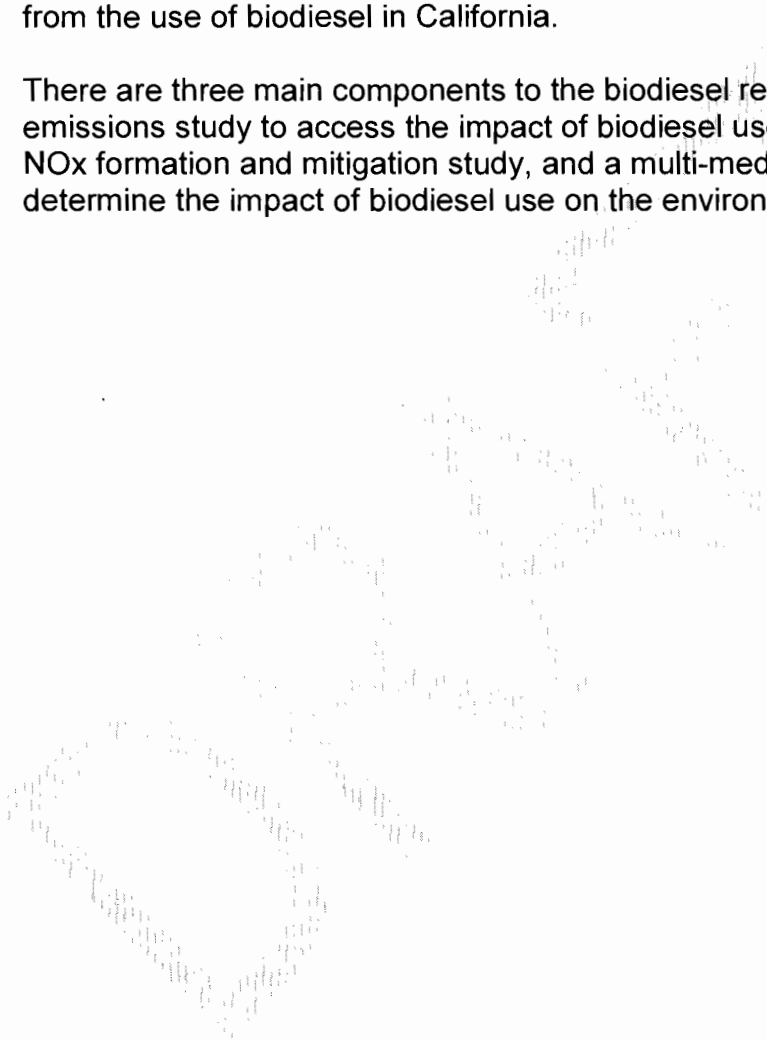
Proposed Biodiesel Research
(March Draft)

The Air Resources Board (ARB) has been tasked to develop a biodiesel program that includes the development of biodiesel fuel specifications and biodiesel strategies to reduce greenhouse gas emissions and to increase the production of biodiesel in California. In order to support these activities, ARB staff is proposing a biodiesel research study to assess the impacts from the use of biodiesel in California.

There are three main components to the biodiesel research, a biodiesel emissions study to access the impact of biodiesel use on air emissions, a NOx formation and mitigation study, and a multi-media evaluation to determine the impact of biodiesel use on the environment and human health.



BIODIESEL EMISSIONS STUDY

A. Objectives

Biodiesel emissions have been studied; however, most of these studies and evaluations are limited in their direct application to the impact of biodiesel use in California (e.g. ARB 15 ppm sulfur fuel (ULSD)).

The purpose of the biodiesel emissions study is to directly address the impact of biodiesel use in California and to fill knowledge gaps in the existing database. The main elements of the study are to compare the emission impacts from the use of biodiesel derived from current and future biodiesel feedstocks common to California to ARB ULSD that includes a wide range of pollutants including criteria, toxics, greenhouse gas emissions, and non-regulated pollutants. Also, the study would evaluate toxic exposure and health effects of biodiesel and evaluate test engines and vehicles that are common to California and test cycles that represent a range of driving conditions that can influence the engine response from biodiesel.

The study will be used to support ARB's regulatory efforts to develop biodiesel fuel specifications. Also, data from this study will support the biodiesel multimedia evaluation and will enhance the emission inventory by providing more representative emissions data of biodiesel use in California. In addition, this study will increase our knowledge and allow the ARB staff to better address key issues such as the potential NOx impact of biodiesel.

