9]
B40 (Karanja)	NA	37.85	4.63	NA	[9]
B60 (Karanja)	NA	37.25	5.42	NA	[9]
B80 (Karanja)	NA	36.47	6.56	NA	[9]
B100 (Karanja)	NA	36.12	9.6	NA	[9]
SB30 (soya bean)	855.4	43.619	3.419	51.7	[13]
SB50 (soya bean)	866.9	42.547	3.571	52.1	[13]
SB80 (soya bean)	874.1	40.705	3.958	59.4	[13]
RB30 (rapeseed)	854.2	43.658	3.496	52.1	[13]
RB50 (rapeseed)	865	42.412	3.636	52.7	[13]
RB80 (rapeseed)	873.9	40.698	4.094	60	[13]
B5 (Citrullus Lonatus)	NA	44	4.9	54	-
B10 (Citrullus Lonatus)	NA	43.2	4.5	55	-
B15 (Citrullus Lonatus)	NA	43	5	56	-
B20 (Citrullus Lonatus)	NA	42.3	5.2	57	-
Diesel	800-845	35	1.9-6	51	[3, 4, 8, 9, 11, 21, 22, 42, 47]

Table 7.
The important physiochemical properties of biodiesel blends and diesel.

6.1 Density

The density values that can be seen in **Table 7** show that B10 (palm oil) has the lowest density at 850 kg/m^3 for the biodiesel blends, but in fact all of the blends have a higher density than petro-diesel at 835.126 kg/m^3. This is a similar outcome to biodiesels by themselves, as the majority of them had higher densities than diesel. It can be seen in **Figure 8**, which represents the blends' densities and compares them to ASTM specifications, that blending in more diesel fuel into the biodiesel lowers the density, as expected. The range of variation from diesels density is 1.78%–5.37%, so relatively there is very little differentiation. In addition, it should be noted that B10 and B20 for palm oil fall under the ASTM D7647 limits that control the B6-B20 blends making them viable options. The density of POME (Palm Oil Methyl Ester) is the highest; accordingly, the density of the blended fuel B30 is 2.6% lower than that of B100 due to the effect of blending with diesel [8]. Furthermore, at biodiesel blending ratios of more than 30% (B30), it can be noticed that they do not comply with ASTM D7647, as their densities are too high; however, they are not covered by this specification. They do comply with ASTM D6751 for pre-blended biodiesels.

6.2 Viscosity

The viscosity results for bended fuel samples range from 3.39 mm^2/s for B20 (karanja) to 9.6 mm^2/s for B100 (karanja) as can be seen in **Table 7**. These data are also visible in **Figure 9** below excluding B100 (karanja), which is extremely viscous, almost 2.67 times that of petro-diesel, and way beyond the limitation of both ASTM D7467 and ASTM D6751. Accordingly, the viscosity of the blend decreases as the methyl ester amounts decrease in the fuel mixture. However, the blended fuel viscosity still meets the blended fuel standard requirements ASTM D7467 for up to 50% biodiesel blending ratio (B50) and RB80. Between B40-B80 Karanja and B100 POME are within the standard requirements ASTM D6751 for pre-blended biodiesel.

