A CRITICAL REVIEW OF BIODIESEL AS A TRANSPORTATION FUEL IN CANADA

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for the
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March 25, 1998

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NOMENCLATURE

ACGHI	American Conference of Government Industrial Hygienist
ANPRM	Advanced Notice for Proposed Rule Making
API	American Petroleum Institute
ASTMA	American Society of Testing and Materials
B20	20% Biodiesel; 80% Diesel Fuel
BOCLE	Ball on Cylinder Lubricity Evaluator
CAA	U.S. Clean Air Act
CAFC	Corporate Average Fuel Consumption (Canadian)
CAFÉ	Corporate Average Fuel Economy
CANMET	Canada Center for Mineral and Energy Technology
CCME	Canadian Council of Ministers of the Environment
CDPF	Ceramic Wall-Flow Diesel Particulate Filter
CEE	Canola Ethyl Ester
CEN	Comité Européen de Normalisation (European Standards Committee)
CFPP	Cold Filter Plugging Point
CGSB	Canadian General Standards Board
CI	Compression Ignition
CME	Canola Methyl Ester
CN	Cetane Number
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CTO	Crude Tall Oil
D-1	No. 1 Diesel Fuel
D-2	No. 2 Diesel Fuel
DI	Direct Injection
DIN	Deutches Institut fur Normung (German Standards Institute)
DOE	U.S. Department of Energy
DOT	U.S. Department of Transport
DPTO	Depitched Tall Oil
EC	European Community
EGR	Exhaust Gas Recirculation
EPA	U.S. Environmental Protection Agency
EPACT	U.S. Energy Policy Act of 1992
ETBE	Ethyl Tertiary Butyl Ether
GC – MS	Gas Chromatography – Mass Spectrometry
GSC	Greenhouse Gasese
GIMVEC	Government Industry Motor Vehicle Energy Committee (Canadian)
HC	Total Hydrocarbon
HFRR	High Frequency Reciprocating Rig
IDI	Indirect Injection
IP	Institute of Petroleum (UK)
IRS	Internal Revenue Service (U.S.)
LN	Lubricity Number
MVSA	Motor Vehicle Safety Act (Canadian)
NBB	National Biodiesel Board
NCWM	National Conference on Weights and Measures
NHTSA	National Highway Traffic Safety Administration
NOx	Oxides of Nitrogen

NPRM	Notice of Proposed Rule Making
NREL	National Renewable Energy Laboratory
OEM	Original Equipment Manufacturer
PAH	Poly Aromatic Hydrocarbons
PDU	Process Development Unit
PM	Particulate Matter
PNA	Poly Nuclear Aromatics (Hydrocarbons)
R & D	Research and Development
REE	Rapeseed Ethyl Ester
RFC – DPF	Regenerable Fiber Coil – Diesel Particulate Filters
RME	Rapeseed Methyl Ester
ROCLE	Roller on Cylinder Lubricity Evaluator
SC	SuperCetane; Biodiesel produced by hydrogenation of Tall Oil
SEE	Soy Ethyl Ester
SME	Soy Methyl Ester
SOF	Soluble Organic Fraction of PM
SOx	Sulfur Oxides
TDC	Top Dead Center
TEE	Tallow Ethyl Ester
TLV	Threshold Limit Value
TME	Tallow Methyl Ester
TOFA	Tall Oil Fatty Acids
Tonne	Metric Ton, 1000 kg
TOR	Tall Oil Rosin
U.S.	United States of America
UN	United Nations
USDA	U.S. Department of Agriculture

EXECUTIVE SUMMARY

Introduction

Biodiesel is a renewable fuel that can be produced from vegetable oils, animal fats, used cooking oil, and waste from the pulp and paper industry. It can be used in its neat form, or as a blend with conventional diesel fuel, in diesel engines without any modifications. Since biodiesel is produced from renewable, domestically grown feedstock, it can reduce the use of petroleum based fuels and possibly lower the overall greenhouse gas emissions from the use of internal combustion engines. Biodiesel, due to it's biodegradable nature, and essentially no sulfur and aromatic contents, offers promise to reduce particulate and toxic emissions. It can be an attractive fuel for use in environmentally sensitive applications such as urban buses, underground mines, marine areas, and national parks. Biodiesel when mixed with diesel fuel, in small quantities, also seems to improve the fuel lubricity, extend engine life, and reduce fuel consumption.

Effects of Feedstock on Biodiesel Properties

Compared to diesel fuel, biodiesel is chemically simple since it contains only six or seven fatty acid esters. However, different esters vary in terms of important fuel properties, such as: Cetane Number (CN); viscosity; Cloud and Pour points; and degree of saturation. The presence of impurities also affects the fuel properties. Therefore, fuel related biodiesel properties are generally affected by the choice of feedstock. For a diesel fuel substitute like biodiesel, a higher CN is desirable whereas higher viscosity and higher Cloud and Pour points are undesirable.

Fatty acid esters with saturated molecules and longer carbon chains have higher CN. The viscosity of biodiesels produced from recycled frying oil and animal fats is generally higher than the ones produced from virgin soy, canola, or rapeseed oils. Cold flow properties such as Cloud and Pour points, which are specially important for the use of fuel in Canadian winters, are also significantly influenced by the type of feedstock. In general, biodiesels produced from animal fats and recycled saturated oils have higher Cloud and Pour points, making them unsuitable for use in cold weather conditions.

Generally speaking, biodiesels have higher CN, higher viscosity, and higher Cloud and Pour points compared to conventional diesel. Biodiesel blends with diesel fuel show a near linear relationship for most of the fuel properties. Hence the properties of B20 (20% biodiesel : 80% diesel) are a lot closer to diesel fuel properties than those of neat (100%) biodiesel.

Status of Biodiesel

The cost of biodiesel without tax in North America (the U.S. and Canada) is about 2 to 3 times more than the selling price of diesel. Based on data for last two decades, the average world price of diesel and soybean oil have been approximately US $200 and US $600 per tonne respectively. In producing biodiesel from vegetable oils, the return on investment and processing cost are essentially compensated by the byproduct credits, making the price of biodiesel approximately the same as the price of vegetable oil. At the present time, this cost differential can only be reduced by offering subsidies to biodiesel or by imposing additional taxes on conventional diesel fuel. In the long run, the cost of biodiesel could be reduced by employing lower cost feedstocks or through innovative technology. In the mean time, the biodiesel producers in North America are seeking its use in niche markets, which are willing to pay higher price for biodiesel's positive environmental and biodegradable attributes. The engine or vehicle manufacturers in North America have not yet approved the use of biodiesel in their products without compromising the warranties.

The current production of biodiesel in the U.S. is estimated at approximately 50,000 tonnes per year (57 million liters), with a potential to produce about 1.5 billion liters per year. Canada does not produce biodiesel commercially, the limited quantities of biodiesel used in research and demonstration projects are produced in small pilot plants. Canada can potentially produce 385 million liters of biodiesel per year, which amounts to roughly 2% of the current diesel consumption of about 19 billion liters per year.

In Europe, due to the government subsidies for biodiesel and higher taxes on diesel fuel, the use of biodiesel has been much more popular. The taxes on diesel fuel in Europe have averaged about US $400 per tonne, bringing the pump price of diesel to the same level as the biodiesel price without any tax. The current production of biodiesel in Europe is estimated at 665,000 tonnes (755 million liters) per year. The total planned production capacity is about 2 million tonnes (2.27 billion liters) per year. Many engine and vehicle manufacturers in Europe including Volkswagen and Mercedes Benz approve the use of biodiesel in their diesel engines.

The biodiesel industry in the U.S. is pursuing a number of initiatives to promote and expand the use of biodiesel, which include:

- Acceptance of B20 as an alternative fuel under the Energy Policy Act (EPACT)
- Getting the Corporate Average Fuel Economy (CAFE) credits for biodiesel
- Developing ASTM Standards for biodiesel and including biodiesel blends in the so-called premium diesel fuel designation
- Seeking special incentives for biodiesel, and
- Aggressive promotion in the niche markets

The U.S. activities will certainly have some impact on biodiesel use in Canada. The main potential for biodiesel use in Canada seems to be as a diesel lubricity enhancer, and in niche markets such as underground mines, and marine applications.

Experience with Biodiesel

The use of biodiesel in diesel engines, either in its neat form or as a blend with diesel fuel, reduces the emissions of particulate matter (PM), carbon monoxide (CO), and gaseous hydrocarbons (HC), but increases the emissions of oxides of nitrogen (NOx). In the case of particulate emissions, the insoluble fraction decreases while the soluble fraction (SOF) increases with a net reduction in total PM. The SOF can be further reduced by using oxidation catalysts. The NOx increase can generally be neutralized by retarding the injection timing of engines. The available data is not sufficient to draw any conclusions on the effect of biodiesel on non-regulated emissions.

Based on biodiesel research and demonstration programs in North America, many other important issues have been identified, which include: inconsistent quality of biodiesel; material compatibility and engine durability problems; loss of engine power; and lack of recognition by the engine/vehicle manufacturers. The production of biodiesel using a continuous process in large scale plants and developing fuel standards under the American Society for Testing and Materials (ASTM) should resolve fuel quality issues, and most likely lead to the fuel’s approval by engine manufacturers. Although many engine durability and power loss problems may be related to fuel quality, more field experience is required to clearly understand these issues.

Research has shown that biodegradation of biodiesel in aqueous solution is much faster than for diesel fuel. Even B20 blend degrades twice as fast as conventional diesel. This attribute of biodiesel is especially attractive for marine application in environmentally sensitive waters. Due to its lower particulates and toxic emissions potential, biodiesel is also considered a desirable fuel for diesel engines in underground mines.

Because biodiesel is produced from renewable feedstocks it should result in a net reduction of carbon dioxide emissions. A critical life cycle emissions assessment of biodiesel, in comparison of diesel fuel, is currently underway in the U.S. The final report is expected by the end of March 1998. Based on personal communications at the National Renewable Energy Laboratory (NREL), it is estimated that, on a life cycle basis, biodiesel would produce significantly less emissions than diesel fuel.

Main Issues and Recommendations

The potential for biodiesel availability in North America is limited to roughly 2% of the current diesel fuel consumption. The present cost of biodiesel is 2 to 3 times higher than diesel. Higher taxes on diesel fuel or tax incentives for biodiesel, to eliminate this price differential, do not seem feasible at this time. Hence biodiesel must find uses in niche markets where its positive attributes may support its higher cost, and preferably in the form of lower level blends in diesel in order to minimize the incremental cost.

Currently biodiesel is produced in small batches using a variety of feedstocks. Many times biodiesel fuel quality is not consistent. The ASTM Standards for biodiesel are being developed in the U.S. that will assure consistent quality and performance, without tying the final fuel to any specific raw material. Canada should also develop biodiesel specifications under the Canadian General Standards Board (CGSB).

For any new fuel to get market acceptance it must be approved by the engine/vehicle manufacturers. If biodiesel is to be used as a blend with diesel fuel, it should also be accepted by the petroleum industry. In order to get these endorsements, it is absolutely essential that biodiesel has the CGSB specifications, as well as solid data to support its environmental benefits and other positive attributes.

Besides the monetary incentives, the government policy and regulations can also help a fuel to find niche markets. If the federal and provincial governments in Canada impose stringent emissions regulations in underground mines, marinas, and other environmentally sensitive areas, it would certainly help biodiesel to enter these markets even at its current higher cost. Efforts should be made to include biodiesel as an alternative fuel under the Canadian Alternative Fuels Act, and to achieve the EcoLogo under the Environmental Choice Program. Federal government should also support research and development efforts to better quantify the environmental and emissions benefits of low-level biodiesel blends in diesel fuel.

1. INTRODUCTION

Biodiesel is an alternative fuel produced from vegetable and tree oils, animal fats, or used cooking oils and fats, that can be used as a substitute for, or an additive to, conventional diesel fuel. Biodiesel has a higher Cetane Number with other characteristics similar to diesel fuel; - thus it can be used in diesel engines without any modifications. Since it is produced from renewable, domestically grown feed-stocks, it can reduce the use of petroleum based fuels and possibly lower the overall greenhouse gas contribution from the use of internal combustion engines. Biodiesel, due to it's biodegradable nature, and essentially no sulfur and aromatic contents, offers promise to reduce particulate and toxic emissions, and is considered to be an attractive transportation fuel for use in environmentally sensitive applications such as urban buses in heavily polluted cities, national parks and forests, marine areas, and underground mining equipment. It is also reported that adding small amounts of biodiesel to conventional diesel can improve fuel lubricity, extend engine life, and increase fuel efficiency.

1.1 Background

Vegetable oils have long been promoted as possible substitutes for diesel fuel. Historical records indicate that Rudolph Diesel, the inventor of the diesel engine, used vegetable oil in his engine as early as 1900 (Peterson, 1986). Castor oil was used in the first diesel engine in Argentina in 1916 (de Vedia, 1944). Gauthier, a French engineer, published a paper in 1928 discussing the use of vegetable oils in diesel engines (Chowdury, 1942). Interest in vegetable oils continued in various parts of the world during the Second World War, but later on, the arrival of peace and the relative abundance of inexpensive fossil fuels made research into diesel substitutes unnecessary. The OPEC embargo of the 1970's and the subsequent rise of fuel prices and the fear of fuel shortages revived the interest in alternative fuels, including vegetable oils as fuel for diesel engines. However, the high viscosity of vegetable oils, which results in poor fuel atomization and fuel injector blockage, makes them best used after conversion to vegetable oil esters which are commonly known as biodiesel.

Recent environmental and domestic economic concerns have prompted resurgence in the use of biodiesel throughout the world. In 1991, the European Community (EC) proposed a 90% tax deduction for the use of biodiesel. Biodiesel manufacturing plants are now being built by several companies in Europe; each of these plants producing about 5.0 million liters of fuel per year. In the United States (U.S.) and Canada, the interest in biodiesel is also growing. Several demonstration programs in North America are using biodiesel to fuel many vehicles, including buses, trucks, construction and mining equipment, and motor boats. Research in using biodiesel to enhance the lubricity of diesel fuel is also underway.

The National Biodiesel Board (NBB), one of the main organizations promoting the use of biodiesel in the U.S., claims that a significant portion of the total U.S. diesel fuel consumption, amounting to roughly 190 billion liters, could be replaced with biodiesel made from vegetable, animal, and microalgal oils. In 1996, the U.S. produced approximately 13 million tonnes (Tyson, 1997) of vegetable oils (soybean, corn, cottonseed, peanut, sunflower, canola, and rendered tallow). If this oil was used solely for biodiesel production, it would be equivalent to 15 billion liters of fuel. Because several animal and vegetable oils are being displaced in the U.S. food market as a result of health issues, biodiesel from these sources could offer a high-value alternative market for U.S. oil seed and tallow producers (BioFacts, 1995)

It is estimated that Canada can easily produce approximately 600 million liters of biodiesel annually (Reaney, 1997), from surplus canola, soy, tallow, and tall oil. The diesel consumption during 1995 in Canada was approximately 19 billion liters per year (Statistics Canada, 1996).

1.2 Objective

The purpose of this study is to provide the Transportation Systems Division of Environment Canada with sufficient information to:

- Make an assessment of the current status and future potential of biodiesel as a transportation fuel in diesel type engines, specially in Canada and the U.S.
- Provide the policy and technical framework to support the future decisions of Environment Canada on the use of biodiesel.

The specific objectives for this study are:

- To review the past work on biodiesel's use as a transportation fuel in diesel engines.
- To analyze the available information on the impact of biodiesel on emissions, engine performance and durability.
- To assess the potential for biodiesel production and use in Canada.

1.3 Methodology

The study was conducted through a comprehensive literature review; telephone and personal interviews; meetings with a number of federal and provincial departments, and industry officials; and a few visits to specific locations in Canada and U.S. where major biodiesel activities are taking place. Based on the available information, Global Change Strategies International (GCSI) has made a careful assessment of the biodiesel potential in Canada. The summary of its findings and recommendations are provided in this report.

2. BIODIESEL PRODUCTION AND ECONOMICS

Vegetable oils offer good ignition characteristics and have been used as fuels in diesel engines at the time of fuel shortages. However, some of the properties of vegetable oils, especially their viscosity and quick oxidation tendency, make them undesirable for use in modern diesel engines. The viscosity of vegetable oils, when used as fuel, can be reduced in at least four different ways: dilution, pyrolysis, microemulsion, and transesterification. Out of these options, transesterification is the current method of choice, by which vegetable oils can be converted to the products called “Biodiesel”, with properties very similar to diesel fuel. Biodiesel can be used in its neat form or as a blend in conventional diesel fuel. Various types of animal fats, used oils and fats, and microalgal oils can also be converted to biodiesel type products. Two technologies exist for conversion of vegetable or biomass derived oils and animal fats to biodiesel.

2.1 Biodiesel by Esterification Process

The traditional technology to produce biodiesel is through “transesterification”, a process that combines vegetable oils, animal fats, and/or microalgal oils with alcohol (ethanol or methanol) in the presence of a catalyst (sodium or potassium hydroxide) to form fatty esters (ethyl or methyl ester). Converting triglyceride oils to methyl or ethyl esters through a transesterification process reduces the molecular weight to one-third that of the oil, reduces the viscosity by a factor of eight, and increases the volatility. The most important variables that influence the transesterification reaction time and conversion efficiency are temperature, catalyst type and its concentration, alcohol to ester ratio, and stirring rate. Purity of reactants, for example, presence of water, free fatty acids, and other contaminants found in unrefined oils (or other feedstocks) is also very important. Figure 1 shows the flow diagram for the transesterification process.

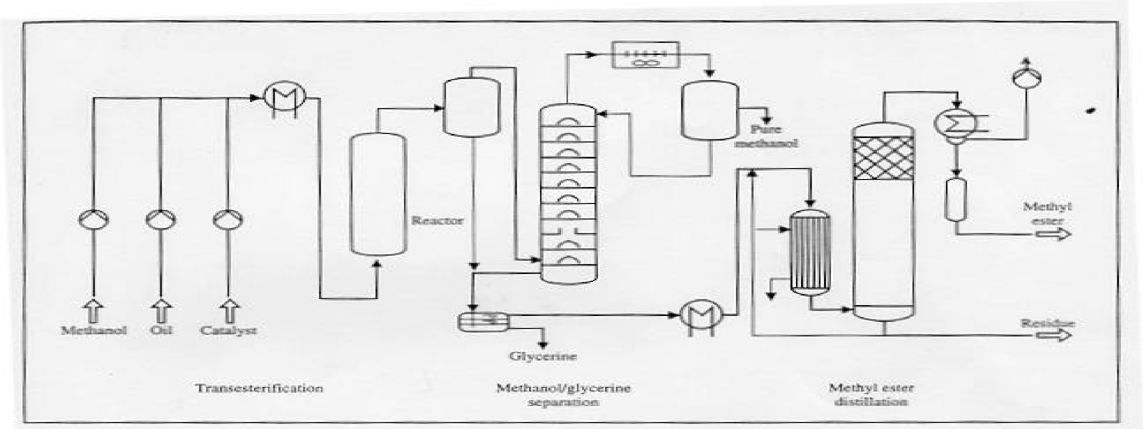

Figure 1: Flow diagram for manufacturing methyl esters via transesterification

A stoichiometric material balance yields the following simplified equation:

Oil or Fat	+	Methanol	=	Methyl ester	+	Glycerol
1000 kg		107.5 kg		1004.5 kg		103 kg

After the reaction, the products are separated into two phases, which facilitates easy removal of glycerol, a valuable industrial byproduct, in the first phase. The remaining alcohol/ester mixture is then separated, and the excess alcohol is recycled. The esters are sent to the cleanup or purification process, which consists of water washing, distillation, vacuum drying, and filtration. The biodiesel produced from this process is commonly referred to as “vegetable ester”. The basic properties of methyl esters produced from different types of vegetable oils are shown in Table 1.

Table 1. Property Data for Methyl Ester Biodiesel Fuels

Source Oil	Density g/cc @ 15.5 °C	Viscosity cSt @ 40 °C	Cetane No.	Heating Value MJ/kg	Cloud Point °C
Palm (Pischinger et al., 1982)	0.880	5.7	62	37.8	+13
Soybean (Schwab et al., 1987)	0.884	4.08	46.2	39.8	+2
Sunflower (Pischinger et al., 1982)	0.880	4.6	49	38.1	+1
Tallow (Ali et al., 1985)	0.877	4.1	58	39.9	+12
Canola (Reaney, 1997)	0.880	4.4	49.6	40.1	-1*

* Pour Point instead of Cloud Point

The cost of producing biodiesel in North America is currently much higher than the price of conventional diesel fuel. For example, the current cost of biodiesel in the U.S. is about $0.66 per liter compared to the pump price of diesel at about $0.30 per liter. At roughly two to three times the cost of diesel fuel, biodiesel simply cannot compete head-to-head economically. In many parts of Europe, tax incentives for biodiesel allow rapeseed oil methyl ester to sell at the pump for about the same price as diesel fuel. In Canada and the U.S. no such tax allowance is currently available. Without that aid, biodiesel has to compete not only with diesel fuel but with other alternative fuels as well.

Roughly 75 to 90 per cent of the cost of biodiesel is the raw materials. In Canada, biodiesel can be made from food-grade canola seed, but that would result in high cost. Lower quality canola oil – from over-heated canola seed, frost-damaged seed, and small fines from the screening process – could also be used, which can be one-fourth the cost of food-grade canola seed. The oil from lower quality feedstock has a pungent odor, and dark brown color, but it does not have any adverse effect on the quality of ester product (Reaney, 1997).

Although oils destined for conversion to biodiesel need not meet the rigorous standards of the edible oil industry, they may still require processing. Depending on the biodiesel fuel standard, which is still being developed, some processing steps may be necessary to reduce sulfur and phosphorus content of oils from off-quality seed.

Another option in reducing the cost of biodiesel is to look to other fats and oils sources that have less competition, where biodiesel could reign as the primary consumer. For example, the use of waste frying oils can substantially reduce the cost of raw materials but may increase the processing cost. Waste frying oil is often hydrogenated oil with a higher pour point, which may present a problem in biodiesel. There can also be problems with the relatively high free fatty acid content in waste oils, which make it more difficult to properly separate the glycerol and esters obtained from the transesterification process. Therefore, in selecting a feedstock, the cost of raw materials, as well as the processing cost and its effect on the quality of biodiesel and other byproducts, need careful assessment.

An important factor in biodiesel economics is the market value of the glycerol produced. Glycerol markets are limited; any major increase in biodiesel production may cause glycerol sales prices to decline, meaning that the biodiesel price would have to cover an increasing share of total costs.

Improvements in the transesterification technology would also lower the cost of production. Currently, biodiesel is produced in small quantities using a batch process. The use of a continuous process would be more efficient and could offer the economies of scale benefits to the production cost of biodiesel.

Based on data for the last two decades the average price of diesel and soybean oil, ignoring peaks, has been around US $200 and US $600 per tonne respectively (Krawczyk, 1996). In producing biodiesel from vegetable oil the return on investment and processing cost are essentially compensated by the byproduct credits, making the price of biodiesel approximately the same as the price of vegetable oil. Prediction of future price ratios becomes difficult because vegetable oil prices are set by the global market, whereas the final sale price of diesel is subject to taxes, which vary from country to country. In Europe, the taxes on diesel fuel have averaged about US $400 per tonne, which brings the pump price of diesel to the same level as the biodiesel price without any tax. However in Canada and the U.S., due to the lack of tax incentives for biodiesel and lower taxes on conventional diesel, biodiesel is currently about three times more costly.

According to a recent market analysis conducted in the U.S., the cost of biodiesel produced in a small-scale operation using soybeans is approximately $0.66 / liter. Large scale production using current technology could reduce biodiesel cost to 0.40 to $0.45 / liter. Additional research advances using existing feedstocks or innovative feedstocks such as microalgae could further reduce the costs. The goal of the US Department of Energy and the National Renewable Energy Laboratory

(DOE/NREL) program is to reduce the cost of biodiesel production by 50-65% i.e. production at $0.26 / liter.

2.2 Biodiesel by Hydrogenation Process

The second process, which involves simultaneous catalytic hydrogenation and cracking of vegetable and tree oils, was developed at the Saskatchewan Research Council under the sponsorship of the Canada Center for Mineral and Energy Technology (CANMET). This process has been used to produce biodiesel type material from “Tall Oil”, a byproduct from the Kraft pulping process. The principal constituents of tall oil are unsaturated C18 fatty acids, resin acids and unsaponifiable hydrocarbons such as di-terpenic alcohols/aldehydes. The biodiesel produced from this process has been given the name “SuperCetane”, due to its high Cetane number close to 60.

The CANMET technology has been licensed to Arbokem of Vancouver, Canada, to market the process worldwide. The world production of tall oil is estimated at about 1.2 million tonnes/year. Well over 60% of that comes from the U.S. BC Chemicals is a leading producer of tall oil in Canada.

In its traditional use, the crude tall oil (CTO) is first depitched and then upgraded by distillation to produce more valuable products such as tall oil fatty acids (TOFA) and tall oil rosin (TOR). The CANMET process, aimed to convert tall oil into higher value products, involves simultaneous catalytic hydrogenation and cracking of the depitched tall oil (DPTO). Two continuous trickle bed reactor systems were used in this program. The first unit, a once through semi-pilot plant with a 750 ml reactor was used for the initial work. The second system, a process development unit (PDU) with a 10 liter reactor which fully simulates the features of the process in commercial units, was used to produce sufficient quantities of SuperCetane for engine testing.

In the production process of SuperCetane, shown in Figure 2, the DPTO feed is pumped into the high pressure system where it combines with hydrogen and the gas-liquid phase passes through a series of electric pre-heaters before entering the catalytic trickle bed reactor. The product is collected in two flash columns, decanted to remove the water, and then distilled in a batch unit to obtain the desired cut. The process gas is recycled after removing the impurities in a series of scrubbers. Long duration pilot-plant runs were successfully carried out at CANMET’s Energy Research Laboratories in Ottawa, to convert tall oil into SuperCetane, and the process is now ready for scale-up.

The boiling point distributions of DPTO and the liquid hydrocarbon product separated in three distinct fractions, naphtha (IBP-160°C), Supercetane (160°C-325°C, diesel fuel cut), and heavy gas oil (325°C +) are shown in Figure 3. Properties of Supercetane and DPTO feed, along with the specifications for No.1

diesel fuel (D-1) for comparison, are given in Table 2.

