What's the Difference between Biodiesel and Renewable (Green) Diesel

by Jesse Jin Yoon ***for Advanced Biofuels USA***

With the intensifying search for a sufficient alternative to oil-based energy, the development of alternative energy sources becomes increasingly relevant. Fuels derived from biomass or biological sources have received much attention. Among the various alternative fuel options, biodiesel and renewable diesel have been gaining traction in popularity.

Although both fuels can be derived from biomass, they are two distinctly different fuels. The purpose of this paper is to define both fuels and provide a general comparison between the two fuels.

DEFINITIONS

Petroleum diesel (Petrodiesel)

Before addressing the comparison between biodiesel and renewable diesel, it is important to first define petrodiesel, more commonly known as "diesel fuel" or simply "diesel."

Diesel fuel is a petroleum distillate rich in paraffinic hydrocarbons.

"Petrodiesel is produced from fractional distillation of crude oil between 200C (392F) and 350C (662F) at atmospheric pressure, resulting in a mixture of carbon chains that typically contain between 8 and 21 carbon atoms per molecule. [1]"

Petrodiesel falls under the specifications outlined by ASTM D975 in the United States and EN 590 in Europe.

The distillation process of crude oil into its fractions, including diesel, is depicted below in Figure 1.

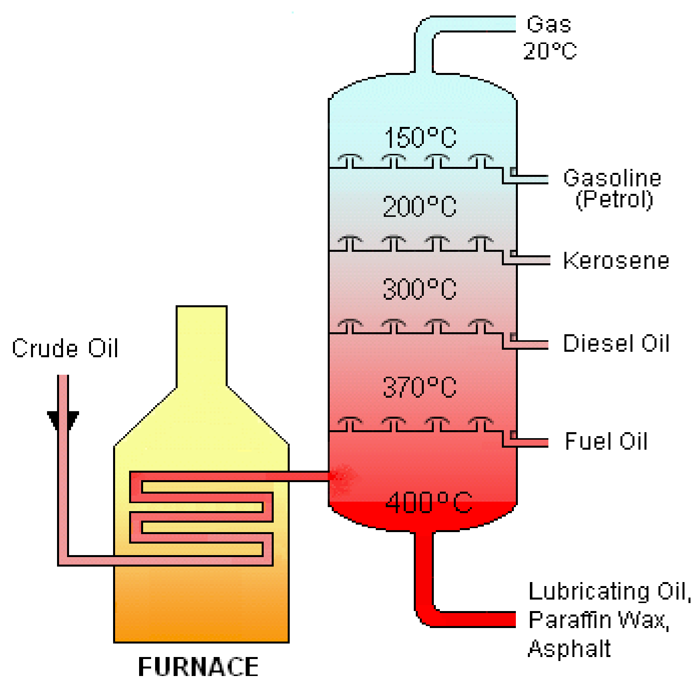


Figure 1. Crude oil is separated into fractions by fractional distillation. The fractions at the top of the fractionating column have lower boiling points than the fractions at the bottom. The heavy bottom fractions are often cracked into lighter, more useful products. All of the fractions are processed further in other refining units. [2]

Biodiesel

Biodiesel is produced using a transesterification process, "reacting vegetable oils or animal fats catalytically with a short-chained aliphatic alcohol (typically methanol or ethanol)." Glycerol is a by-product of this transesterification process. [3]

Biodiesel is defined under the standard of ASTM D6751 as "a fuel comprised of mono-alkyl esters of long-chain fatty acids derived from vegetable oils or animal fats." Biodiesel is also referred to as FAME (fatty acid methyl ester) or RME (rape seed methyl ester) in Europe.

Figure 2

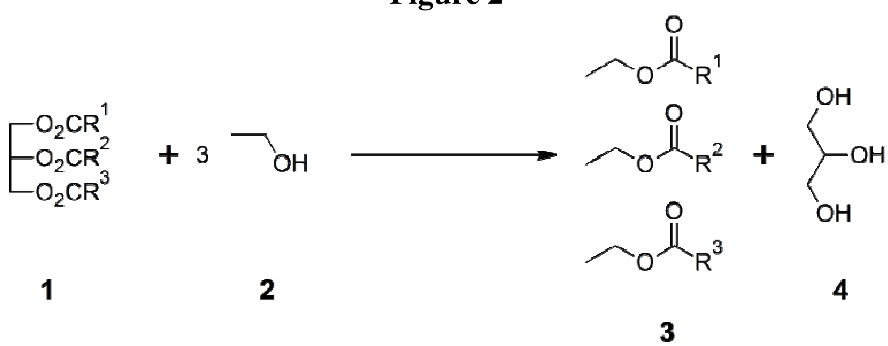


Figure 2. Transesterification of triglycerides from animal fats or plant oil (1) with methanol (2) to yield biodiesel (3) and glycerol (4). [3]

Biodiesel is chemically different from petrodiesel and renewable diesel because it contains oxygen atoms (note the "O" in the biodiesel (3) structure above). This leads to different physical properties for biodiesel. [13]

Biodiesel is created using a large variety of feed stocks. [4]