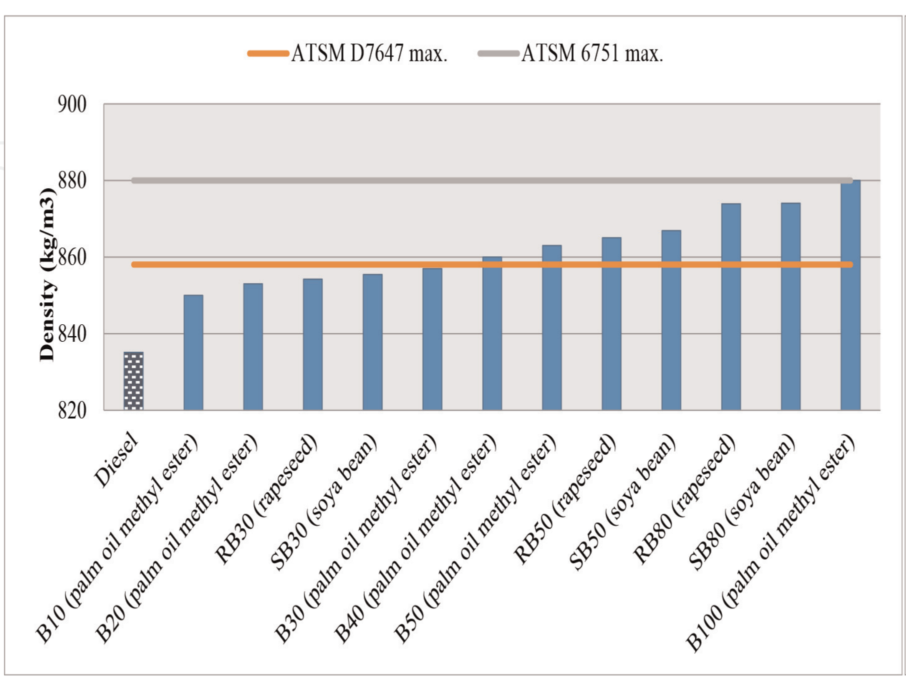

Figure 8.
Density comparison of various kinds of biodiesel blends.

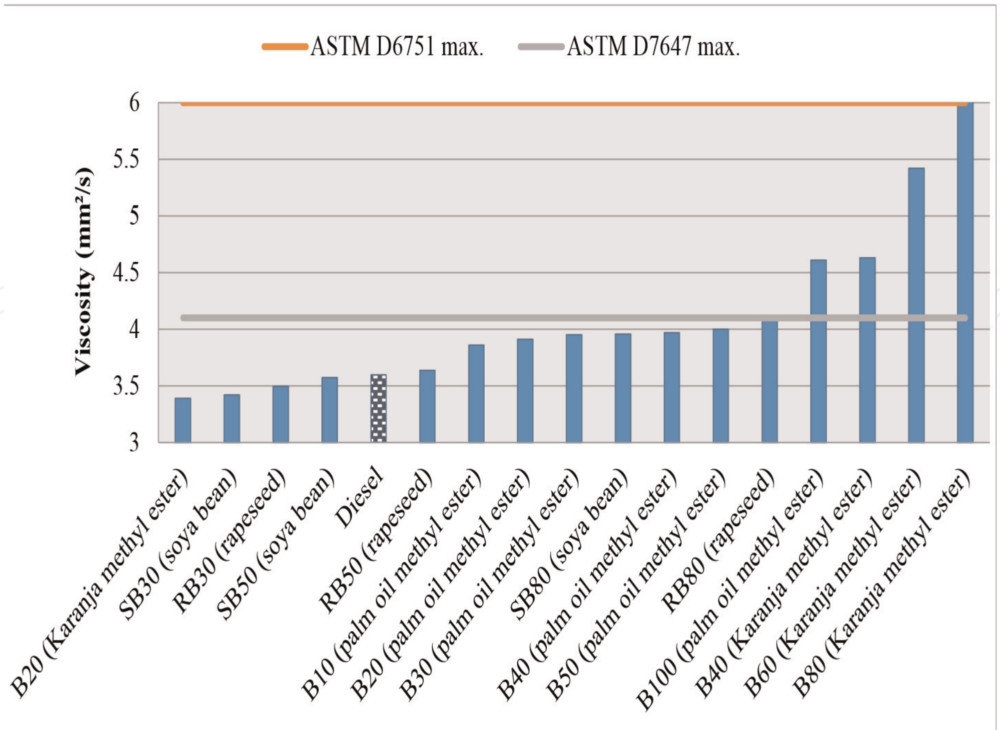

Figure 9.
Viscosity comparison of various kinds of biodiesel blends.

6.3 Calorific value

As mentioned in the previous section, the heating value is not specified in the biodiesel standards ASTM D6751 but is prescribed in EN 14213 with a minimum value of 35 MJ/kg [8]. The values of heating value from **Table 7** are compared to this limitation in **Figure 10,** and all of them obtain and exceed this minimum requirement.

