BACKGROUNDER ON RENEWABLE FUELS FOR DIESEL ENGINES

Introduction

Rising energy prices, increasing US dependence on foreign oil, and concern about environmental impacts associated with transportation has heightened public interest in alternative fuels, including renewable fuels in recent years. This paper provides a brief overview of issues relating to the production and use of renewable fuels derived from biomass resources for use in diesel engines. It is intended to serve as a summary compilation of technical facts and to guide those readers interested in more details on the issues to additional sources of information.

Overview of Biomass Conversion Technologies

The use of non-petroleum-based fuels derived from renewable (biomass) resources in a compression ignition (diesel) engine is not a novel concept. In fact Rudolf Diesel, the inventor of the diesel engine, first operated his invention on peanut oil over a century ago. While it is possible to operate a modern diesel engine on raw or unrefined vegetable oils or animal greases, it is strongly discouraged. These substances are substantially more viscous and less stable in comparison to the petroleum-based diesel fuel for which the modern diesel engine is designed and their use could cause significant performance and maintenance problems that shorten engine life. To avoid these issues, vegetable oils and other biomass feedstocks are typically further processed to produce fuels for use in diesel engines. The table below briefly summarizes the

Biofuel Type	**Name**	**Feedstock**	**Conversion Process**	**Commercial Status**
Biodiesel from oil seed crops	Fatty Acid Methyl/Ethyl Ester (FAME/FAEE) Rapeseed Methyl Ester (RME)	Soybeans, cotton seed, rapeseed, sunflower, peanut, palm	Transesterification	Commercial
Biodiesel from animal fats/waste	FAME/FAEE	Animal fats/ Waste cooking/frying oil	Transesterification	Commercial
Bioparaffin	NExBTL, H-bio	Vegetable Oils and Animal Fat	Hydrogenation, Thermal Depolymerization (refining)	Demonstration and pilot plant
Synthetic biofuels	Biomass-to-liquids (BTL)	Lignocellulosic material	Gasification and Fischer-Tropsch synthesis	Demonstration and pilot plant

conversion processes either in use or under development. The process of reacting oils of biologic (plant and/or animal) with methanol or ethanol to form esters (transesterification) has been established since the mid-1800s and was originally developed to distill the glycerin used for making soap. It produces a fuel commonly known as “biodiesel” in the US and as fatty acid methyl ester (FAME) or fatty acid ethyl ester (FAEE) in Europe. Esters are more stable and burn more cleanly than the vegetable oils, animal fats or waste greases from which they are derived.

Biodiesel is currently the principal renewable fuel for diesel engines that is in commercial production in the US. As such, biodiesel is the focus of the balance of this paper. There are, nevertheless, other processes for producing fuels from biomass resources for diesel engines that require brief mention because they are the subject of ongoing research and development. In Europe, for instance, the potential for substantial greenhouse gas emissions reductions is driving interest in the "biomass-to-liquids" (BTL) process. (1)[*] This so-called "biomass-to-liquid" (BTL) thermochemical conversion process relies upon the same technology used to gasify and synthesize fossil fuels (i.e., gas-to-liquids and coal-to-liquids) and is well known. Biomass is gasified by reacting it with air, oxygen or steam in the presence of a catalyst to create a synthetic gas containing carbon monoxide and hydrogen. Any other elements in the biomass are removed during the gasification step. The carbon monoxide and hydrogen is then further processed via Fischer-Tropsch synthesis to make straight chain hydrocarbons or paraffins for diesel fuel. (2)

Unlike the production of fatty acid methyl esters which use only the oil derived from plant or animal material, BTL consumes the entire plant, thus theoretically broadening the biomass resource base available, requiring less land use per unit of energy and potentially providing even greater benefits in terms of wells-to-wheels greenhouse gas emissions reductions (because the main conversion process is fueled by the biomass itself). (3) In addition, BTL diesel is high in cetane and contains almost no sulfur or aromatics, making it a better performing and cleaner burning fuel than petroleum-derived diesel. (3,4) However, issues such as land and biomass resources, material collection and handling requirements, plant size, wells-to-wheels energy efficiency and high capital and operating costs will likely limit the widespread application of BTL particularly in the near term. (3) While there are some demonstration and pilot-scale BTL plants operating in Europe, there is no current commercial BTL production in the US. According to recent projections made by the US Energy Information Administration (EIA), commercial-scale BTL production in the US is unlikely even by the year 2030. (5)

