Biodiesel Research - 1996 and Beyond

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Abstract
Several universities, government, and private sector research laboratories have actively investigated the use of biodiesel as a fuel for use in diesel engines during the last decade. The National Biodiesel Board has utilized input from these entities to develop a market plan for the commercialization of Biodiesel as a transportation fuel in the United States. The procedures used to identify research that was needed for each market is identified and as well as the specific research needed.

Keywords: biodiesel, biodiesel blends, diesel, material compatibility

Introduction

A combination of factors has pushed energy from biomass into the forefront of policy and industry discussions. Large harvests of traditional crops, dependence on foreign energy sources and environmental problems have increased interest in renewable energy sources. Biodiesel, a diesel fuel substitute processed from vegetable oils, animal fats, or waste grease, has been processed commercially in Western Europe since 1990. The qualities of this fuel, environmentally as well as technically, have pushed it closer to the final stages of commercialization in the United States.

The National Biodiesel Board (NBB) is a trade association based in Jefferson City, Missouri, dedicated to creating markets for biodiesel. The biodiesel industry, although only four years old, is striving to create sustained, viable markets. Successful commercialization of an alternative fuel involves many stakeholders. Current efforts to commercialize biodiesel by NBB involves using the advice of these stakeholders to identify specific niche markets for biodiesel.

NBB has developed a research agenda to advance the biodiesel industry. Efforts, to date, have centered on core research issues that impact engine performance; issues such as materials compatibility, durability, emissions, and operating performance.

The NBB research agenda, developed to enhance the commercialization of biodiesel as a transportation fuel in the United States, has refocused over the past year as it began to address specific research issues associated with promising niche markets for biodiesel. A systematic process is followed to ensure that significant research issues that have been identified by the industry are investigated in a scientific manner.

Purpose and Objectives

The overall purpose for this paper is to describe a systematic procedure that can be used to identify and fund biodiesel research needed for 1996 and beyond. Specifically this paper will:

Provide an overview of the need for a systematic and sustained approach to conduct biodiesel research.

Describe the systematic and sustained approach for biodiesel research that has been adopted the National Biodiesel Board to facilitate the commercialization of biodiesel in the United States.

Discuss basic research needed by the biodiesel industry prior to the commercialization of biodiesel in the United States.

Discuss the applied research needed by the biodiesel industry prior to the commercialization of biodiesel in the United States.

Overview of Need for a Systematic Biodiesel Research Approach

Several agencies across the United States have funded biodiesel research during the last five years. The culminations of these efforts have been extremely beneficial for the commercialization of biodiesel. Initially, scientific inquiry was conducted to facilitate biodiesel sales in general and some duplication of efforts from these agencies surfaced. Although replication of research is beneficial, it became quite clear that a more focused research approach would facilitate biodiesel sales.

Research Approach

The NBB, acting on behalf of the biodiesel industry, has developed a short term marketing approach that addresses specific research and marketing barriers. This information is documented in the 1996-1998 Biodiesel Marketing Plan. The marketing plan details the steps associated with selling volumes of biodiesel in four niche markets: Urban Transit, Regulated Fleets, Marine, and Underground Mining. In addition, sufficient interest has occurred in both the aviation and premium diesel markets to justify a formal assessment of these niche markets.

Each market has been broken into four distinct steps required for commercialization:

1) Assessment

2) Research Regulatory Initial Awareness

3) Full Scale Promotion

4) Maintenance

The initial assessment of a specific market begins with an independent pre-market evaluation. Simultaneously, a task force in each market, containing representatives from the respective industry, is formed. Qualified and respected industry representatives are invited to participate in market specific industry task forces. Continuous evaluation is conducted as to the composition of the task force and potential new members that can contribute and increase the viability and output of the task force. Task force members are asked to provide input concerning the marketing activities, review them for completeness and provide a sound, independent market perspective.