B. Evaluate the Emissions Impacts of Biodiesel in California

Most of the national studies have evaluated biodiesel in comparison with federal diesel at 330 ppm sulfur. The US EPA draft technical report suggests that the emission benefits of biodiesel are reduced when compared to cleaner diesel fuels. For example, when compared to a clean diesel fuel, B100 shows a PM reduction of 35 percent to a 45 percent reduction when compared to an average diesel fuel. For NOx, the increase is 30 percent when compared to a clean diesel fuel, however when compared to an average diesel fuel the NOx increase is only 10 percent. Since ARB 15 ppm sulfur and low aromatic diesel fuel (ULSD) is among the cleanest diesel fuels in the world, benefits and disbenefits of biodiesel and biodiesel blends need to be compared to ARB ULSD to obtain a more accurate measure of the impact of biodiesel use in California. Therefore, this study will directly evaluate the impact of biodiesel use in California by comparing the emission differences between ARB ULSD to biodiesel and biodiesel blends common to California.

Soy-based biodiesel is the fuel used in most of the national studies and only limited research is available on biodiesel derived from other feedstocks. Currently, California is not a large producer of soy or other vegetable oils that can be used to produce biodiesel. However, in California, recycled grease is an available biodiesel feedstock that is used to produce biodiesel. Other potential feedstocks include trap grease, palm oil, and algae derived biodiesel. Because of the potential importance of these feedstocks and the limited emissions data on these feedstocks another objective of the biodiesel emissions study is to characterize the emissions from feedstocks other than soy-based biodiesel.

C. Evaluate the Potential for NOx Increases in California from the Use of Biodiesel

Biodiesel has been shown to increase NOx emissions under certain test conditions. However, there is some uncertainty on the degree of the impact over different driving cycles. Part of the uncertainty stems from the different results that are obtained from engine and chassis dynamometer tests, which are two standardized methods for testing mobile sources. Generally, engine dynamometer tests show a clear relationship where an increase in the biodiesel blend level results in an increase in NOx emissions while this relationship is not as pronounced in chassis dynamometer tests. The issue of NOx increase will be addressed by gaining additional insight into the differences between chassis and engine dynamometer tests.

One explanation for the differences between chassis and engine dynamometer testing is that the engines are operated at different load and speed combinations. If biodiesel behaves differently from diesel at different load and speed combinations then the hypothesis is that under chassis test conditions biodiesel emits less NOx than for engine test conditions. Recently, the US EPA has reported that NOx emission differences between biodiesel and diesel fuel have been shown to be load dependent, therefore when biodiesel is tested on test cycles with a lower average load the NOx increase is lower when compared to diesel fuel than those test cycles with a higher average load, however this evaluation was conducted on a single engine. The ARB study will further refine the NOx difference by testing an additional engine. Also, the same engine will be tested on both engine and chassis dynamometers using identical test cycles; a procedure until recently that could not be done. For example, chassis test cycles such as the Urban District Drive Schedule (UDDS) will be simulated on the engine dynamometer. This should allow for a further refinement on our understanding on the differences between chassis and engine testings and to help determine if other factors besides load can affect NOx emission differences between biodiesel and diesel fuels. Understanding differences are important in how data generated from these tests can be used in determining the NOx impact caused by biodiesel use.

D. Evaluate Toxic Emissions and Health Effects

The data available on toxic species and health effects is more limited than on criteria emissions and based mainly on soy-based biodiesel and at a limited number of blend levels; therefore this study will address some of the data gaps by testing biodiesel from other feedstocks. Analysis of toxics species including volatile organic compounds (VOCs), carbonyls, polycyclic aromatic hydrocarbons (PAHs), and metals such as total chromium and chromium (VI) will be conducted. Toxic data will be collected on the biodiesel feedstocks and blend levels tested.

In addition, an in-depth toxic species characterization will be conducted however; due to resource and cost constraints, this assessment will be conducted on a limited set of samples. The species analyzed will include nitro-PAHs and an expanded list of PAHs and carbonyls. Also, biological analysis that measure genotoxic and inflammation effects to access potential health effects will be assessed.