In another process that is being explored by some companies, vegetable oils and animal fats are depolymerized in the presence of hydrogen to yield hydrocarbons that are then blended into diesel fuel. The oil or fat is pressurized and combined in a reactor with hydrogen in the presence of a catalyst similar to those used in hydrotreaters at petroleum refineries. The products of this process are alkanes which can then be directly incorporated into a petroleum refinery stream. This bioparaffin diesel fuel is similar in quality to BTL diesel. Proponents of this process claim that it is less capital-intensive than a BTL/Fischer-Tropsch project yet results in a comparable high quality product. (6) However, bioparaffins also share with biodiesel the problem of feedstock cost and availability. Vegetable oils are expensive, especially if they are food grade. The world's first bioparaffin plant is being built at a petroleum refinery in Finland and interest in this approach is increasing in Europe, Australia and South America, but it has not yet been introduced or tested in the US. (6, 7, 8, 9)

[*] Numbers in ( ) denote references which are listed at the end of this paper.

What is Biodiesel?

Biodiesel, as defined by the ASTM International (formerly known as the American Society for Testing and Materials), is a fuel blendstock comprised of long chain fatty acids derived from vegetable oils, recycled cooking grease or animal fats, and containing only one alcohol molecule on one ester linkage.[†] It is typically produced by chemically reacting a vegetable oil or animal fat with an alcohol such as ethanol or methanol in the presence of a catalyst to yield mono alkyl esters and glycerin. Methyl soyate, or soydiesel, made by reacting methanol with soybean oil, is the main form of biodiesel in the United States. Waste animal fats, used frying oil, peanuts, cottonseed, sunflower seeds, and canola (a variant of rapeseed) also are potential feedstocks that are being investigated as a way to reduce biodiesel production costs.

The term "biodiesel blend" refers to mixtures of petroleum-derived diesel fuel and a bio-based ester additive such as soydiesel.[‡] These mixtures may contain the bio-based additive in concentrations ranging from 2 percent (B2) to levels approaching 100 percent (B100) by volume.[§] Engines are capable of running on 100% bio product, although the practice is strongly discouraged by engine manufacturers. The most popular forms of biodiesel blends currently used in the United States include B2, B5 and B20.

Current Biodiesel Production and Usage

The use of biodiesel has grown dramatically since the US Congress first provided an incentive the 1998 Energy Conservation and Recovery Act which allows federal and state fleet managers to meet the 1992 EPACT alternative fuel vehicle acquisition requirements by using biodiesel added to petroleum diesel at blend concentrations of 20% by volume or higher.

According to the National Biodiesel Board, the US production of biodiesel grew from 500,000 gallons in 1998 to 75 million gallons in 2005 (largely as a result of recently enacted federal excise tax incentives) and is estimated to have reached 150 million gallons in 2006. (10)

As of late April 2006, according to the National Biodiesel Board, there are 65 biodiesel plants currently in operation with a reported total maximum annual biodiesel production capacity of 395 million gallons. (11, 12) 58 biodiesel plants are currently under construction or expansion with a reported total annual production capacity of 714 million gallons coming on line in the next 18 months, and an additional 36 plants representing 755 million gallons of maximum annual production capacity are reportedly beyond the planning stage, but not yet under construction. (13, 14) About two-thirds of the existing and planned biodiesel production capacity is based on the dedicated use of soybean oil as the principal feedstock. This is consistent with the fact that

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[†] This effectively excludes raw or unrefined vegetable oils which contain three ester linkages. In addition, biodiesel should not be confused with "e-diesel." The latter is typically defined as diesel fuel splash blended with up to 15% ethanol by volume. "E-diesel" is not the subject of this paper

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[§] Blends of biodiesel and petroleum-derived diesel are commonly designated as "BXX" where "XX" represents the biodiesel concentration in the mixture in units of percent by volume.

much of the existing biodiesel production capacity is located in Midwestern states such as Iowa, Illinois, Minnesota and Ohio which also are large agricultural producers of soybeans that have been experiencing excess production capacity, product surpluses, and declining prices. (15, 16) (Not surprisingly, the large majority of the infrastructure for distributing biodiesel to the end-user – i.e., retail outlets – also is heavily concentrated in the Midwestern states.) About 10% of existing and planned biodiesel production capacity is based on canola and other oilseed feedstocks, while under 5% relies upon yellow grease, recycled cooking oil or beef tallow, and the balance is equipped to use any oilseed, fat or recycled grease as the raw material for biodiesel. (12, 13, 14)