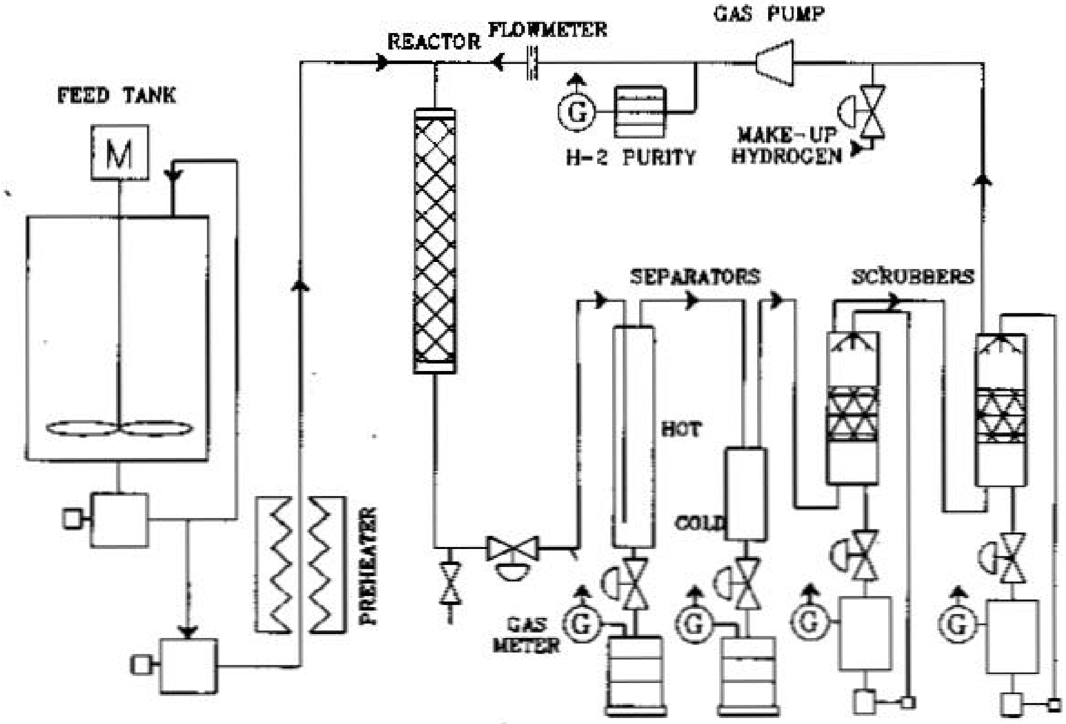

Figure 2: Schematic of CANMET SuperCetane Process

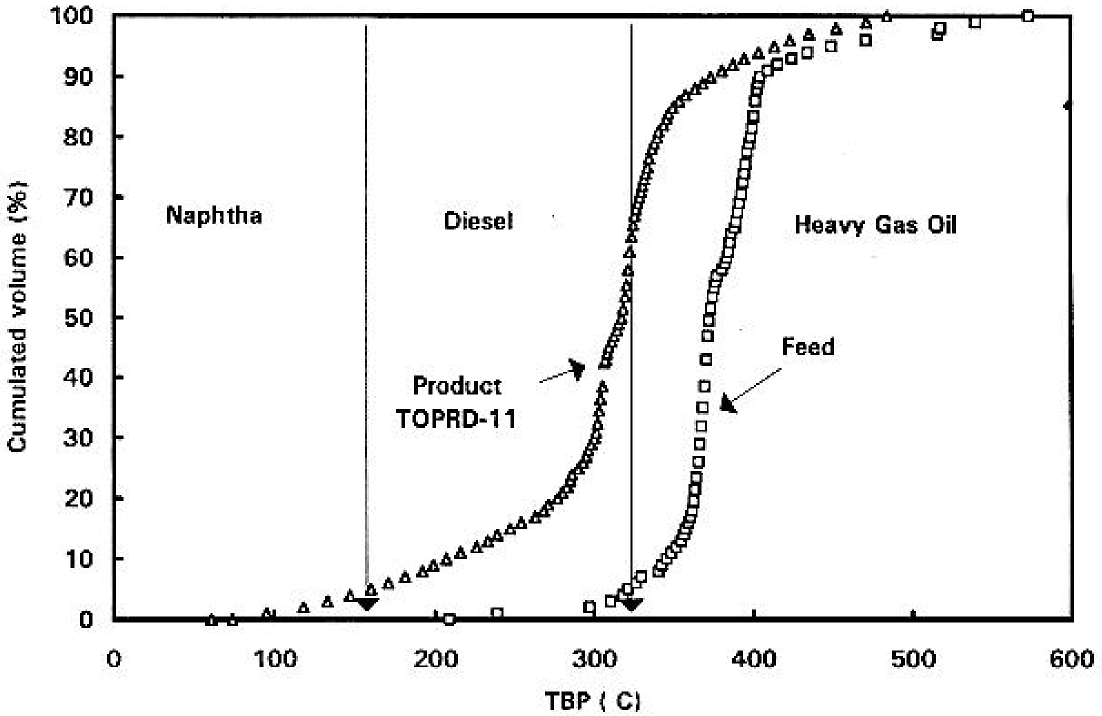

Figure 3: True boiling point distribution of DPTO and a sample of liquid hydrocarbon products

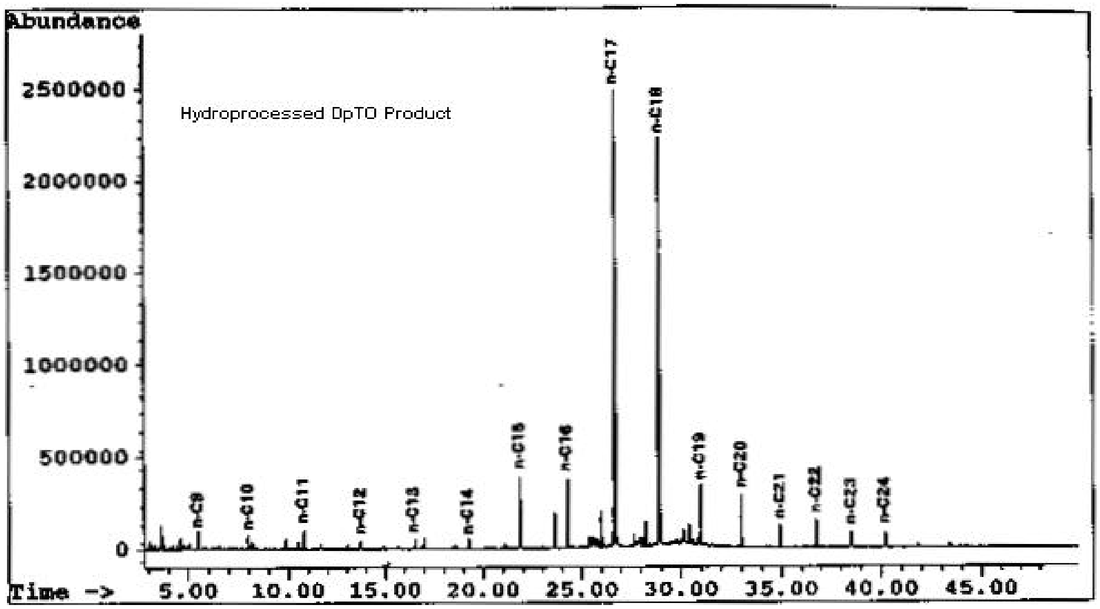

Figure 4: Chromatogram of SuperCetane Product

Table 2. Properties of Feed, SuperCetane (SC) and Specification of Diesel No. 1 (D-1)

Property	DPTO	SC	D - 1
Density, g/mL	0.9616	0.8297	0.850
API, 60/60 °F	15.7	39.0	-
C, wt %	79.1	86.4	-
H, wt %	11.0	13.5	-
O, wt %	9.5	0.02	-
N, ppm	58	1.3	-
S, ppm	993	18.6	500
Mercaptan S, ppm	-	50	
Acid Number, g KOH/g	152.2	<0.05	0.1
Distillation			
10% Recovered, °C	345	225	215
90 % Recovered, °C	404	322	288
End Point, °C	573	344	316
Cetane Number	-	64	40

The GC-MS analysis indicates that the predominant components of SuperCetane are normal alkanes which range from n-C9 to n-C24. The n-C17 and n-C18 alkane components account for approximately 72% of total alkanes in the product (Feng, Wong and Monnier, 1993). The chromatogram of the product shown in Figure 4 clearly depicts two intense peaks associated with n-C17 and n-C18 alkanes. The chromatogram for conventional diesel fuel, shown in Figure 5, indicates the presence of alkanes from n-C10 to n-C22. The Cetane Number of the product was greater than 55. The GC-MS analysis further revealed that the sulfur content in SuperCetane is extremely low, while the cyclic hydrocarbon and aromatic contents are much lower than in diesel fuel.

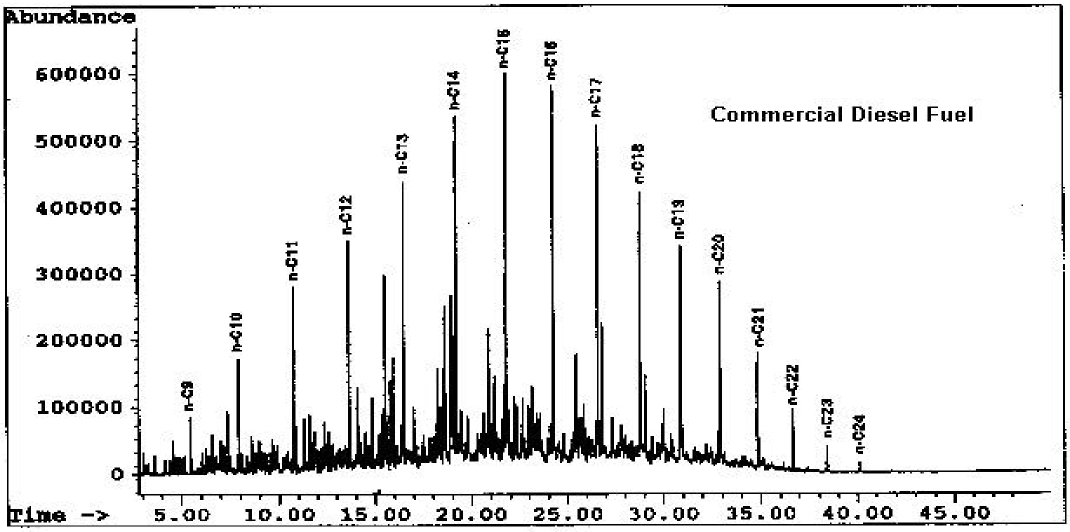

Figure 5, Chromotogram of Conventional Diesel Fuel

The production cost for SuperCetane, including the capital and operating costs in a large scale plant is estimated at 10 to 12 cents per liter (Monnier, 1997). The cost of the tall oil as raw material could vary from 8 to 20 cents per liter of SuperCetane. Thus the total cost of this product could range between 18 to 32 cents per liter, which makes it economically more attractive than vegetable esters currently costing about 66 cents per liter.

3. AVAILABILITY OF FEEDSTOCKS

Some basic data on the availability of vegetable oils are given in Tables 3 and 4. Global resources of vegetable oils and fats amount to approximately 62 million tonnes per year (Krawczyk, 1996). Vegetable oils are predominantly used as food with smaller amounts being used for chemical purposes. At the present time use of vegetable oils as a source of fuel (as vegetable oil esters or biodiesel) is relatively very small. There are three regions in the world where the use of biodiesel can be envisioned: North America which produces about 17 million tonnes of vegetable oil annually; continental Europe, with the production of about 16 million tonnes; and Southeast Asia, which now produces about 8 million tonnes. These three regions account for more than 66% of the global production of vegetable oils.

Table 3. Global Production of the Major Vegetable Oils

Oil	Production in Million Tonnes
Soybean	12.0
Rapeseed	8.5
Cottonseed	5.0
Sunflower	7.0
Peanut	3.5
Coconut	2.6
Linseed	0.5
Palm	10.0
Olive	1.6
Other	10.9
Total	61.6

Table 4. Distribution of Vegetable Oil Production Among Different Regions of the World

Region	Million Tonnes
North America	16.6
South America	7.4
China	3.0
India, Pakistan, Bangladesh	3.7
Former USSR	6.2
Europe (without former USSR)	9.8
Africa	3.1
Malaysia, Philippines, Indonesia	8.0
Others	3.8
Total	61.6

The current global production of vegetable oil exceeds its consumption in terms of human food, animal feed and industrial use. It is estimated that from the surplus vegetable oils, biodiesel production of about 3 to 5 million tonnes per year is possible now. The proponents of biodiesel claim that the use of this renewable fuel could result in many benefits which may include improvement of air quality in some of the world's most polluted regions; a positive contribution in reducing greenhouse gas emissions; a biodegradable fuel with very low toxic emissions; and, creation of a new industry with many new jobs.

In the U.S. much of the current interest in biodiesel production comes from soybean producers who are faced with an excess of production capacity, product surpluses, and declining prices. Soy Methyl Ester (SME), made by reacting methanol with soybean oil, is the main form of biodiesel in the U.S. Annual U.S. production of vegetable oils and fats in 1996 was about 13 million tonnes. Assuming a 10% surplus available for biodiesel production suggests a potential production rate of approximately 1.5 billion liters of biodiesel per year. Current biodiesel production capacity in U.S. is estimated between 190 to 570 million liters per year. The wide range of reported production capacity is most likely due to the fact that not all methyl ester produced is used as biodiesel. There are more than 130 biodiesel producers, with NOPEC, Agricultural Environmental Products, and Twin Rivers Technologies being the leaders.

3.1 Feedstocks in Canada

In Canada, the 1996 production of canola and soybean seeds was projected at 5 and 2.17 million tonnes respectively (Canadian Grains Industry Handbook, 1996). The oil yield from canola is approximately 40% whereas from soybean it is about 20%. This would amount to a potential production of 2 million tonnes of canola oil and 434 thousand tonnes of soy oil. The actual production of canola and soy oils in 1996 in Canada was only 1.153 million tonnes and 166 thousand tonnes respectively, the balance of oil seeds was exported. Tallow production in Canada has been about 200 thousand tonnes per year, while the tall oil potential is estimated at roughly 180 thousand tonnes per year.

Assuming 10% of canola and soy oil potential targeted for biodiesel production would result in 277 million liters of biodiesel per year. Assuming 25% of tallow and tall oil destined for biodiesel production would produce 108 million liters of biodiesel per year. This adds up to a possible production of 385 million liters of biodiesel per year, which amounts to only about 2% of the Canadian diesel consumption of approximately 19 billion liters per year.

Therefore, it is clear that the use of biodiesel should be targeted towards niche markets where it could provide maximum environmental benefits. These issues are discussed later in the report.

4. EFFECT OF FEEDSTOCK ON BIODIESEL PROPERTIES

Biodiesel is chemically simple, since no more than six or seven fatty acid esters make up the biodiesel mixture. Different esters vary a great deal in terms of important fuel properties, such as: Cetane Number (CN); density; viscosity; melting point; cold flow characteristics such as Cloud and Pour points; heating value; and, degree of saturation. The property data for the pure component esters assembled by Professor L. Davis Clements of the University of Nebraska from a number of literature sources are shown in Table 5 (Clements, 1996). Since different vegetable oils and animal fats may contain different types of fatty acids, the fuel related biodiesel properties are generally affected by the choice of raw material. The data for actual biodiesel fuels, methyl and ethyl esters of various vegetable oils and tallow summarized in Table 6 (Graboski, 1997), indicate the small differences attributable to the use of different raw materials. The data for soy esters produced by using various alcohols are shown in Table 7. It should be mentioned that since the data come from different sources, the values of the properties listed in various tables may not be identical. Some of the important biodiesel properties are discussed in the following sections.

The chemical composition and properties of biodiesel depend on the length and degree of unsaturation of the fatty acid alkyl chains. Fatty acids can be saturated or unsaturated. A saturated acid is one that cannot chemically add hydrogen, whereas an unsaturated acid can be hydrogenated. The saturated acids exhibit higher freezing points than the unsaturated acids. The boiling points of the acids are dependent on the length of the carbon chain but nearly independent of the degree of unsaturation. The effects of chemical structure on melting and boiling points also apply to esters of the fatty acids, although their values for esters are significantly lower as shown in Table 8.

In view of significant variation in biodiesel properties based on the raw material and sometimes the process conditions, major efforts are underway to develop fuel specifications for biodiesel that will assure consistent quality and performance, but not tie the final fuel to any specific raw material. One of the on-going projects in the U.S. is looking at producing biodiesel from low-cost feedstocks (details given in Appendix C). This project involves producing, testing, and characterizing emissions from biodiesel produced from eight different feedstocks. The project will establish data on fuel characteristics that can be used to support feedstock-neutral specifications for biodiesel.

Table 5. Pure Component Property Data for Fatty Acid Methyl Esters

Ester	Density g/cc @ 15.5 °C	Viscosity Cst @ 40 °C	Cetane	Heating Value MJ/kg	Melting Point °C
Palmitate	0.867	4.37	74	39.4	30.6
Stearate	0.867	5.79	75	40.1	39.1
Oleate	0.878	4.47	55	39.9	-19.8
Linoleate	0.890	3.68	33	39.7	-35.0
Source	Janarthanan et al., 1996	Janarthanan et al., 1996	Bagby & Freedman, 1989	Freedman & Bagby, 1989	Teoh and Clements, 1988

Table 6. Summary of Important Properties for Various Biodiesels (Graboski, 1997)

Fuel	Cetane Number	Flash Point ^{0}C	IBP ^{0}C	T1O ^{0}C	T50 ^{0}C	T90 ^{0}C	EP ^{0}C	Sp. Gr	HHV MJ/Kg	LHV MJ/Kg	Cloud Point ^{0}C	Pour Point ^{0}C	CFPP ^{0}C	Viscosity at 40 ^{0}C CS	Iodine Number
D-2	40-52	60-72	185	210	260	315	345	0.85	44.9	43.4	-25 to -15	-25 to 5	-10 to -20	2.6	8.6
Soy ME	50.9	131	299	328	336	340	346	0.885	40.4	37.0	-0.5	-3.8	-4.4	4.08	133.2
RME	52.9	170	326	340	344	348	366	0.883	40.7	37.3	-4.0	-10.8	3.6	4.83	97.4
Soy EE	48.2	160	-	-	336	344	-	0.881	40.0	-	-1.0	-4.0	-	4.41	123.0
REE	64.9	185						0.876	40.5	-	-2.0	-15.0	-	6.17	99.7
Tallow ME	58.8	117	209	324	328	342	339	0.876	40.2	-	13.9	9	11	4.8	
Frying Oil EE	61	124						0.872	40.5	37.2	9	8	-	5.78	

Table 7. Fuel Properties of some Soybean Esters (data taken from Schwab, 1987)

Ester	Viscosity* (mm^{2}/s)	Cetane No.	Heat of Combustion (MJ/kg)	Cloud Point (^{o}C)	Pour Point (^{o}C)
Soy Methyl Ester (SME)	4.08	46.2	39.8	2	-1
Soy Ethyl Ester (SEE)	4.41	48.2	40.0	1	-4
Soy Butyl Ester (SBE)	5.24	51.7	40.7	-3	-7
DF2**	2.39	45.8	45.2	-19	-23

* Viscosity determined at 40 ^{0}C

** Diesel Fuel No.2 as used in the reference Schwab, 1987.

Table 8. Effect of Chemical Structure on Melting and Boiling Points of Fatty Acids and their Methyl Esters (Graboski, 1997)

			Acid		Methyl Ester	
Acid Chain	No. of Carbons	Structure	Melting Point, ^{0}C	Boiling Point, ^{0}C	Melting Point, ^{0}C	Boiling Point, ^{0}C
Caprylic	8	$CH_3(CH_2)_6COOH$	16.5	239	-40	193
Capric	10	$CH_3(CH_2)_8COOH$	31.3	269	-18	224
Lauric	12	$CH_3(CH_2)_{10}COOH$	43.6	304	5.2	262
Myristic	14	$CH_3(CH_2)_{12}COOH$	58.0	332	19	295
Palmitic	16	$CH_3(CH_2)_{14}COOH$	62.9	349	30	415
Palmitoleic	16	$CH_3(CH_2)_5CH=CH(CH_2)_7C00H$	33	--	0	--
Stearic	18	$CH_3(CH_2)_{16}COOH$	69.9	371	39.1	442
Oleic	18	$CH_3(CH_2)_7CH=CH(CH_2)_7C00H$	16.3	--	-19.9	--
Linoleic	18	$CH_3(CH_2)_4CH=CHCH_2CH=CH(CH_2)_7C00H$	-5	--	-35	--
Linolenic	18	$CH_3CH_2CH=CHCH_2CH=CHCH_2CH=CH(CH_2)_7CO0H$	-11	--	--	--
Arachidic	20	$CH_3(CH_2)_{18}C00H$	75.2	--	50	--
Eicosenoic	20	$CH_3(CH_2)_7CH=CH(CH_2)_9COOH$	23	--	-15	--
Behenic	22	$CH_3(CH_2)_{20}COOH$	80	--	54	--
Erucic	22	$CH_3(CH_2)_7CH=CH(CH_2)_{11}COOH$	34	--	--	--

4.1 Cetane Number

Cetane Number (CN) is one of the prime indicators of the quality of diesel fuel. It relates to the ignition delay time of a fuel upon injection into the combustion chamber. The shorter the ignition delay time, the higher the CN and vice versa. High CN rating suggests easy cold start and low idle noise. Some researchers have observed a correlation between high CN and low NOx emissions. The Cetane scale is based on two compounds, namely hexadecane with a Cetane of 100 and heptamethylnonane with a Cetane of 15. The CN scale also shows that straight-chain, saturated hydrocarbons (alkanes) have higher CN compared to branched-chain or aromatic compounds of similar molecular weight and number of carbon atoms. The CN of biodiesel is generally higher than conventional diesel. The effect of blending biodiesel on CN is almost linear for mixtures of esters with No. 1 or No. 2 diesel fuels (Graboski, 1997).

Reported values of CN in the literature for biodiesel vary widely. For soybean oil-derived biodiesel, the values range from 48 to as high as 67. A recent study (Van Gerpen, 1996) has shown that the CN of biodiesel depends on the distribution of fatty acids in the original oil or fat from which it was produced. The longer the fatty acid carbon chains and the more saturated the molecules, the higher the Cetane Number. The unsaponifiable matter in biodiesel does not appear to have an impact on the CN.

4.2 Density

Density is the weight of a unit volume of fluid. Specific gravity is the ratio of the density of a liquid to the density of water. No. 2 diesel has a specific gravity of about 0.85, while the value for biodiesel ranges between 0.87 to 0.89. Fuel injection equipment operates on a volume metering system, hence a higher density for biodiesel results in the delivery of a slightly greater mass of fuel. However, biodiesels have a lower energy content on both volumetric and mass basis. Therefore, although the injection system delivers a larger mass of biodiesel fuel, the actual energy delivered is less than for No. 2 diesel.

4.3 Viscosity

Viscosity is another important property of biodiesel since it affects the operation of fuel injection equipment, particularly at low temperatures when the increase in viscosity affects the fluidity of the fuel. Biodiesel has higher viscosity than conventional diesel fuel. High viscosity leads to poorer atomization of the fuel spray and less accurate operation of the fuel injectors. The viscosity of biodiesel and biodiesel blends also increases more rapidly as temperature is decreased compared to diesel. Certain impurities also tend to significantly increase the viscosity of biodiesel.

4.4 Cold Flow Properties - Cloud Point, Pour Point, and CFPP

Other important parameters for low temperature operations of a fuel are Cloud Point and Pour Point. The Cloud Point is the temperature at which wax first becomes visible when the fuel is cooled. The Pour Point is the temperature at which the amount of wax out of solution is sufficient to gel the fuel, thus it is the lowest temperature at which the fuel can flow. Neither parameter measures the intermediate temperature at which the amount of wax becomes sufficient to restrict the flow in a vehicle fuel system. In many instances the Cloud Point underestimates the ability of the fuel to perform at low temperatures, while the Pour Point tends to be over-optimistic. Biodiesel has higher Cloud and Pour Points compared to conventional diesel.

A test which has become widely accepted in Europe and other temperate regions of the world to predict low-temperature performance is the Cold Filter Plugging Point of Distillate Fuels (CFPP), IP 309/80. The method is also published as a European Standard by CEN, EN116:1981, as a national standard in various countries around the world. The CFPP measures the highest temperature at which wax separating out of a sample can stop or seriously reduce the flow of fuel through a standard filter under standard test conditions. The CFPP does not correlate well with low-temperature performance of North American fuels in North American equipment, and it is not included in the ASTM Book of Standards (Owen and Coley, 1995).

In Canada during winter months, D-2 is often diluted with D-1 or kerosene to meet wintertime performance specifications. The Cloud and Pour points are varied by the refiners to meet the local climate conditions. The Cloud, Pour, and CFPP values for various biodiesels are included in Table 6. All biodiesel fuels exhibit poor cold flow properties with Cloud and Pour points 10 to 15°C higher than those of D-2. Highly saturated tallow esters are poorer in this respect than soy and rape esters. The data on blends of soy methyl ester and tallow methyl ester with D-1 and D-2 fuels indicate that Cloud and Pour points increased with the increasing ester content (Midwest Biofuels, 1993). The effect with D-1 was significantly larger than with D-2, as shown in Figure 6.

Special additives are routinely used to improve the cold flow properties of diesel fuel. These additives do not prevent wax formation but keep the small wax crystals from combining with each other. The use of such additives has also been tested with biodiesels with successful results. A recent study (Dunn et al., 1997) investigated the refrigeration of vegetable oils to induce crystallization of the high freezing point components. The lower freezing liquid phase was separated. Yields of soy ester, having a Cloud point of -20°C, were only 30% by weight using this method. When commercial cold flow improver additives were blended prior to refrigeration, the ester yield increased to 80% for a Cloud point of -11°C.