E. Tested Pollutants and Toxic Analytes

Given in the following table are the proposed pollutants to be tested.

Proposed Pollutants to be Tested

Pollutants

Regulated pollutants

- Oxides of nitrogen (NOx)
- Particulate matter (PM)
- Carbon Monoxide (CO)
- Total hydrocarbons (THC)

Greenhouse gases

- Nitrous oxide (N_2O)
- Carbon Dioxide (CO_2)
- Methane and non methane hydrocarbons

Toxics

- Volatile organic compounds (VOCs)
- Carbonyls
- PAH
- Metals and Cr/Cr^{+6}

Others pollutants

- Nitrogen Dioxide (NO_2)
- Ultra fine particulate matter
- Elemental carbon /organic carbon (EC/OC)

In-depth characterization

- Expanded list of carbonyls including Unsaturated carbonyls
- Expanded number of PAHs
- Nitro-polycyclic aromatic hydrocarbons (nitro-PAHs)

Biological analyses

- Genotoxicity using Ames assays
- Inflammation using human lung and macrophage assays
- DNA damage using comet assay

F. Proposed test design

1. Reference fuel: ARB ULSD diesel fuel will be used as the reference fuel that will serve as the baseline comparison to all biodiesel and biodiesel blends.

2. Feedstocks: The study will evaluate two biodiesel feedstocks. Soy is a common feedstock nationally and imported biodiesel would likely be derived from this and recycled grease commonly used in California will be extensively evaluated. Two other feedstocks that have the potential to be commonly used in California may be evaluated if resources allow. Examples of future feedstocks to be considered are trap grease, palm oil, and algae derived biodiesel.

3. Biodiesel blend levels: Four biodiesel blend levels will be evaluated. Proposed blends levels are 5% biodiesel (B5), 20% biodiesel (B20), 50% biodiesel (B50), and 100% biodiesel (B100).

4. Engine dynamometer tests. Two engines will be tested on up to three test cycles. To cover a range of driving conditions common to California for heavy-duty diesel engines three test cycles will be selcted from the following: Federal Test Procedure heavy-duty transient cycle (FTP), simulated UDDS, the ARB transient cycle, and a steady state test cycle. Also, efforts will be made to make the test cycles consistent with the proposed US EPA biodiesel study. Currently, the US EPA is proposing to use the FTP and the simulated UDDS at two difference loads. To obtain valid statistical measurements replicate tests will be conducted per engine/fuel combination

5. Chassis dynamometer tests. Up to four vehicles, including two off road vehicles will be tested on up to three test cycles. One of the vehicles will be tested with and without a retrofitted aftertreatment device.

6. Suggested test cycles include the UDDS, steady state, and ARB transient test cycle. Replicate tests will also be conducted.

7. NOx evaluation. A key component of the NOx evaluation is to determine if there is a bias between engine and chassis tests, therefore one engine will be tested on both engine and chassis dynamometers. The engine while still in a vehicle will be tested on up to three test cycles on a chassis dynamometer. Subsequently, the engine will be removed from the vehicle and tested on an engine dynamometer using the same identical test cycles and engine conditions. This will be accomplished by programming the test

cycles and engine power and rpm settings on the engine dynamometer.

G. Expanding the scope and depth of the study.

The core study described in part F meets the basic technical needs assessment. Although the total funding and resources committed to this study are adequate, additional resources and funding can provide greater in-depth evaluation of the issues identified as well as provide evaluation of areas not funded by this study. The following is a list of areas where additional research would be beneficial and add significantly to our knowledge base.