It is important to place the scale of biodiesel production and usage into perspective. In 2004, total on-road diesel fuel consumption amounted to 37.1 billion gallons or 2.4 million barrels per day. (19) At 75 million gallons, current domestic biodiesel production constitutes less than 0.2% of on-road diesel demand.[**] If one includes the heating oil, off-road and farm diesel sectors – potential markets representing an additional 12.4 billion gallons of distillate demand (in 2004) being targeted by biodiesel suppliers – then the fraction contributed by current domestic biodiesel production is even less. According to the US Department of Energy (DOE), the maximum biodiesel production from existing and potential future feedstocks will amount to no more than 0.203 MMBDOE by 2015. (21) Given that the DOE also is projecting a 30% growth in total highway diesel demand between 2004 and 2015, it is doubtful that domestic biodiesel production will displace more than about 7% of on-road diesel consumption in the near to medium term. (22)

Until the start of the Minnesota mandate for B2 biodiesel in September 2005, biodiesel usage was largely limited to rural areas and to demonstration programs sponsored by government agencies and private industry. It is currently being used in transit bus and heavy-duty truck fleets operated by private organizations as well as by municipal, state, local, and federal government agencies. (23, 24, 25)

Properties and Performance Characteristics of Biodiesel

In February 2002, ASTM International issued ASTM D6751 which established specifications that neat biodiesel (B100) must meet as a blending component in petroleum-based diesel fuel in concentrations of up to 20% by volume. [††] (27) These specifications (shown in Appendix A) help to ensure minimum product qualities by setting bounds on the biodiesel production process with respect to the completeness of the esterification reaction process, the removal of glycerin,

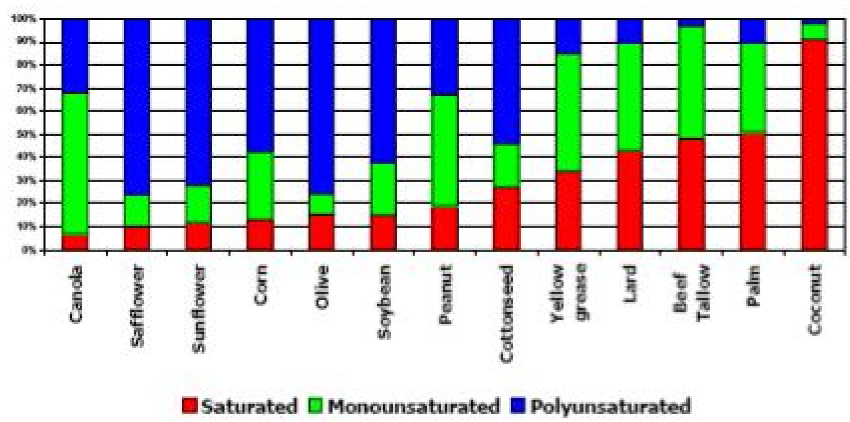
[**] This paper does not address imports of biodiesel fuel. Current market conditions and the availability of favorable tax incentives and other subsidies have provided a stimulus for biodiesel imports as evidenced by the fact that at least one company imported over 1 million gallons of biodiesel from Ecuador between late 2005 and early 2006, and has announced plans to grow the import shipments to 3 million gallons per month. (20) However, future trends in import volumes are far from clear.

[††] There are currently no ASTM specifications for finished biodiesel blends or B100 as a fuel. There are, however, efforts to achieve a consensus to (a) modify the ASTM D975 standard for diesel fuel to include biodiesel up to B5, (b) develop a new ASTM standard for finished B20 biodiesel blends, and (c) update B100 blendstock specifications. (26) For instance, the Engine Manufacturers Association recently proposed a specification for finished B20 biodiesel blends to facilitate further testing and evaluation of how such fuels perform in diesel engines. (75)

catalyst and alcohol, and the absence of free fatty acids. For instance, the acid number limit is used to control the level of free fatty acids in biodiesel as fuels with a high acid number have been shown to increase fueling system deposits and may increase the likelihood for corrosion. The limits for free and total glycerin control the levels of these compounds which – at high levels – have been associated with injector deposits, clogged fueling systems and filter plugging during cold weather operation.

Biodiesel properties are a direct function of the carbon chain length and proportion of saturated versus unsaturated fatty acids present in the fuel plus the presence of additives. As shown in the figure on the following page, this varies depending upon feedstock. Biodiesel made from feedstocks that contain highly saturated fatty acids (such as yellow grease, beef tallow, palm and coconut oil) tend to exhibit high cloud and pour points, high cetane number, and better stability. Biodiesel made from feedstocks with high polyunsaturated content (such as soy and sunflower) have low freezing points, lower cetane number and poor stability. (23, 28)

Fatty Acid Content of Selected Biodiesel Feedstocks



Source: Reference No. 23

The table below compares selected properties of typical neat biodiesel and current, typical low sulfur diesel. (23) In general, biodiesel has a higher cetane rating than typical petroleum diesel fuel. It also contains 11% oxygen by weight. The minimum flash point (a measure of fire safety) for biodiesel is higher than for diesel to ensure that any excess alcohol used in the manufacturing process has been removed. Furthermore, the viscosity of biodiesel tends to be higher than that for typical diesel fuel. (28)