- Virgin oil feedstock; rapeseed and soybean oils are most commonly used, soybean oil alone accounting for about ninety percent of all fuel stocks in the US. It also can be obtained from field pennycress and jatropha and other crops such as mustard, flax, sunflower, palm oil, coconut, and hemp.
- Waste vegetable oil (WVO);
- Animal fats including tallow, lard, yello w grease, chicken fat, and the by-products of the production of Omega-3 fatty acids from fish oil.
- Algae, which can be grown using waste materials such as sewage and without displacing land currently used for food production.
- Oil from halophytes such as salicornia bigelovii

Biodiesel can be used in its pure form, or blended with petrodiesel as an additive. Biodiesel in its pure form is designated B100 where the "100" refers to 100% biodiesel. Biodiesels blended with petrodiesel follow a similar nomenclature. For instance, a blended fuel comprised of 20% biodiesel and 80% petrodiesel is called B20.

Renewable (Green) Diesel

Renewable Diesel, often called "green diesel" or "second generation diesel," refers to petrodiesel-like fuels derived from biological sources that are chemically not esters and thus distinct from biodiesel. Renewable diesel is chemically the same as petrodiesel, but it is made of recently living biomass. [5]

The definition of renewable diesel is not as straight forward as that of biodiesel. The term "renewable diesel" has been defined separately by the Department of Energy (DOE) with the Internal Revenue Service (IRS) and the Environmental Protection Agency (EPA). The specifics of the definitions can be found in the **appendix.** [6]

In addition, the terms renewable diesel and green diesel have been further distinguished based on the processing method to create the fuel with petrodiesel-like chemical composition. A brief description of this can be found in the **appendix.** [7]

For the purpose of this discussion, the term "renewable diesel" will refer to all diesel fuels derived from biomass that meet the standards of ASTM D975 and are not mono-alkyl esters.

There are three primary methods for creating renewable diesel, hydrotreating, thermal conversion, and Biomass-to-Liquid. [8]

Renewable diesel can be made from the same feed stocks as biodiesel since both require the tricylglycerol containing material from biomass.

Renewable diesel blends follow the same nomenclature as biodiesel. Renewable diesel in its pure form is designated R100 while a blend comprised of 20% renewable diesel and 80% petrodiesel is called R20. Because renewable diesel is chemically the same as petrodiesel, it can be mixed with petrodiesel in any proportion but users may need to add an additive to address lubricity issue associated with compounds with no oxygen.

<u>FUEL PRODUCTION</u>

Biodiesel

Transesterification
Transesterification is a chemical process where an ester is reacted with an alcohol to form another ester and another alcohol. For the creation of biodiesel, triglyceride oils (esters) are reacted with methanol (alcohol) to produce biodiesel (fatty acid alkyl esters) and glycerin (alcohol). The process can be seen below in figure 3 where R1, R2, and R3 are long hydrocarbon chains, often called fatty acid chains. [9]

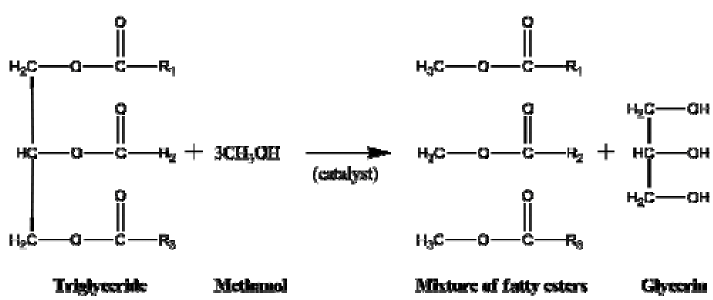


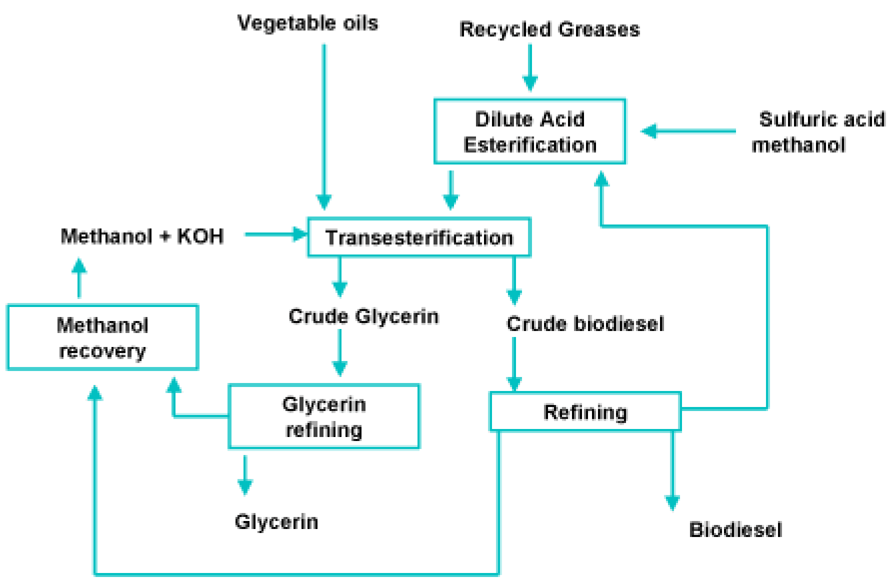
Figure 3

As shown in the diagram above (Figure 3), the triglyceride contains three separate ester functional groups and can react with three molecules of methanol to form three methyl esters (fatty esters) and glycerol (glyceride). The catalyst for this reaction is sodium hydroxide or another strong base such as potassium hydroxide. These hydroxides cause the methanol to dissociate and produce the methoxide ion, which is the actual catalytic agent that drives the reaction forward to create biodiesel.