Relevant biodiesel research and marketing information, including the market evaluation study is prepared for the industry task force. Conference calls or meetings are used to facilitate discussions on biodiesel and its potential market penetration in each respective market. Summaries of these meetings are produced and distributed to each member of the task force, complete with a set of recommendations that is generated from the task force. Each task force member is asked if the summaries accurately depict the conclusions of the group.

BASIC RESEARCH NEEDS

Schumacher (1996) reported physical and chemical properties associated with the mixing of biodiesel with petroleum diesel fuel. Some of these chemical and physical properties were nonlinear in nature, however, the analysis conducted by Schumacher did not reveal data points that were lower than either of the parent blendstocks (biodiesel or low sulfur petroleum diesel fuel).

Changing these chemical and physical properties to meet the needs of the biodiesel user may be needed for some of these attributes. For example, cold flow properties must be improved for biodiesel and biodiesel blends. Several researchers have experimented with petroleum cold flow improvers to no avail. Experimental cold flow improvers designed to work with biodiesel have not solved the problem. The incremental amount of flow improver added needed to improve the cold flow characteristics of the biodiesel and biodiesel blends exceeded the amount recommended by the manufacturer. The monetary value of the cold flow improver that was needed to improve the cold flow characteristics of the biodiesel and biodiesel blends added $0.08 per gallon for the end user (Schumacher & Fisher, 1994).

One future research area that exists is a function of the analytical variation of the commonly accepted test procedure. Some ASTM test procedures commonly accepted by the petroleum industry fail to quantify the variable in question. For example, the aromatics of biodiesel are essentially nil (Schumacher, 1996), yet D1319 produces aromatic levels that exceed the aromatics of petroleum diesel fuel. An inexpensive, reliable procedure to quantify aromatics will be needed as the EPA and CARB have placed a limit on the aromaticness of the fuel for human health reasons.

The biodiesel industry is just on the verge of beginning the research needed to determine the human health effects associated with biodiesel fueling. Researchers believe that these

issues may be a key factor concerning the commercialization of biodiesel (Howell, 1996). Researchers have noted reductions in PAH, aldehyde and ozone precursor emissions. However, benzene, formaldehyde and acrolein exhaust emission have either produced mixed or slightly greater emissions levels. Additional research will be needed to further quantify these preliminary findings and to determine the implications for the biodiesel industry.

Issues such as biodegradability, cytoxicity, carcinogenic, and microbial stability have only recently been investigated by biodiesel researchers. The preliminary findings are quite good, however, as pointed out by Krahl (1996) variation could exist due to the fact that some engines are fueled with different biodiesel feedstocks. Krahl only examined 100% neat biodiesel from rapeseed. No attempt was made to determine if another feedstock (ie soy methyl esters) or if blends of biodiesel and petroleum diesel would exhibit similar benefits. Krahl also observed that the size of the PM when fueling with biodiesel was larger than when fueling with petroleum diesel fuel. Krahl reasoned that the "particle size" effect could impact the cytotoxicity, mutagenaity, and carcenogenaity of biodiesel exhaust. Further research must be conducted to quantify these findings as this will enable biodiesel to penetrate environmentally sensitive niche markets.

Research concerning properties such as the thermal and oxidative stability, and detergency is currently under investigation by the NBB and the Northwest Regional Biomass Program. Although data may be available at the time this paper is presented, the likelihood that additional research may be needed to quantify these parameters is strong. Research reported by the University of Missouri indicated that gum forming tendencies exist when biodiesel is blended with modern transportation fuels. The formation of gums on fuel system components has been noted in injection pumps that have been fueled with 100% neat biodiesel and with a 40/60 biodiesel/diesel fuel blend. The gum deposit did not hamper the operation of the BOSCH and Stanadyne pumps. However, this was not the case for the PT pump when testing an N14 Cummins engine on a 20/80 biodiesel/diesel fuel blend. Upon disassembly of the PT pump, several internal components were coated with a gum-like deposit. The gum-like deposit prevented the PT pump from delivering a full charge of fuel to the engine. Samples of the gum deposits were taken and are undergoing analysis at the University of Missouri.