The energy content of neat biodiesel is 8% lower (on a gallon basis) compared to typical petroleum-derived No. 2 diesel, so some reduction in fuel economy and power can be expected with fuels containing biodiesel. But, users of B20 or lower blends in fleet demonstration tests generally report little noticeable reduction in vehicle performance and fuel economy. (23, 24, 25, 27, 29)

Selected Properties of Typical No. 2 Diesel and Biodiesel Fuels

Fuel Property	Diesel	Biodiesel
Fuel Standard	ASTM D975	ASTM D6751
Lower Heating Value, Btu/gal	~129,050	~118,170
Kinematic Viscosity, @ 40 °C	1.3-4.1	4.0-6.0
Specific Gravity kg/l @ 60°F	0.85	0.88
Density, lb/gal @ 15 °C	7.079	7.328
Water and Sediment, vol %	0.05 max	0.05 max
Carbon, wt %	87	77
Hydrogen, wt %	13	12
Oxygen, by dif. Wt %	0	11
Sulfur, wt %*	0.05 max	0.0 to 0.0024
Boiling Point, °C	180 to 340	315 to 350
Flash Point, °C	60 to 80	100 to 170
Cloud Point, °C	-15 to 5	-3 to 12
Pour Point, °C	-35 to -15	-15 to 10
Cetane Number	40-55	48-65
Lubricity SLBOCLE, grams	2000-5000	>7,000
Lubricity HFRR, microns	300-600	<300

* On-road diesel fuel sulfur content will be capped at 15 ppm in 2006.

Neat biodiesel has good lubricity properties and contains essentially no sulfur or aromatics in comparison to petroleum diesel. The enhanced solvent property characteristic of biodiesel can cause fuel line and filter clogging problems particularly in engines that have never been exposed to this fuel. In light of the onset of ultra-low (15 ppm) sulfur highway diesel fuel, there has been heightened interest in the lubricity improvements offered by biodiesel. Some proponents for biodiesel claim that the addition of just 1% biodiesel to conventional diesel fuel can improve lubricity by up to 65%. (30, 31, 32) Since there is little (6 – 24 ppm) sulfur in the fuel, some argue that biodiesel might work well with the advanced aftertreatment technologies that are being developed to enable heavy-duty engine manufacturers to comply with stringent emissions standards in 2007.

Neat biodiesel has a relatively high pour point so it will tend to gel and/or form crystals more quickly than petroleum diesel in cold weather conditions. Biodiesel has poor cold flow properties due to the presence of saturated fatty acids. In cold weather conditions this increases the difficulty of producing blends with conventional petroleum diesel that are uniform. A recent study evaluated the operating parameters associated with blending biodiesel into petroleum-based diesel at 2 percent by volume under wintertime temperature conditions typical of

Minnesota. The study concluded that biodiesel must be kept at least 10°F above its cloud point for the blending to successfully avoid forming crystals or gel in the mixture. (33)

Users of blends containing 20 percent biodiesel will typically experience a decrease in cold flow properties (cold filter plugging point, cloud point, pour point) in the range of about 3 to 5°F relative to petroleum-derived diesel. (23, 24, 34) The amount of decrease is a function of the feedstock as blends containing biodiesel made from yellow grease have higher cloud and pour points than those made from soybean. Nevertheless, the difference in cold flow properties points to the potential for vehicles running on biodiesel blends to exhibit more drivability problems at less severe winter temperatures than for vehicles operating on petroleum diesel.

Biodiesel is biodegradable, but this property could lead to increased biological growth during storage unless appropriate precautions are taken. (23, 35)

Biodiesel will generally soften and degrade certain types of elastomers and natural rubber compounds over time. Using high percent biodiesel blends can impact fuel system components that contain elastomers that are incompatible with biodiesel – found primarily on model year 1980 and older diesel engines. (23, 34)

Biodiesel also is more susceptible than petroleum diesel to oxidative degradation. (23, 35) Factors effecting stability include the degree of natural antioxidant content, carbon chain length and degree of saturation of the biodiesel feedstock, and the presence of glycerides. For instance, high natural antioxidant content leads to lower deposits; the low C18:2/C18:3 content of biodiesel feedstocks such as grease and tallow contributes to lower oxidation deposits; and high glyceride content produces high oxidation deposits. (36) A 2004 DOE survey of the qualities of B100 and B20 blends found high levels of peroxide formation in the B20 blends and suggested that this finding further "reinforced the need for an [ASTM] oxidation stability requirement for B100 and perhaps also for B20." (72)