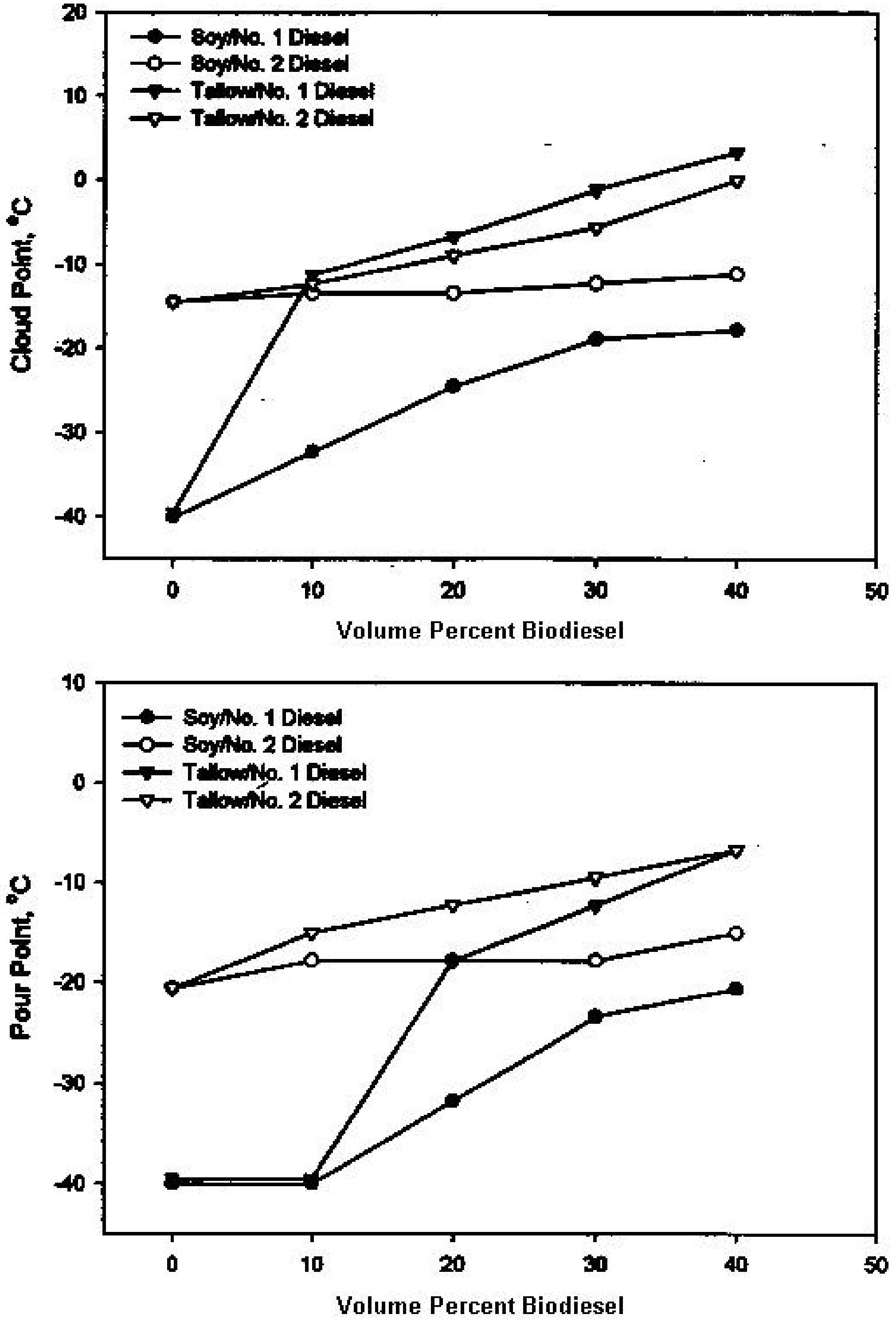

Figure 6: The Effect of Biodiesel Blends on Cloud and Pour Points

4.5 Storage and Stability

The term stability encompasses thermal stability under both hot and cold temperatures, resistance to oxidation, polymerization, water absorption, and microbial activity. The main source of instability in biodiesels is the unsaturated fatty acid chains. The metals and elastomers in contact with biodiesel during storage can also affect its stability. The presence of water in biodiesel can cause rust formation and corrosion, specially in the presence of acids and hydroperoxides formed by fuel oxidation. Presence of water also helps microbial growth, which can occur at the interface of biodiesel and any free water phase.

The ASTM standard D-975 allows up to 500 ppm water in D-2. As the solubility of water in D-2 is only about 50 to 60 ppm, any water above this limit will separate out at the bottom of the tank or stay suspended as an emulsion. The solubility of water in SME is approximately 1500 ppm, while in B20 blend of SME in D-2 it is about 40 to 60 ppm. Thus blending a water saturated biodiesel with D-2 can result in the separation of water phase providing a potential site for microbial growth (Van Gerpen et al., 1997).

Oxidation stability of diesel fuel is measured by ASTM D-2274. Oxidation of biodiesel leads to the formation of hydroperoxides which can polymerize to form insoluble gums and cause plugging in fuel systems and filters. It was reported that certain components in biodiesel are natural antioxidants and that these are removed if biodiesel is purified by distillation (Van Gerpen et al., 1997). Interestingly, presence of hydroperoxides improves the Cetane Number of biodiesel. Hence more research is needed to understand the maximum acceptable hydroperoxide level in biodiesel.

4.6 Iodine Number

Iodine number is a measure of the degree of unsaturation of the fuel (DIN 53241, IP 84/81). Unsaturation can lead to deposit formation and storage stability problems with biodiesel, as mentioned above. Soy and rape methyl esters have iodine numbers of approximately 133 and 97 respectively, as shown in Table 6. Data for tallow esters are not found, but a lower iodine number is expected based on the greater degree of saturation. Research at Mercedes-Benz (Shafer, 1994) suggests that biodiesel with iodine number greater than 115 is not acceptable because of excessive carbon deposits.

In another study (Prankl and Worgetter, 1996), 5 biodiesel fuels ranging in iodine number from 100 to 180 were tested in a single cylinder engine for over 250 hours. No significant differences in cleanliness and formation of deposits on cylinder, combustion chamber, valves and injectors were noticed. Based on the test results it was not possible to ascertain the effect of iodine number on deposit formation.

5. STATUS OF BIODIESEL

Biodiesel is being currently promoted by two sectors with strong public voices:

- oilseed producers such as soybean, canola, and rapeseed farmers ;
- environmentalists and sustainable development advocates concerned about the impact of fossil fuel consumption on global climate.

Getting market place acceptance of biodiesel remains an uphill battle. Besides its higher cost, other impediments to biodiesel's progress are the total supply and availability, and an acceptable and consistent quality. Invariably the cost, supply and quality of a product go hand in hand. If the quality of biodiesel as a transportation fuel or as a component of diesel fuel is acceptable and consistent then more biodiesel can find its way in niche markets. The more uses that can be identified for biodiesel, the more it can be produced. A greater demand for biodiesel would result in bigger plants, process improvements, and use of lower cost feedstocks which would ultimately lower the cost of biodiesel.

Researchers are now looking at biodiesel specifications which may standardize and regulate the quality of the fuel to ensure satisfactory engine performance and engine durability. Although different vegetable oils and fats result in slightly varying biodiesel characteristics, the pedigree of the feed material would be of secondary importance if the fuel met the quality specifications that govern performance in the engine.

Germany has already approved and adopted the fuel standards for biodiesel, DIN V 51606. These are shown in Table 9 (Krawczyk, 1996). Austria, Italy, and other European countries have also established or are planning to adopt similar standards for the use of biodiesel as a motor fuel. In the U.S., biodiesel fuel specifications have been drafted and are currently being evaluated by the American Society for Testing & Materials (ASTM). The proposed standards for neat biodiesel are shown in Table 10 (NBB, 1997).

Engine manufacturers in the U.S. are pressing for premium diesel fuel specifications because of the potential of cleaner diesel to reduce engine emissions and improve engine performance. Some refiners may be producing and marketing a cleaner or so-called premium diesel, however, currently there is no standard for such a fuel. The National Conference on Weights and Measures (NCWM) is addressing this issue.

The ASTM/NCWM Joint Premium Diesel Task Force has finished deliberations and has passed on their recommendations for premium diesel specifications and testing methods to the main body. Lubricity, which is biodiesel's primary benefit in premium diesel blends, was not included in the task force's list of premium diesels measurable characteristics, but was listed as a possible specification if the industry can develop improved lubricity test methods. Current lubricity test methods are not accurate enough to distinguish between conventional diesel and premium diesel lubricity levels.

5.1 Biodiesel in Europe

Biodiesel developments in Europe are primarily a result of government subsidies and programs. In general, subsidies are given to the farmers, which make oilseed crops less expensive as a raw material for producing biodiesel. As well, in order to limit food over-production in Europe, some land must be set aside for non-food uses according to European Union directives.

Since Europe has a larger population density and greater pollution problems compared to Canada, countries are forced to initiate environmental programs to curb pollution and encourage the use of renewable energy. Countries such as Netherlands and Germany have established targets for renewable energy market penetration as part of their plans to limit greenhouse gas emissions. Europe also has a much larger share of diesel vehicles, thus potentially a greater market for biodiesel. Many engine and vehicle manufacturers in Europe have tested and approved biodiesel. In many European countries due to the higher price of diesel fuel and tax incentives on biomass derived renewable fuels, the use of biodiesel has become economically attractive (Venendaal, 1997).

In France, one pilot plant of 1000 tonnes/year capacity, and five industrial esterification plants with a total capacity of 240,000 tonne/year of rape methyl ester (RME) are in commercial operation, while an additional capacity of 190,000 tonne/year is planned. A close collaboration between oil companies and the agricultural sector has resulted in an institutional structure for the production and supply of mostly blended diesel (5vol.% biodiesel in diesel fuel - B5). One of the incentives for RME production at such a large scale in France has been the 100% tax relief on pilot units and experimental projects for methyl esters used as biofuels for engines and boilers.

In Germany, the first experimental biodiesel plant with a capacity of 1000 liters/day was built in 1991 in Leer. In 1995, a commercial plant with a capacity of 60,000 tonnes/year was installed at the same site. Present transesterification capacity in Germany is 265,000 tonnes/year. Three more plants with a total capacity of about 160,000 tonnes/year are planned. The positive results of previous experiments with RME in common diesel engines have resulted in wide spread use of biodiesel in Germany. As an example, taxis in Freiburg and Berlin are running on RME, while since August 1995 all new Volkswagen diesel models are suited for the use of RME. By the same time about 350 service stations were selling RME in Germany.

Table 9. Biodiesel Standard DIN V 51606 (Germany)

Properties	Units	Testing Procedures	Limits min.	Limits max.
Density at 15 °C	g/mL	ISO 3675	0.875	0.900
Kinematic Viscosity at 4 °C	mm^2/s	ISO 3104	3.5	5.0
Flashpoint (Pensky-Martens)	°C	ISO 2719	100	
Cold Filter Plugging Point	°C	DIN EN 116		
Apr. 15 – Sep.30				0
Oct. 1 - Nov. 15				-10
Nov. 16 - Feb. 28				-20
Mar. 1- April 14				-10
Sulfur Content	% by mass	ISO 4260		0.01
Carbon Residue (10% distillation)	% by mass	ISO 10370		0.30
Cetane Number		ISO 5165		49
Ash	% by mass	ISO 6245		0.01
Water	mg/kg	ASTM D 1744		300
Total Dirt	mg/kg	DIN 51419		20
Copper Corrosion (3h at 50 °C)				1
Neutralization Number	mg/KOH			0.5
Methanol	% by mass	To be agreed		0.3
Monoglycerides	% by mass	To be agreed		0.8
Diglycerides				0.1
Triglycerides				0.1
Free Glycerol				0.02
Total Glycerol				0.25
Iodine Number	g Iodine/100g	DIN 53241 Part I		115
Phosphorus	mg/kg	To be agreed		10

Biodiesel based on rapeseed oil and sunflower oil is produced commercially in Austria. Total installed capacity of biodiesel is 35,000 tonnes/year, and by the end of 1995, the price of biodiesel was nearly the same as conventional diesel. In Austria, the tax exemption for neat biodiesel is about 95%. Austria had some problems with the sunflower methyl ester. Initially, due to the high iodine content of sunflower oil, the ester was not approved as diesel fuel substitute by engine manufacturers, as it may lead to carbon built-up in the engine and cause polymerization of lubricating oil. Therefore, sunflowers with lower oil iodine number were developed. However, the higher content of saturated fatty acids and the wax content results in poor cold temperature flow properties as compared to RME and conventional diesel fuel. It was therefore suggested that sunflower based biodiesel should be used as automotive fuel in the countries with mild climate in southern Europe.

Industrial production of biodiesel based on both rape and sunflower is also common in Italy. Total installed capacity of biodiesel production in Italy is about 1.1 million tonnes/year. In 1994/95, a total production of 76,500 tonnes of methyl ester was reported. The large difference between the installed capacity and actual production was due to the high cost of production and uncertain government policy about the tax relief. Italy has a quota system, which restricts the amount of biodiesel each year for tax exemption.

Biodiesel is also finding some interest in Ireland, Denmark, Finland, Belgium and England. However, at the present time either due to the lack of indigenous feedstock or higher production cost it is not widely used.

5.2 Biodiesel in the U.S

Currently there are many companies in the U. S. which produce biodiesel. Some of the well-known companies are NOPEC Corporation, Twin Rivers Technologies, Agricultural Environmental Products, Columbia Foods, and Pacific Biodiesel. The present cost of biodiesel is about two or three times higher than conventional diesel fuel. The current production of biodiesel in U.S. is estimated at 50,000 tonnes per year (NBB, 1997). The fuel specifications for biodiesel are being developed under the American Society for Testing & Materials (ASTM). The engine or vehicle manufacturers have not yet approved the use of biodiesel in their products.

Table 10. Proposed Biodiesel Specification* (100% Biodiesel), July, 1996

Property	ASTM Method	Limits	Units
Flash Point	93	100.0 min.	°C
Water & Sediment	1796	0.050 max.	vol. %
Carbon Residue, 100% sample	4530**	0.050 max.	wt. %
Sulfated Ash	874	0.020 max.	wt. %
Kinematic Viscosity, 40 °C	445	1.9 - 6.5	mm^2/s
Sulfur	2622	0.05 max.	wt. %
Cetane	613	40 min.	
Cloud Point	2500	By Customer	°C
Copper Strip Corrosion	130	No. 3b max.	
Acid Number	664	0.80 max.	mg KOH/g
Free Glycerin	GC***	0.020 max.	wt. %
Total Glycerin	GC***	0.240 max.	wt. %

* This specification is in the process of being evaluated by ASTM. A considerable amount of experience exists in the US with a 20% blend of biodiesel with 80% petroleum-based diesel. Although biodiesel can be used in the pure form, use of blends of over 20% biodiesel should be evaluated on a case by case basis until further experience is available.

** Or equivalent ASTM testing method.

*** Austrian (Christiana Planc) update of USDA test method.

The National Biodiesel Board (NBB) in U.S. was established in 1992 through investment of time and dollars by farmers. In the last 5 years, biodiesel has moved from an experimental fuel to a legitimately recognized source of alternative energy. At the present time biodiesel is not exempt from road tax in most states and localities. The efforts of NBB in this direction are covered in Section 6 of this report.

Biodiesel demonstration programs in the U.S. have usually focused on the markets that have the greatest chance of choosing biodiesel despite its higher cost. These markets place a premium on biodiesel’s biodegradability, non-toxicity, lower emissions profile, and overall environmental benefits. For example, an University of Idaho study showed that biodiesel degraded up to four times faster than conventional diesel, and a 50:50 blend biodegraded in one-third the time required by diesel fuel. The 100% biodiesel-powered truck project in Yellowstone National Park is another example of a pristine environment that benefits from a biodegradable fuel such as biodiesel (Peterson, 1996).

According to NBB surveys, in 1992, 98% of the mass transit operators had never heard of biodiesel. In 1994, transit managers ranked biodiesel second to compressed natural gas as their top alternative fuel choice. More recently, a 1996 study by the Energy Resources Center at the University of Illinois at Chicago showed that 45% of the Chicago area fleet managers might consider using biodiesel despite its higher cost merely because it would be an easy switch as an alternative fuel.

The NBB claims that more than 100 biodiesel demonstrations using thousands of vehicles have logged more than 10 million road miles with biodiesel blends. Longevity tests, including three one-million-mile tests and more than thirty 50,000-mile tests, show the ability of the fuel to perform similarly to diesel fuel with no adverse effects on the engines. Once the cost of biodiesel comes down to encourage greater usage, such demonstrations will help allay fears that biodiesel is new or untested. In the meantime work proceeds on expanding the niche markets.

In the U.S., the urban transit market has received the most attention so far, because it was the first major diesel market segment regulated as a result of the Clean Air Act Amendments of 1990. The NBB estimates that approximately 80% of the 58,000 mass transit buses in operation nationwide (consuming more than 2 billion liters of diesel annually) are subject to this regulation, which pertains to particulate matter reductions, where biodiesel can play an important role.

Government fleet vehicles regulated under the Energy Policy Act of 1992 (EPACT) consume nearly 3.8 billion liters of diesel fuel each year. The NBB expects that approval of a 20% blend (B20) of biodiesel in diesel fuel under EPACT would lead to substantial sales of biodiesel.

Approximately one million diesel powered recreational marine vessels annually use about 380 million liters of diesel fuel. Other marine applications include oceangoing commercial ships, research vessels, and the U.S. Coast Guard Fleet. The NBB estimates this potential market for biodiesel at about 10 million liters per year.

In underground mining applications, harmful emissions must be controlled. Biodiesel releases less particulate matter into the air for potential inhalation by miners. In addition, biodiesel’s higher flash point provides a safer working environment in the mines. Over 750 million liters of diesel fuel is used annually in mining applications. The NBB estimates that this market could use up to 6 million liters of biodiesel annually.

Since very large volumes of diesel fuel are currently being used in U.S., in so called biodiesel niche markets, getting a foot in the door can result in big gains in biodiesel usage. Whether based on reducing vehicle emissions or minimizing overall environmental impact, and foreign dependence for transportation fuels, government regulations have made the difference in European biodiesel programs. In the U.S., fuel tax assistance or other government regulations could certainly play a vital role in promoting the use of biodiesel.

The Department of Energy (DOE) has funded over $1.7 million in biodiesel projects that were either defined by NBB or were directly applicable to the NBB commercialization program. The DOE funded projects include, Health Effects Testing ($350 K +), ASTM Specification support ($100 K), and Life Cycle Analysis ($500 K).

Biodiesel research and commercialization programs in the U.S. are being developed with the support and cooperation of USDA, DOE, DOT and EPA. Examples include USDA funding for biodiesel production improvements and additization studies at their Peoria and Philadelphia laboratories; DOE's establishing a separate biodiesel department and fully funded program within their Office of Transportation Technologies; the NREL and Regional Biomass Energy Programs; and EPA's approval of B20 Retrofit/Rebuild packages for CAA compliance.

The goal of NREL's biodiesel program for 1998 is to develop a diesel fuel substitute that can compete with diesel in terms of performance as well as cost. NREL plans to support existing biodiesel industries to attain market share and become viable long-term industries while investing in R&D to reduce biodiesel cost.

In the past NBB played the role of a market developer in its efforts to position biodiesel in the energy market. In 1997, NBB's role and approach has changed significantly. It has now revised its objective from "market" development to "marketer" development. NBB has realized that petroleum and fuel companies are in a much better position to market fuels. They are well established and know their business and their customers. NBB has now adopted an approach to initiate contacts, educate product development executives, and promote biodiesel benefits, etc. so as to market biodiesel concept to the institutions which are in the business of marketing fuels and fuel additives rather than trying to enter into marketing themselves.

The U.S. is also supporting research and development in the use of biomass and alternative fuels to reduce emissions of greenhouse gases. The President of the United States announced on October 22, 1997, a R & D package of incentives and tax breaks aimed at stimulating innovation for renewable and alternative forms of energy. In December 1997, the U.S. joined all other Parties to the UN Framework Convention on Climate Change in adopting the Kyoto Protocol which contains a 7% reduction target for the U.S. from 1990 levels by 2008-2012. Further announcements are expected this winter from the Administration aimed at stimulating R&D in alternative fuels sector.

The following statement about biodiesel by DOT in the April 24, 1997, Federal Register clearly speaks for the increasing interest in this fuel, "Biodiesel improves the environment, enhances national energy security, creates economic development opportunities, and increases the sale of rural domestic agricultural commodities."

5.3 Biodiesel in Canada

At the present time there is no commercial production of biodiesel in Canada. The small quantities of biodiesel used in research and demonstration projects were made in a pilot plant in Saskatoon. The CANMET pilot plant located at the government Energy Research Laboratory in Ottawa produced SuperCetane for limited testing. Currently there are no fuel specifications for biodiesel in Canada, and engine and vehicle manufacturers do not endorse the use of biodiesel in their products.

Agriculture & Agri-Food Canada evaluated vegetable oils and its esters under the National Energy Program in the early 1980's as diesel fuel substitutes or additives (Stumborg, 1996). Three separate studies were commissioned to determine the procedures, complexity, and cost of producing canola esters. Methyl, ethyl, and isopropyl esters of canola were produced using standard procedures. Efficient production of methyl ester required 0.5 wt.% sodium hydroxide as the catalyst while ethyl and isopropyl esters required from 1.5 to 5.0 wt.% sulfuric acid as the catalyst. In all cases, the concentration of alcohol was kept at approximately five times stoichiometric requirements as lower concentrations did not produce satisfactory yields of esters. Economic calculations, based on a 270,000 liter per year community scale processing plant to produce canola ester, revealed that ester production would add approximately $0.38 CDN per liter to the raw oil cost. This would result in the cost of biodiesel being much higher than the rack price of diesel fuel (about $0.25 CDN per liter).

A second study (Nye and Southwell, 1983) attempted to simplify the esterification process and lower the costs. The optimum recipe for methyl or ethyl ester production was found to be a mixture of 1.0 wt.% sodium hydroxide, 200% excess alcohol, 24°C reaction temperature, and mechanical agitation with one hour reaction time.   Large bench scale tests achieved 85% of theoretical ester yields.

Lawson and Thurston (1986) commissioned a subcontract with Croda (Leek) Ltd. Of England to develop a canola ethyl monoester for engine testing. Using a recipe of 77.2 wt.% dried canola, 20.7 wt.% ethanol, and 2.1 wt.% sodium methoxide, a 94% conversion of canola oil to ECM was attained. The final yields were 80.3% ECM, 5.5% ethanol distillate, and 14.2% glycerin by weight. Economics of production were not assessed.

In 1994, Agriculture and Agri-food Canada and the Saskatchewan Canola Development Commission investigated the feasibility of biodiesel and analyzed a number of Canadian markets/industries that currently use diesel fuel and may hold future potential for using biodiesel (Blondeau, 1996). The markets which were researched included mining, urban transit, marine, national parks, ski resorts, forestry, petroleum exploration, and government fleet vehicles. It was revealed that Canada has many potential markets for biodiesel, however, there are several concerns which must be addressed before biodiesel can get into these applications. The concerns include: high price of biodiesel compared to conventional diesel; lack of engine and vehicle manufacturers' approval of biodiesel usage; the performance and quality of biodiesel; and the availability of biodiesel.

The mining industry, particularly underground mining where workers are exposed to high levels of diesel emissions, could accrue significant benefit from biodiesel. Urban transit operations in large cities could also benefit from biodiesel in reducing particulate and toxic emissions. The use of biodiesel in marine applications, due to its higher biodegradability and the potentially damaging effects of diesel spills, could also be useful. The National Parks and ski resorts are considered to be environmentally sensitive areas. Biodiesel could reduce the adverse effects of diesel emissions and spills on wildlife in these areas.

Based on the U.S. experience, the biodiesel price in Canada will be two to three times higher than conventional diesel fuel. Without any tax incentives or government regulations no industry is willing to pay substantially higher fuel prices. Table 11 provides the response of various industries with respect to the biodiesel cost (Blondeau et.al., 1996).

Table 11. Summary of Blend and Pricing Results for Biodiesel Survey

	Price Respondents are Willing to Pay for Biodiesel	% Blend
Mining	5% more than diesel	20%
Petro. Exp.	5% to 10% more than diesel	20%
Marine	10% more than diesel	100%
Skiing	10% more than diesel	100%
Transit	NA	20%
Forestry	10% more than diesel	20%
Parks	NA	100%

In most industries the initial cost of the equipment is quite high. Therefore, companies do not want to experiment with a new fuel or fuel additive unless the engine or vehicle manufacturers are willing to cover any damage that may be incurred.

Although it is generally known that biodiesel and biodiesel blends reduce certain emissions and engine wear, the actual engine wear and emissions benefits for specific engine types are not known. For any industry it is important to know the exact benefits before deciding on a new fuel. Power equivalency to diesel fuel is also an important consideration in many applications. Many industries are also not sure about the consistent quality and availability of biodiesel. Because many companies operate in remote areas or change sites frequently, having a reliable distribution system is important to them.

The recent tests conducted at the University of Saskatchewan at Saskatoon using low percentage (1 to 2 %) of a canola oil derivative and methyl ester in diesel fuel have shown markedly reduced engine wear, and improved low temperature fuel economy (Hertz, 1997). This is important in view of the concerns related to poor lubricity of low sulfur diesel and hydrotreated diesel especially during winter months in Canada.

6. REGULATORY AND FUEL SPECIFICATION ISSUES

There are many issues related to government regulations and fuel specifications which impact on the use of biodiesel as a transportation fuel either in its neat form or as a diesel fuel component. The majority of these issues pertain to the U.S., while a few refer to Canada.

6.1 U.S. Biodiesel Initiatives

6.1.1 Substantially Similar Regulation

Section 211(f) of the Clean Air Act (CAA) prohibits any fuel or fuel additive to be introduced into commerce unless it is either “substantially similar” (“sub sim”) to fuel used to certify the emissions of a vehicle or has been granted a waiver from the requirement under Section 211(f)(4). This regulation was initially proclaimed for gasoline. In 1991, EPA published an Advance Notice of Proposed Rule Making (ANPRM) on a diesel fuel “sub sim” definition that generated a number of comments. These comments, including those from the American Petroleum Institute (API), encouraged the agency to develop a broad definition to possibly encompass oxygen and the additive content. The final Notice of Proposed Rule Making (NPRM) on a diesel “sub sim” regulation was delayed and has not been published as yet.

In the meantime, under Section 211(b)(2), on June 1, 1993, EPA issued a final rule requiring the inclusion of health effects and other emissions data as part of an expanded fuel and fuel additive registration requirement. Hence for biodiesel to remain legal for commercial sale in the U.S., it must be tested in accordance with the requirements of Section 211(b) of the CAA. The National Biodiesel Board (NBB) has defined the requirements, developed the testing protocols and executed the program on behalf of the soybean industry.

The NBB, with some funding from the Department of Energy (DOE), is investing over $2.5 million for Tier I and Tier II testing. Based on the negotiations between NBB and EPA, the deadline for submitting the Tier I test data and to sign a binding contract to perform Tier II health effects testing has been extended till March 17, 1998.

NBB plans to submit a waiver petition for biodiesel under the substantially similar regulation to EPA. It is believed that the application will not tie biodiesel to any feedstock or method of processing. Waving the full testing requirements of the Substantially Similar rule will potentially save the biodiesel industry hundreds of thousands of dollars in additional testing costs and accelerate approval of biodiesel blended fuels by EPA by more than one year.

6.1.2 Energy Policy Act (EPACT)

The Energy Policy Act in the U.S. was passed in 1992, and is administered by the Department of Energy. The main goal of EPACT is to reduce U.S. reliance on imported petroleum by 30% before the year 2010. The intent of the regulation is to increase U.S. energy self sufficiency by displacing imported petroleum through the promotion of alternative fuels and alternative fueled vehicles. EPACT requires that by the year 2000, vehicles that run on alternative fuels must represent 75% of all affected vehicle purchases for government fleets and 90% of all affected vehicle purchases by companies that manufacture alternative fuels. The Clean Cities Program, also created under EPACT, involves more than 40 major U.S. cities that have volunteered to expand the use of alternative fueled vehicles.