1. Increase the breath of the NOx evaluation by testing one or two additional engines. There are a number of different engine technologies that may behave differently with respect to NOx than the engine that will be tested. This will allow the study to be applied to greater breath of engines.
2. Conduct a more-in-depth study of feedstocks and blend levels. Currently only two feedstocks and three blend levels will be studied in-depth. Additional funding would allow for an in-depth study of other feedstocks. This is important because feedstocks such as algae base biodiesel and trap grease may displace current feedstocks, as the dominant feedstocks used in California, therefore emissions characterization of these feedstocks are likely to be needed.
3. Expand the study to include light-duty vehicles. As diesel fueled light-duty vehicles are introduced into California there will be increasing need to evaluate the emissions impact of these vehicles when fueled with biodiesel.
4. Expand the in-depth study of toxics and biological assays. Currently, the in-depth characterization will be conducted on a limited set of samples. Additional funding in this area could expand the types of feedstocks and blend levels tested.
5. ARB is in consultation with the Office of Health Hazard Assessment to compile a list of additional toxic species and biological assays that are recommended to be included in this study. Although the discussions have not been finalized, initial recommendations include expanding the study to include other types of toxics species such as oxy-PAHs and to expand the study to include biological assays that cover other biological end-points such as immunotoxicology and pulmonary oxidative damage.
6. Conduct research on the effect biodiesel has on verified hardware devices. Although it is commonly thought that biodiesel does not effect the emissions from retrofitted devices, little data is available to substantiate that assumption.

H. Resources and Funding

The total resources committed to this program are significant consisting of internal support from ARB's two emissions test laboratories, ARB's MLD Southern Analytical Laboratory, and Research Division. The emissions test laboratories will perform chassis dynamometer tests and measure criteria emissions. MLD will conduct the bulk of the toxic and unregulated pollutant tests. Research Division will provide technical assistance in test design and test coordination.

However, ARB does not have the facilities, resources, and staff to conduct the engine dynamometer tests for the NOx impact evaluation and the specialized toxic species characterization. Also, assistance will be needed in the design of the emissions tests and coordination of emission test activities as well as the need to compile and evaluate the data and prepare the final report. Thus, an outside laboratory or laboratories with specialized expertise are needed to assist this study. A detailed description of the tasks that will be assigned to an outside laboratory includes:

Task 1: Design, and coordinate the overall test activities and prepare the final report. The lead contractor will work with ARB staff to design and coordinate the biodiesel emissions test. This will involve coordinating test activities between test laboratories and subcontractors, conduct specified tests, and perform QA/QC functions. The contractor will receive the field, laboratory and quality assurance data generated from all laboratories and perform the final data reduction and prepare the final report.

Task 2: Conduct engine emission tests. Since the ARB does not have an engine emissions test laboratory, a contractor will need to be selected that will conduct the engine emissions tests. The engine tests are an essential part of the NOx impact study as well as measuring other criteria emissions and selected unregulated test data. Part or all of the fuel properties study will be conducted at the engine test laboratory facility.

Task 3: Conduct an in-depth toxics species characterization. A contractor with specialized chemical and biological sampling analysis expertise will be selected to conduct an in-depth toxics species characterization. Finally, the contractor must prepare a final report detailing methods and results.

The total cost to fund the outside laboratory activities is estimated to be about $750,000 depending on the amount of in-kind contributions that are made available for the study. The following table provides the estimated cost breakdown on a task basis.

Estimated Cost of the Biodiesel Emissions Study

Evaluate the Emissions Impacts of Biodiesel in California

	Core	Expanded
1: Design and Coordinate test	$100,000	
2. Regulated emissions two feedstocks and two engines	$425,000	
Additional feedstock at three blend levels		$ 45,000
Additional blend level		$ 45,000
Additional engine, one feedstock		$135,000
Additional test cycle one feedstock		$ 45,000
3. Toxics		
Two feedstocks, two engines, three blend levels and baseline		
Chemical tests	$110,000	
Biological tests	$115,000	
Toxics for additional feedstock, test cycle, or vehicle		$ 50,000[1]
Total Cost	$750,000	

[1]Substantial cost saving may be possible with additional samples due a fix base cost for preparing, sampling, and analyzing the samples.

Notes on expanded test elements

Include light duty vehicles. The cost of conducting a study on light duty vehicles is dependent on the scope of the study and what kind of in-house support is available. ARB has the capability to conduct light duty vehicle testing; however, availability of the laboratory would need to be discussed. However, testing at ARB laboratories would substantially lower the cost of the study.

Include assays for other biological endpoints. Currently no estimate is given on conducting other biological assays. As previously stated, discussions with OEHHA are underway to get a list of other biological tests that are recommended. Once the list is finalized a cost estimate will be provided.

NOx Formation and Mitigation Study

A. Objective

The objective of this study is to identify the principle NOx formation mechanism and to find ways to mitigate NOx emissions from biodiesel use. Blend levels of biodiesel has been correlated to NOx emissions and the higher blends of biodiesel tend to have higher NOx emissions. Feedstocks and driving conditions also effect NOx emissions. In addition, other regulated and unregulated pollutants will be characterized to identify any potential negative effects of these NOx mitigation strategies.