The Minnesota biodiesel mandate, which took effect in September 2005, highlights the need for careful control of product quality and consideration of ambient temperature conditions to avoid vehicle performance issues. This mandate was suspended three times in the ensuing winter months as officials investigated complaints regarding clogged fuel filters. Preliminary tests identified some batches of soybean-based biodiesel blends containing high levels of glycerin that is more susceptible to gelling in cold weather. Although there have recently been fewer biodiesel performance-related complaints in Minnesota, it is difficult to determine, at the time of this writing, whether the product quality issues have been resolved for they may have simply been obscured by the onset of warmer ambient temperatures.

Emissions, Air Quality and Health Impacts

The available data on vehicle emissions associated with the use of biodiesel are limited and show mixed results. In general, neat biodiesel usually reduces total exhaust hydrocarbons (THC) and carbon monoxide (CO) in conventional diesel engines but increases nitrogen oxides (NOx) by a small amount compared to emissions from petroleum diesel fuel. (29, 37, 38, 39) The magnitude (and sometimes the direction) of the emissions impacts varies as a function of the engine/vehicle technology tested, duty cycle, test methods employed, and the characteristics of the base fuel being used for comparison. For example, biodiesel generally reduces emissions of inorganic carbon particulate matter (PM) but increases emissions of the soluble organic fraction (SOF) of PM. (42) Since SOF is more prevalent in cold-start and low-speed driving, tests with vehicles and over duty cycles which emphasize this component (such as light-duty vehicles operated over the US LA-4 driving cycle) tend to show increased PM from biodiesel whereas tests that are weighted towards warm engines (characterized by most US heavy-duty engine testing) typically show reduced PM with biodiesel. (40, 41, 42)

In addition, as mentioned earlier, the chemical composition of the underlying biodiesel feedstock directly impacts the properties of the fuel and, consequently, the emissions associated with its use. In particular, biodiesel made from feedstocks that contain higher levels of unsaturated fatty acid chains (e.g., soy, canola) tend to produce higher NOx emissions than more saturated feedstock materials (e.g., tallow). (39)

The emissions impacts associated with biodiesel blends scale relatively in proportion to the biodiesel content of the mixture.

The US Environmental Protection Agency (EPA) published a technical assessment of the impact of biodiesel on exhaust emissions. To support this effort, EPA examined many sources of test data on the emissions effects of biodiesel and created a master database for subsequent analysis. Generally, the EPA assessment showed that increasing biodiesel blend concentration reduced HC, CO, and PM emissions, but increased NOx emissions. (37)

A key concern regarding the EPA assessment is that it is based on tests performed on relatively old (early 1990s) heavy-duty diesel engine technology. The absolute magnitude of the effects of biodiesel is greatly diminished in diesel engines equipped with particulate filters (in particular those that will be certified to the EPA PM emissions standards for the 2007+ model years.) However, there is virtually no public information available on the emissions response of modern technology heavy-duty engines equipped with advanced aftertreatment systems to fuels containing biodiesel. (36, 43) There also are little data available on the emissions characteristics of biodiesel used in light-duty or off-highway diesel engines.[‡‡]

A DOE-sponsored comparative study of the "well to wheels" emissions impacts of soy-based biodiesel versus petroleum diesel in an urban bus found that biodiesel substantially reduced lifecycle emissions of CO, SOx and CO_2 but increased lifecycle HC and NOx which contribute to ground level ozone formation. The increased lifecycle HC for biodiesel was attributed to the emissions produced during the farming and agricultural feedstock processing operations. (44) The estimate of substantial lifecycle CO_2 emissions reductions may be optimistic as it is based upon the assumption that biodiesel production has no impact on soybean production, prices or resource allocation, nor does it account for resource implications associated with crop rotation.

[‡‡] The EPA Assessment concluded that the results of biodiesel tests in heavy-duty diesel engines cannot be generalized to cover light-duty or off-road diesel engines. (37)

The DOE study also is based upon the use of natural gas for the soybean oil extraction process, but recent reports suggest an increasing interest in the use of coal for the production of renewable fuels from biomass and this would ultimately reduce the greenhouse gas benefit attributed to biodiesel. (45) Moreover, others have noted that certain agricultural practices associated with soybean production can potentially increase greenhouse gas emissions. (46)

As noted above, the use of biodiesel tends to increase NOx emissions. Some effort has been devoted to exploring the use of additives such as cetane improvers and antioxidants, the use of alternative diesel blend stocks (e.g., kerosene and Fischer-Tropsch diesel) in biodiesel blends, and/or changes in biodiesel feedstock composition as a means to ameliorate the NOx increase, but the results have met with only limited success. (47, 48)