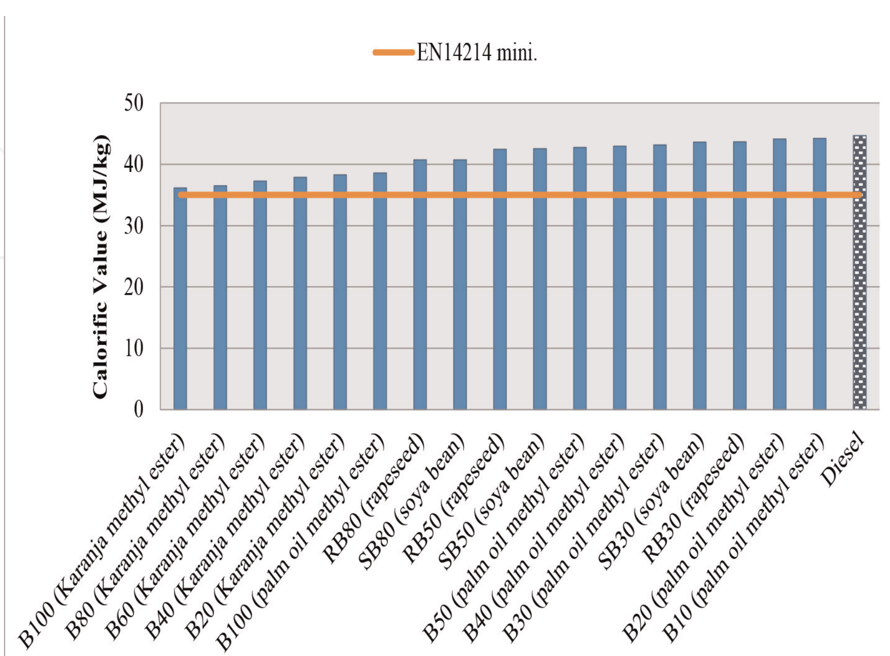

Figure 10.
Calorific value comparison of various kinds of biodiesel blends.

It can be seen in **Figure 10** that the heating value of the POME-diesel blend decreased with a higher volumetric percentage of the POME, the same could be said for Karanja, Soya bean, and Rapeseed diesel blends. The range of differentiation from Petro-diesels calorific value that can be seen is 0.94–19.11% with B100 Karanja at the bottom end and B10 POME with the closest value to diesel. Accordingly, the blended fuel heating value decreases with increasing biodiesel ratios in blended fuel, which is attributed to the relative composition of biodiesel, which has oxygen, present in the structure. Oxygen is not a component of the conventional diesel and results in reduced carbon and hydrogen contents [8].

6.4 Lubricity

Biodiesel gasoline blends provide extensively higher lubricity than traditional diesel; for instance, B2 can offer as much as a 65% development in lubricity [46]. To assess lubricity, a tribological check may be carried out, which measures the scale of the wear and tear mark in an HFRR (excessive frequency reciprocating rig) check [42]. Results from literature for this check can been seen in **Table 7** for numerous opportunity diesel fuels [42, 43, 47, 50, 52–54]. The smaller the wear and tear scare, the higher the lubricating homes of the gasoline, and they need to follow ASTM D6079 most cost of 520 μm [5, 23].

7. Engine performance with biodiesel

This section is going to concentrate on biodiesel as a whole as well as Fischer-Tropsch diesel. First, the engine performance will be examined by combining data from several different reports. **Table 8** below shows biodiesel and F-T diesel

Fuel-biodiesel and its blends	References	CO	CO_2	NO_x	HC	Smoke
Mahua oil; B20, B40, B60, B100	[55]	Decrease	Increase	Increase 11.6%	Decrease 32%	—
Karanja oil; B20, B40, B60, B80, B100	[55]	Decrease 94% and 73% for B20 and B100	—	Decrease 26%	Increase	Decrease 80% and 20% for B20 and B100
Jatropha oil; B10, B20, B40, B50 and B100	[55]	Decrease 24% for B100	—	Increase 24% for B100	Decrease	Decrease 45% for B70 and 60% for B100
Cottonseed oil; B10, B20, B30, B40, B50, and B100	[55]	Decrease 24% for B30	Increase	Increase 10% for B30,	Decrease	Decrease 14% for B10
Soybean oil; B100	[55]	Decrease	Increase	Increase	Decrease	Decrease
Rapeseed oil; B5, B20, B70 and B100	[55]	Decrease 12%, 25%, 31% and 35%	—	Increase 12% for B100, 9% for B70 and 6% for B20	Decrease	Decrease 45% for B70 and 60% for B100