Biodiesel was not mentioned by name as an alternative fuel in the original version of EPACT. However 100% neat biodiesel has subsequently been added as an allowable option to meet the regulations. In October 1997, DOE announced that it is beginning the rule-making process for inclusion of B20, as an approved alternate fuel under EPACT.

The alternative fuel market in the U.S. is essentially governed by EPACT. So far none of the Original Equipment Manufacturers' (OEMs) have biodiesel on their list of alternative fuels. The potential users of B20 have stated that they would use the fuel if B20 was declared an alternative fuel and there were vehicles approved for its use (NBB, 1997). So, the solution to the apparent "Catch 22" scenario is: Attain alternative fuel designation for B20 so that consumer demand can be created for B20 capable vehicles in order to satisfy the business case requirements of the OEMs. NBB is currently pursuing this plan.

6.1.3 Urban Bus Retrofit Standards

Since 1995, EPA has imposed new emissions requirements for rebuilt, heavy-duty diesel engines (model year 1993 or earlier) used in urban buses in cities with more than 750,000 residents to reduce particulate matter emissions. The fleet operators are given the option of complying with these standards in either one of two ways:

<u>Option 1</u>: Each vehicle must meet a particulate matter (PM) standard of 0.05 - 0.10 g/hp-hr (depending on the engine) at the time its engine is rebuilt, with no increase in HC, CO, or NOx. This could be accomplished through the use of exhaust after-treatment technology as long as the cost of such equipment does not exceed US $7,940. If this is not possible, the operator would be required to use retrofit equipment that achieved a 25% reduction in PM for a cost of no more than US $2,000.

Option 2: A fleet operator may establish an annual emissions requirement for the entire fleet " set up in a manner that yields an emission reduction equivalent to that expected from Option 1."

In June 1995, Twin Rivers Technologies, Inc. (TRT) submitted a biodiesel certification package to EPA that involves use of B20, engine timing changes, and a catalyst. EPA published a notice of intent to certify the Twin Rivers biodiesel package in the Federal Register on December 15, 1995. The comment period closed on January 28, 1996. NBB submitted extensive comments to EPA in support of certification of the biodiesel package as a retrofit/rebuild technology. Final approval of the Twin Rivers retrofit/rebuild package was granted on October 22, 1997.

On November 20, 1997, EPA published a notice of intent to certify a biodiesel-based package for Detroit Diesel two-stroke engines from model year 1979 -1993. Comment period closes January 5, 1998.

6.1.4 Corporate Average Fuel Economy (CAFE) Program

The National Highway Traffic Safety Administration (NHTSA) of the U.S. Department of Transport (DOT) administers the CAFE program. CAFE establishes fleet average fuel economy goals for major auto manufacturers. Manufacturers that fail to meet CAFE standards for their vehicles are subject to large fines from DOT. The Alternative Motor Fuels Act of 1988, amended the CAFE program to offer additional credits to auto manufacturers towards CAFE calculations if they build and sell alternative fuel vehicles.

In May 1995, NBB filed a petition before NHTSA for including biodiesel and biodiesel blended fuels under the CAFE program. Inclusion of biodiesel in this program would provide OEMs with a business case for warranting the fuel in their products. In April 1997, the Department of Transport (DOT) has made a commitment to initiate a rule-making process to include biodiesel and biodiesel blends in the CAFE program (NBB, 1997). NHTSA is waiting on DOE's proposed B20 rule before addressing this issue.

6.1.5 Diesel Fuel Quality Issues and ASTM Specifications

California has regulated sulfur content in diesel fuel to a maximum of 0.05wt%, while aromatic content is limited to 10 vol% for large refineries (50,000 barrels per day or more production) and 20 vol% for small refineries. In October 1993, EPA also mandated sulfur content at 0.05 wt% for all on-road diesel fuel sold in the U.S. Soon after these regulations came into effect, there were many complaints about failure of O-rings in diesel fuel pumps and injectors, and rotary fuel injector-pump scuffing caused by lower lubricity of low-sulfur diesel.

The Subcommittee E-2 on Burner, Diesel, Gas Turbine Fuels of the American Society for Testing & Materials (ASTM), concluded that low-sulfur diesel may be responsible for equipment failures due to reduced lubricity. The industry was asked to take voluntary action, through the use of additives or other means, to bring the diesel lubricity to levels prior to October 1993. At the present time , ASTM D 975, Standard Specification for Diesel Fuels, does not include a specification for lubricity. The Society of Automotive Engineers (SAE) is developing a lubricity test method.

Subcommittee E-2 is well aware of the potential role of biodiesel as a component of or as alternate to conventional diesel fuel. A task force was established in mid-1993 to develop an ASTM specification and new test methods for biodiesel in each of these applications. Many members expressed interest about the potential of improved lubricity and materials compatibility associated with biodiesel use in diesel fuel. Specifications for biodiesel have been drafted and are being currently evaluated by ASTM (See Table 10).

6.1.6 The Clean Fuel Fleet Program

The 1990 CAAA created the Clean Fuel Fleet Program, which is being implemented in the 22 poorest air quality areas in the U.S. The program administered by the EPA, is designed to accelerate the introduction of low-emission vehicles operating on clean-burning fuels.

The Clean Fuel Fleet Program, which will begin in 1998, requires certain federal, state, and local vehicle fleets to use designated “clean alternative fuels”. The list of designated fuels as originally published included natural gas, liquified petroleum gas (propane), alcohols such as ethanol and methanol, electricity, and reformulated gasoline and diesel fuel, but not biodiesel. Biodiesel was added to the list later. It is anticipated that soon there will be efforts to include B20 under this program.

6.1.7 Interagency Greenhouse Gas Control Efforts

The Clinton administration took the first steps towards proposing a federal policy that would limit emissions of greenhouse gases (GHG), especially from the transportation sector which is the largest single source of such emissions. This has been an important issue for Vice President Al Gore and could have a positive effect on national efforts to implement a biodiesel program. President Clinton’s Climate Change Action Plan includes a voluntary greenhouse gas reduction program called “Climate-Wise”.

Overall the plan is designed to encourage the voluntary implementation of various measures to reduce GHG emissions, including the use of “renewable resources and energy efficient technologies,” industrial process efficiency improvements, and “innovative transportation programs that reduce fossil fuel use”.

Other programs in place or planned as part of the Administratio's Climate Change Program include a program for Renewable Energy commercialization for Biomass, projected to generate by 2010 energy cost savings of $0.9 Billion and CO_2 equivalent emissions savings of 8.9 megatonnes. As well, numerous voluntary programs designated to reduce vehicular emissions, may open up new markets for biodiesel.

6.1.8 Biodiesel Taxation Issue

The Internal Revenue Service (IRS) taxes on-highway diesel fuel at the rate of 24.4 cents per gallon. A number of exemptions are provided for other uses of diesel. As with gasoline, diesel fuel for on-highway use is also eligible for a reduced rate of excise tax if it is blended with no less than 10 vol% qualified alcohol. To date, IRS has not issued any regulation that would grant similar treatment to other oxygenates including esters.

Unless the IRS revises its regulation to define esters as alcohols, or issues private letter rulings to that effect, no ester will qualify for a rate of taxation lower than that for conventional diesel fuels. In a March, 1990, letter ruling to ARCO Chemical Co., IRS has interpreted the Section 40 income tax credit (54 cents/gallon of qualified alcohol) as applicable to the manufacture of ETBE used as a motor fuel. If this generic IRS interpretation is also extended to the motor fuel excise tax provisions (Sections 4081 and 4091), an opportunity for a tax credit or exemption would exist for biodiesel.

6.1.9 Biodiesel Bills in the Senate and the House

Senators Johnson, Wellstone, and Grassley, on September 2, 1997, introduced a Bill to include biodiesel and biodiesel blends in conventional diesel under the EPACT as alternative fuels.

Another Bill (H8025) for the same purpose was introduced in the U.S. House of Representatives on September 26, 1997, by Mr. Shimkus and Ms. McCarthy.

It was argued that when the EPACT was passed in 1992, biodiesel was not included in the list of alternative fuels because the fuel was new, untested, and unproved. However, today this is not the case. In fact biodiesel offers many environmental and emissions benefits compared to conventional diesel. Hence biodiesel and its blends in conventional diesel should be recognized as alternative fuels under EPACT. The details of these Bills are given in Appendix B.

6.2 Canadian Biodiesel Initiatives

6.2.1 Alternative Fuels Act

On June 22, 1995, with the passage of Bill S-7, the Alternative Fuels Act became law in Canada. This Act specifies aggressive legislative targets for the use of alternative fuel vehicles by all federal government departments and agencies. Under the Act, federal government departments and Crown Corporations must purchase alternative fuel vehicles, where they are cost-effective and operationally feasible, according to the following schedule:

50 % of all vehicle purchases in 1997 / 98;
60 % of all vehicle purchases in 1998 / 99;
75 % of all vehicle purchases in 1999 / 2000, and every year thereafter

By the year 2004, 75 % of all federal vehicles are to be operating on alternative fuels, where cost-effective and operationally feasible. While the Act provides a basic framework for the conversion of a portion of the federal government fleet to alternative fuels, a series of regulations must still be enacted before the provisions of the legislation can be formally implemented.
The alternative fuels identified in the Regulations (T.B. 824505) dated September 19, 1996, pertaining to this Act, include ethanol, methanol, propane, natural gas, hydrogen, and electricity. Biodiesel is not included by name in the list of alternative fuels at the present time.

6.2.2 Motor Vehicle Safety Regulations

Recognizing that motor vehicles continue to be a major contributor to air pollution, the Canadian Council of the Ministers of the Environment (CCME) established the "Task Force on Cleaner Vehicles and Fuels" in November 1994. The Task Force developed the options and recommendations for national emission standards for motor vehicles. On October 23, 1995, the CCME accepted the Task Force's recommendations that the Department of Transport immediately update its vehicle emission regulations under the Motor Vehicle Safety Act (MVSA) to harmonize them with the U.S. federal standards in place under the U.S. Clean Air Act.

On June 8, 1996, Transport Canada made the announcement in Canada Gazette Part I, proposing that the new regulations - to harmonize standards with the U.S.- becomes effective with the 1998 model year. These standards would be the same as those referred to as the U.S. federal Tier I exhaust emission standards. Furthermore, the amendment would ensure that Canadian emission standards continued to be in harmony with the U.S. for each subsequent model year.

6.2.3 Diesel Fuel Regulations

Recognizing the harmful effects of sulfur in diesel fuel, Environment Canada announced on September 28, 1996, in Canada Gazette Part I, that effective October 1, 1997, all diesel fuel sold in Canada for use in on-road vehicles will be low sulfur diesel, which will not contain more than 0.05 wt.% sulfur. This regulation brings the sulfur content in Canadian diesel fuel to the same level as in the U.S.

6.2.4 Canadian General Standards Board (CGSB) Specifications

Similar to the ASTM Standards in the U.S., the Canadian General Standards Board (CGSB) sets the specifications for transportation fuels commonly used in Canada. The CGSB is a consensus body comprised of producer and user industries as well as the federal and provincial governments. Although the CGSB Standards are not mandatory, they are enforced by many provinces and are also used for major commercial transactions in Canada. For any new transportation fuel to be accepted by the engine and vehicle manufacturers, and consumers in Canada, it is essential that the fuel should meet a CGSB Standard. Generally CGSB Standards follow the corresponding ASTM Standards, and are comparable with some minor exceptions.

At the present time biodiesel does not have a CGSB Standard. When the proposed ASTM Standard for biodiesel gets approved in the U.S., developing a CGSB Standard will not be difficult. However, the process to develop biodiesel standards in Canada should be initiated now.

6.2.5 Company Average Fuel Consumption (CAFC) Program

The CAFC Program in Canada was initiated in the late 1970’s to mirror the CAFÉ Program in the United States. The Motor Vehicle Fuel Consumption Act was passed in Canada in 1981 to enforce the CAFC standards, the Act was not proclaimed at that time. The decision not to proclaim the Act was based on a commitment by the Canadian vehicle manufacturers and importers that they would meet or exceed the requirements of the standards on a voluntary basis. The program is monitored through the Government Industry Motor Vehicle Energy Committee (GIMVEC).

Unlike CAFE, the CAFC does not provide any incentives for vehicle manufacturers to increase the production of alternative fuel vehicles.

6.2.6 Tax Subsidies and Incentives

In 1980, the federal government in Canada enacted a National Energy Policy, which emphasized energy security as well as energy conservation. To encourage the use of alternative fuels in the transportation sector a grant program was implemented through the Department of Energy, Mines, and Resources. Under this program purchase of, or conversion to a natural gas or propane vehicle was subsidized by a fixed sum of money. The fuel tax on natural gas and propane was also lowered in many parts of the country.

In 1990, ethanol-gasoline blends were granted the EcoLogo under the Environmental Choice Program. Effective April 1, 1992, the federal excise tax of 8.5 cents per liter was also waived on fuel ethanol produced from biomass. Currently both ethanol and methanol produced from biomass get the 10 cents per liter excise tax rebate from the federal government. Many provinces also offer tax incentive for biomass derived ethanol.

Currently, biodiesel does not qualify for any of the above mentioned subsidies or tax incentives. Biodiesel also does not have a strong lobby to support its cause as an alternative fuel in Canada.

7. EXPERIENCE OF USING BIODIESEL IN DIESEL ENGINES

In order to discuss the role of biodiesel in reducing harmful emissions from diesel engines, it is important to understand the sources of pollutants and various engine and fuel-related factors that can affect their formation and emission. The detailed description of diesel engine technology including background information on the types of pollutants emitted by diesel engines, their formation mechanisms, and the effects of different engine and fuel variables on emissions levels is given in Appendix A.

7.1 Effect on Emissions from On-Road Vehicles

The use of biodiesel as a fuel in diesel engines has been actively investigated in Europe and North America during the last decade. Biodiesel's ability to reduce certain emissions was recognized by many investigators. The individual programs were operated under different conditions in terms of the type of engine and fuel. The fuels used were either neat biodiesel, or biodiesel blends in conventional diesel at different volumetric ratios, as well as biodiesel produced from different feedstocks. Due to these differences the results were often mixed and sometimes even conflicting.

For example, Ziejewski, et al. (1984), Reece, et al. (1993), Scholl, et al. (1993), and Schumacher, et al. (1992,1993) reported reductions in smoke density when fueling with biodiesel as compared to No. 2 diesel. Reece, et al. also noted reductions in smoke density with a 20 vol% biodiesel and 80 vol% diesel blend. Ziejewski used sunflower derived biodiesel, Reece used rapeseed biodiesel, while Scholl and Schumacher used soybean biodiesel. Srinivasan, et al. (1991), however, noted increase in smoke density when using karanja based biodiesel. Marshall (1993), Schumacher, et al. (1992), Mittelbach, et al. (1985,1988), and Scholl, et al. (1993) noted reductions in HC and CO emissions. Niehaus, et al. (1985), however, noted increases in HC and CO, and reduction in NOx emissions.

Based on the results of many studies in the U.S. which looked at different biodiesel to diesel ratios, 20 vol% biodiesel and 80 vol% diesel fuel combination (B20) was found to be most favorable. In view of the substantially large database on emissions results using different engines and different type of biodiesel fuels, the best approach to understand the effects of biodiesel blends on EPA regulated emissions, as compared to conventional diesel, is to look at some of the most recent studies using B20 as fuel. The reported data from some of the recent biodiesel studies using 2-stroke engines are summarized in Table 12. Similar data based on studies using modern 4-stroke engines are shown in Table 13.

Table 12. Heavy-Duty Transient Test Composite Emissions Summary for 2-Stroke Engines

Reference	Engine Type	Fuel	Nox	PM	CO	HC	SOF	% change in PM	% change in NOx
			g / bhp-hr						
Fosseen, 1994	6V-71N-77MUI	D-2	9.96	0.83	3.59	2.01	0.729	--	--
		B20 SME	10.2	0.81	2.73	1.43	0.73	-2.4	2.4
Manicom et al, 1993	6V-92TA-91DDECH	D-1	4.23	0.197	1.51	0.72	0.079	--	--
		B20 SME	4.46	0.175	1.32	0.56	0.089	-11.2	5.4
Stotler, 1995	6V-92TA-87DDC	D-2	10.77	0.59	0.71	--	--	--	--
		B20 SME	11.1	0.56	0.63	--	--	-5.1	3.1
Sharp, 1994	6V-92TA-88DDECH	D-2	8.52	0.2	1.6	0.6	0.116	--	--
		B20 SME	8.93	0.2	1.39	0.53	0.142	0	4.8
Fosseen, 1995	6V-71N-77MUI	D-2	11.72	0.282	3.18	0.86	0.212	--	--
	stock rebuild	B20 SME	11.88	0.323	3.1	0.74	0.26	14.5	1.4
Fosseen, 1994 A	6V-92TA-81/89MUI	D-2	10.06	0.268	2.16	0.42	0.144	--	--
		B20 SME	10.5	0.26	1.81	0.36	0.171	-3.0	4.4
Prakash, 1996	6V-92TA-DDC	ARB Cert. D	5.34	0.27	1.24	0.546	0.141	--	--
		B20 SME	5.52	0.263	1.14	0.448	0.161	-2.6	3.4
		B20 CME	5.54	0.257	1.2	0.437	0.158	-4.8	3.7
Prakash, 1996	6V-92TA-DDC	EPA Cert. D	5.62	0.265	1.19	0.436	0.133	--	--
		B20 CME	5.87	0.238	1.04	0.363	0.145	-10.2	4.4

Table 13. Heavy-Duty Transient Test Composite Emissions Summary for 4-Stroke Engines

Reference	Engine Type	Fuel	NOx	PM	CO	HC	SOF	% change in PM	% change in NOx
				g /	bhp-hr				
Graboski et al, 1996	DDC Series 60 91 DDECH	D-2	4.64	0.30	4.46	0.164	--	--	--
		B20 SME	4.69	0.26	4.14	0.143	--	-13.72	1.14
Stotler, 1995	Cummins L-10 87 MUI	D-2	5.64	0.31	2.33	0.89	--	--	--
		B20 SME	5.78	0.28	1.96	0.82	--	-9.4	2.5
ORTECH, 1995	Cummins N-14 87 MUI	D-2	6.32	0.37	2.20	0.58	0.10	--	--
		B20 SME	6.52	0.31	2.12	0.47	0.106	-14.8	3.0
Sharp, 1996	Cummins B5.9	D-2	4.37	0.106	1.47	0.30	0.05	--	--
		B20 RME	4.39	0.093	1.14	0.22	0.05	-12.3	0.5
		B20 REE	4.31	0.10	1.24	0.23	0.06	-5.7	-1.4
Marshall, 1995	Cummins L-10 -92	D-2	5.01	0.105	1.46	0.27	--	--	--
		B20 SME	5.17	0.092	1.22	0.25	--	-12.4	3.2
Starr, 1997	DDC Series 60 260 KW	D-2	4.76	0.222	2.77	0.072	--	--	--
		B20 SME	4.57	0.184	2.25	0.057	--	-17.1	-4.0

The use of biodiesel in diesel engines, either in its neat form or as a blend with diesel fuel, reduces the emissions of particulate matter (PM), carbon monoxide (CO), and gaseous hydrocarbons (HC), but increases the emissions of oxides of nitrogen (NOx). In the case of particulate emissions, the insoluble fraction decreases while the soluble fraction (SOF) increases, with a net reduction in total PM.

In a study using soybean methyl ester (SME), Scholl, et al. (1993) found that “the conditions which have the highest peak pressure and rate of pressure rise at a given load and timing also tend to have the highest concentration of NOx”. However, with respect to these conditions, “there is no detectable difference between SME and diesel fuel. This indicates that the differences in NOx emissions for the two fuels are attributable to changes in ignition delay and burning rate only”. The authors concluded that “in terms of combustion behavior and exhaust emissions characteristics, SME can basically be regarded as interchangeable with diesel fuel”. Based on a recent study from the Southwest Research Institute (Starr, 1997), it seems that modern diesel engines with electronic controls may not show NOx increase with biodiesel blends.

The reason for NOx increase with biodiesel blends is still under debate. Some of the possible hypotheses include: (i) Biodiesel reduces the insoluble (soot) fraction of PM emissions. While oxygenated fuels have a lower adiabatic flame temperature, the soot particles are good heat absorbers. The reduction in soot particles contributes to increase in temperature thus increase in NOx emissions. (ii) During the combustion process, the double bonds in biodiesel break down into smaller hydrocarbon molecules. How these molecules behave in terms of changing the ignition delay and burning rate is not known. , (iii) The differences in the viscosity, surface tension and boiling point for the biodiesel can change the spray characteristics and burn pattern. This may lead to different relative duration of the premixed versus diffusional burn regimes, and thus may have different pollutant formation characteristics.

The reduction of net total PM associated with B20 is due to a reduction in the insoluble portion, generally composed of carbon soot. As a result, catalytic converters, which reduce the soluble component, may be more effective in reducing PM with B20 than with conventional diesel. The lower soot is a positive indication of biodiesel’s effect on engine longevity. If used in heavily populated areas, B20 or other biodiesel blends should have a beneficial impact on human health by reducing fine particles and enhancing catalyst performance. In areas where a slight NOx increase is not likely to be a concern, biodiesel or biodiesel blends can be used with no modifications to diesel engine, fuel system or support infrastructure.

One of the simplest techniques to lower NOx emissions is to retard the injector pump timing. This reduces the rate of pressure rise and the peak pressure in the combustion chamber. The technique has proven successful in reducing NOx emissions to levels equal or below the NOx values for conventional diesel. In a diesel engine there is an inverse correlation between emissions of NOx and particulate matter. As an engine is optimized to reduce NOx emissions, the particulate emissions generally increase. In order to achieve NOx reduction and maintain the benefit of lower particulate emissions, many people have used the combination of timing change with an oxidation catalyst.

The data in Table 14 shows the effect of timing change and use of oxidation catalyst on NOx and PM emissions. The data suggest that in some cases using biodiesel with a catalyst and timing change provides very little benefit compared to a stock engine with catalyst and D-2. This may be due to the fact that the oxidation catalyst can only reduce the SOF component of PM. The effect of using biodiesel with oxidation catalyst and timing change for some of the data (Forseen, 1994 A) is shown in figure 7.

A number of studies have been conducted using different blends of biodiesel and sometimes biodiesel produced from a different feedstock. The reported data from the literature are shown in Table 15. In general, with the increasing concentration of biodiesel in the blend, the emissions of NOx increased while PM decreased. The percent change in NOx and PM as a function of biodiesel in the blend is plotted in Figure 8. Based on linear regression, the increase in NOx emissions is rather flat at about 4%, whereas PM emissions show a continuously decreasing trend with increase in biodiesel percentage in the blend. In one study (Sharp, 1996), blends of ethyl esters of soy produced smaller increases (if at all) in NOx and also smaller reduction in PM compared to the corresponding methyl esters. The differences between canola and soy methyl ester blends were not significant (Prakash, 1996).