Some feedstocks require a pretreatment reaction before they can go through the transesterification process. Feedstocks with more than 4% free fatty acids, which include inedible animal fats and recycled greases, must be pretreated in an acid esterification process. This process reacts the feedstock with an alcohol such as methanol in the presence of a strong acid catalyst such as sulfuric acid in order to convert the free fatty acids into biodiesel. The remaining trigylcerides are converted to biodiesel using the transesterification process.

The overall biodiesel production process is outlined in Figure 4 below. [10]

Biodiesel Production Process (Figure 4)



- **Acid Esterification.** Oil feedstocks containing more than 4% free fatty acids go through an acid esterification process to increase the yield of biodiesel. These feedstocks are filtered and preprocessed to remove water and contaminants, and then fed to the acid esterification process. The catalyst, sulfuric acid, is dissolved in methanol and then mixed with the pretreated oil. The mixture is heated and stirred, and the free fatty acids are converted to biodiesel. Once the reaction is complete, it is dewatered and then fed to the transesterification process.
- **Transesterification.** Oil feedstocks containing less than 4% free fatty acids are filtered and preprocessed to remove water and contaminants and then fed directly to the transesterification process along with any products of the acid esterification process. The catalyst, potassium hydroxide, is dissolved in methanol and then mixed with and the pretreated oil. If an acid esterification process is used, then extra base catalyst must be added to neutralize the acid added in that step. Once the reaction is

complete, the major co-products, biodiesel and glycerin, are separated into two layers.

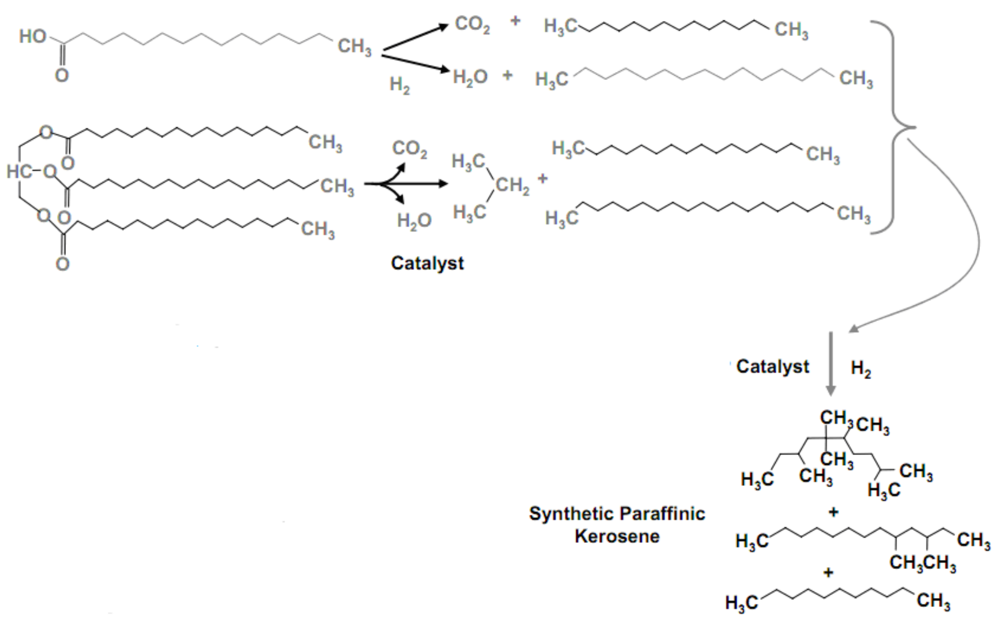
- **Methanol recovery.** The methanol is typically removed after the biodiesel and glycerin have been separated, to prevent the reaction from reversing itself. The methanol is cleaned and recycled back to the beginning of the process.
- **Biodiesel refining.** Once separated from the glycerin, the biodiesel goes through a clean-up or purification process to remove excess alcohol, residual catalyst and soaps. This consists of one or more washings with clean water. It is then dried and sent to storage. Sometimes the biodiesel goes through an additional distillation step to produce a colorless, odorless, zero-sulfur biodiesel.
- **Glycerin refining.** The glycerin by-product contains unreacted catalyst and soaps that are neutralized with an acid. Water and alcohol are removed to produce 50%-80% crude glycerin. The remaining contaminants include unreacted fats and oils. In large biodiesel plants, the glycerin can be further purified, to 99% or higher purity, for sale to the pharmaceutical and cosmetic industries. [10]