The issue of NOx formation associated with biodiesel fueling has been investigated by several biodiesel researchers. Although researchers have noted increases in NOx when fueling with biodiesel and biodiesel/diesel fuel blends, some researchers report little if any increase (Peterson, 1996 & Sharp, 1996). According to the literature, oxygenated fuels tend to increase NOx emissions. Researchers at Southwest Research Institute (Ulman, et al., 1994) conducted a number of tests to verify these phenomena. Ulman found that diesel fuel that had been oxygenated produced higher NOx emissions than reference diesel fuel. Ulman recelebrated the series 60 engine to meet 1998 clear air standards. He found that when the four grams per brake horsepower-hour (g/bhp-hr) NOx calibration was used rather than the five g/bhp-hr calibration, the NOx increase associated with the use of an oxygenated fuel was not statistically different from reference diesel NOx emissions. Fuels that have a high cetane number tend to reduce

NOx emissions. Biodiesel is an oxygenated fuel, approximately 10 percent by volume, that exhibits cetane characteristics which exceed that of petroleum diesel fuel.

The effect of the acid number of the biodiesel is not completely understood. Researchers believe that the acid number impacts material compatibility, storage, handling, and the smell of the biodiesel. Indirectly, some preliminary material compatibility work has been conducted at Southwest Research Institute, but for the most part, biodiesel researchers generally have selected elastomers that are compatible based on trial and error. Researchers believe that the acid number may be causing the fuel filter plugging and also that it contributes to the thermal instability of the biodiesel and/or biodiesel blend. Indirectly the higher acid numbers may impact the cetane value of the fuel. The acid number of the biodiesel is positively correlated with peroxide number. Peroxide number of the biodiesel is positively correlated with certain number. Thus, higher acid numbers may boost the cetane number of the biodiesel.

A summary of some of the basic research needed to commercialize biodiesel as a transpiration fuel in the United States is outlined in Table 1. Some of the work needed to more completely understand each of these needs has already begun under the direction of researchers at the United States Department of Agriculture -Department of Energy, the National Renewable Energy Laboratory, the Pacific Northwest Regional Biomass Program, and Universities across the United States.

Table 1. Basic research needs that should be conducted to further the commercialization of biodiesel as a transpiration fuel in the United States.

BASIC RESEARCH NEEDS
Blend Characterizations- Fuel Characteristics, Emissions, Additives
Cold Flow Properties- Neat Fuel, Blends, Additives
Standardization of Analysis Procedures- Fuel Analysis, Emissions HC, PM
Human Health Effects - Cytoxicity, Carcinogenic, Life of Catalytic Converter, Emissions
Microbial and Biodegradability Tendencies- Neat Fuel, Blends, Additives
Storage/Stability- Acid Number, Peroxide Number, Oxidative Stability, Thermal Stability
NOx Formation- IDI engines, DI engines, Duty Cycle, Additives, Engine Timing
Engine Durability- Neat Fuel, Blends, Additives, Engine Technologies
Other- Lubricity, Cetane, Handling, Life Cycle Analysis

APPLIED RESEARCH NEEDS

Underground Mine Market Research Issues

The research topics found in Table 2 were identified by the NBB Underground Mine Market Task Force when establishing the "next steps" needed to achieve significant market penetration for biodiesel in the underground mine market.

Table 2. Research that should be conducted with biodiesel fueled underground mine engines as identified by the NBB Underground Mining Market Task Force.

Top Priority Underground Mine Research	Research of Secondary Importance
Real-world, in-use durability testing	Exhaust After treatment Durability testing
Emissions Certification (NOx waiver)	Human Health Effects

Members of the task force indicated that engine performance data including torque, horsepower, fuel economy, etc. was lacking. Each major OEM representative on the task force emphasized that in-field testing of new technologies was essential. Research conducted in the laboratory will not entirely depict how a technology will perform in the "real world." Pilot programs that involve a small number of engines for extended periods of time were recommended.