Table 14. The Effect of Timing Change and Oxidation Catalyst on Transient Composite Emissions

Reference	Engine Type	Setup	Fuel	NOx	PM	CO	HC	SOF	%Change in PM	%Change in Nox
				g/ bhp-hr						
Sharp,1994	6V-92TA-88DDECII	Stock	D-2	8.52	0.2	1.6	0.6	0.116	-	-
		Stock	B20 SME	8.93	0.2	1.39	0.53	0.142	0	4.8
		1 deg	B20 SME	8.2	0.21	1.59	0.55	0.134	5	-3.8
		Catalyst	B20 SME	9.12	0.11	0.95	0.21	0.058	-45	7
		Catalyst+1 deg	B20 SME	8.35	0.12	1.05	0.25	0.053	-40	-2
		Catalyst+1 deg	D-2	8.18	0.14	1.21	0.29	0.049	-30	-4
Fosseen,1995	6V-71N-77MUI	Stock	D-2	11.72	0.282	3.18	0.86	0.212	-	-
	Rebuild	Stock	B20 SME	11.82	0.323	3.1	0.74	0.26	14.5	1.4
		Catalyst	D-2	11.72	0.159	1.64	0.42	0.0095	-43.6	0
		Catalyst	B20 SME	12.11	0.166	0.86	0.38	0.118	-41.1	3.3
		4 deg	D-2	8.31	0.378	3.88	1.02	0.221	34	-29.1
		4 deg	B20 SME	8.48	0.375	3.4	0.81	0.26	33	-27.7
		Catalyst+4 deg	B20 SME	8.47	0.213	0.94	0.42	0.119	-24.5	-27.7
Fosseen,1994A	6V-92TA-81/89MUI	Stock	D-2	10.06	0.268	2.16	0.42	0.114	-	-
		Stock	B20 SME	10.5	0.26	1.81	0.36	0.171	-3	4.4
		Catalyst	B20 SME	10.4	0.15	1.08	0.14	0.064	-44	3.4
		1.5 deg	D-2	9.69	0.27	2.19	0.35	-	0.8	-10.1
		1.5 deg	B20 SME	10	0.24	1.77	0.32	-	-10.5	-0.6
		2 deg	B20 SME	9.61	0.263	2.03	0.33	0.159	-1.9	-4.5
		Catalyst+2 deg	B20 SME	9.35	0.161	1.54	0.11	0.058	-39.9	-7.1
		3 deg	B20 SME	9.04	0.27	2.19	0.35	-	0.8	-10.1

ORTECH,1995	Cummins N-14-87MUI	Stock	D-2	6.32	0.369	2.2	0.58	0.1	-	-
		Stock	B20 SME	6.52	0.314	2.12	0.47	0.106	-14.8	3
		deg ?	B20 SME	6.19	0.384	1.87	0.63	0.173	4.1	-2.1
		Catalyst	B20 SME	6.73	0.225	1.17	0.18	0.05	-39.1	6.4
		Catalyst + deg?	B20 SME	6.1	0.283	1.32	0.29	0.065	-23.4	-3.5
Sharp,1996	Cummins B5.9	Stock	D-2	4.37	0.106	1.47	0.3	0.05	-	-
		Catalyst	D-2	4.25	0.073	1.42	0.25	0.02	-31.1	-2.8
		Stock	B20 RME	4.39	0.093	1.14	0.22	0.05	-12.3	0.5
		Catalyst	B20 RME	4.33	0.064	0.97	0.15	0.02	-39.6	-0.9
		Stock	B20 REE	4.31	0.1	1.24	0.23	0.06	-5.7	-1.4
		Catalyst	B20 REE	4.3	0.067	0.94	0.16	0.03	-36.8	-1.6

Table 15. Effect of Biodiesel Concentration on Transient Composite Emissions

Reference	Engine Type	Fuel	NOx	PM	CO	HC	SOF	%Change in PM	%Change in NOx
				g/	bhp-hr				
Manicom,1993	6V-92TA-91DDECII	D-1	4.23	0.197	1.51	0.72	0.079	-	-
		B10 SME	4.38	0.186	1.43	0.63	-	-5.6	3.6
		B20 SME	4.46	0.175	1.32	0.56	0.089	-11.2	5.4
		B30 SME	4.8	0.173	1.14	0.54	-	12.2	13.5
		B40 SME	4.86	0.162	1.07	0.43	-	-17.8	14.9
ORTECH,1995	Cummins N-14-87MUI	D-2	6.32	0.369	2.2	0.58	0.1	-	-
		B10 SME	6.45	0.331	2.2	0.52	0.09	-10.3	2
		B20 SME	6.52	0.314	2.12	0.47	0.106	-14.8	3
Graboski,1996	DDC Series60-91DDECII	D-2	4.64	0.3	4.46	0.16	-	-	-
		B20 SME	4.69	0.259	4.14	0.14	-	-13.7	1.1
		B35 SME	4.68	0.222	3.67	0.15	-	-26.1	1
		B65 SME	4.85	0.165	3.18	0.12	-	-45.1	4.6
		SME	5.17	0.102	2.36	0.09	-	-66	11.5
Sharp,1996	Cummins B5.9	D-2	4.37	0.106	1.47	0.3	0.05	-	-
		B20 RME	4.39	0.093	1.14	0.22	0.05	-12.3	0.5
		B20 REE	4.31	0.1	1.24	0.23	0.06	-5.7	-1.4
		B50 RME	4.3	0.087	0.97	0.16	0.06	-24.5	-1.6
		B50 REE	4.25	0.092	1.03	0.17	0.06	-13.2	-2.7
		RME	4.52	0.08	0.9	0.09	0.06	-24.5	3.4
		REE	4.26	0.091	0.95	0.11	0.05	-14.2	-2.5
Prakash,1996	6V-92TA-DDC	EPA Cert.D	5.62	0.265	1.19	0.44	0.13	-	-
		B6 CME	5.72	0.244	1.06	0.41	0.14	-7.9	1.8
		B10 CME	5.81	0.243	1.02	0.38	0.14	-8.3	3.4
		B20 CME	5.87	0.238	1.04	0.36	0.15	-10.2	4.5
		ARB Cert.D	5.34	0.27	1.24	0.55	0.14	-	-
		B6 CME	5.47	0.247	1.24	0.51	0.16	-8.5	2.4
		B20 CME	5.54	0.257	1.2	0.44	0.16	-4.8	3.8
		B40 CME	5.82	0.244	0.95	0.35	0.18	-9.6	9
		ARB Cert.D	4.43	0.257	1.22	0.57	0.13	-	-
		B20 SME	4.7	0.27	1.12	0.48	0.16	-5.1	6.1
		B30 SME	4.78	0.258	1.03	0.42	0.17	-0.4	7.9
		B40 SME	4.89	0.258	0.95	0.38	0.18	-0.4	10.4

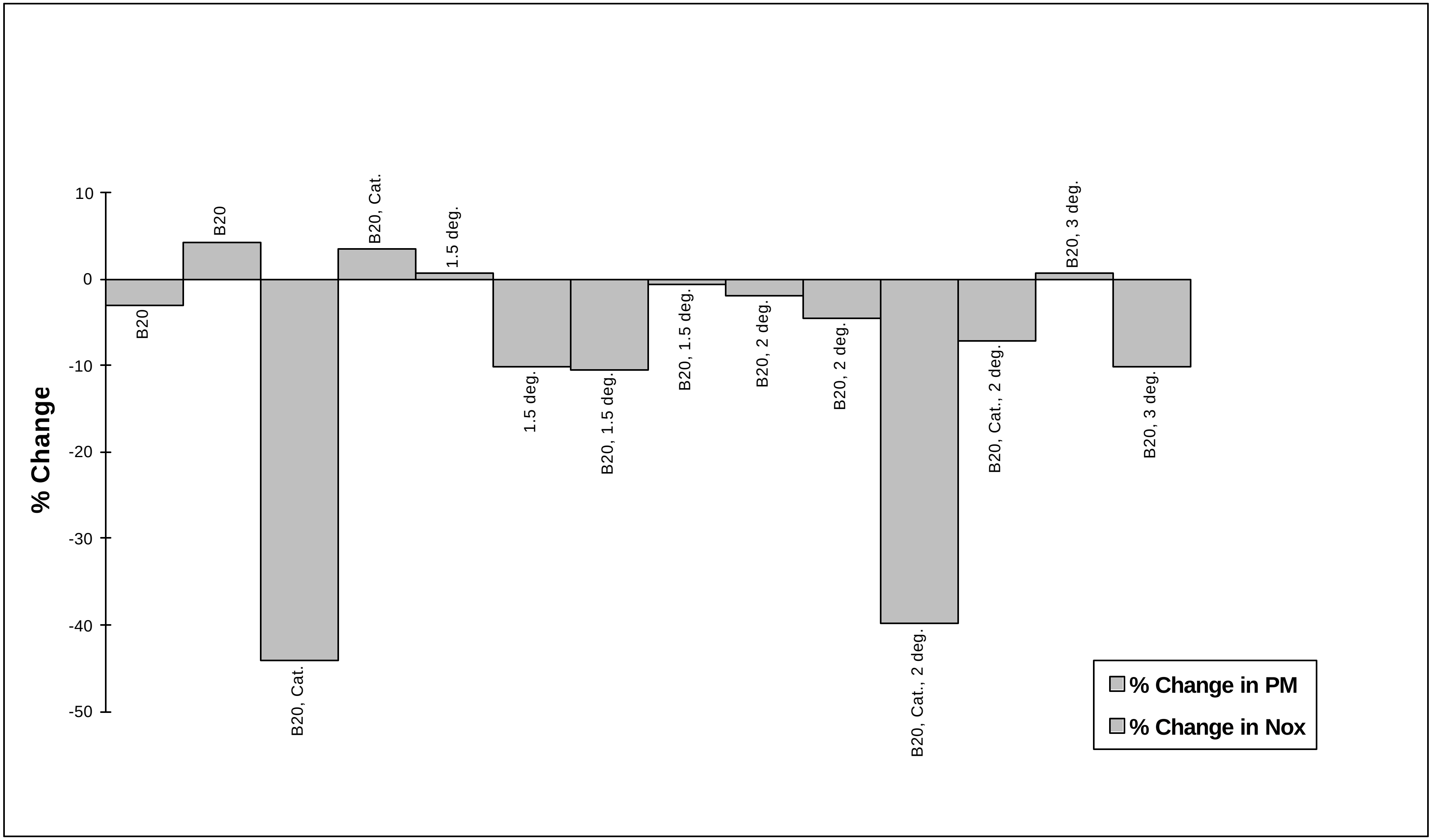

Figure 7: Effect of Biodiesel, Catalyst, and Timing Change on Nox and Emissions

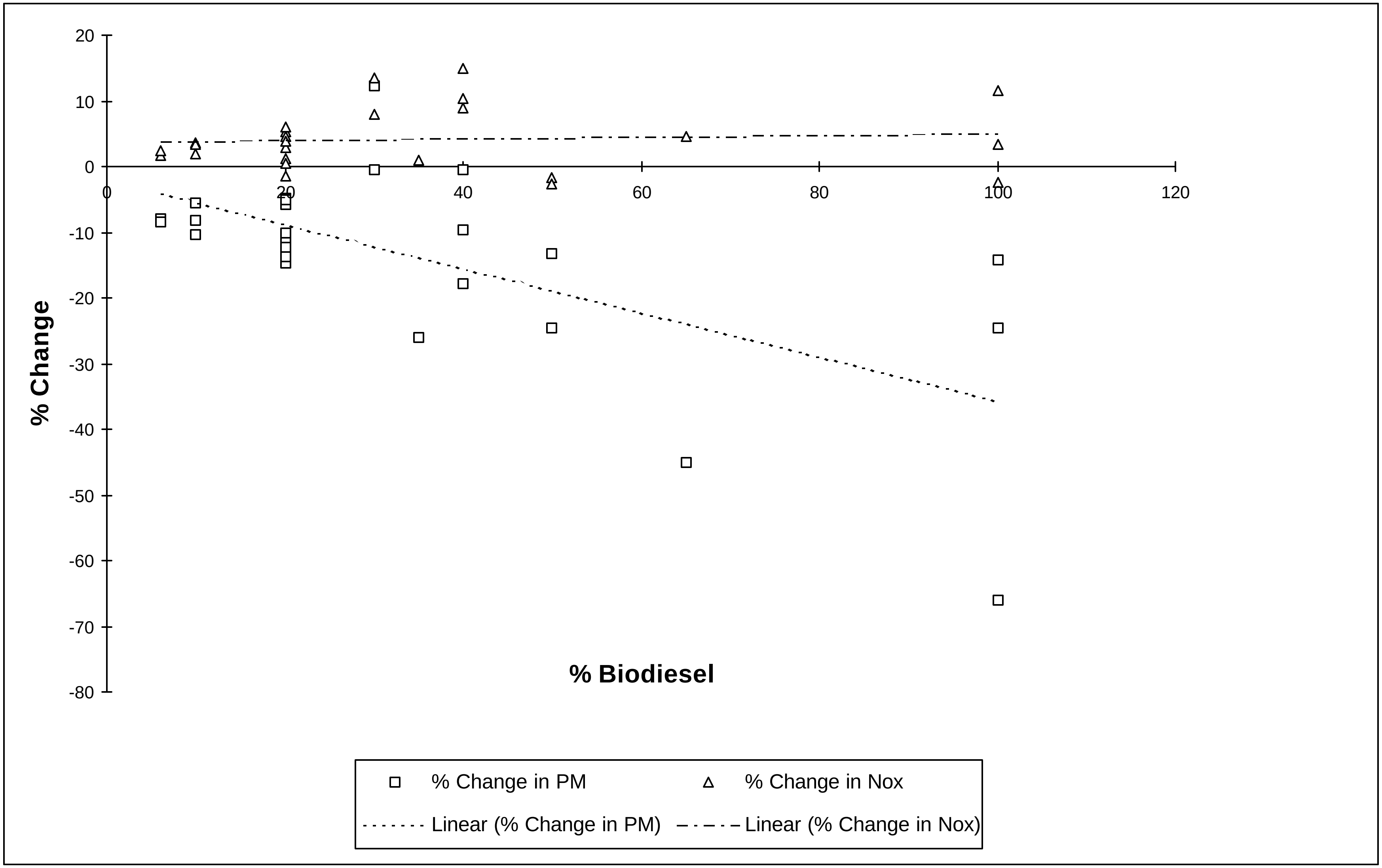

Figure 8: Effect of Biodiesel Concentration NOx and PM Emissions

7.2 Experience with SuperCetane

The emissions tests using 20 and 40 volume percent blends of SuperCetane in D-2 were conducted at the Mobile Sources Emissions Laboratory of Environment Canada in Ottawa. The test engine used was a Detroit Diesel 6V71. The average composite values of regulated emissions using the EPA transient cycle are shown in Table 16 (Hendren, 1996). The trends of increase in NOx and reduction in PM emissions with the use of SuperCetane were similar to the trends for ester type biodiesels. The SuperCetane was also used for a field demonstration in Canada Post vehicles in Vancouver, B.C. The drivers did not notice any significant differences in the performance of the vehicles between SuperCetane blend and conventional diesel. The emissions from these vehicles were not measured.

Table 16. Effect of the blends of SuperCetane on Regulated Emissions (g/bhp/hour)

Fuel	NOx	PM	CO	HC
D-2	12.85	0.93	6.2	0.61
20% SC	13.32	0.81	5.6	0.26
40% SC	13.17	0.80	5.0	0.40

7.3 Unregulated Emissions

Besides the regulated emissions from diesel engines, there is increasing concern about the emissions of air toxics, carcinogenic, and reactive hydrocarbon compounds. As the regulatory authorities may in future limit the emission of specific compounds, it is important to have an understanding of the impact of biodiesel on these emissions. The toxic emissions from diesel engines can be divided into two groups: Those in the HC portion of the gaseous emissions; and, the heavier hydrocarbons including the multi-ring poly-aromatic compounds (PAH) found in the SOF portion of PM. Many volatile hydrocarbons are known to have carcinogenic or mutagenic activity. The important ones are 1,3-butadiene, benzene, formaldehyde, and acetaldehyde. Very limited data on these emissions, while using biodiesels, are available in North America or Europe. Thus, at the present time it is difficult to draw any conclusions on unregulated emissions from biodiesel or biodiesel blends. This area clearly needs more research in future.

The Chassis Dynamometer testing of two buses using 2-stroke engines with D-2 and B20 SME reported aldehyde emissions (Howes and Rideout, 1995). The data shown in Table 17, indicate that for the 1981 DDC 8V-71 powered bus the aldehyde and particulate emissions were higher while NOx emissions were lower compared to D-2. The use of an oxidation catalyst reduced these emissions below the baseline level. The other bus powered by the 1988 DDC 6V-92 engine, showed much smaller differences in aldehyde emissions between biodiesel and D-2.

Table 17. Chassis Dynamometer Emissions Results for B20 SME using NY Bus Composite Cycle

	NOx g/mile	PM g/mile	%SOF	Aldehydes g/mile
1981DDC 8V-71				
D-2	35.2	0.91	51.8	0.40
B20 SME	30.7	1.48	72.2	0.42
B20 + Catalyst	32.2	0.89	48.3	0.25
B20 + Timing change	26.3	1.55	67.1	0.48
B20 + Catalyst + Timing change	34.3	1.12	49.4	0.30
1988 DDC 6V-92TA				
D-2	27.3	1.30	65.5	0.31
B20 SME	27.1	1.46	68.0	0.31
B20 + Catalyst	23.7	1.02	51.0	0.28
B20 + Timing change	26.9	1.79	52.0	0.39
B20 + Catalyst + Timing change	-	1.21	36.5	0.34

7.4 Other Issues

Besides the effect of biodiesel on emissions, there are many other issues which are relevant to the use of biodiesel in diesel engines since they influence engine performance and durability. Some of the important issues, including mixing of biodiesel in conventional diesel, loss of engine power, cold start problems, material compatibility, engine wear and effect on the engine lubricating oil are addressed below. Schumacher et al. (1996) have reviewed these issues based on the experience derived from various biodiesel research and demonstration programs. The pertinent problems and future research needs identified in the above reference are reproduced in Table 18. The “x” indicates that problems were noted when the engine was fueled with biodiesel. Problems which were encountered more often could be interpreted as requiring more attention. For example, fuel quality issues and loss of power were consistently reported by operators (73%). Fuel filter plugging was the next concern at 64%, while cold start and material compatibility problems were reported by about 45% of the operators.

Table 18. Pertinent Problems and Future Research Needs

Problem Noted	MU 5.9L Pickups	St. Louis 6V92 Urban Buses	MU 5.9L & 7.3L Navistar	MU Tractor Testing	MSMC Ford Pickup	St. Joe Diesel Loco-motive	NBB 1000 hr Testing	Mercedes Taxis	Cedar Falls Demo	Boone County Demo
Algae Growth	X									
Blending with Diesel		X								
Cold Start Tendencies	X				X	X				X
Condition of Lube Oil								X	X	
Cooling System Issues		X		X						
Exhaust Emissions	X	X						X		
Fuel Economy	X	X	X						X	X
Fuel Filter Plugging	X	X	X		X		X	X		
Fuel Quality	X		X	X	X	X	X	X		X
Injector(s) Failure	X	X								
Material Compatibility	X			X	X					X
Smoke Increases	X		X	X	X	X				
Power	X		X	X	X		X			X
Paint Problems	X									X
Rusting of Tanks										
Storage and Handling		X								

7.4.1 Blending of Biodiesel with Diesel Fuel

To achieve consistent performance from biodiesel blends it is necessary that the biodiesel and diesel fractions are thoroughly mixed. Initially, the biodiesel industry in the U.S. advocated splash blending of biodiesel in diesel fuel. Research has indicated that splash blending in many cases was ineffective; specially when blending in large storage tanks or when the two fuels were at different temperatures. Inadequate mixing could result in segregation of biodiesel and contribute to problems of fuel filter plugging.

Further research is needed to determine the amount of agitation required to ensure adequate mixing of biodiesel and diesel fuel. Research is also needed to determine whether conditions exist under which biodiesel could separate from conventional diesel fuel while in storage or in the vehicle fuel tank.

7.4.2 Loss of Engine Power

Biodiesel on a volumetric basis contains slightly less energy than conventional diesel fuel. Hence using biodiesel without any change in the fuel injection system would result in a slight loss of engine power. Schumacher (1994) reported that very small differences in power were detected until the concentration of biodiesel exceeded 50 vol%.

However, some operators have complained about significant power loss with biodiesel. Research suggests that fuel filter plugging, the gum like accumulation in injection pumps, and injector cavitation may be responsible for the reported power loss. All these problems are attributable to biodiesel fuel quality issues.

7.4.3 Cold Starting

Biodiesel has higher cloud and pour point temperatures than diesel fuel, which can create starting problems during cold weather. Researchers at the University of Missouri and the University of Idaho installed fuel tank heaters in the vehicles operating on biodiesel to minimize these tendencies. The cold start issue could also restrict the use of biodiesel in many parts of Canada during winter.

Thus cold start properties for biodiesel and biodiesel blends need to be improved. Since some of the chemical and physical properties associated with biodiesel and diesel are nonlinear, the performance of cold flow improvers generally used for diesel has not been very satisfactory in biodiesel blends. In addition, the incremental amount of flow improvers or additives needed to improve the cold flow characteristics of biodiesel and biodiesel blends has exceeded the amount recommended by the manufacturers. One important issue for these additives is their effect on the biodegradability of the fuel, which is an important attribute of biodiesel.

7.4.4 Material Compatibility

Biodiesel may not be compatible with certain materials which could lead to premature failure or replacement of components. For example, nitrile rubber fuel lines had to be replaced on test vehicles operating on biodiesel. The fuel pump diaphragms and fuel valves were also prematurely deteriorated by biodiesel, affecting the fuel delivery to the engine, and needed to be replaced. Peterson (1997) reported that stainless steel fuel tanks were needed for neat biodiesel. The biodiesel industry recognizes the solvent capabilities of biodiesel and that problems may surface when fueling with neat biodiesel. However, no hard data are currently available concerning material compatibility problems associated with biodiesel blends. In Europe, engine tests and used oil analysis conducted by Mercedes-Benz indicate that blends up to 20 vol% methyl ester do not show any significant adverse side-effects on fuel system materials (ABA,IRI,1994).

A related issue is whether biodiesel with its excellent solvency characteristics, will dissolve existing gums and sediments in fuel storage tanks, which may cause fuel filter plugging.

7.4.5 Engine Durability and Impact on Lubricating Oil

While engine durability testing of biodiesel blends is ongoing, most studies have shown no appreciable difference between biodiesel and conventional diesel fuel. Based on wear-metal analysis of the engine lubricating oil, engine wear rates were well within the specified range for the engines in 200, 500, and 1000 hours tests (Clark, 1984). A study by the University of Idaho showed that conventional diesel "consistently produced higher concentrations of iron, aluminum, chromium, and lead in crankcase oil" as compared to biodiesel (Perkins, 1991). In the same study, while a slight decrease in oil viscosity was observed , it remained within the allowable limits. This was attributed to fuel dilution of the crankcase oil.

Blackburn, et al. (1983) noted unacceptable levels of ester contamination in lubricating oil. Peterson, et al. (1996) reported dilution of engine oil in test vehicles operated on neat ethyl ester of rapeseed oil. However, engine oil analysis of five buses fueled with B20 soy methyl ester, Schumacher, et al. (1995A), indicated that dilution of engine oil was negligible. Some other studies using neat biodiesel, Schumacher (1997), suggest that fuel dilution of engine oil is not a problem. The Engine Manufacturers Association (EMA) has taken a conservative stand on this issue. The EMA recommends that when using biodiesel, the normal oil change interval should be cut by half to minimize problems associated with engine lubricating oil (EMA, 1995). Some engine manufacturers in Europe, where biodiesel is used in neat form, have also recommended that engine oil be changed more frequently for biodiesel-fueled engines.

7.5 Niche Markets

Biodiesel and its blends in diesel fuel, like B20, are attractive alternatives to diesel fuel in environmentally sensitive niche markets such as urban buses, underground mines, national parks and forests, and marine applications. Several federal agencies in the United States have conducted or are planning to conduct extensive biodiesel pilot programs. These agencies include: US Army, US Postal Service, The National Park Service, and the US Bureau of Mines.

In November 1996, ten Canadian mining companies, three diesel engine manufacturers, CANMET, ORTECH Inc., and the University of Minnesota committed to a 3-year multi-million-dollar research program called "Diesel Engine Evaluation Program", or DEEP in short. One of its objectives is to develop a tool box that mining companies can pick from to protect underground mine workers.

7.5.1 Urban Buses

Demonstration projects in the U.S., involving urban buses, to test biodiesel's reliability and performance in a real world situation have accumulated more than 10 million road miles. Transit authorities in Erie, Pennsylvania; Sioux Falls, South Dakota; Cincinnati, Ohio; Baltimore, Maryland; and Oakland, California have all used B20 blends with favorable results (Gay, 1997). Other more recent demonstrations of biodiesel include operating the entire fleet of convention shuttle buses on B20 during the Democratic National Convention held in Chicago, Illinois, in August 1996, and operating two shuttle buses for the White House Conference on Global Climate Change held in Washington, DC, in October 1997. These demonstrations were essentially to get the operating experience and raise public awareness about the use and benefits of biodiesel as a clean fuel. The emissions results and other issues related to the use of biodiesel in on-road vehicles, described in sections 7.1 to 7.4, cover its usage in urban buses.

7.5.2 Underground Mining Application

Faced with possible tough new legislation to limit diesel exhaust in underground mines, the mining companies in the U.S. are looking to up-grade equipment, implement after-treatment technology, and switch to cleaner fuels like biodiesel for their diesel engines. The recommended threshold limit value (TLV), for 1995-1996, for diesel particulate matter from the American Conference of Governmental Industrial Hygienists (ACGIH) is 0.15 mg of respirable combustible dust per cubic meter, which is about one-sixth of the presently recommended value in Canada. Typical mean concentrations of diesel PM in U.S. and Canadian mines range from 0.2 to 1.5 mg/m3.

If Canada were to adopt the U.S. mining regulations, major efforts will be needed to reduce diesel emissions. In Ontario alone, there are 2,250 operating diesel units in underground mines. The cleaner electronically controlled units represent only 11% of the current operating fleet (Whiteway, 1997). Mines in Ontario consume about 28 million liters of diesel fuel per year. Biodiesel with a much higher flash point and twice the lubricity of low sulfur diesel would offer added safety and extended life to diesel equipment. Many mining companies are aggressively promoting DEEP to understand new techniques to reduce diesel emissions. The University of Minnesota, ORTECH, CANMET, and Michigan Technological University will initiate a project, under DEEP, to evaluate the impact of a 50% blend of biodiesel and use of oxidation catalysts on emissions and air quality in an underground mine.

The U.S. Bureau of Mines tested neat SME, and a blend of 30% SME and 70% conventional diesel in a Caterpillar 3304 PCNA engine operating for approximately 50 hours on each fuel (McDonald, 1995). Compared to low sulfur diesel, neat SME increased soluble diesel PM but greatly decreased the insoluble fraction, for a net decrease in total PM. The use of an oxidation catalyst further reduced the soluble and total PM. NOx did not change for the 30/70 blend and was lower for neat SME. Extracts of particulate and vapor phase organic material were found to be significantly less mutagenic for SME when compared to low sulfur diesel.

Field tests on a CAT 3306 PCNA engine at the Homestake mine in Lead, South Dakota in

1995 showed that biodiesel reduced the particulate emissions to about 0.28 mg per cubic meter from about 0.67, a reduction of about 55% (USBM, 1995).

The University of Minnesota conducted a project to compare the cost of using neat biodiesel, and blends of biodiesel with conventional diesel, to the cost of using other emission controls in underground mines (Bickel, et al., 1997). The results suggest that for light-duty industrial diesel engines, the cost of using biodiesel was about 25-40% lower than for a Regenerable Fiber Coil Diesel Particulate Filter (RFC-DPF) if neat biodiesel is priced at US$1.50 per gallon. If 50% biodiesel blend could be employed to reach PM reduction goals, biodiesel would also be competitive with RFC-DPF at a price of US$3.00 per gallon. In heavy-duty engines and equipment, due to high consumption of fuel, neat biodiesel priced at US$3.00 per gallon was not competitive with existing PM control technologies like Ceramic Wall-flow Diesel Particulate Filter (CDPF).

7.5.3 Marine Applications

Due to increasing concerns about diesel spills in water bodies, biodiesel is gaining a lot of interest in marine applications. Divers and boat owners are aware of water pollution issues and recognize biodiesel's cleaner burning and biodegradable attributes. Studies at the University of Idaho compared the biodegradability of biodiesel, conventional diesel, and dextrose (sugar) in aqueous solutions. Biodiesel samples were 95% degraded at the end of 28 days. The diesel fuel was approximately 40% degraded after 28 days. The B20 blend degraded twice as fast as conventional diesel. In the U.S. current markets for biodiesel are in the environmentally sensitive waters of the Florida keys, San Francisco Bay, Maryland's Chesapeake Bay, and the Great Lakes.

The NOPEC Corporation first offered 20% biodiesel blends as premium diesel in 1995 in Florida, priced about 20 cents per gallon more than regular diesel. Since then the demand for biodiesel in Florida is gradually increasing. NOPEC has joined hands with the Florida Restaurant Association to recycle used cooking oil into biodiesel. The Lakehead plant with a capacity of approximately 75 million liters per year, currently uses 50% virgin soybean oil and 50% waste oil. NOPEC's plan is to increase waste oil share to 90%. Based on a recent market survey Florida alone offers a potential for about 8 million liters of biodiesel per year.

Coastal Properties, owner of nine marinas that fuel more than 4,000 vessels annually in Chesapeake Bay, has started selling biodiesel at all its stations. Neat biodiesel can be purchased either at the pump or in 5-gallon jugs with a standard label that explains how to blend biodiesel and conventional diesel at a 20:80 ratio (Biofuels Update, 1997). The biodiesel fuel is being provided by the Florida based NOPEC Corporation.

A project funded by the U.S. DOE through NREL for marine biodiesel use and awareness in the San Francisco Bay and Northern California area has been recently completed. This project included the establishment of a fuel distribution and marketing infrastructure for biodiesel in California's recreational marine market.