Renewable Diesel

Hydrotreating *(hydroprocessing or hydrodeoxygenation) "Green Diesel" Process*

The hydrotreating process is a process utilized by petroleum refineries today to remove contaminants such as sulfur, nitrogen, condensed ring aromatics, or metals. In this process, feedstock is reacted with hydrogen under elevated temperature and pressure to change the chemical composition of the feedstock. In the case of renewable diesel, hydrogen is introduced to the feedstock in the presence of a catalyst to remove other atoms such as sulfur, oxygen and nitrogen to convert the triglyceride molecules into paraffinic hydrocarbons. In addition to creating a fuel that is very similar to petrodiesel, this process creates propane as a byproduct. Because this process requires fossil fuel-derived hydrogen, this process is not 100% renewable and this must be considered when calculating the energy return, greenhouse gas emissions (GHG) and carbon life cycle. [11]

Hydrotreating Process (Figure 5) [12]



Many companies are utilizing this hydrotreating process as the basis for their renewable diesel projects. For instance, ConocoPhillips and Dynamic Fuels are working with Tyson Foods to convert waste animal fat into renewable diesel. Other companies utilizing this technique include Neste Oil Corporation in Finland, Eni in Italy, and Petrobas in Brazil. [13]

Since this process is currently used by many petroleum refineries, renewable diesel blends can be produced with existing refineries by co-processing the feedstock with petrodiesel. The advantages of this option when compared to constructing a stand alone operation are still under debate. [11]

Thermal Depolymerization *(hydrothermal processing, thermal conversion, cracking, pyrolysis, rapid thermal processing) "Renewable Diesel" Process*

Thermal depolymerization is another process that can convert biomass or other carbon-containing material into a "bio-oil" that is then refined into a petrodiesel-like fuel. Conversion temperatures are typically 570-660 degrees Fahrenheit with a pressure range of 100-170 atmospheres. The process converts the large polymers (cellulose, hemi-cellulose, lignin, and proteins) of biomass into smaller molecules. As a result of this process, organic vapors, pyrolysis gases, and charcoal are produced. The vapors are condensed to produce pyrolysis oil or bio-oil. [11]

Changing World Technologies are currently utilizing this method to process slaughterhouse waste and other carbon-containing solid waste to create a fuel that can meet the standards of both ASTM D396 and ASTM D975.

Biomass-to-Liquid (BTL) and Fischer-Tropsche

Yet another process for making renewable diesel fuel is to convert biomass (predominately cellulosic material) through high-temperature gasification into synthetic gas or "syngas," a gaseous mixture rich in hydrogen and carbon monoxide. The Fischer-Tropsche process is then used to catalytically convert the syngas to liquid fuel. This technology has been applied to coal (coal-to-liquids fuel or CTL), and natural gas (gas-to-liquids fuel or GTL) in addition to BTL. [11]

When an organic material is burned, it can be completely oxidized or gasified to carbon dioxide and water, or it can be partially oxidized to carbon monoxide and hydrogen. The partially oxidized gasification reaction is accomplished by restricting the amount of oxygen during the combustion process. The resulting carbon monoxide and hydrogen mixture is the syngas which is the starting material for the Fischer-Tropsche process. The Fischer-Tropsche process is a set of chemical reactions that converts the syngas to into liquid hydrocarbons. The overall process can be seen below. [13]

BTL & Fischer Tropsche Process (Figure 6) [14]

1) Synthesis Gas Formation

$$CH_n + O_2 \xrightarrow{\text{(Catalyst)}} \tfrac{1}{2}\, n\, H_2 + CO$$

2) Fischer-Tropsch Reaction

$$2n\, H_2 + CO \xrightarrow{\text{Catalyst}} -(CH_2-)_n- + H_2O$$

3) Refining

$$-(CH_2-)_n- \xrightarrow{\text{(Catalyst)}} \text{Fuels, lubricants, etc.}$$

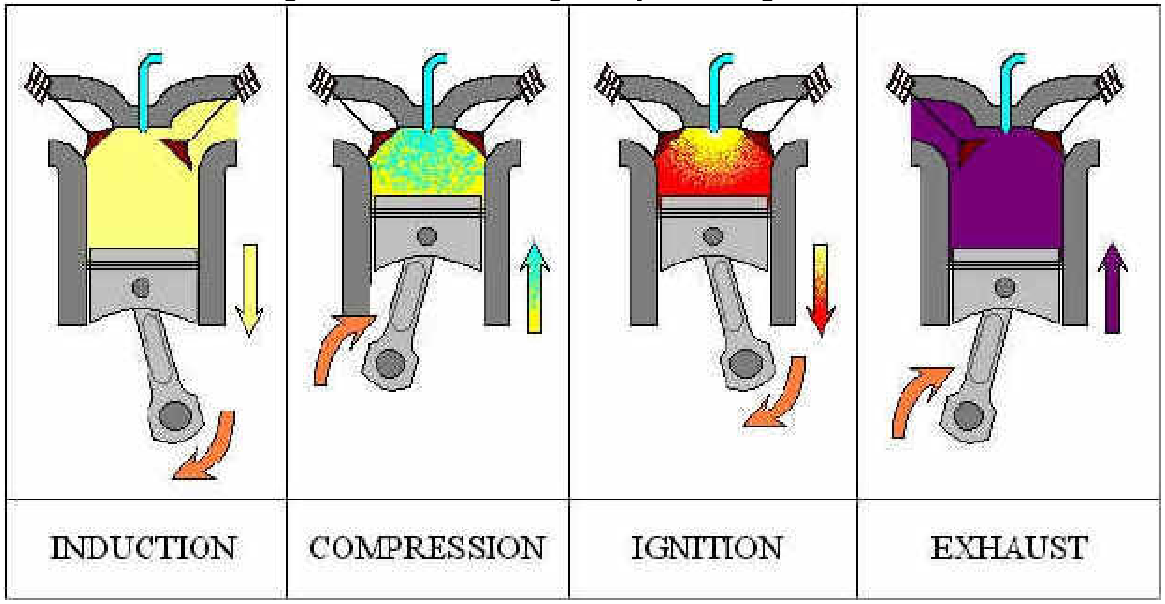
Renewable diesel produced from BTL can be created using any source of biomass while other processes are limited to mainly lipids, oils obtained from recently living biomass. [13]