Engine and injector life were noted as key issues by the underground mine industry task force. Most engines used in underground mines are Indirect Injected (IDI), however, Direct Injected (DI) engines are gaining a foothold in the marketplace. The Series 60 is the highest volume DDC engine in underground mine applications. The only significant differences between on and off-road Series 60 engine is engine fuel injection timing and the fact that lower pressure injectors are used in the off-road versions. DDC representatives indicated that they were more interested in conducting in-field durability tests, with at least 500 hours of operation.

The industry task force suggested that a durability test (in-field or lab) with a DI turbocharged engine may present the best configuration to evaluate. The higher engine operating temperatures represent a challenging scenario for biodiesel fueling of diesel engines in underground mines.

Therefore, NBB plans to conduct a limited number of pilot usage programs to test biodiesel using duty cycles/loads that represent real-world conditions with at least 500 hours of operation

Marine Market Research Issues

The research topics found in Table 3 were identified by the NBB Marine Market Task Force when establishing the "next steps" needed to achieve significant market penetration for biodiesel in the marine market.

A retail test market program was initiated in the Florida Keys to determine if the assumptions of the Arthur D. Little market summary were valid. Results of the Florida Keys test market suggest that the recreational marine market offers opportunities for biodiesel.

Therefore, NBB plans to secure funding for two pilot usage programs to test biodiesel with two Nationally Recognized Marine Areas.

Table 3. Research that should be conducted with biodiesel fueled marine engines as identified by the NBB Marine Market Task Force.

Top Priority Marine Research	Research of Secondary Importance
Conduct extensive review of marine literature	Engine Performance Data
Storage and Handling	Power
Material Compatibility	Emissions
Real-world, in-use durability testing	Fuel Economy

Aviation Market Research Issues

The United States Air Force tests and operates planes for hundreds of thousands of miles both within the United States and abroad. Safety and monetary concerns have dictated that these planes must be fueled with a new fuel JP-8. JP-8 replaces Jet A which is an extremely flammable fuel presently used for military aviation.

Switching to JP-8 is not an easy task. Military and civilian mechanical engineers have been working nonstop to enable the air force to use JP-8. JP-8, unlike Jet A fuel, has experienced thermal stability problems. Fuel fouling of the ingniters has become the biggest problem for test aircraft. As such, fuel fouling of the ingniters has been identified as the biggest problem confronting the use of the "next generation" aircraft of the United States Air Force.

Since JP-8 is not as flammable as Jet A fuel, ignition and lean blow out have been identified as concerns to address when evaluating JP-8 (initial evaluations suggest that these problems are directly linked to the chemical composition of JP-8).

Representatives from the United States Air Force have inquired to determine if biodiesel can either reduce or eliminated the issues identified. They are impressed that biodiesel is nontoxic and has a very high flash point of 425 degrees F. They also noted that the oxygen content in the fuel should facilitate its combustion in the jet engine.

Due to the inherent properties associated with biodiesel as a fuel for diesel engines, the United States Air Force has indicated their willingness to evaluate biodiesel as a fuel extender/additive for modern air craft. Specifically, thermal stability, fouling and lean

blowout tests are recommended for testing with Wright Labs to evaluate Biodiesel as a fuel additive for modern aircraft.

Table 4. Anticipated research needs that should be conducted to further the commercialization of biodiesel as a military aviation fuel in the United States.

ANTICIPATED AVIATION RESEARCH NEEDS
Thermal Stability
Injector Fouling Tendencies
Lean Blow Out Tendencies
Flashpoint
Microbial and Biodegradability Tendencies
Engine Durability
Lubricity

Government Fleet Research Issues

Both EPACT and the Clean Fuel Fleet Program (part of the Clean Air Act Amendments of 1990) require the purchase of AFV's. Since a diesel engine requires minimal, if any, modifications in order to utilize biodiesel blends, a diesel engine or a vehicle which is warranted by an OEM as a biodiesel flexible fueled vehicle can be used to meet the requirements of these regulations. This project is intended to develop and maintain a relationship with the marketing and planning divisions of OEM's to present the sales opportunities that exist for diesel engines that are capable of being fueled with biodiesel.