Fuel-biodiesel and its blends	References	CO	CO_2	NO_x	HC	Smoke
Jojoba oil, B100	[55]	Increase	—	Increase	Increase	—
Neem oil; B5, B10, B15	[55]	Decrease	—	Increase	Decrease	Decrease
Waste cooking oil; B5, B10, B20 and B30	[55]	Decrease 6.75%, 7.33%, 8.32% and 13.1%	—	—	Decrease 105%, 19.9%, 27.7% and 36%	—
Aprocpt seed kemel oil; B5, B20, B50, B100	[56]	Decrease	Decrease	Increase	Decrease 18.66% for B100 and 2.66% for B5	Decrease
Rice bran oil, B100	[55]	Decrease 25.8%	Increase 20%	Increase 4%	Decrease 54%	Increase 27.93%
Castor Bean oil; B10, B25, B50 and B100	[55]	Decrease	Decrease	Increase 44.6%	—	—
Paradise oil, B20, B40, B50 and B100	[55]	—	—	Increase 5% and 8% for B50 and B100	Decrease 22% and 27% for B50 and B100	Decrease 33.5%, 39.4% for B50, B100

Table 8.
Comparison of diesel and different biofuels' emissions at different test conditions.

compared to petro-diesel in term of engine performance from two papers, which had gathered information from several sources.

7.1 Power

Engine power is an important characteristic that affects vehicle acceleration and handling. Using **Table 8** above it can be said that most researchers agree that power and engine torque for biodiesel decrease, with 70.4% majority. This is generally established to be due to the lower heating value and high viscosity of biodiesels, though some fluctuations in results can be noted [3, 4]. FT diesel, on the other hand, sees a unanimous performance between similar and decreased power display. In regard to biodiesel blends, it would be true and as expected to say engine power increases with a decreasing biodiesel ratio, due to the increasing amount of petro-diesel in the mixture. As a comparison, according to Ali et al., the brake power achieved for diesel fuel was about 0.5, 1.6, and 2.7% higher than that of the blended fuel B10, B20, and B30, respectively, at the same engine conditions [8]. Also Murugesan et al. [9] reported that the torque produced for B20 and B40 was 0.1–1.3% higher than that of diesel due to complete combustion of fuel.

7.2 Economy

The Brake-Specific Fuel Consumption (BSFC) is a gauge of the fuel flow rate per unit power output and is a measure of an engine economy performance [8]. In **Table 8** it can be seen that pure biodiesel was found to more commonly increase the fuel consumption of an engine when compared to diesel by agreement between 87.1% of the references studied, whereas FT diesel sees a decrease with a settlement of 83%. Biodiesel has a Higher BSFC due to its lower calorific value [3, 4, 7, 8, 11, 13], though some researchers have demonstrated that the increase of biodiesel fuel consumption ratio is more than lower heating value ratio. With this in mind, they determined that the high density of biodiesel could also contribute to this factor [3]. However, biodiesel blends with 20% or less biodiesel content have been noticed to reduce fuel consumption and give higher brake power because of complete combustion [4]. As a comparison, the BSFC of B20 and B40 was found to be 0.8–7.4% lower than diesel in one case [9]. Looking back at **Figure 6** in the previous section, it is displayed that the only two diesel fuels with a higher heating value than petro-diesel are FT and jojoba biodiesel, which explains the decrease in fuel consumption displayed in **Table 8** for FT diesel and is why jojoba would be expected to also show a decrease. This could be one of the sources of the inconsistent trends in **Table 6** for biodiesel with 12.9% of the sources finding the BSFC to be similar or lower than that of diesel.

7.3 Efficiency

The Brake Thermal Efficiency (BTE) is the ratio of the thermal power available in the fuel to the power that the engine delivers to the crankshaft [8]. However, in one case where the efficiency stayed the same, despite the better fuel consumption of FT diesel, it was noted that parameters such as injection pressure, injection timing, and EGR rate among others were more important in maximizing the engine efficiency than the calorific value of the fuel [13]. This could explain the fluctuations in the data provided in **Table 8**. For biodiesel blends it was found in some instances that the BTE slightly increased with increasing biodiesel ratios due to the high oxygen content of the blended fuel compared to mineral diesel, which enhances the fuel combustion process, and the additional lubricity provided by the biodiesel [8]. In other cases, this increase in efficiency was found to be true up to a point, say B40, but then from B60 to B100 efficiency decreased and became lower than that of petro-diesel [9]. Density affects engine power, emissions, and fuel consumption particularly in constant injection systems [21]. Many research studies have been done to investigate the effect of using biodiesel on engine performance and efficiency for examples: Use of kernel oil as biodiesel in four-stroke diesel engine increases brake specific fuel consumption and reduces the brake thermal efficiency [57] due to the lower calorific value and higher viscosity of the biodiesel [56]. In addition, Jatropha biodiesel, linseed biodiesel, karanja oil methyl ester, and neat vegetable oil decrease brake thermal efficiency [55, 56]. Rao et al. [58] stated that decrease in thermal efficiency is due to the early start of combustion, increase of compression work and heat loss. In contrast, some experimental results stated that increase in efficiency of engine by using biodiesels, for example, laforgia, observed that use of biodiesel in an indirect injection diesel engine increases the thermal efficiency by 10% with comparison of diesel fuel [59]. By investigation of all researchers' works, it is clearly observed that the efficiency in high load increases in all types of fuels including diesel fuel. This increase in use of biodiesel is lower than use of diesel in CI engine. Mahua, palm, and jatropha biodiesels decrease the efficiency higher than other types of biodiesels.