One of the concerns associated with biodiesel is that the increased NOx emissions may have a detrimental air quality impact as NOx is a precursor to the formation of ozone and particulate matter in the atmosphere. However, a recent study conducted by Environ, Inc., suggests that the widespread use of blends containing 20 volume percent biodiesel in heavy-duty trucks will have negligible impacts on ozone and only small (i.e., < 3 percent) effects on particulate matter. (49)

Biodiesel is the only alternative fuel registered with the US EPA as a fuel and fuel additive under Section 211(b) of the Clean Air Act. The results of the battery of health effects testing required to achieve this status demonstrated that biodiesel exhaust had a non-toxic effect on health. (50) Furthermore, available test data indicate that the use of biodiesel substantially reduces emissions of air toxics such as poly-nuclear aromatic hydrocarbons and nitro-poly-nuclear aromatic hydrocarbons consistent with reductions in overall exhaust hydrocarbon emissions. Formaldehyde and acetaldehyde emissions also are lower with B100 biodiesel compared to petroleum-based diesel fuel. (51)

Biodiesel is more costly than conventional diesel fuel

Biodiesel generally costs more to manufacture than conventional petroleum diesel. (52) The feedstock cost of the oil or grease used to make biodiesel is the largest component of its production cost. It takes about 7.3 pounds of soybean oil, which costs about 21-24 cents per pound[§§] to produce a gallon of biodiesel. Feedstock costs alone, therefore, are at least $1.50 per gallon of soy biodiesel. Fats and greases cost less and produce less expensive biodiesel, but their supply is more limited and localized.

The difference between the cost of biodiesel and the cost of petroleum diesel has likely been narrowing due to gains in the price of crude oil in recent months which have outpaced those of the feedstocks used to make biodiesel. One available survey indicates that the before tax national average price of biodiesel in March 2006 was $3.05/gallon for B100, $2.14/gallon for B20 and $1.93/gallon for B2, in comparison to $1.91/gallon for #2 diesel fuel. (53) Unfortunately, this survey does not collect information on the energy contents of the fuels that correspond with the price data gathered. If one had such data to express these values on a per

[§§] According to the February 10, 2006 edition of the US Department of Agriculture, *Oil Crops Outlook*

BTU basis, then the differences in costs would be even greater given the lower energy content of neat biodiesel and of biodiesel blends relative to #2 diesel fuel. In addition, since January 1, 2005 the availability of federal excise tax credits for the sale of biodiesel blends has altered the comparative economics of biodiesel versus petroleum-based diesel.

Given blending, climatic and marketing considerations, fuel marketers and distributors will incur increased capital and operating costs to install and maintain separate tanks to store and blend biodiesel. In northern areas, these tanks must be heated to offset extremely cold winter temperatures.[***]

Biodiesel has been touted as a lubricity enhancer when added to petroleum diesel fuel at blend levels in the range of 1-2% by volume. There has been substantial promotion by producers of biodiesel for its use as a low-level lubricity additive for ultra-low sulfur petroleum-based diesel fuel which – unadditized – can have poor lubricity properties. It is important to recognize, however, that even at these low levels, the cost of biodiesel as a lubricity additive is in the range of two orders of magnitude greater than that which would be incurred through the use of conventional diesel additives. (54)

Due to the enhanced solvency characteristic associated with methyl esters, neat biodiesel has a tendency to dissolve accumulated sediments in diesel storage and engine fuel tanks. This can result in clogged or burst fuel filters. While the problem is much greater with blends containing high levels of biodiesel, it may also occur with B20 and lower blends, particularly with vehicles never before exposed to this product. (23)

Energy, and Resource Impacts

Available studies of the lifecycle energy balance associated with biodiesel show widely divergent results. Advocates for biodiesel often quote the aforementioned DOE study which concluded that for every unit of fossil energy used in the production of soy-based biodiesel, 3.2 units of energy are gained when the fuel is burned. (44) On the other end of the spectrum, a study by Pimentel and Patzek found that the energy balance for biodiesel was negative – i.e., the energy input for the production of biodiesel was 2% higher than the energy embodied in the fuel. (55) Other studies performed at the University of California, Davis and at the Argonne National Laboratory (ANL) have shown positive energy balances for biodiesel ranging from 133% to 236%, respectively. (46, 56) However, a recent review suggests that there are significant differences in the assumptions, data, definitions and methodologies among the various studies that need to be resolved if the estimates of the lifecycle energy balance of biodiesel are to be robust in any way. (57)