The research needed to facilitate the growth of this market has largely been outlined in Table 1.

Each OEM that chooses to take advantage of this opportunity will be faced with a significant challenge. The engine must be certified with the alternative fuel, in this case 100% biodiesel as only 100% biodiesel has been classified as an *alternative fuel* by the Environmental Protection Agency (EPA). Although a significant amount of research has been conducted in Europe using 100% biodiesel, Europeans utilize an emission test cycle that is not accepted by the United States EPA. Of the basic research needs outlined in Table 1, Engine durability and engine exhaust emissions are paramount. The durability of the engine *fuel system* when fueled with 100% biodiesel is equally important. OEM's will require that a range of engine technologies be tested in an effort to more completely understand the effect of biodiesel on the engine they warranty. Testing will be conducted both in the laboratory and under "real-world" operating conditions.

Premier Diesel Fuel Market Research Issues

The blend levels of biodiesel and petroleum diesel fuel that have been recommended by preliminary market research suggest that engine durability and emissions certification will not be necessary to enter the premium diesel fuel market. Additional research will be needed concerning lubricity. HFRR testing conducted with a 1% biodiesel/99% JP-8 blend indicated positive results. Adding 1% biodiesel to the JP-8 elevated the lubricity of the blend to acceptable levels. However, data are unavailable for #1 and #2 low sulfur diesel and blends of #1 and #2 diesel fuel that have been additized with 1% biodiesel.

Much biodiesel research that has been conducted as of late focused on blends of biodiesel and diesel fuel that exceeded a 10% blend. The real effect associated with the use of 1% blend have not been quantified concerning cetane number, effect on the effectiveness of petroleum additives, flashpoint, microbial and biodegradablilty tendencies, and storage and handling. Hard "research-based" data for each of these characteristics may provide the "marketing edge" needed.

Table 5. Anticipated research needs that may be need to further the commercialization of a premier diesel fuel that has been additized by biodiesel.

ANTICIPATED PREMIER DIESEL FUEL MARKET RESEARCH NEEDS
Additives Thermal Stability, Oxidative Stability, Cold Flow Characteristics
Cetane Number
Flashpoint
Lubricity
Microbial and Biodegradability Tendencies
Storage & Handling Effect on Hoses, Tank Residues and Sediment

Summary

The purpose of this paper was to describe biodiesel research needed for 1996 and beyond. The rationale to develop a systematic and sustained biodiesel research agenda was presented. The National Biodiesel Board has set in place a systematic and sustained approach for a biodiesel research plan that is expected to facilitate the commercialization of biodiesel in the United States.

The biodiesel research initially focused on scientific inquiry designed to facilitate biodiesel sales in general. Some duplication of research resulted as the number of biodiesel research funding agencies escalated. Although replication of research is beneficial, it became quite clear that a more focused research approach would facilitate biodiesel sales.

Basic research needs were presented in addition to applied research needed by specific biodiesel niche markets. Basic research needs included: blend characterization; cold flow properties; standardization of analysis procedures; human health effects; microbial and biodegradability tendencies; storage/stability; NOx formation; engine durability and other issues such as lubricity, handling, and life cycle analysis.

Applied research needs were based on specific niche markets. Although market task forces were not in place for all markets, research specific to ***aviation markets*** (thermal stability, injector fouling tendencies, lean blow out tendencies, flashpoint, microbial and biodegradability tendencies, engine durability, and lubricity); ***premier diesel markets*** (additives, cetane number, flashpoint, lubricity, microbial and biodegradability tendencies, and storage & handling); ***marine markets*** (conduct extensive review of marine literature, storage and handling, real-world, in-use durability testing, and material compatibility); ***underground mining markets***, (Real-world, in-use durability testing and emissions certification (NOx waivers)); and ***EPACT or regulatory markets*** were discussed.

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