Recently a proposal has been made to create biodiesel awareness and demand, and to establish the distribution system for biodiesel in the Great Lakes marine market. The National Biodiesel Foundation and two local companies have secured initial funding from the Great Lakes Regional Biomass Energy Program. They are now seeking to cost-share the remaining market development costs of introducing biodiesel into the Great Lakes region with the Great Lakes Protection Fund.

In Canada, a significant potential for biodiesel use exists in the B.C. coastal area and in the Great Lakes.

7.5.4 Biodiesel as a Lubricity Enhancer

Biodiesel can be used as an additive to create a premium diesel product that provides superior fuel lubricity to protect against wear of critical engine parts (NBB, 1997). Blends of biodiesel as low as 1% can provide measurable fuel lubricity benefits for a net cost of about 1 cent per liter. Premium diesel fuels featuring biodiesel as an additive are currently available to the general public in several Midwestern states as a cooperative venture between Farmland Industries and AG Processing, Inc.

Fuel lubricity is important because in many fuel pumps the moving parts are actually lubricated by the diesel fuel itself. Lubricity is measured by the Ball On Cylinder Lubricity Evaluator (BOCLE) test, and the High Frequency Reciprocating Rig (HFRR) test. The BOCLE test is accurate to ≈ 200 g and fuels with good lubricity give BOCLE values in the 4,500 to 5,000 range (higher number means better lubricity). For the HFRR test, scar values over 0.4 mm are considered unsatisfactory. Lubricity data for diesel fuels and blends of biodiesel, summarized in a recent paper (Graboski, 1997), are reproduced in Table 19. These results indicate that soybean and rapeseed methyl esters have superior lubricity compared to conventional low sulfur diesel, and that the lubricity of diesel fuel can be improved by blending small amounts of biodiesel in it.

Table 19. Results of Lubricity Tests for Biodiesel Blends (Graboski, 1997)

FUEL	BOCLE "g"	HFRR "scar-mm"
Conventional low sulfur diesel	4,250	0.405
Conventional low sulfur diesel	4,200	0.492
SME	6,100	-
RME	7,000	0.140
REE	> 7,000	0.085
B2 – SME	4,400	-
B5 –SME	4,500	-
B10 – SME	5,200	-
B20 – SME	5,200	0.193
B30 – SME	-	0.206
B20 – RME	4,600	0.190
B50 – RME	5,550	0.180
B20 – REE	4,700	0.165
B50 – REE	5,700	0.165

A new lubricity measurement technique called Roller On Cylinder Lubricity Evaluator (ROCLE) has been developed at the University of Saskatchewan, Canada (Galbraith and Hertz, 1997), which yields a dimensionless lubricity number (LN). Based on this technique a range of lubricity numbers from 0.5 for kerosene to 1.7 for canola vegetable oil were recorded. The addition of 2% canola methyl ester to low sulfur D-1 produced lubricity equivalent to D-2 high sulfur fuel.

A field study conducted during the winter months of 1997 in Saskatoon, Canada, using 3 diesel powered vehicles, evaluated the effectiveness of low concentrations of a canola oil derivative (COD-AC2) and CME in reducing engine wear. The results from this study indicate that COD and CME at blend levels of 1or 2 percent in low sulfur winter diesel fuel markedly reduced the engine wear (Hertz, 1997). The 3 test vehicles also recorded a 6% to 10% increase in fuel economy when operating on low level blends of COD and CME in diesel fuel. None of the test vehicles encountered any problems related to cold start, drivability, or power loss.

7.6 Life Cycle Analysis

Many studies have been conducted to assess the economics, energy balance, and life-cycle costs of biodiesel and biodiesel blends compared to diesel fuel. In April 1994, the consulting firm of Booz-Allen & Hamilton completed a technical and economic assessment report of biodiesel as a transportation fuel. The report identified and analyzed the attributes of biodiesel and compared these attributes to conventional diesel fuel as well as other alternative fuels. It was reported that B20 can be cost competitive and an attractive alternative fuel for urban bus fleets which are mandated to reduce harmful PM emissions under the CAA (Booz-Allen & Hamilton, 1995).

In March 1996, another study compared the total capital and operating costs of biodiesel, in an urban bus fleet, with conventional diesel, methanol, and natural gas. In this study, the researchers from the Department of Agriculture and Applied Economics, University of Georgia, concluded that biodiesel blends of as much as 35% are cost competitive with alternative fuels such as natural gas and methanol (Ahouissoussi et al, 1996).

A life-cycle analysis conducted for the government of France in 1993 demonstrated that after taking into account all relevant costs, inputs, emissions, waste and externalities, biodiesel was directly competitive with conventional diesel fuel, even at a substantially higher market price (Paris, France, 1993). In another study, the life-cycle energy balance calculations for rapeseed methyl ester in Europe show an energy value of 2.5 to 3.5 times for biodiesel fuel (Krawczyk, 1996).

An extensive life-cycle analysis of all emissions from biodiesel fuel compared to diesel fuel is currently being conducted by the U.S. DOE’s National Renewable Energy Laboratory (NREL) in cooperation with the U.S. Department of Agriculture and EPA. Based on personal discussions during our visit to NREL, it appears that the greenhouse gas emissions from biodiesel may be as low as 20 to 30% compared to diesel. It should be mentioned that NREL was not willing to reveal any numbers prior to the publication of this report which is expected to be out in March 1998 (Tyson, 1998).

8. SUMMARY OF MAJOR BIODIESEL ISSUES AND RECOMMENDATIONS

Availability, Cost, Tax Incentives, and Markets

Canadian biodiesel potential is estimated at approximately 385 million liters per year which is roughly 2% of the current diesel fuel consumption. The cost of biodiesel remains about 2 to 3 times higher than conventional diesel. Although efforts are being made to reduce the cost by employing a greater share of cheaper feedstocks and by innovative research, it seems highly unlikely that biodiesel cost will be comparable to diesel in the near future. Higher taxes on diesel fuel or tax incentives for biodiesel, to compensate for the higher cost of biodiesel, also do not seem feasible at this time. Hence biodiesel must find uses in niche markets in which the impacts on the environment or health and safety are sufficient to support its higher price.

In Canada, biodiesel blends could have a potential market in underground mines and marine applications. In view of the cold Canadian winters and biodiesel's inferior cold flow properties, biodiesel use in urban buses and for other on-road transport may not be attractive. Biodiesel's claims for enhancing the lubricity of diesel fuel, and improving the fuel economy of diesel engines/vehicles should be further explored. If the benefits of using biodiesel at low levels (1 or 2 % in conventional diesel) can be substantiated then it may open a potential market. Federal government support for a test program to evaluate the effect of low level biodiesel blends on diesel engine fuel economy, and fuel lubricity would be very timely.

At this point in time, it is not possible to project biodiesel demand in Canada, since biodiesel has not yet penetrated in any of the niche markets mentioned above. Compared to Canada, there are many more driving forces in the U.S. to push for the use of biodiesel as a diesel fuel component. The Canadian markets will most likely follow and depend on the acceptance of biodiesel in the U.S. markets. If the use of biodiesel becomes popular in the U.S., the Canadian biodiesel or its feedstocks may eventually find a market in the U.S. As the same time, based on the U.S. experience similar niche markets may open up in Canada. If the Canadian biodiesel production is not in place, the initial demand will utilize the imports from the U.S.

Fuel Quality and Specifications

Currently biodiesel is produced in small batch operations using a variety of feedstocks. This results in a large variation in its quality. Process improvement is needed to enable the industry to manufacture biodiesel continuously and under reproducible conditions rather than in small, individual batches.

When producing biodiesel as a fuel, there are many considerations, namely: origin (vegetable oils vs. Animal fats) ; history (virgin oil vs. Recycled oil) ; and, chain lengths (C16 vs. C18, methyl vs. Ethyl alcohol). The NBB defines biodiesel as alkyl esters of triglycerides. This broad definition does not limit the fuel to feedstock or origin. It relies on the chemical definition of biodiesel – a biodiesel molecule is biodiesel, regardless of its origin. Efforts are underway to develop ASTM standards for biodiesel which should resolve the origin and history issues. Canada should also develop biodiesel specifications under the CGSB.

Acceptance by Engine Manufacturers and Petroleum Industry

Before any new fuel can be commercially used in the transportation sector, it must be approved by the engine and vehicle manufacturers, so as not to disrupt their warranties. If biodiesel is used as a blend with diesel fuel, it should also be accepted by the petroleum industry. For getting these endorsements, it is absolutely essential that biodiesel has a consistent quality and CGSB specifications. It should also have good data to support its environmental claims and beneficial attributes.

Government Policy and Regulations

Many times government policy and regulations can support a fuel to find niche markets. For example, if federal or provincial governments in Canada impose stringent emissions regulations in mines, marinas, and other environmentally sensitive areas, it would certainly help biodiesel to enter these markets even at its higher cost. Efforts should be made to include biodiesel in the list of approved alternative fuels under the Alternative Fuels Act. The biodiesel industry in Canada should also consider requesting approval to use the EcoLogo under the Environmental Choice Program.

Based on the preliminary information from NREL and review of the available data, it seems likely that the ongoing life-cycle evaluation of biodiesel in the U.S. will come out positive in favor of biodiesel. If it is true then biodiesel can contribute, in a small way, in achieving greenhouse gas emission reduction targets accepted by Canada at Kyoto. For example, assuming that the life cycle CO_2 emissions for biodiesel are 20% that of diesel fuel, and that all of the potential biodiesel production in Canada (385 million liters per year representing roughly 2% of diesel consumption) is used as a diesel fuel component, the greenhouse gas emissions attributable to diesel use can be reduced by about 1.6% (80% reduction in 2% of diesel use).

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APPENDICES

APPENDIX A - DIESEL ENGINE TECHNOLOGY

The compression ignition (CI) engine was conceived by Dr. Rudolf Diesel (1858-1913) to improve on the relatively poor thermal efficiency of the early, spark-ignition gasoline engines by employing higher compression ratio. Diesel had visualized a compression-ignition engine which could run on a variety of fuels, injected by air blast and ignited by the hot compressed air. The modern CI engine has evolved out of a combination of Diesel's original concept and that of a contemporary British engineer, Herbert Akroyd-Stuart. Since the turn of the century, the diesel engine, its fuel injection system (developed predominantly by Robert Bosch) and the fuel itself have been evolving in parallel with the spark ignition engine and its fuels, though at a different pace.

Most of the diesel engines in commercial vehicles (generally larger than 2.5 liters) are direct injection (DI) engines, in which the fuel is injected directly into the cylinder and burned in a combustion chamber defined by the cylinder head and the piston. Smaller size engines suitable for passenger cars were developed around the indirect injection (IDI) system, where the fuel is injected and ignited in a prechamber connected to the working cylinder by a narrow passage through which the burning gases expand to force down the piston. The IDI engines have a lower efficiency than DI engines because of higher thermal and pumping losses, but they are not as critical of fuel quality.

In the early years, the availability of low-priced gasoline in U.S. reduced the incentive to adopt the more economical and fuel efficient diesel engine for road transport. However, since the end of the Second World War the automotive diesel has found its place in the U.S. powering buses and long-distance freight transport, but not in passenger cars. With respect to on-highway heavy-duty diesel engines and vehicles, the U.S. Environmental Protection Agency (EPA) first issued emission standards in the early 1970s. In view of increasing concerns about air quality and the potential health effects, EPA has been gradually tightening the heavy-duty emission standards under the Clean Air Act Amendments of 1990. The emission standards were modified for 1994 and then for 1998 model year vehicles and engines. The EPA also implemented regulations for diesel fuel quality, limiting sulfur content to 0.05% by weight, a minimum Cetane Number of 40 or a maximum aromatic content of 35% by volume. Although diesel engines produce many different types of pollutants, one of the most significant (as well as visually obvious) pollutants is soot and other particulate matter. One effective measure for reducing these emissions is to substitute an alternative non-soot producing fuel for diesel fuel.

A.1 Diesel Combustion

Diesel engine emissions are determined by the combustion process. As opposed to Otto-cycle engines (which use a more or less homogeneous charge) all diesel engines rely on heterogeneous combustion. During the compression stroke, a diesel engine compresses only air. The process of compression heats the air to about 700 to 900 degrees Celsius, which is well above the self-ignition temperature of diesel fuel. Near the top of the compression stroke, liquid fuel is injected into the combustion chamber under tremendous pressure, through a number of small orifices in the tip of the injection nozzle. The quantity of fuel injected with each stroke determines the engine power output.

The high pressure injection atomizes the fuel. As the atomized fuel is injected into the chamber, the periphery of each jet mixes with the hot air already present. After a brief period known as the <u>ignition delay</u>, this fuel air mixture ignites. In the <u>premixed burning phase</u>, the fuel/air mixture formed during the ignition delay period burns very rapidly, causing a rapid rise in cylinder pressure. The subsequent rate of burning is controlled by the rate of mixing between the remaining fuel and air, with combustion always occurring at the interface between the two. Most of the fuel injected is burned in this <u>diffusion burning phase</u>, except under very high loads.

A mixture of fuel and exactly as much air as is required to burn the fuel completely is called a “stoichiometric mixture”. The air-fuel ratio λ is defined as the ratio of the actual amount of air present per unit of fuel to the stoichiometric amount. In diesel engines, the fact that fuel and air must mix before burning means that a substantial amount of excess air is needed to ensure complete combustion of the fuel within the limited time allowed by the power stroke. Diesel engines, therefore, always operate with overall air-fuel ratios which are considerably lean of stoichiometric (λ greater than one).

The air-fuel ratio in the cylinder during a given combustion cycle is determined by the engine power requirements, which govern the amount of fuel injected. Diesel engines operate without throttling, so that the amount of air present in the cylinder is essentially independent of power output, except in turbocharged engines. The minimum air-fuel ratio for complete combustion is about $\lambda = 1.5$. This ratio is known as the smoke limit, since smoke increases dramatically at air-fuel ratios lower than this. The smoke limit establishes the maximum amount of fuel that can be burned per stroke, and thus the maximum power output of the engine.

A.2 Pollutant Formation in Diesel Engine

The principal pollutants emitted by diesel engines are oxides of nitrogen (NOx), sulfur oxides (SOx), particulate matter (PM), unburned hydrocarbons (HC), and carbon monoxide (CO). Diesel engines are also responsible for visible smoke, unpleasant odors, and noise. In addition, like all engines using hydrocarbon fuels, diesels emit significant amounts of carbon dioxide (CO_2), which is responsible for the global warming or the “greenhouse effect”. With thermal efficiencies typically in excess of 40%, however, diesel engines are the most fuel-efficient of all common types of combustion engines. As a result, they emit less CO_2 to the atmosphere than any other type of engine doing the same work.

The NOx, HC, and most of the particulate emissions from diesel engines are formed during the combustion process, and can be controlled by appropriate modifications to that process, as can most of the unregulated pollutants. The sulfur oxides, in contrast, are derived directly from sulfur in the fuel, and the only feasible control is to reduce fuel sulfur content. Most SOx is emitted as gaseous sulfur dioxide (SO_2), but a small fraction (typically up to 5%) occurs in the form of particulate sulfates.

Diesel particulate matter consists mostly of three components: soot formed during combustion, heavy hydrocarbons condensed or adsorbed on the soot, and sulfates. In older diesel engines, soot was typically 40 to 80 percent of the total particulate mass. Developments in in-cylinder emissions control have considerably reduced the soot contribution to particulate emissions in modern diesel engines. Most of the remaining particulate mass consists of heavy hydrocarbons adsorbed or condensed on the soot. This is referred as the soluble organic fraction of the particulate matter, or SOF. The SOF is derived partly from the lubricating oil, partly from unburned fuel, and partly from compounds formed during combustion. The relative importance of each of these sources varies from engine to engine.

In-cylinder emission control techniques have been most effective in reducing the soot and fuel-derived SOF components of the particulate matter. As a result, the relative importance of the lubricating oil and sulfate components has increased. Lubricating oil emissions can be reduced by controlling oil consumption or modifying the oil , but this may adversely affect engine durability. The only known way to reduce sulfate emissions is to reduce sulfur content in diesel fuel.

The gaseous hydrocarbons and the SOF component of the particulate matter emitted by diesel engines include many known or suspected carcinogens and other toxic air contaminants. These include polynuclear aromatic compounds (PNA) and nitro-PNA, formaldehyde and other aldehydes, and other oxygenated hydrocarbons. The oxygenated hydrocarbons are also responsible for much of the characteristic diesel exhaust odor.

A.2.1 Oxides of Nitrogen

The oxides of nitrogen are formed from nitrogen and free oxygen at high temperatures close to the flame front. The rate of NOx formation in a diesel engine is a function of oxygen availability, and is exponentially dependent on the flame temperature. In the diffusion burning phase, flame temperature depends on the heating value of the fuel, the heat capacity of the reaction products and any inert gases present, and the starting temperature of the initial mixture. In the premixed burning stage, the local air-fuel ratio also affects the flame temperature, but this ratio varies from place to place in the cylinder and is very hard to control.

In diesel engines, most of the NOx is formed early in the combustion process, when the piston is still near top-dead-center (TDC). This is when the temperature and pressure of the charge are greatest. Research (Wade et al., 1987 ; Cartellieri and Wachter, 1987) indicates that most NOx is actually formed during the premixed burning phase. It has been

found that reducing the amount of fuel burned in this phase can significantly reduce NOx emissions.
NOx can also be reduced by actions which reduce the flame temperature during combustion. These actions include delaying combustion past TDC, cooling the air charge going into the cylinder, reducing the air-fuel mixing rate near TDC, and exhaust gas recirculation (EGR). Since combustion always occurs under near-stoichiometric conditions, reducing the flame temperature by “lean-burn” techniques, as in spark-ignition engines, is impractical.

A.2.2 Particulate Matter

Diesel soot is formed only during the diffusion burning phase of combustion. Primary soot particles, which are small spheres of carbon approximately 0.01µm in diameter, are formed by the rapid polymerization of acetylene at moderately high temperatures under oxygen-deficient conditions. The primary particles then agglomerate to form chains and clusters of linked particles, giving the soot its characteristic fluffy appearance. During the diffusion burning phase, the local gas composition at the flame front is close to stoichiometric, with an oxygen-rich region on one side and a fuel-rich region on the other. The moderately high temperatures and excess fuel required for soot formation are thus always present.

Most of the soot formed is subsequently burned during the later portions of the expansion stroke. Typically, less than 10% of the soot formed in the cylinder survives to be emitted into the atmosphere. Soot oxidation is much slower than soot formation, however, and the amount of soot oxidized is heavily dependent on the availability of high temperatures and adequate oxygen during the later stages of combustion. Conditions which reduce the availability of oxygen (such as poor mixing, or operation at low air-fuel ratios), or which reduce the time available for soot oxidation (such as retarding the combustion timing) tend to increase soot formation.

The SOF component of diesel particulates consists of heavy hydrocarbons condensed or adsorbed on the soot. A significant part of this material is unburned lubricating oil, which is vaporized from the cylinder walls by the hot gases during the power stroke. Some of the heavier hydrocarbons in the fuel may also come through unburned, and condense on the soot particles. Finally heavier hydrocarbons may be synthesized during combustion by pyrosynthesis (Williams et al., 1987).

A.2.3 Hydrocarbons

Diesel HC emissions (as well as the unburned-fuel portions of the particulate SOF) occur primarily at light loads. They are due to excessive air-fuel mixing, which results in some volumes of air-fuel mixture which are too lean to burn. Other HC sources include fuel deposited on the combustion chamber walls or in combustion chamber crevices by the injection process; fuel retained in the orifices of the injector which vaporizes late in the combustion cycle; and partly reacted mixture which is subjected to bulk quenching by too rapid mixing with air. Adehydes (as partially reacted hydrocarbons) and small amounts of CO produced by diesel engines are probably formed in the same processes as the HC.

The presence of polynuclear aromatic hydrocarbons and their nitro-derivatives in diesel exhaust are of special concern, since these compounds include many known mutagens and suspected carcinogens. A significant portion of these compounds are apparently derived directly from the fuel. Typical diesel fuel contains several percent PNA by volume. Most of the larger and more harmful PNAs, on the other hand, appear to form during the combustion process, possibly by the same acetylene polymerization reaction that produces soot.

A.2.4 Visible Smoke

Visible smoke is due primarily to the soot component of diesel particulate matter. Under most operating conditions, the exhaust plume from a properly adjusted diesel engine is normally invisible, with a total opacity of two percent or less. Visible smoke emissions from heavy-duty diesels are generally due to operating at air-fuel ratios at or below the smoke limit, or to poor air-fuel mixing in the cylinder. These conditions can be prevented by proper design.

A.2.5 Noise

Diesel engine noise is due principally to the rapid combustion (and resulting rapid pressure rise) in the cylinder during the premixed burning phase. The greater the ignition delay, and the more fuel is premixed with the air, the greater this pressure rise and resulting noise emissions will be. Noise and NOx emissions thus tend to be related, and reducing the amount of fuel burned in the premixed burning phase will reduce both.

A.2.6 Odor

The characteristic diesel exhaust odor is believed to be due primarily to partially-oxygenated hydrocarbons (aldehydes and similar species), which are formed due to incomplete combustion of fuel. The most significant aldehyde species are formaldehyde, acetaldehyde, benzaldehyde, and acrolein (a powerful irritant). Aldehyde and odor emissions are closely linked to total HC emissions. Experience has shown that modifications which reduce total HC tend to reduce aldehydes and odor as well.

A.3 Influence of Engine Variables on Emissions

The engine variables having the greatest effects on diesel engine emissions are the air-fuel ratio, rate of air-fuel mixing, fuel injection timing, compression ratio, and the temperature and composition of the charge in the cylinder. Most techniques for in-cylinder emission control involve manipulating one or more of these variables.

A.3.1 Air-Fuel Ratio

The air-fuel ratio in the combustion chamber has an extremely important effect on emission rates for HC and particulate matter. Figure 1 shows the typical relationship between air-fuel ratio λ and emissions in a diesel engine. As discussed above, the power output of the engine is determined by the amount of fuel injected at the beginning of each power stroke. At very high air-fuel ratios (corresponding to very light load), the temperature in the cylinder after combustion is too low to burn out residual hydrocarbons, so emissions of gaseous HC and particulate SOF are high. At lower air-fuel ratios, less oxygen is available for soot oxidation, so soot emissions increase. As long as λ remains above about 1.6, this increase is relatively gradual. Soot and visible smoke emissions show a strong non-linear increase below the smoke limit (at about $\lambda = 1.5$).

In naturally aspirated engines (those without a turbocharger), the amount of air in the cylinder is independent of the power output. Maximum power output from these engines is normally “smoke-limited”, that is limited by the amount of fuel that can be injected without exceeding the smoke limit. Maximum fuel settings on these engines represent a compromise between smoke emissions and power output.

In turbocharged engines, increasing the fuel injected per stroke increases the energy in the exhaust gas, causing the turbocharger to spin more rapidly and pump more air into the combustion chamber. For this reason, power output from turbocharged engines is not usually smoke-limited.

A.3.2 Air-Fuel Mixing

The rate of mixing between the compressed air and the injected fuel is among the most important factors in determining diesel engine performance and emissions. During the ignition delay period, the mixing rate determines the amount of fuel that mixes with the air, and is thus available for combustion during the premixed burning phase. The higher the mixing rate, the greater the amount of fuel burning in premixed mode, and the higher the noise and NOx emissions will tend to be.

In the diffusion burning phase, the rate of combustion is limited by the rate at which air and fuel can mix. The more rapid and complete this mixing, the greater the amount of fuel that burns near the piston top-dead-center, the higher the fuel efficiency, and lower the soot emissions. Too-rapid mixing, however, can increase HC emissions (especially at light loads) as small volumes of air-fuel mixture are diluted below the combustible level before they have a chance to burn. Unnecessarily intense mixing also dissipates energy through turbulence, increasing fuel consumption.

Air-fuel mixing rates in present emission-controlled engines are based on extensive optimization to ensure rapid and complete mixing under nearly all operating conditions. Poor mixing may still occur during “lug-down” or high-torque operation at low engine speeds. Maintenance problems such as injector tip deposits can also degrade air-fuel mixing, and result in greatly increased emissions.

A.3.3 Injection Timing

The timing relationship between the beginning of fuel injection and the top of the compression stroke has an important effect on diesel engine emissions and fuel economy. For best fuel economy, it is preferable that combustion begin at or somewhat before TDC. Since there is a finite delay between the beginning of injection and the start of combustion, it is necessary to inject the fuel somewhat before this point (generally 5 to 15 degrees of crankshaft rotation before).

Since fuel is injected before the piston reaches TDC, the charge temperature is still increasing as the charge is compressed. The earlier fuel is injected, the cooler the charge will be, and the longer the ignition delay. The longer ignition delay provides more time for air and fuel to mix, increasing the amount of fuel that burns in the premixed combustion phase. In addition, more fuel burning at or before TDC increases the maximum temperature and pressure attained in the cylinder. Both of these effects tend to increase NOx emissions.

On the other hand, earlier injection timing tends to reduce particulate and light-load HC emissions. Fuel burning in premixed combustion forms little soot, while the soot formed in diffusion combustion near TDC experiences a relatively long period of high temperatures and intense mixing, and is thus mostly oxidized. The end of injection timing also has a major effect on soot emissions. Fuel injected more than a few degrees after TDC burns more slowly, and at a lower temperature, so that less of the resulting soot has time to oxidize during the power stroke.

Therefore, injection timing must compromise between PM emissions and fuel economy on one hand and noise, NOx emissions, and maximum cylinder pressure on the other. Compared to uncontrolled engines, modern emission-controlled engines generally exhibit moderately retarded timing to reduce NOx, in conjunction with high injection pressure to limit the effects of retarded timing on PM emissions and fuel economy. Great precision in injection timing is necessary, since a change of even one degree crank angle can have a significant impact on emissions. The optimal injection timing is a complex function of engine design, engine speed and load, and the relative stringency of emissions standards for the different pollutants. To attain the required flexibility and precision of injection timing has posed a major challenge to engine manufacturers.

A.3.4 Compression Ratio

Diesel engines rely on compression heating to ignite the fuel, so the engine’s compression ratio has an important effect on combustion. A higher compression ratio results in a higher temperature for the compressed charge, and thus in a shorter ignition delay and higher flame temperature. The effect of shorter ignition delay is to reduce NOx emissions, while the higher flame temperature would be expected to increase them. In practice, these effects nearly cancel out each other, so the changes in compression ratio have little effect on NOx emissions.

Emissions of gaseous HC and of the SOF fraction of the PM are reduced at higher compression ratios. Engine fuel economy, cold starting, and maximum cylinder pressures are also affected by the compression ratio. To ensure adequate starting ability under cold conditions, most diesel engines require a compression ratio in the range of 15 to 20 or more.