BTL technology is mainly still in the research and development stages. Currently, Choren in Germany is working with Shell and VW on a BTL fuel it calls SunDiesel. Choren has built a plant in Freiberg, Germany with an estimated annual capacity of 18 million liters of SunDiesel.

Use in Combustion Diesel Engines

All the fuels above can be used to power a compression-ignition engine, more commonly referred to as a diesel engine. A diesel engine is an internal combustion engine that uses the heat of compression to initiate ignition to burn the fuel, which is injected into the combustion chamber during the final stage of compression. This is different than gas engines or spark ignition engines which use a spark plug to ignite an air-fuel mixture. The diesel engine is modeled on the Diesel cycle, a thermodynamic cycle both developed by Rudolf Diesel in 1897. The figures below describe the stages of the diesel engine cycle. [15]

Stages of the Diesel Engine Cycle (Figure 7) [16]



FUEL PROPERTIES

Biodiesel is chemically different than petroleum diesel and renewable diesel and as a result, has different chemical and physical properties. Below is a list of some of the properties most commonly used to describe a diesel fuel. See **appendix** for definitions.

<u>Diesel Fuel Properties</u> [12] [17]

Properties	Petrodiesel	Biodiesel	Renewable Diesel
Cetane#	40-55	50-65	75-90
Energy Density, MJ/kg	43	38	44
Density, g/ml	0.83-0.85	0.88	0.78
Energy Content, BTU/gal	129 K	118 K	123 K
Sulfur	<10 ppm	<5 ppm	<10 ppm
NOx Emission	Baseline	+10	-10 to 0
Cloud Point, C	-5	20	-10
Oxidative Stability	Baseline	Poor	Excellent
Cold Flow Properties	Baseline	Poor	Excellent
Lubricity	Baseline	Excellent	Similar

Use in Diesel Engines

Renewable Diesel

As you can see from the table above, renewable diesel possesses properties similar to petrodiesel and thus can be used to displace petrodiesel in any quantity. This is because renewable diesel is chemically similar to petrodiesel. Again, for the purpose of this paper, the term "renewable diesel" refers to all diesel fuels derived from biomass that meet the standards of ASTM D975 and are not mono-alkyl esters. As result of their similarities, renewable diesel users must be aware that lubricity may be an issue and may need to use additives to address this issue. Users must make sure to utilize an additive that is compatible with renewable diesel in order to avoid engine damage.

Although renewable diesel fuel meeting ASTM D975 standards should operate fine in your vehicle, it would still be wise to consult with your engine manufacturer before making the switch to R100 or any level blend.

Biodiesel

Biodiesel on the other hand, possesses properties that are dissimilar to petrodiesel. Biodiesel users must be aware of these differences for they may affect the operation of their diesel engine.

Some of biodiesel's properties can present benefits over traditional petrodiesel. The use of biodiesel can include a reduced net CO2 emissions, reduced HC and CO emissions, and lower visible smoke. Biodiesel also has a higher cetane number, contains no aromatics, and is non toxic and biodegradable. Lastly, biodiesel has low sulfur content and improves lubricity.

On the other hand, some properties of biodiesel present concerns. Biodiesel may not be compatible with certain metals causing corrosion. These metals include zinc, copper-based alloys, tin, and lead. Biodiesel can also cause certain elastomers and seals to swell or harden.

There is also concern with the increase of NOx emissions, especially at higher blend levels. This is especially critical to consider when using biodiesel in newer vehicles equipped with certified emission control technologies for the more stringent 2007 NOx emission standards.

Biodiesel can also negatively impact low-temperature operability due to its higher cloud point and pour point properties. Biodiesel compatible additives may need to be utilized to address these low-temperature issues. Other additives may need to be utilized to address the poorer thermal and oxidative stability of biodiesel. Again, additives used must be compatible with biodiesel fuel.