The degree to which vegetable-based biodiesel can displace petroleum fuels is limited both by the availability of cropland that provides the vegetable source and by the availability of alternative higher value options for use of the biodiesel feedstock inputs. One report has

[***] Biodiesel has a higher "cloud point" temperature that makes it more vulnerable to gelling which can cause engine performance problems in colder environments.

estimated that devoting all of the available land in Europe to produce the rape seed methyl ester-based biodiesel would only reduce crude oil demand by < 3%. (58)
It also is worthwhile noting again that DOE projections show that even if all existing and future available feedstocks were devoted to domestic biodiesel production, this would displace no more than about 7% of on-road diesel demand in the near-term (i.e., 2015). (21, 22)

Concerns of Original Equipment Manufacturers and Users

Engine manufacturers are concerned about the long-term oxidative and thermal stability of biodiesel and the resulting impact on deposit formation; the increased risk of corrosion; and the compatibility of biodiesel with seals and composite materials of fuel systems in existing vehicles. In particular, the stability properties of biodiesel are not fully understood and appear to depend upon the feedstock source, severity of processing, and presence of stability additives. There is a general paucity of data relating biodiesel fuel stability, fuel stability test results and deposit formation in engines. While research has recently been conducted to compare several stability test methods using representative biodiesel fuels, there remains a lack of agreement on the appropriate procedure and limit to incorporate as a stability specification in ASTM D6751. (59) Indeed, the absence of a stability specification in ASTM D6751 is perceived to be a key barrier to the increased acceptance of biodiesel by engine and fuel injection equipment manufacturers.

There also have been concerns raised regarding the impact of biodiesel blends on fuel system component durability. Recent research on this topic focused on an evaluation of the durability performance of engine fuel pumps operated for 500 hours on a matrix of B5 and B20 biodiesel blends of different levels of oxidation. (60) The results suggested that the B5 blends, even with highly oxidized biodiesel, appeared compatible with the materials and components tested. Un-oxidized B20 blends also appeared to be compatible with the tested components, but the test results for highly oxidized B20 biodiesel suggested the potential for significant operability problems, although this may have been due to the fact that the biodiesel used in the study was oxidized to a greater extent than would likely occur in actual practice.

The lack of consensus on an acceptable specification for oxidation stability has reportedly been a major stumbling block in the development of an ASTM standard for finished blends of B20. In the absence of such a specification, most of the original equipment manufacturers generally recommend against the use of diesel fuel that contains more than 5 percent biodiesel by volume. (61) Nevertheless, some manufacturers are approving the use of blends containing up to 20 percent biodiesel by volume in selected fleet operations provided that the fuel meets US military specifications (which includes the requirement that the biodiesel be consumed within 6 months so as to alleviate stability concerns associated with long term storage). (62, 63)

The "World-Wide Fuel Charter" published by the automobile manufacturers recommends against the use of diesel fuel that contains more than 5% biodiesel by volume. (64) This recommendation is based on concerns about the effects of vegetable-derived methyl esters (biodiesel) with respect to: 1) high viscosity under low temperature conditions; 2) the hygroscopic tendency of biodiesel and the consequent risk of corrosion due to high water content; and 3) the compatibility of biodiesel with seals and composite materials of fuel systems in existing vehicles.

Organizations representing the trucking industry have voiced cautious support for the use of biodiesel blends up to B5 as a means for extending the nation's supply of diesel fuel and to help ensure adequate fuel lubricity as the US transitions to ultra-low sulfur diesel (ULSD) in 2006. (65) However, truckers have generally opposed state biodiesel mandates such as that recently established in Minnesota because of concerns about the supply and higher cost issues usually associated with boutique fuels. (66) In addition, particularly after the experience in Minnesota with the distribution of off-spec fuel and the occurrence of clogged filters during the first few weeks of the mandate in late 2005, truckers have raised questions as to whether existing fuel standards are adequate to ensure consistent quality and trouble-free engine operation. (67)

Some environmental groups such as the Sierra Club view biodiesel blends as only marginally less polluting than petroleum-derived diesel. They are concerned that proposals to encourage the use of biodiesel will shift the focus away from natural gas which they perceive to be a cleaner transportation fuel.[†††]

Federal Incentives for Biodiesel

The US Department of Agriculture has offered subsidies for the expansion of biodiesel production through the Commodity Credit Corporation. These subsidies amount to $1.45 - $1.47 per gallon for soybean oil biodiesel and $0.89 - $0.91 per gallon for yellow grease biodiesel. (52) This program is currently scheduled to end in the summer of 2006.