A.3.5 Charge Temperature

Reducing the temperature of the air charge going into the cylinder has benefits for both PM and NOx emissions. Reducing the charge temperature directly reduces the flame temperature during combustion, and thus helps to reduce NOx emissions. In addition, the colder air is denser, so that (at the same pressure) a greater mass of air can be contained in the same fixed cylinder volume. This increases the air-fuel ratio in the cylinder and thus helps to reduce soot emissions. By increasing the air available while decreasing piston temperatures, charge-air cooling can also make possible a significant increase in power output. Although, excessively cold charge air can reduce the burnout of hydrocarbons, and thus increase light-load HC emissions. This can be counteracted by advancing injection timing, or by reducing charge air cooling at light loads.

A.3.6 Charge Composition

NOx emissions are heavily dependent on flame temperature. By altering the composition of the air charge to increase its specific heat and the concentration of inert gases, it is possible to decrease the flame temperature significantly. The most common way of accomplishing this through exhaust gas recirculation (EGR). At moderate loads, EGR has been shown to be capable of reducing NOx emissions by a factor of two or more, with little effect on particulate emissions. Although soot emissions are increased by the reduced oxygen concentration, particulate SOF and gaseous HC emissions are reduced, due to the higher in-cylinder temperature caused by the hot exhaust gas. EGR cannot be used at high loads, however, since the displacement of air by exhaust gas would result in an air-fuel ratio below the smoke limit, thus creating very high soot and PM emissions.

A.4 Emissions Tradeoffs

It is apparent from the foregoing discussion that there is an inherent conflict between some of the most powerful NOx control techniques in diesel engines and particulate emissions. This is the basis for the much discussed “tradeoff” relationship between NOx and particulate emissions in diesel engines. This “tradeoff” is not absolute, since various NOx control techniques have varying effects on soot and HC emissions, and the importance of these effects varies as a function of engine speed and load. However, these tradeoffs do place limits on the extent to which any one of these pollutants can be reduced. To minimize the emissions of both of these pollutants simultaneously requires careful optimization of the fuel injection, air-fuel mixing, and combustion processes over the full range of engine operating conditions.

It is generally believed that alternative fuels like biodiesel have the potential to reduce particulate emissions in diesel engines. This is partly because biodiesel contains no sulfur, thus it does not produce sulfate fraction in PM emissions.

Biodiesel also does not contain aromatic hydrocarbons including PNA, therefore the SOF fraction of particulate matter and gaseous HC emissions are much less toxic in nature.

APPENDIX B - BIODIESEL SENATE AND HOUSE BILLS IN THE U.S.

HOUSE BILL 8025

105th CONGRESS

1st Session

H. R. 2568

To amend the Energy Policy Act of 1992 to take into account newly developed renewable energy-based fuels and to equalize alternative fuel vehicle acquisition incentives to increase the flexibility of controlled fleet owners and operators, and for other purposes.

IN THE HOUSE OF REPRESENTATIVES

September 26, 1997

Mr. SHIMKUS (for himself, Ms. MCCARTHY of Missouri, Mr. GUTKNECHT, Mr. EVANS, Mr. HASTERT, Mr. KLUG, Mrs. EMERSON, Mr. HULSHOF, Mr. WELLER, Ms. DANNER, Mr. SKELTON, Mr. GILCHREST, Mr. BEREUTER, Mr. LATHAM, Mr. NUSSLE, Mr. THOMPSON, Mr. EWING, Mr. LEACH, Mr. GANSKE, Mr. BOSWELL, Mr. COSTELLO, Mr. THUNE, Mr.LAHOOD, and Mr. TRICKLAND) introduced the following bill; which was referred to the Committee on Commerce.

A BILL To amend the Energy Policy Act of 1992 to take into account newly developed renewable energy-based fuels and to equalize alternative fuel vehicle acquisition incentives to increase the flexibility of controlled fleet owners and operators, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, ENERGY POLICY ACT (House of representatives - September 26, 1997)

[Page: H8025]

The SPEAKER pro tempore. Under a previous order of the House, the gentleman from Illinois [Mr. Shimkus] is recognized for 5 minutes.

Mr. SHIMKUS. Mr. Speaker, in 1992, Congress passed the Energy Policy Act which set Federal requirements on the use of alternative fuel vehicles such as ethanol-powered cars. This legislation required Federal, State, and city fleets to use vehicles that are cleaner and better for our environment. This act listed fuels and vehicle types that can be used by fleet managers to comply with this act.

Unfortunately, biodiesel was not one of the listed alternative fuels at the time because the industry was new, untested, unproven. However, today, that is not the case. As a result, I am introducing a bill, along with the gentlewoman from Missouri [Ms. McCarthy], to classify biodiesel as an alternative fuel under the Energy Policy Act of 1992.

Biodiesel is a renewable alternative fuel for diesel engines derived from soybeans. Once biodiesel is classified as an alternative fuel under this bill, it will be used immediately in conventional diesel engines with no engine modifications needed. A few examples of the type of vehicles using this B-20 mix are heavy-duty fleet vehicles such as city buses, boats, and trucks.

The diesel engines will use biodiesel in blends of 20 percent biodiesel and 80 percent petroleum diesel, which is the most efficient, energy-efficient, and environmentally beneficial mix.

[TIME: 1230]

The use of biodiesel will help to save on capital expenditures as fleets will be able to modify and improve their existing vehicles, as opposed to purchasing completely new fleets.

The production, sale, and use of biodiesel will create a new market for our farmers, and, in turn, boost our economy. Because it runs cleaner than regular diesel fuel, the use of biodiesel also means that fewer emissions, as an example, particulate matter, hydrocarbons, and carbon monoxide, are released to our environment.

By granting alternative fuel status to biodiesel this bill will promote economic development and energy security. Biodiesel means jobs and tax revenues for processing a greater portion of our domestic soybean oil in the United States.

The emerging biodiesel market offers a stable, long-term market for efficiently produced domestic soybeans that will directly benefit American farmers. The use of domestic biodiesel also improves national energy security by displacing imported energy, such as foreign oil.

It is important to note that this legislation does not create a tax break or a new Federal mandate. This bill will simply allow the biodiesel industry to compete in the alternative fuel market, giving fleet vehicle managers more flexibility in complying with the mandates required at the Federal level.

The production, sale, and use of biodiesel is good for the environment, good for family farmers, good for the economy, and good for our energy security. As a Congressman from one of the largest agricultural producer States in the United States, creating new markets for our family farmers, helping the economy, and keeping our air clean is very important to me.

In a time that we are looking for answers to environmental concerns, new markets for family farmers and a boost for the economy and energy security, biodiesel makes sense for everyone.

H.R.2568

Energy Policy Act Amendments of 1997 (Introduced in the House)

SENATE BILL FOR BIODIESEL

SPONSOR: Senator Johnson, (introduced 09/02/97)

OFFICIAL TITLE AS INTRODUCED:
A bill to amend the Energy Policy Act of 1992 to take into account newly developed renewable energy-based fuels and to equalize alternative fuel vehicle acquisition incentives to increase the flexibility of controlled fleet owners and operators, and for other purposes.

STATUS: In committee

STATUS: Detailed Legislative History

Senate Action(s)

September 2, 1997:

Read twice and referred to the Committee on Energy and Natural Resources.

THE BIODIESEL ENERGY DEVELOPMENT ACT OF 1997

Mr. CRAIG. Mr. President, today I am pleased to introduce, along with Senators Johnson, Wellstone, and Grassley, the Biodiesel Energy Development Act of 1997. This legislation is an important step in helping achieve a very important goal of this Nation--that of shifting the focus of national energy demand away from imported oil toward renewable or domestically produced energy sources, as stated in the Energy Policy Act of 1992, also known as EPACT.

To reach its goal, which is to replace 10 percent of petroleum by the year 2000 and 30 percent by the year 2010 with alternative fuels, EPACT requires Federal and State government fleets, and a limited number of private fleets, to purchase alternative-fueled vehicles [AFV's].

Dedicated AFV's are vehicles that can only run on alternative fuels. Natural gas vehicles and electric vehicles are two of the most common AFV's. Flexible fueled vehicles [FFV's] are those vehicles which can run on alternative fuels, such as methanol and ethanol, petroleum fuels, or a combination of the two.

Current EPACT mandates, incentives, and grants exclude biodiesel fuel blends from being designated as an alternative fuel or from it being an option for controlled fleet owners and operators. EPACT offers little incentive for the use of heavier duty FFV's where biodiesel would be most appropriate, as fleets may obtain credit for heavier duty FFV's only after they have fulfilled their light duty AFV purchase requirements. In addition, EPACT does not allow the conversion and warranty of existing vehicles to FFV standards when they are overhauled or rebuilt. Mr. President, the exclusion of biodiesel as an alternative fuel only impedes the ability of the fleets to meet EPACT mandates.

Let me spell out some of the benefits that biodiesel provides. Biodiesel is a cleaner burning fuel that is made from natural, renewable sources such as vegetable oils, and is domestically produced. From these facts, alone it is evident that the use of biodiesel can reduce the United States' dependence upon imported oil.

Biodiesel also helps achieve a stated goal of this administration, which is to protect the environment by reducing emissions that may damage the ozone layer and contribute to the greenhouse effect. Biodiesel does just that.

When used in a 20-percent blend with petroleum diesel, biodiesel results in a significant reduction in visible smoke and odor and reduces particulate matter by as much as 14 percent. When used in combination with an oxidation catalyst, biodiesel reduces particulate matter by 45 percent, carbon monoxide emissions by 41 percent, and total hydrocarbons by 65 percent.

Mr. President, biodiesel does all of this without forcing expensive engine modifications, reducing the payload capacity of vehicles, or reducing the range of vehicles. Biodiesel performs similarly to petroleum diesel in terms of torque, horsepower, and miles per gallon.

In short, biodiesel performs just as well as petroleum diesel, and yet provides users with all of the benefits of alternative fuels. In addition, once the biodiesel market takes off, it is estimated that it could add more than $11 billion to the States that grow oilseed crops. Biodiesel is also biodegradable and nontoxic, resulting in little to no environmental threat.

The Biodiesel Energy Development Act would solve many of the problems in EPACT, and help fleets reach EPACT's goals. This legislation would designate a biodiesel-petroleum diesel blend as an alternative fuel; equalize incentives between AFV's and alternative fuels; equalize incentives between different types of AFV's; increase the flexibility of EPACT fleet owners and operators in meeting existing mandated AFV purchase requirements; and provide an incentive-based solution regarding flexible-fuel use in AFV's.

Mr. President, it is time we enabled the fleets that are mandated by EPACT to purchase AFV's with the option of using biodiesel fuel. I urge my colleagues to support this important legislation.

APPENDIX C

BIODIESEL RESEARCH PROJECTS IN USA (1994-95)

Project Management, Market Development, and Public Outreach for Biodiesel

Directing Organization: U.S. Department of Energy (DOE), 1000 Independence Avenue, SW, Washington, DC 20585
Project Manager: J.J. Sheehan, (303) 275-4420

Contractor: National Renewable Energy Laboratory (NREL), 1617 Cole Boulevard, Golden, CO 80401-3393

Principal Investigator: J.J. Sheehan, (303) 275-4420
Contract Number: DE-AC02-83CH10093
Contract Period: 10/94–9/95

Contract Funding (Source):
FY 1995: $70,900 (DOE)

Objective: Establish strategic and operational plans for biodiesel, coordinate and support market development activities in the biodiesel industry and DOE, and increase public awareness of and support for biodiesel technology.

Approach/Background: Biodiesel is a renewable diesel fuel substitute produced by chemically reacting an alcohol with a natural oil. The approach to DOE's biodiesel project has changed dramatically during the past 2 years. DOE's focus was on long-term research for biodiesel produced via microalgal conversion of waste CO2 from fossil- fueled power plants to natural oils. This research is necessary in the long run to provide a resource base of natural oils sufficient to meet the needs of the transportation sector. The current project has both a short-term and a long- term focus. The near-term focus is on opportunities for biodiesel made from vegetable oil and animal fats.

Status/Accomplishments: We have made great strides in developing a coordinated strategy for establishing a U.S. biodiesel industry. For the first time, we have a strategic plan that identifies several critical paths for biodiesel, and thus focuses our limited resources on activities most critical to achieving our goals.

Public support for biodiesel is increasing exponentially. Two years ago, biodiesel was virtually unheard of in the United States. Today, it is being tested in environmentally sensitive areas, and in niche markets such as mining, buses, government fleets, and marine use. Much of the increased interest is due to the efforts of the National Biodiesel Board (NBB). NREL has developed a working relationship with the NBB that allows each to leverage the other's limited R&D, market development, and outreach funds.

Major Project Reports: See bibliography. Summary Date: September 1995

Existing Technology Options for Production of Biodiesel from Low-Cost Feedstocks

Directing Organization: U.S. Department of Energy (DOE), through the National Renewable Energy Laboratory (NREL), 1617 Cole Boulevard, Golden, CO 80401-3393
Project Manager: J.J. Sheehan, (303) 275-4420

Contractor: MARC-IV, 6807 W. 202nd Terrace, Bucyrus, KS 66013

Principal Investigator: S. Howell, (913) 681-0400
Contract Number: ACF-5-14418-01
Contract Period: 1/95–12/95

Contract Funding (Source):
FY 1994: $25,000 (DOE)

Objective: Determine technology options for producing and evaluating biodiesel from low-cost feedstocks at the pilot scale.

Approach/Background: The cost of biodiesel produced from virgin soybean oil in the United States is $2.50 to $3.50 per gallon. This high cost remains the greatest obstacle to market penetration for biodiesel in blends or as a neat fuel. Three-quarters of the production cost is associated with the feedstock itself. Our work focuses on determining the feasibility of using lower-cost feedstocks, such as recycled cooking oils and waste from animal processing operations. We have joined forces with the Fats and Proteins Research Foundation and the National Biodiesel Board to conduct a techno-economic analysis of conventional (off-the-shelf) technologies available today for processing these low-cost feedstocks, which have special processing issues. The greatest issue is the increased level of free fatty acids found in recycled materials. Once we identify technologies that can handle higher levels of free fatty acids, we will establish a plan to produce pilot-scale quantities of biodiesel made from these feedstocks. We will also test to establish the fuel's physical and chemical characteristics and their impact on engine and fuel performance.

Status/Accomplishments: Preliminary results indicate a variety of technology options that can handle 10%–15% levels of free fatty acids in the feedstock. We would like to be able to handle higher levels of free fatty acid, but these technologies offer the opportunity to process waste restaurant grease and other materials. We have determined that pilot-scale operations, which negating the need for constructing our pilot plant, are available for producing biodiesel from these feedstocks. A final report from MARC-IV, which will be the basis for negotiating a subcontract for the next phase of research, is anticipated in early FY 1996. This will include producing and testing fuel.

Major Reports: None.

Summary Date: September 1995

New Process Options for Biodiesel Conversion and Glycerol Utilization

Directing Organization: U.S. Department of Energy (DOE), 1000 Independence Avenue, SW, Washington, DC 20585

Project Manager: J.J. Sheehan, (303) 275-4420

Contractor: National Renewable Energy Laboratory (NREL), 1617 Cole Boulevard, Golden, CO 80401-3393

Principal Investigator: J.J. Sheehan, (303) 275-4420
Contract Number: DE-AC02-83CH10093
Contract Period: 10/94–9/95

Contract Funding (Source):
FY 1995: $57,900 (DOE)

Objective: Assess alternative process technologies for converting natural oils to biodiesel and using the glycerol by- product.

Approach/Background: Biodiesel is a renewable diesel fuel substitute produced by chemically reacting an alcohol with a natural oil. When the natural oils are in the form of triglycerides, this reaction is known as transesterification, and is carried out today using basic catalysts such as NaOH or methoxide. Most transesterification processes do not work well with feedstocks that contain high levels of free fatty acids. The intent of this work is to identify processes that are more efficient than current conventional catalyst processes, and less sensitive to free fatty acid content. A more flexible process allows the use of a range of lower-cost feedstocks. The other major economic factor in converting natural oils to biodiesel is using glycerol. Even for niche applications, the volume of biodiesel production required to meet these small markets will result in a level of glycerol production that far exceeds current market demands. New, high-volume markets for glycerol are needed if it is to retain any value as a credit in the process.

Status/Accomplishments: We have focused on developing enzymatic catalysts to improve the flexibility of the transesterification process. To this end, we are putting in place a three-way CRADA with the USDA's Agricultural Research Service and the Fats and Proteins Research Foundation (FPRF) to collaborate on the initial evaluation of lipase enzymes as catalysts for transesterification. Researchers at USDA's Eastern Regional Research Center are conducting bench-scale experiments on biodiesel production using a variety of commercial lipase preparations. They have demonstrated that lipases exhibit much greater flexibility in handling a range of feedstocks that contain as much as 50% free fatty acids. FPRF, a nonprofit, private research organization, is supplying expertise on and samples from waste restaurant grease collection operations. NREL will use this information to establish the economic viability of enzymatic esterification with current commercial lipases.

We have also established a partnership with ARCO Chemical to evaluate the production of di-tert-butyl glycerol (DTBG) as a complementary fuel additive product derived from the glycerol by-product. ARCO has tested DTBG as an oxygenate for diesel fuel. We will analyze DTBG production, coupled with biodiesel production.

Major Project Reports: None.

Summary Date: September 1995

Life-Cycle Assessment of Biodiesel

Directing Organization: U.S. Department of Energy (DOE), through the National Renewable Energy Laboratory (NREL), 1617 Cole Boulevard, Golden, CO 80401-3393

Project Manager: J.J. Sheehan, (303) 275-4420

Contractor: Ecobalance, Inc., 1 Church Street, Rockville, MD 20850

Principal Investigator: J. Besnainou, (301) 309-0800
Contract Number: ACG-5-15297-01
Contract Period: 8/95–5/96

Contract Funding (Source):
FY 1995: $50,000 (DOE)
FY 1995: $50,000 (USDA)

Objective: Produce an analytical tool for evaluating the energy, environmental, and economic benefits of producing biodiesel in the United States from lipid sources.

Approach/Background: Life-cycle analysis (LCA) (first used by the Coca Cola Company 20 years ago) is now gaining world-wide prominence as a valuable tool for understanding the impacts of new products and processes on the environment and on corporate bottom lines. Such an analysis forces an assessment of the impacts of a given product from the extraction of any and all raw materials from the earth to the processing, distribution, and use of the product.

The definition of renewable fuels should be based on an LCA. The approach for this study is based on an exciting new set of software tools for LCA developed by Ecobalance. Thus, rather than simply producing a report on the life-cycle benefits of biodiesel, we will produce licensable software tools that companies and government entities can use to evaluate specific scenarios or product and process improvements for biodiesel.

Because of the near-term opportunities for biodiesel, this analysis will first focus on producing biodiesel from sources of natural oils. In the future, it will be expanded to include biodiesel via microalgal conversion of waste CO2 to natural oils.

Status/Accomplishments: To be worthwhile, an LCA must have broad-based input from all stakeholders. Thus, we built a consortium of biodiesel stakeholders to provide input on all assumptions, approaches, and system boundaries for the analysis. We have established a Biodiesel Working Group, an unprecedented collection of private and government interests that includes USDA, DOE, EPA, the City of Chicago, the National Biodiesel Board, Exxon, ARCO Chemical, Cargill, Twin Rivers Technologies, the Energy and Environmental Studies Institute, and the American Petroleum Institute. A scoping document has been drafted. We encourage anyone interested in providing input to contact the project manager.

Major Project Reports: None.

Summary Date: September 1995

CO2 Mitigation in Fossil Fueled Power Plants Using Microalgae with Coproduction of Biodiesel

Directing Organization: U.S. Department of Energy (DOE), 1000 Independence Avenue, SW, Washington, DC 20585

Project Leader: J.J. Sheehan, (303) 275-4420

Contractor: National Renewable Energy Laboratory, 1617 Cole Boulevard, Golden, CO 80401-3393

Principal Investigators: K.L. Kadam and K. Zeiler, (303) 384-6866
Contract Number: DE-AC02-83CH10093
Contract Period: 10/94–9/95

Contract Funding (Source):
FY 1995: $67,000 (DOE)

Objective: Establish a technoeconomic model of microalgae technology for CO2 mitigation with coproduction of biodiesel.

Approach/Background: Microalgae are unique photosynthetic organisms in that they accumulate high levels of natural oils, thrive in high-salinity water, and use CO2 (an important green- house gas) as their sole carbon source. Microalgae grown in ponds can be used to trap CO2 from power- plant flue gas while producing a feedstock for biodiesel. Status/Accomplishments: A spreadsheet-based economic model was developed for microalgae production using CO2 from flue gases. This model predicts costs within 2% of those predicted by an earlier FORTRAN model, but is much easier to use. It has been used to assess targets for lipid content and growth rate of genetically engineered algae.

Because CO2 collection is the single largest cost factor, we developed a model that predicts costs for recovering and delivering CO2 from flue gas, in lieu of using market costs for CO2. The process steps include monothanolamine (MEA) extraction, compression, dehydration, and transportation to the ponds. This approach yields a delivered CO2 cost of $41/mt, versus a market price of $66/mt of CO2. The model has also shown that MEA extraction is 40% less expensive than the simpler route of direct flue gas utilization.

We have used our models to establish mid- and long-term targets for this technology. An improved process in the mid-term will result in a net cost $20/mt of CO2 mitigated. This is very competitive with other mitigation technologies. In the long term, we hope to identify process goals that reduce mitigation costs to zero, by reducing process costs and increasing biodiesel yields as a by-product credit.

Major Project Reports: See bibliography.

Summary Date: September 1995

Genetic Transformation of Microalgae for Enhanced Production of Natural Oils as a Feedstock for Biodiesel

Directing Organization: U.S. Department of Energy (DOE), 1000 Independence Avenue, SW, Washington, DC 20585

Project Manager: J.J. Sheehan, (303) 275-4420

Contractor: National Renewable Energy Laboratory (NREL), 1617 Cole Boulevard, Golden, CO 80401-3393

Principal Investigators: T. Dunahay and P. Roessler, (303) 384-6280/384-6253
Contract Number: DE-AC02-83CH10093
Contract Period: 10/94–9/95

Contract Funding (Source):
FY 1995: $167,000 (DOE)

Objective: Develop genetic transformation systems for microalgae as tools for creating genetically engineered microalgae capable of enhanced natural oil production.

Approach/Background: When grown in mass culture, microalgae can accumulate storage oil. They may therefore be an excellent feedstock for producing biodiesel fuel. The economics of producing biodiesel from microalgae would be significantly improved if microalgal strains with improved oil production characteristics could be developed. Genetic engineering can introduce these desirable characteristics into microalgae, but genetic transformation systems are not available for most microalgal species.

Status/Accomplishments: We have developed a genetic transformation system for diatoms, an abundant group of microalgae with excellent potential for biodiesel production. This system is based on expressing a bacterial antibiotic resistance marker gene under the control of regulatory regions from an algal gene. Genetically transformed cells can be identified by their ability to grow in the presence of certain antibiotics. We have used this system to introduce additional native and foreign genes into the diatoms Cyclotella and Navicula. This represents a major advance in the field of algal biotechnology.

Major Project Reports: See bibliography.

Summary Date: September 1995

Isolation of a Polyubiquitin Gene Promoter for Expression of Foreign Genes in Microalgae

Directing Organization: U.S. Department of Energy (DOE), through the National Renewable Energy Laboratory (NREL), 1617 Cole Boulevard, Golden, CO 80401-3393

Project Manager: J.J. Sheehan, (303) 275-4420

Contractor: George Mason University, 4400 University Drive, Fairfax, VA 22030-4444

Principal Investigator: A. Christensen, (703) 993-1025
Contract Number: XCH-4-14406-01
Contract Period: 10/94–9/96

Contract Funding (Source):
FY 1995: $44,698 (DOE)

Objective: Isolate an algal ubiquitin gene and assess the ability of its regulatory regions to mediate foreign gene expression in microalgae.

Approach/Background: A major focus of the biodiesel project at NREL is to investigate the use of microalgal lipids for producing biodiesel fuel. One goal is to optimize lipid production in microalgae by manipulating the flow of carbon into lipids via genetic engineering. The availability of promoters and other regulatory regions from a variety of algal genes will enhance our ability to accomplish this goal. Ubiquitin, a highly conserved protein, is expressed at high levels in many kinds of cells. The focus of this project is to isolate and characterize the regulatory regions from a microalgal ubiquitin gene and assess the ability of these gene sequences to mediate the expression of foreign genes in oil-producing microalgae.

Status/Accomplishments: We screened a gene library from the diatom Cyclotella cryptica for the presence of ubiquitin gene sequences using a maize ubiquitin gene as a probe. We isolated and characterized a clone via restriction mapping and nucleotide sequencing. Preliminary results from the sequence analysis confirm the presence of an algal ubiquitin gene. We will analyze this clone to characterize the promoter and terminator regulatory regions for use in microalgal gene expression systems.

Major Project Reports: None.

Summary Date: September 1995

Biochemistry and Metabolic Engineering of Microalgae for Enhanced Biodiesel Production

Directing Organization: U.S. Department of Energy (DOE), 1000 Independence Avenue, SW, Washington, DC 20585

Project Manager: J.J. Sheehan, (303) 275-4420

Contractor: National Renewable Energy Laboratory (NREL), 1617 Cole Boulevard, Golden, CO 80401-3393

Principal Investigators: P. Roessler and E. Jarvis, (303) 384-6253/384-6147
Contract Number: DE-AC02-83CH10093
Contract Period: 10/94–9/95

Contract Funding (Source):
FY 1995: $358,000 (DOE)

Objective: Elucidate the biochemistry of microalgal lipid synthesis and develop metabolic engineering strategies for optimizing their production.

Approach/Background: Creating genetically engineered microalgae with enhanced capabilities for producing biodiesel requires knowledge of the biochemical pathways that affect lipid accumulation. We hope to manipulate these pathways to alter the quantity and quality of lipids synthesized.

Status/Accomplishments: We are investigating two approaches to enhance lipid production rates in microalgae:

1. Introduce additional copies of the gene that encodes acetyl-CoA carboxylase (ACCase), an enzyme that plays a key role in lipid synthesis (preliminary results show that microalgal cells genetically engineered in this manner have enhanced ACCase activity)
2. Reduce the rates of synthesis of other compounds, such as storage carbohydrates, to provide more substrate for lipid synthesis.

We have cloned an important gene involved in microalgal carbohydrate metabolism, which may be a target for inactivation.

Major Project Reports: See bibliography.