Lastly, biodiesel has lower energy content than petrodiesel. Although this lower value may not be noticeable at blend levels of B2 or B5, users of high blend levels or B100 may notice a drop in power output as well as fuel efficiency. [18]

Biodiesel and Manufacturers

Over the past few years, manufacturers have been working to support the use of biodiesel in their engines and equipment. However, it is important to recognize that manufacturers have limited field experience with biodiesel from which to base their recommendations for biodiesel use. Never-the-less, many manufacturers permit the use of biodiesel at blends of B2, B5 and even B20 in their engines. As a biodiesel user, it is important to check with the vehicle manufacturer before using biodiesel in any engine.

For instance, John Deere has been a known supporter of biodiesel and committed to environmentally friendly engine solutions. They were one of the first off-highway engine manufacturers to factory fill biodiesel in North America. John Deere prefers the use of B5 but will allow concentrations up to B20 in their engineers through Tier 3/Stage IIIA models, including all non-emissions-certified engines. Note that blends up to B20 can only be used if the biodiesel (B100) meets ASTM D6751, EN 14214 or equivalent specification. For this reason, biodiesel users are strongly encouraged to purchase biodiesel blends from a BQ-9000 Certified Marketer and to source from a BQ-9000 Accredited Producer, as certified by the National Biodiesel Board.

WARNING: CHECK WITH YOUR MANUFACTURER BEFORE USING BIODIESEL!

Although John Deere takes the above stance on their engines, users must realize that John Deere does not manufacture all engines used in their equipment. As a result, the equipment you purchased from John Deere may have an engine from a different manufacturer and thus different recommendations for the use of biodiesel.

Biodiesel use is still relatively new and still growing. Manufacturers continue to test, study, and research the effect of biodiesel in their engines and equipment. As a result, a manufacturer's stance on biodiesel is continuously changing as they release new vehicles and gain more field experience. For this reason, it is critical to check with your engine manufacturer before using biodiesel, at any blend level, in your engine. [19]

Appendix

"How the Government Defines Renewable Diesel and Biodiesel for Tax Credits and Engine Acceptance" [6]

For tax credit purposes, the Department of Defense (DOE) and the IRS broadly define renewable diesel. A definition of and tax credit for renewable diesel were included in Energy Policy Act (EPAct) of 2005.

The term 'renewable diesel' means fuel derived from biomass (as defined in section 45K(c)(3)) using a thermal depolymerization process which meets-

(A) the registration requirements for fuels and fuel additives established by the Environmental Protection Agency under section 211 of the Clean Air Act (42 U.S.C. 7545), and
(B) the requirements of the American Society of Testing and Materials D975 or D396.

The Environmental Protection Agency (EPA) issued its rule on the federal renewable fuel standard (RS).21. EPA includes renewable diesel as one of two parts of the definition of biodiesel. One part is the common definition of biodiesel as a mono-alkyl ester. The other part is for Non-ester renewable diesel.

EPA defines renewable fuel broadly to include potential future fuels.

EPA made a distinction between biodiesel and renewable diesel using equivalence values. The equivalence values determine how to add volumes of different fuels together for the purpose of RFS (Renewable Fuel Standard) tracking. Biodiesel (mono-alkyl esters) has an equivalence of 1.5. Non-ester renewable diesel has an equivalence value of 1.7. This reflects that EPA views renewable diesel as higher energy content than traditional biodiesel.

EPA elaborates on its definition of biodiesel in section III.B.2. (p. 23917) of its rule.

EPA's sub-definition of non-esters renewable diesel in this section states that the term refers to a motor vehicle fuel or fuel additive that:

1) meets the registration requirements for fuels and fuel additives established by the Environmental Protection Agency under section 7545 of this title (Clean Air Act Section 211);
2) is not a mono-alkyl ester;
3) is intended for use in engines that are designed to run on conventional, petroleum-derived diesel fuel, and
4) is derived from non-petroleum renewable resources. Current examples of a non-ester renewable diesel include: "renewable diesel" produced by the Neste or UOP process, or diesel fuel produced by processing fats and oils through a refinery hydro-treating process.

"Defining the Alternatives" [7]

Renewable Diesel has been defined as the product of using thermal depolymerization to create fuel. The IRS's ruling refers to any biomass process using heat as "thermal depolymerization" and the processed fuel is eligible for the $1-per-gallon blender's tax credit.

To many, especially chemical engineers, the term "thermal depolymerization" means something more specific. According to NREL's Robert McCormick, thermal depolymerization "means a chemical process driven exclusively by heat and pressure without the use of a catalyst." This process is considered identical or at least very similar to pyrolysis and can be in the presence of steam, which could be called hydrothermal processing-still a form of thermal depolymerization.

Thermal depolymerization, the feedstock is heated to temperatures between 570 and 660 degrees Fahrenheit, under pressure between 100 to 170 atmospheres. The reaction time is between 15-30 minutes.

Hydrotreating or hydroprocessing does not fall under the chemical engineer's definition of thermal depolymerization. The term "green diesel" has been used for hydrotreated fuels, which is hydrogenation conducted on molybdenum-or tungsten-sulfide-based catalysts supported on alumina and promoted with cobalt or nickel. "In hydrotreating, the goal is to catalyze reactions that use hydrogen to primarily remove sulfur but also to remove nitrogen and oxygen. Typically, hydrotreating requires temperatures between 600 to 700 degrees Fahrenheit with a lower pressure range than used for thermal depolymerization, 40 to 100 atmospheres. Reaction times vary from 10 to 60 minutes.