Pure biodiesel (B100) is considered an alternative fuel under the Energy Policy Act of 1992 (EPAct). Lower-level biodiesel blends are not considered alternative fuels. However, the Energy Conservation and Reauthorization Act of 1998 gave operators of covered fleets[‡‡‡] the option of using biodiesel credits to offset alternative-fuel vehicle purchase requirements. One EPAct credit may be earned for every 450 gallons of B100 purchased for use in biodiesel blends of 20% or higher in vehicles over 8,500 lbs GVWR.

The JOBS Act enacted by the US Congress in 2004 provides for a federal tax credit for biodiesel. The credit equates to a one penny per percent of biodiesel in a fuel blend made from agricultural products like vegetable oils, and one-half penny per percent for recycled oils. This incentive is taken by petroleum distributors. The incentive was originally scheduled to sunset on December 31, 2005, but it is now available (as a result of the recently enacted Energy Policy Act of 2005) through 2008.

[†††] In a December 30, 2005 article focusing on biodiesel, the New York Times quoted Daniel Becker, Director, Global Warming and Energy Program, Sierra Club, as saying that he "would prefer to see wider use of a cleaner alternative fuel, like natural gas." (68)

[‡‡‡] Covered fleets include vehicles (excluding law enforcement, emergency and military vehicles) owned by Federal and State agencies and alternative fuel providers that are capable of being fueled at central locations.

State Activity Concerning Biodiesel

Texas has expressed concern about the ability of biodiesel to comply with its regulations requiring the use of low emissions diesel fuel ("TxLED") to reduce NOx emissions and other pollutants from diesel powered vehicles and non-road equipment in 110 counties out of compliance with Federal ambient ozone standards. The Texas Commission on Environmental Quality (TCEQ) has determined that blending biodiesel into TxLED is not acceptable unless the blend has been shown via testing to be equivalent to TxLED with respect to NOx emissions reduction. (69) The TCEQ has co-sponsored a test program to evaluate up to 3 different B20 + additive formulations for NOx reduction equivalency in this regard. (70) The test program is currently ongoing. In the interim, under the presumption that biodiesel blends currently make up only a small portion of the Texas diesel market such that the NOx impact is likely to be of "no measurable significance," the TCEQ issued a ruling (to sunset on December 31, 2006) that allows a biodiesel producer to blend no more than 100,000 barrels per year of B100 biodiesel with compliant TxLED provided that the biodiesel meets ASTM D6751 standards and certain other requirements. (69)

Several states (particularly in the Midwest) have established incentives to subsidize investments in biodiesel production and infrastructure and to encourage biodiesel use. As previously mentioned, Minnesota has a mandate in place which requires the use of 2% biodiesel in the majority of the state's diesel fuel pool. The governor of the state of Washington recently signed similar legislation that requires at least 2% of the state's diesel sales by volume consist of biodiesel. The law takes effect on November 1, 2008 or when in-state biodiesel feedstock production can support the 2% requirement – whichever comes first. (71) For details on of all of the various biodiesel-related incentives and requirements in currently in place in every state, the reader is encouraged to consult the comprehensive listing maintained by the US Department of Energy, Alternative Fuels Data Center. (72) The National Biodiesel Board also has provided a fairly comprehensive state-by-state summary of recent legislative activity (through May 2006) regarding biodiesel incentives. (74)

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APPENDIX A

ASTM D6751-03a Specifications for Biodiesel (B100) Blend Stock

Property	ASTM Method	Limits	Units
Flash Point	D93	130.0 min.	°C
Water and Sediment	D2709	0.050 max.	% vol.
Kinematic Viscosity, 40°C	D445	1.9 - 6.0	mm2/s
Sulfated Ash	D874	0.020 max	% mass
Sulfur *	D5453	0.0015 max. (S15)	% mass
		0.05 max. (S500)	
Copper Strip Corrosion	D130	No. 3 max.	
Cetane Number	D613	47 min.	
Cloud Point	D2500	Report to Customer	°C
Carbon Residue**	D4530	0.050 max.	% mass
Acid Number	D664	0.80 max.	mg KOH/g
Free Glycerin	D6584	0.020 max.	% mass
Total Glycerin	D6584	0.240 max	. % mass
Phosphorus Content	D4951	0.001 max.	% max.
Distillation Temperature, 90% Recovered (T90)***	D1160	360 max.	°C

* Sulfur content of on-road diesel fuel to be lowered to 15 ppm in 2006

**Carbon residue shall be run on the 100% sample

***Atmospheric equivalent temperature

In addition to the above, ASTM D 6751-03a includes the following workmanship specification: "The biodiesel fuel shall be visually free of un-dissolved water, sediment, and suspended matter."

Source: Reference No. 27