Summary Date: September 1995

LIST OF ON-GOING PROJECTS ON BIODIESEL IN THE US

Multi-Feedstock Biodiesel Project (in earlier phases titled Cost-Effective Options for Testing of Biodiesel from Low-Cost Feedstocks)

Research funded by: U.S. Department of Energy (DOE), Office of Fuels Development through National Renewable Energy Laboratory, Fats and Proteins Research Foundation, Illinois Soybean Association, and the National Biodiesel Board

Project Manager: S. Tyson, (303) 275-4616

Performing Organizations: Institute of Gas Technology, P.O. Box 91127, Chicago, IL 60693, Chemol Co. Inc., Colorado Institute for Fuels & High Altitude Engine Research, Systems Lab Services Americoach Systems Inc. (tentative), Columbus Foods, NOPEC (tentative), City of Chicago

Principal Investigators: C. Blazek, (847) 768-0552, F. Wellons, (910) 333-3054, M. Zarkaria, (910) 333-3071, M. Graboski, (303) 299-3143, R. Lawrence, (913) 621-3603, C. Ferrone, (312) 251-3100, M. Gagliardo, (773) 265-6500, M. Rehberg, (941) 683-7199 ext. 113, M. Sigmon (312) 744-3635
Contract Number: ACG-7-15177-002
Contract Period: 4/97–4/98

Contract Funding:
FY 1996: $40,000
FY 1997: $139,000

Objectives: This project explores the issues associated with producing biodiesel from low-cost feedstocks, including animal rendering wastes and recycled cooking oils. Central research issues include modifications to production technology, cost tradeoffs, characterization and performance of the biodiesel fuel and blends with petrodiesel, and demonstration trials. In the early phases of this project, a research facility was envisioned, where various technological options could be explored. As the project evolved, a private entrepreneur volunteered to construct the facility to produce these experimental biodiesel fuels. The project is currently in Phase III.

Approach / Background: Project work has occurred in three phases as follows:

Phase I. Determined the goals and objectives of a pilot plant and develop the activities list, time line, and costs for Phase II.
Phase II. Identified all major activities required to determine the commercial feasibility of producing and selling biodiesel made from low-cost feedstocks, e.g., equipment/technology for the plant, equipment sizing and scale-up considerations, facility needs (utilities, storage), analytical needs, timetables, personnel needs, total project cost.

Phase III. This phase is now focused on production deployment issues for biodiesel produced from recycled (waste) fats and oils. This phase involves producing, testing, and characterizing emissions from biodiesel production from eight feedstocks. The main objective is to determine ways to reduce the cost of biodiesel by using new, lower-cost feedstocks lowering processing costs. Specific tasks are:

Laboratory tests will be conducted to establish the properties and characteristics of neat biodiesel from winter and summer yellow grease, beef tallow (edible and non-edible), pork lard, acidulated soapstock, soybean oil, and rapeseed oil. The project will establish data on fuel characteristics that can be used to support feedstock-neutral specifications for biodiesel.

The neat biodiesel will be blended with petrodiesel in 20:80 proportions for EPA emission testing using a DDC series 60 bus engine. The data gained will be used to develop a report for EPA. Columbus Foods of Chicago is constructing a production facility and will produce the fuels used in the demonstration portion of the project. Fuel field demonstrations will be done in cooperation with American Sightseeing—Chicago, a major transport operator with previous experience in biodiesel field trials. The company will provide six buses for biodiesel testing and two control buses. Each bus is expected to accrue 30,000 miles annually. The project hopes to stimulate production and further research activity for the industry.

Status/Accomplishments: The first phase of the project began in 1994. The second phase was completed in April 1997. The third phase was initiated in March 1997, and is off to a slow start. Columbus Food started plant shakedown in August 1997 and anticipates full production status for soy methyl esters by late 1997. Producing the waste grease and tallow/lard methyl esters may require further facility or process modifications. Chemol is preparing feedstocks for the engine testing component of the project, which should commence by late 1997. NOPEC has offered to supply the demonstration fuels until Columbus Food begins production. IGT is still negotiating with the initial demonstration fleet. Several other fleets are under consideration in case negotiations are unsuccessful.

Phase II produced a comprehensive report detailing the best method to meet the goals of the project. Selected biodiesel facilities in Europe are described in detail, and several economic feasibility scenarios are presented.

Publications and Presentations:

1. Multi-Feedstock Biodiesel Project Phase II - Final Report
2. Phase III reports (forthcoming)

Close-Out of Microalgae Component of Biodiesel Program

Research funded by: U.S. Department of Energy, Office of Fuels Development through the National Renewable Energy Laboratory

Project Manager: S. Tyson, (303) 275-4616

Performing Organizations: National Renewable Energy Laboratory, 1617 Cole Boulevard, Golden, CO 80401, University of Hawaii (tentative), 2540 Dole Street, Holmes Hall 246, Honolulu, HI 96822

Principal Investigators: T. Dunahay, (303) 499-3715, J. Benemann, (510) 939-5864, P. Roessler, (303) 275-3733, O. Zaborski, (808) 956-8146
Contract Numbers: ACG-7-17030-01, ACG-7-17031-01, ACO-17026-01
Contract Periods: 3/97–12/97, 7/97–12/97, 4/97–3/98, 12/97–3/98

Contract Funding:
FY 1997 $36,000
FY 1996 $25,000
FY 1996 $31,180

Objectives: Summarize the historical state of knowledge in microalgae research by documenting the selection of microalgae specimens and the genetic research associated with developing improved strains of microalgae.

Approach/Background: In FY 1996, DOE’s Aquatic Species Program was closed out and staff was laid off or reassigned. In FY 1997, the department asked NREL to develop a formal close-out document summarizing 18 years of research. Further, NREL needed to find a permanent depository for the microalgae collection that had been developed during the course of the program. To meet these requests, contracts were set with previous program staff and other industry experts to summarize project’s research and accomplishments.

Status/Accomplishments: The project was initiated in February 1997 and is scheduled to be completed by March 1998 with the transfer of the algae collection. The close-out report should be available by early 1998.

Publications and Presentations:

1. Closeout report is forthcoming.

Oxidative and Thermal Stability Testing Method(s) for Biodiesel

Research funded by: U.S. Department of Energy (DOE), Office of Fuels Development through National Renewable Energy Laboratory, Fats and Proteins Research Foundation, Illinois Soybean Association, and the National Biodiesel Board

Project Manager: S. Tyson, (303) 275-4616

Performing Organization: Southwest Research Institute, 6220 Culebra Road, P.O. Drawer 38510, San Antonio TX 78228-0510.

Principal Investigators: S. Westbrook, (210) 522-3185, L. Stavinoha, (210) 522-2586
Contract Number: ACG-7-17066-01
Contract Period: 9/97–7/98

Contract Funding:
FY 1997: $88,365

Objectives:

1. Provide documentation for selecting stability methods for biodiesel by conducting a literature search on the importance of oxidative and thermal stability of fuel on diesel engine performance
2. Identify and evaluate potential analytical measurement techniques for oxidative and thermal stability
3. Perform limited proof-of-concept bench scale testing of recommended methods
4. Develop a round-robin test matrix protocol that will correlate test results obtained by the selected analytical methods with actual fuel injection equipment and engine performance in the field.

Background: A lack of applicable test methods for oxidative stability needs to be resolved to recommend proper ASTM test methods and standards for biodiesel. At present, European and some U.S. engine manufacturers are using the iodine value as an indicator of oxidative stability. There is an ongoing industry dispute concerning the relative merits of these test methods, leading to the need to review test methods and recommend alternatives if appropriate.

Status/Accomplishments: Work in progress

Publications and Presentations:

1. Oxidative Stability Literature Review Report (forthcoming)
2. Potential Analytical Measurement Techniques for Oxidative and Thermal Stability Report (forthcoming)
3. Recommended Rating System and Analysis Report (forthcoming)
4. Recommendations for Stability Method(s) for Biodiesel,
5. Letter Report (forthcoming) 6.Round-Robin Test Protocol Report (forthcoming)

Marine Biodiesel and Education Project for San Francisco Bay and Northern California

Research funded by: U.S. Department of Energy (DOE), Office of Fuels Development through National Renewable Energy Laboratory, Fats and Proteins Research Foundation, Illinois Soybean Association, and the National Biodiesel Board

Project Manager: S. Tyson, (303) 275-4616

Performing Organization: Cytoculture International Inc., 249 Tewksbury Avenue , Point Richmond, CA 94801-3829

Principal Investigator: R. Von Wedel (510) 233-0102
Subcontract Number: ACG-7-16688-01
Contract Period: 11/96–10/97

Contract Funding:
FY 1996: $60,000

Objectives: This project involves the establishment of a fuel distribution and marketing infrastructure for biodiesel in California's recreational marine market.

Approach/Background:

1. Promote the sales of biodiesel in the California recreational marine market by supporting the activities of a local contractor who shall establish fuel docks and other elements of a marketing infrastructure of biodiesel
2. Purchase as much as 4,000 gallons of biodiesel and analyze biodiesel samples as available from current biodiesel producers
3. Review federal, state, and local restrictive regulations that pertain to storage, handling, and dispensing of all fuels (hydrocarbons) at designated or permitted fuel docks at marinas, yacht clubs, and other locations suitable for recreational boats
4. Educate boaters and fuel dock distributors by developing a handbook, pamphlet, and presentation on biodiesel information
5. Establish a “biodiesel fuel dock” by setting up at least five distributors for retail sales at a new or current retail fuel dock targeted and promoted primarily for recreational boaters
6. Survey as many as100 current biodiesel users in Northern California for feedback on satisfaction, observations, and possible problems associated with the use of biodiesel in their boats.

Status/Accomplishments: Work in progress

Publications and Presentations:

1. Report on Diesel Fuel Dock Environmental and Tax Regulations (forthcoming)
2. Technical Handbook on Marine Biodiesel (forthcoming)
3. Biodiesel Information for Boaters (forthcoming)
4. Report on Use of Marine Biodiesel in Recreational Boats (forthcoming)

Life Cycle Assessment of Petroleum Diesel and Biodiesel

Research funded by: U.S. Department of Energy (DOE), Office of Fuels Development through National Renewable Energy Laboratory, and U.S. Department of Agriculture, Economic Research Service Office of Energy and New Uses (USDA/ERS/OENU)

Project Manager: S. Tyson, (303) 275-4616

Performing Organization: National Renewable Energy Laboratory, 1617 Cole Boulevard, Golden, CO 80401

Principal Investigators: J. Sheehan, (303) 384-6136, J. Duffield, (202) 501-6255, H. Shapouri, (202) 501-6677, V. Camobreco (301) 548-1753, M. Graboski (303) 299-3143
Contract Number: ACG-7-16690-01
Contract Period: 1/97–12/97

Contract Funding:
FY 1995: $30,761
FY 1996: $64,800
FY 1997: $46,663

Objective: Policy makers and energy planners require information that describes the energy and environmental characteristics of producing biodiesel in the United States from soybean oil and diesel fuel from petroleum to make decisions and recommendations.

Approach/Background: Quantify and compare the comprehensive sets of environmental flows (to and from the environment) associated with both biodiesel and petroleum-based diesel, over their entire life cycles. The project has four phases:

Phase 1. Establish an approach to life-cycle assessment (LCA). This phase is complete.
Phase 2. Develop a supporting data set for LCA. This stage is being finalized.
Phase 3. Conduct LCA. This stage is 90% complete.
Phase 4. Finalize results. The project is currently in the 4th phase.

Status/Accomplishments: A Biodiesel Working Group has been established that consists of private and government interests and includes USDA, DOE, EPA, the City of Chicago, the National Biodiesel Board, Exxon, ARCO Chemical, Cargill, Twin Rivers Technologies, the Energy and Environmental Studies Institute, and the American Petroleum Institute.

All data have been collected and preliminary results have been generated. The analysis is undergoing internal peer review among the principal investigators. A draft peer review report will be available by late 1997, and the project will be completed within 3 months after that.

Publications and Presentations:

1. Coulon, R, V. Camobreco, J. Sheehan, J. Duffield (1996). Life cycle assessment of biodiesel versus petroleum biodiesel fuel. SETAC 17 Annual Meeting— Abstract Book. Partnerships for the Environment: Science, Education and Policy. Washington, D.C., November 17–21. Published by Society of Environmental Toxicology and Chemistry, Pensacola, FL.
2. Life Cycle Assessment of Petroleum-Based Diesel Fuel and Biodiesel—Final Study on the Life Cycle Inventory Comparison (forthcoming, August 1997)
3. Life Cycle Assessment of Petroleum-Based Diesel Fuel and Biodiesel—Preliminary Report on the Life Cycle Inventories (forthcoming, June 1997)
4. Life Cycle Assessment of Petroleum-Based Diesel Fuel and Biodiesel—Data Summary Document. July 1996.
5. Life Cycle Assessment of Petroleum-Based Diesel Fuel and Biodiesel—Final Scoping Document. December 1995.

Establishment of a Biodiesel Consortium in Philadelphia

Research funded by: U.S. Department of Energy (DOE), Office of Fuels Development through National Renewable Energy Laboratory

Project Manager: S. Tyson, (303) 275-4616

Performing Organization: Seasoned Energy Development Ltd. P.O. Box 7955
Philadelphia, PA 19101-7955

Principal Investigator: W. Campbell, (215) 422-4587
Contract Number: ACG-7-16661-01
Contract Period: 2/97–11/97
Contract Funding:
FY 1996: $13,850

Objectives: The main purpose of project is to promote the establishment of a biodiesel industry working group in the Philadelphia area.

Approach/Background: To establish a consortium of stakeholders from the Philadelphia area including (but not limited to) local universities, local city and state government entities, diesel refiners and distributors, local animal renderers and restaurant grease collectors, the National Biodiesel Board, and biodiesel producers. The project will coordinate activities of the consortium through a monthly newsletter and quarterly meetings.

Status/Accomplishments: Several newsletters have been produced and two meetings held to date

Publications and Presentations:

1. Monthly newsletter

Development of Premium Diesel Standards

Research funded by: U.S. Department of Energy (DOE), Office of Fuels Development through National Renewable Energy Laboratory and Fats and Protein Research Foundation

Project Manager: S. Tyson, (303) 275-4616

Performing Organization: James Peeples, Esq., 5894 South 6th Street Falls Church, VA 22041

Principal Investigators: J. Peeples, (703) 578-3655
Contract Number: CAG-6-16279-01
Contract Period: 7/96–10/97

Contract Funding:
FY 1996: $30,500

Objectives: This project provides technical support to NREL by representing biodiesel benefits while developing an agenda for premium diesel specifications and biodiesel's potential roles in this market.

Approach/Background:

1. The National Conference on Weights and Measures is developing recommended specifications for premium diesel fuels. So-called premium diesel fuels abound in the marketplace, but there are no regulations or standards for what comprises premium diesel fuel. Engine manufacturers have been pressing for such a specification because of the potential to improve engine emissions and performance offered by an appropriately defined premium diesel fuel. The consultant will attend meetings of this conference to represent issues and concerns related to biodiesel.
2. Develop a "How To" Guide for Biodiesel Supplier Compliance with Federal Regulations: As new biodiesel producers appear in the U.S. fuel market, they face a sometimes bewildering array of regulations governing the production, sale, and use of biodiesel.

Status/Accomplishments: The ASTM/NCWM Joint Premium Diesel Task Force has finished deliberations and has passed on recommendations for premium diesel specifications and testing methods to the main body of the relevant organizations. Lubricity, which is biodiesel's primary benefit in premium diesel blends, was not included in the task force's list of premium diesel's measurable characteristics, but was listed as a possible sixth specification if the industry can develop improved lubricity test methods. Current lubricity test methods are not accurate enough to distinguish between "average" diesel and premium diesel lubricity levels. It is hoped that the ASTM lubricity task force will take up this issue in future meetings, as this is an industry wide issue. NREL will proceed with developing the necessary data to show the lubricity benefits of biodiesel in low-level blends in FY 1998 to help producers penetrate this high-value market. Various letter reports describing progress in the ASTM/NCWM Premium Diesel Task Force meetings were provided during the course of the contract period. A rough draft of the “How To” guide has been submitted.

Publications and Presentations:

1. “How To” Regulatory Compliance Guide (draft).

Technoeconomic Analysis of Enzymatic Esterification of Highly Fatty Acid Feedstocks

Research funded by: U.S. Department of Energy (DOE), Office of Fuels Development through National Renewable Energy Laboratory and U.S. Department of Agriculture, Eastern Regional Research Center

Project Manager: S. Tyson, (303) 275-4616

Performing Organization: National Renewable Energy Laboratory, 1617 Cole Boulevard, Golden, CO 80401

Principal Investigators: J. Sheehan, (303) 384-6136, T. Foglia, (215) 233-6480, G. Pearl, (309) 829-7744
Contract Number: CRADA 58-3K95-M-395
Contract Period: 8/95 - ongoing

Contract Funding:
FY 1996: $42,020
FY 1998: $5,000

Objectives: A three-way Cooperative Research and Development Agreement (CRADA) was developed between NREL, the Agricultural Research Service (ARS), and the Fats and Protein Research Foundation (FPRF) to conduct a preliminary feasibility study of the potential of enzymatic processing of low-cost sources of lipids such as recycled cooking oils and animal fats with various alcohols as a first step in determining the commercial potential of this new technology for use in biodiesel and biolubricant production.

Approach/Background:

1. NREL, ARS, and FPRF will jointly conduct experimental and technoeconomic studies of the potential of biocatalysis for producing biodiesel or biolubricants. The research will compare the effectiveness of various enzymes as catalysts for biodiesel production relative to traditional inorganic catalysts currently in use.
2. Experimental work will involve batch experiments conducted at ARS's research facility

in Philadelphia using commercially available enzymes.

3. Technoeconomic analysis will be conducted by NREL using experimental data from ARS, as well as technical input on the process provided by both ARS and FPRP. Computer models will be developed to estimate the cost of biodiesel produced via the enzymatic route. The models will also be used in sensitivity studies to determine the types of improvements in enzyme performance needed to make this process technology commercially available.

Status/Accomplishments: Researchers at USDA's Eastern Regional Research Center have conducted experiments to evaluate the performance characteristics of biodiesel made from various feedstock sources and combinations using enzymatic conversion processes. The project has also examined the use of additives to improve critical fuel parameters such as cloud point and pour point. FPRF, a nonprofit, private research organization, has supplied expertise on and samples from waste restaurant grease collection operations. NREL has taken the lead in developing a computer spreadsheet model of enzymatic biodiesel production to establish a baseline understanding of the costs involved.

Publications and Presentations:

1. Project Final Report (forthcoming)

Toxicity of Particle and Semi-Volatile Emissions from SME and Biodiesel Blended Fuels

Research funded by: U.S. Department of Energy, Office of Fuels Development through the National Renewable Energy Laboratory, the National Biodiesel Board, and Caterpillar Inc.

Project Manager: S. Tyson, (303) 275-4616

Performing Organizations: Colorado Institute for Fuels and High Altitude Engine Research (CIFER), Colorado School of Mines, University of California - Davis

Principal Investigators: M. Graboski, (303) 299-3143, and N. Kado (916) 752-4830
Contract Number: ACG-7-17106-01 and ACG-7-xxxxx
Contract Periods: 10/97–3/98 and 10/97–9/98

Contract Funding:
FY 1997: $36,000.
FY 1997: $114,000

Objectives: The purpose of this research is to develop a body of data for submission to EPA that describes the chemical and biological characteristics of vapor- and solid-phase particulate emissions to support the registration of biodiesel under 40 CFR 79, Section

211 (f) “Registration of Fuels and Fuel Additives.” Biodiesel fuels made from feedstocks other than soy oil are currently included in EPA's biodiesel registration, but EPA has requested data showing the actual chemical and biological characteristics of engine emissions from esters of non-soy fats and oil. No one knows if these data will be substantially similar or significantly different from SME.

Tasks involve performing cold start emission tests on five candidate biodiesel fuels and one reference fuel and certain unregulated emissions analysis on a 1990 Detroit Diesel Series 60 engine using a fixed-stand dynamometer. The test matrix includes periodic testing of a reference fuel to evaluate any engine drift.

Approach/Background: One group of toxicologically important compounds that may be present in diesel, and potentially in biodiesel exhaust emissions, are polycyclic aromatic hydrocarbons (PAHs) and their substitute derivatives nPAHs. Some PAHs and nPAHs are potent mutagens and carcinogens in laboratory animals and humans. Bioassay tests are also employed to determine the mutagenic potential of the particulate exhaust emissions. This research may be very timely as the current suit against California refineries and trucking associations progresses, which charges that diesel exhaust emissions are a health hazard. Previous research on RME and REE indicates that biodiesel may reduce the toxic nature of petroleum exhaust. NREL took advantage of several ongoing engine tests to collect data for this project.

CIFER portion of the project: This project takes advantage of ongoing research under the Multi-Feedstock Biodiesel Project, by placing a separate subcontract with CIFER to perform additional research. The previous IGT/ CIFER contract specified that CIFER run only hot transient tests on biodiesel blends made from waste grease and animal fats to minimize costs. Additional information on emissions has been requested since the initiation of that subcontract, and this project is designed to add funds to CIFER to perform the additional emissions analysis. Specifically, it requires CIFER to include cold transient tests, C1-C12 and aldehyde speciation, and additional particulate samples collection for bioassay analysis while conducting research to support the Multi-Feedstock Biodiesel Project. All biodiesel tested in this portion of the project are 20% biodiesel/80% test diesel blends.

NBB and Caterpillar portion of the project: NBB is working cooperatively with Caterpillar to collect emissions data from a 3406 D test engine at Caterpillar’s Peoria, Illinois, laboratory. NREL will support the UCD staff time and expenses necessary to collect sufficient quantities of particulate and SOF emissions for testing. NBB and Caterpillar share in the remainder to the engine testing costs. Only neat SME is tested in this part of the test.

University of California - Davis: UCD will conduct chemical analyses on the particulate and vapor emissions from SME from the Caterpillar testing and bioassay tests to determine the mutagenic potential of the particular emissions. USDA will also conduct bioassay analyses on the biodiesel blends used in the Multi-Feedstock Biodiesel Project, which include yellow grease, tallow, lard, soy, and acidulated soapstocks.

Status/Accomplishments: The project has just been initiated and will run through September 1998.

Publications and Presentations:

1. Health-related emissions from various biodiesel blends in a ddc series 60 engine (forthcoming)
2. Bioassay analysis of biodiesel produced from low value feedstocks (forthcoming)
3. Chemical and bioassay analysis of sme pm emissions from a caterpillar 3406/435 HP (forthcoming)

Biodiesel Research Progress: 1992–1997

Research funded by: U.S. Department of Energy, Office of Fuels Development through the National Renewable Energy Laboratory

Project Manager: S. Tyson, (303) 275-4616

Performing Organizations: Information Resources, Inc. 1925 N. Lynn Street, Suite 1000, Arlington, VA 22209 and Dyncorp Information and Engineering Technology, Energy Programs Group, 6101 Stevenson Avenue Alexandria, VA 22304

Principal Investigators: J. Hamilton, (703) 522-0612 and J. Finnell, (703) 461-2029
Contract Numbers: ACG-7-17046-01 and ACG-7-xxxxx-xx
Contract Period: 5/97-10/97

Contract Funding:
FY 1997 $30,000
FY 1997, $15,000

Objectives: To improve coordination and to focus future research NREL commissioned IRI to develop a summary of biodiesel research during the past 5 years. An ancillary intent of this report is to support the development of a strategic plan for DOE biodiesel research.

Approach/Background: Biodiesel research has expanded to many organizations in recent years, and the effort of determining who is doing what, and what remains to be done, is very time consuming for the industry research groups.

Status/Accomplshiments: The project is approximately 95% finished and is undergoing final peer review.

Publications and Presentations:

1. Biodiesel Research Progress: 1992–1997 (forthcoming)

Biodiesel Fuel Certification and Quality Assurance

Research funded by: U.S. Department of Energy, Office of Fuels Development, through the National Renewable Energy Laboratory and the National Biodiesel Board

Project Manager: S. Tyson, (303) 275-4616

Performing Organization: National Renewable Energy Laboratory, 1617 Cole boulevard, Golden CO 80401

Principal Investigators: S. Tyson, (303) 275-4616 and S. Howell, (816) 635-5772

Contract Funding:
FY 1997: $25,000
FY 1998: $25,000

Objectives: For many years, biodiesel research and demonstrations progressed without any concern over fuel quality. The industry held the belief that industrial-grade methyl esters were sufficient for fuel use. Over the years, it became evident that fuel quality was an extremely important issue, and NBB has moved to develop proposed ASTM standards for biodiesel. This project is the second step in institutionalizing fuel quality standards throughout the industry.

Approach/Background: NBB has decided to move forward with testing industry fuel samples against the proposed ASTM biodiesel standards, working with the producers to develop adequate fuel quality assurance programs within each company, and to “certify” producers to regularly meet fuel specifications. NREL has decided to move forward with a report that discusses the importance of fuel quality and fuel specifications from the consumer point of view, including contractual mechanisms for purchasing biodiesel on spec. This report will also include protocols for consumers and other entities in the fuel handling chain necessary for maintaining fuel quality all along the fuel distribution and storage process once biodiesel leaves the producer’s dock.

Status/Accomplishments: Project will begin in FY 1998 and conclude by June 1998.

Publications and Presentations:

1. Biodiesel Fuel Quality Standards and Recommended Operating Protocols for Maintaining Fuel Quality (forthcoming)

DOE’s Biodiesel Strategic Plan

Research funded by: U.S. Department of Energy, Office of Fuels Development, through the National Renewable Energy Laboratory
Project Manager: S. Tyson, (303) 275-4616

Performing Organization: National Renewable Energy Laboratory 1617 Cole Boulevard Golden, CO 80401

Principal Investigator: S. Tyson, (303) 275-4616

Contract Funding:
FY 1997: $25,000
FY 1998: $25,000

Objectives: NREL will organize and hold a series of meetings with biodiesel stakeholders to determine the industry's research and development objectives and needs. A draft strategic plan will be developed from these meetings and shared with the stakeholders for comment. A meeting may be held in conjunction with a biodiesel conference or NBB meeting to work out differences of opinion to the extent possible. A final report will be submitted to DOE and used to prioritize future DOE biofuels research agendas.

Approach/Background: In 1996, DOE closed out the microalgae component of the biodiesel project and drastically altered the direction of the remaining research at NREL. DOE may use this plan to develop research agendas and recommended budget levels for future years.

The NREL biodiesel project is currently directed toward supporting the commercialization of the biodiesel industry. Due to the limited amount of federal and private research funds available, the highest priority research activities must receive support, research must be coordinated whenever appropriate, and long- and short-term objectives must be adequately addressed. To assist that effort, both NBB and NREL have been working with other agencies and the biodiesel industry to improve the organization's understanding of how the biodiesel industry will grow, where the major marketing opportunities are, and what the technical and regulatory barriers to biodiesel development are.

Status/Accomplishments: Several meetings have been held with producers, USDA, NBB, DOE and RBEP managers, and others to flesh out the major issues facing the biodiesel industry today. A draft strategic plan will be prepared by the end of 1997 for distribution and comment. A final strategic plan will be available by June 1998.

Publications and Presentations:

1. DOE's Biodiesel Strategic Plan (forthcoming)