To clarify, the IRS includes the following in its definition of Renewable Diesel
(2) Thermal depolymerization is a process for the reduction of complex organic materials through the use of pressure and heat to decompose long-chain polymers or hydrogen, oxygen, and carbon into short-chain hydrocarbons with a maximum length of around 18 carbon atoms. A process may qualify as thermal depolymerization even if catalysts are used in the process. [21]

Biodiesel Terms and Definitions:

Ash – Ash is a measure of the amount of metals contained in the fuel. Ash forming materials may be present in three forms: (i) abrasive solids, (ii) soluble metallic soaps, and (iii) residual biodiesel catalyst. Abrasive solids and biodiesel catalyst materials result in wear of fuel system and internal engine components exposed to fuel after injection. Metallic soaps can contribute to deposits in the fuel system. All ash forming compounds can contribute to the accumulation of materials on diesel particulate filters, requiring filter maintenance. The levels specified are May 31, 2006 considered acceptable for engine performance; however, more stringent requirements may be necessary for optimal particulate filter maintenance intervals.

Cetane Number – Cetane number is a measure of the fuel's ignition and combustion quality characteristics. Biodiesel blend stock typically has a higher minimum cetane level than that of petroleum diesel. Fuels with low cetane numbers will cause hard starting, rough operation, noise and increased smoke opacity. The level specified is consistent with EMA's requested increase in the minimum cetane number for petroleum diesel fuel.

Cloud Point – Cloud point is a test used to characterize the low temperature operability of diesel fuel. It defines the temperature at which a cloud or haze appears in the fuel under prescribed test conditions. The cloud point for biodiesel blends is generally higher than it is for petroleum diesel fuel. To avoid component precipitation in vehicle fuel tanks and blockage of fuel filters, the traditional blending practices for D1 and D2 for a given ambient temperature should be modified prior to blending with biodiesel. Alternative low temperature operability test methods such as Cold Filter Plugging Point (CFPP) and Low Temperature Flow Test may be agreed to between the supplier and the purchaser of the fuel.

Copper Strip Corrosion – The copper strip corrosion test indicates potential compatibility problems with fuel system components made of copper alloys such as brass and bronze. The limit specified is the same as that for petroleum diesel fuel.

Flash Point – The flash point temperature is the minimum temperature at which the fuel will ignite (flash) on application of an ignition source under specified conditions. Flash point varies inversely with the fuel's volatility. Flash point minimum temperatures are required for proper safety and handling of fuels. Note that the biodiesel component must meet a flash point criteria, prior to blending, for the purpose of assuring that the biodiesel component does not contain methanol. It is not possible, however, to rely on the flash point of the blend for the same purpose inasmuch as the flash point of the petroleum component is much lower.

Kinematics Viscosity – Kinematics viscosity affects injector lubrication and fuel atomization. Biodiesel fuel blends generally have improved lubricity; however, their higher viscosity levels tend to form larger droplets on injection that cause poor combustion and increased exhaust smoke. The limits established provide an acceptable level of fuel system performance for D1 and D2 fuel blends.

Lubricity – Lubricity is a measure of the fuel's ability to provide adequate lubrication of the components of the fuel system, including fuel pumps and injectors. The precision required in the manufacturing of these components and the significant influence of abnormal wear require that they be adequately protected from scuffing, scratching, wearing, etc. that may affect their fuel delivery characteristics. The level specified is consistent with that recommended by suppliers of fuel injection equipment for modern diesel engines.

Physical Distillation – Distillation provides a measure of the temperature range over which a fuel volatizes or turns to a vapor. D1 typically has a greater volatility than D2; however, the inclusion of biodiesel at B20 blend levels results in comparable T90 temperature characteristics. Volatility directly affects the engine's ability to operate as intended. Biodiesel does not have a traditional petroleum distillation characteristic; however, the addition of biodiesel to petroleum diesel in a blend can result in an increase in T90 distillation temperature. Higher volatility, as represented by a lower T90 temperature, generally provides better engine performance, while lower volatility generally provides better fuel economy. The T90 temperature specified has been evaluated for engine performance with biodiesel blends, up to B20, where the petroleum diesel fuel utilized in the blend met the requirements of ASTM D975.

Rams bottom Carbon Residue – The Rams bottom Carbon residue test is intended to provide some indication of the extent of carbon residue that results from the combustion of a fuel. The limit specified is the same as that for petroleum diesel fuel.

Sulfur – Sulfur levels in fuel are regulated by various governmental agencies to assure compatibility with emission standard requirements. In the United States there are currently three sulfur grades: S5000, S500, and S15, for both D1 and D2 petroleum diesel fuel. Biodiesel blends may not exceed the applicable maximum sulfur levels as defined for petroleum diesel.