The significance of NOx emissions for biodiesel use is important since NOx emissions contribute to formation of both ozone and PM 2.5. Both are significant air pollution problems in California.

Also, if biodiesel blends are determined to increase NOx emissions then it is important to find mitigation strategies that make biodiesel NOx neutral or better when compared to CARB diesel use. This study will address this in three ways: changes in fuel specifications, incorporate biodiesel as a feedstock in the petroleum refinery process, and use additives to reduce NOx from biodiesel use.

B. NOx Formation

Building on the existing literature and the biodiesel research study a characterization of the mechanism for NOx formation will be used to determine what biodiesel fuel properties can cause an increase in NOx. Additional research will be conducted to isolate which fuel properties can most effectively mitigate a NOx increase. A wide range of biodiesel feedstocks and biodiesel blend levels will be investigated.

C. Fuel Specifications

Conduct a study to determine if a NOx neutral biodiesel fuel can be obtained by controlling an appropriate set of fuel specifications. For example, determine if specifications such as distillation and density can be adjusted to result in a NOx neutral biodiesel fuel.

A second approach is to determine if match blending of biodiesel with diesel can be used to be used to produce NOx neutral fuel. Match blending is where the diesel portion is adjusted so that the biodiesel blend has the same physical properties as diesel.

Using the above approaches various biodiesel fuels of varying blend levels and from various feedstocks will be tested against CARB diesel fuel using standardized emissions test procedures.

D. Refinery process

Evaluate the viability of incorporating biodiesel feedstocks into the refinery process to produce non-oxygenated feedstocks that can be used to produce diesel fuel. These second-generation renewable diesel fuels will be compared to CARB ultra low sulfur diesel fuel using standardized emission test procedures.

E. Fuel Additives

Evaluate the impact of fuel additives on reducing NOx emissions. Select promising fuel additives and test various biodiesel fuels against CARB ULSD fuel using standardized emission test procedures. Various additives and additive levels and biodiesel feedstocks will be tested.

F. Resources and Funding

Cost is estimated to be about $450,000 to conduct the NOx mitigation study. Because of the number of potential NOx mitigation strategies that need to be addressed, additional research may need to be conducted. To address this need the ARB is proposing that any additional tests be conducted at ARB's heavy-duty diesel engine dynamometer facility in Los Angeles. This will require an upgrade to the heavy-duty dynamometer facility at additional cost. ARB staff will work with stakeholders such as CRC in fleshing out the details of this study.

MULTIMEDIA EVALUATION

A. Requirements for Multimedia Evaluation

Health and Safety Code Section 43830.8 requires that any regulation that establishes a specification for motor vehicle fuel cannot be adopted until multimedia evaluation has been conducted. Since ARB is planning to develop regulations specifying biodiesel fuel specifications, a multimedia evaluation will be conducted.

B. Objectives and Goals

The multimedia evaluation will be conducted on biodiesel feedstocks and blend levels that will likely be used in California. This will include an evaluation of impacts to the environment and human health. The evaluation will be designed to compare the impacts of biodiesel and biodiesel blends against ARB ULSD fuel.

C. Process

The multimedia evaluation design and study will be conducted in accordance with the draft guidelines for multimedia evaluations of fuels. The Cal/EPA multimedia fuels working group will provide additional guidance in the design and in conducting the multimedia evaluation.

1. The study will first look at the available literature to determine what is available and applicable to the multimedia evaluation.
2. Where knowledge gaps exist, actual experimental data will be obtained to fill these knowledge gaps.
3. Appropriate modeling will be used to help estimate the impacts of biodiesel use.
4. The findings will be given in the form of a final report.

Cal/EPA multimedia fuels working group will evaluate the report generated from the multimedia evaluation and the finding will be peer reviewed by the University of California. The final multimedia evaluation and recommendations must be approved by the California Environmental Policy Council.

D. Resources and Funding

Cost is estimated to be about $300,000 to conduct the full multimedia evaluation; however, not included in this cost estimate is in generating the basic air emissions data that will be obtained from the literature and data obtained from the biodiesel emissions study.