The performance of an engine is reflected in power output, fuel consumption, efficiency, and economy. Nearly all sources agree that alternative fuels, such as biodiesel and FT diesel, can be used in diesel engines with little or no modifications [60].

To improve the properties of biodiesel blending is an option, either with petro-diesel or by blending biodiesels from two or more feedstock [3].

7.4 Emissions characteristics of biodiesel

All engines produce exhaust gases when they run. These gases, however, are neither good for the environment nor human health. Use of fossil fuels in transportation facilities increased emissions of harmful pollutants. The hydrocarbons from engine exhausts form ground-level ozone, which is the major element of smog. Ozone affects human health such as lung disease and eye irritation and many other cancer issues [55]. Due to these reasons, fuels must meet the stringent emission norms set by the different regulating authorities throughout the world. The main pollutants from engine exhaust gases, which are considered for this review investigation, are carbon monoxide, carbon dioxide, nitrogen oxides, hydrocarbon, and particulate matter.

Table 8 presents the emission characterization from several research works. Results were shown by increase and decrease with the help of readers to understand the advantage and disadvantage of biofuels in the case of emission. Karanja oil blends decrease the CO by 94% and smoke by 80%, rapeseed oil blends decrease the CO by 35%, and rice bran oil blends decrease HC by 54%. Most of the biofuels increase the amount of NO_x in exhaust emissions, which can use some after treatment to solve this issue. In conclusion, types of biodiesels, purity, types of engines, and experiment condition affect the amount of exhaust gas emissions. Main disadvantage of biodiesel is increase of NOx emissions, which can be overcome by some engine modifications.

8. Conclusion

In conclusion, this literature review content covers the extensive chemical and physical properties of biodiesel and FT diesel while comparing them to mineral diesel, as well as giving an overview of their performance in CI engines. Many of the sources used in writing this report agree that biodiesel fuels are very appropriate substitute for oil fuels and are potentially suitable for reducing pollutant emissions in diesel engines, with modified combustion equipment. However, this report establishes rapeseed and soybean 30% blends to be the best alternative fuels examined here, performing within the limits demanded by the ASTM specifications and beyond the standard performance of petrol-diesel. Fischer-Tropsch also appears to be a sustainable option in the case of straight biodiesels, though POME blends between 10 and 30% performed just as well. In addition, if the current production of biomass-derived fuel was to grow, it could bring about some ethical issues and competition for produce could bring up the price of food over the globe. This could mean more starving children in third-world countries. To solve this issue, non-edible sources of oil, which can compete with edible oils, could be cultivated in non-arable lands. This would involve cultivating wasteland for biodiesel production to minimize the use of limited arable lands for growing edible oil crops for biodiesel production. Overall, further experimentation and investigation are suggested to find the most opportune solution to overcome the global oil shortage. As per ASTM standards, the calorific value of biodiesel and blends is within the range, while the flash point of pure biodiesel and its blends is slightly above that of pure diesel. Since fuel does not easily spark when exposed to flame, it is safe to handle during storage and therefore recommended for CI engines. The cetane numbers are all greater than those of pure diesel and meet ASTM standards. When burning in CI engines, Citrullus lanatus biodiesel and its blends will have the shortest possible ignition delay. A low fluidity was observed when using the fuels on CI engines, as all the pour points conformed to ASTM standards. Though fossil oils are commercially still available at low prices, and only tax credits are currently making bio-fuels a viable option, in the future this will change and research must be done to prepare for this.

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