Water and Sediment – Fuel should be clear in appearance and free of water and sediment. The presence of these materials generally indicates poor fuel handling practices. Water and sediment can shorten filter life or plug fuel filters, which can lead to engine fuel starvation. In addition, water can promote fuel corrosion and microbial growth. The level of water specified is within the solubility level of water in fuel and, as such, does not represent free water. Limits are established to allow measured results to be compared to a maximum level acceptable for proper engine operation.

Sources

1. Wikipedia – Diesel Fuel
    a. http://en.wikipedia.org/wiki/Diesel_fuel
2. Fuel-Saver.org
    a. http://www.fuel-saver.org/Thread-Hydrocarbon-cracking-System?page=27
3. Wikipedia – Biodiesel Production
    a. http://en.wikipedia.org/wiki/Biodiesel_production
4. Wikipedia – Biodiesel
    a. http://en.wikipedia.org/wiki/Biodiesel
5. Wikipedia – Green Diesel
    a. http://en.wikipedia.org/wiki/Renewable_diesel
6. Lane, Jim. "Bioenergy PROFITS Princicples: How the Government Defines Renewable Diesel and Biodiesel for Tax Credits and Engine Acceptance." *Biofuels Digest* 8 Jan. 2010. Web-page.
    a. http://www.biofuelsdigest.com/blog2/2010/01/08/bioenergy-profits-principles-how-the-government-defines-renewable-diesel-and-biodiesel-for-tax-credits-and-engine-acceptance/
7. Kotrba, Ron. "Defining the Alternatives." *Biodiesel Magazine* 11 Feb. 2008. Web-page.
    a. http://www.biodieselmagazine.com/articles/2121/defining-the-alternatives
8. "Biodiesel and Other Renewable Diesel Fuels." *National Renewable Energy Laboratory* Nov. 2006. Web-page.
    a. http://www.nrel.gov/docs/fy07osti/40419.pdf

9. Van Gerpen, John H., Peterson, Charles L., Goering, Carroll E. "Biodiesel: An Alternative Fuel for Compression Ignition Engines." *ASAE Distinguished Lecture No. 31*, pp. 1-22.
    a. https://engineering.purdue.edu/~dbuckmas/teaching/ASM345/Engines/Fuel/Biodiesel%20DL%20by%20Van%20Gerpen%20et%20al%202007.pdf
10. US Department of Energy: Energy Efficiency and Renewable Energy
    a. http://www1.eere.energy.gov/biomass/abcs_biofuels.html
11. "Renewable Diesel Technology." *Renewable Diesel Subcommittee of the WSDA Technical Work Group*
    a. http://agr.wa.gov/bioenergy/docs/RenewableDieselWhitePaperFINAL.pdf
12. Kalnes, Tom. Marker, Terry. Shonnard, Dr. David. Koers, Kenneth. "Green Diesel and Biodiesel, A Technoeconomic and Life Cycle Comparions." *1st Alternative Fuels Technology Conference* 18 Feb. 2008. Web-page.
    a. http://www.uop.com/renewables/Presentations/Green_Diesel_AFTC_Kalnes%20rev2.pdf
13. Rapier, Robert. "Renewable Diesel Primer." *R-Squared Energy Blog* 17 Jan. 2009. Web-page.
    a. http://www.energystocksblog.com/2009/01/19/renewable-diesel-primer/
14. Schubert, Paul. Leviness, Steve. Acuri, Kym. Stranges, Anthony. "Development of the modern Fischer-Tropsch process (1958-1999)." Syntroleum 29 Aug. 2001. Web-page.
    a. http://www.fischer-tropsch.org/primary_documents/presentations/acs2001_chicago/chic_slide03.htm
15. Wikipedia – Diesel Engine
    a. http://en.wikipedia.org/wiki/Diesel_engine
16. http://www.myrctoys.com/faqs/engine-diagrams-and-animations
17. "Properties of Fuel"
    a. http://www.afdc.energy.gov/afdc/pdfs/fueltable.pdf
18. "Changes in Diesel Fuel: The Service Technician's Guide to Compression Ignition Fuel Quality." 2007. Web-page.
    a. http://www.biodieselautomotive.org/technical-resources/biodiesel-specifications/changes-diesel-fuel-manual
19. "John Deere Clarifies Position on Use of Biodiesel." *John Deere Press Release* 12 Nov. 2007. Web-page.
    a. http://www.deere.com/en_US/rg/infocenter/infoevents/pr/2007/biodiesel.html
20. Biodiesel Terms and Definitions
    a. http://www.thecoreiv.com/images/stories/biodiesel_terms_and_definitions.pdf
21. "Internal Revenue Bulletin – April 23, 2007 – Notice 2007 – 37." Internal Revenue Service 23 Apr. 2007. Web-page
    a. http://www.irs.gov/irb/2007-17_IRB/ar13.html

ADVANCED
BIOFUELS USA

__Advanced Biofuels USA__, an educational nonprofit organization, advocates for the adoption of advanced biofuels as an energy security, economic development, military flexibility, climate change mitigation/pollution control solution. The key tool to accomplish this mission is their web site, www.AdvancedBiofuelsUSA.org, a one-stop-shop library for industry professionals and the general public; from teachers and students to journalists, legislators, policy-makers, etc.

Contact us at 301-644-1395 or info@AdvancedBiofuelsUSA.org