# IMPACT OF SOY-BASED BIODIESEL BLENDS ON OFF-ROAD ENGINE EMISSIONS: THE CASE OF TRANSPORTATION REFRIGERATION UNITS


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California Environmental Protection Agency
AIR RESOURCES BOARD

# Introduction

- This project is part of a multimedia evaluation on the use of biodiesel as an alternative to diesel fuels.
- The data will be used to support two of the Air Resources Board's major programs: a) the Diesel Risk Reduction Program and b) the Low Carbon Fuel Standard.
- Previous studies had found that biodiesel reduces gaseous emissions and particulate matter (PM). However, these studies also had reported a slight increase of Nitrogen Oxides ($NO_x$) emissions.
- This presentation includes quantitative emission data for: THC, CO, $CO_2$, $CH_4$, $NO_x$, $N_2O$ and PM for soy-based biodiesel blends B5, B20, B50 and B100 compared to California ultralow sulfur diesel (ULSD/B0).

Fuel Properties

| | ULSD | Biodiesel B100 |
|---|---|---|
| Cetane # | 57 | 48 |
| Sulfur, ppm | 3.3 | 0.7 |
| C Residue, wt% | 0.03 | 0.033 |
| Aromatics, vol% | 18.6 | NA |
| Nitrogen, ppm | 0.8 | NA |
| Glycerin | N/A | 0.08 |
| Water | <0.02 | <0.01 |
| T90, °F | 615 | 662 |
| Flash Point, °F | 153 | 337 |
| Viscosity@40°C | 2.9 | 4.2 |

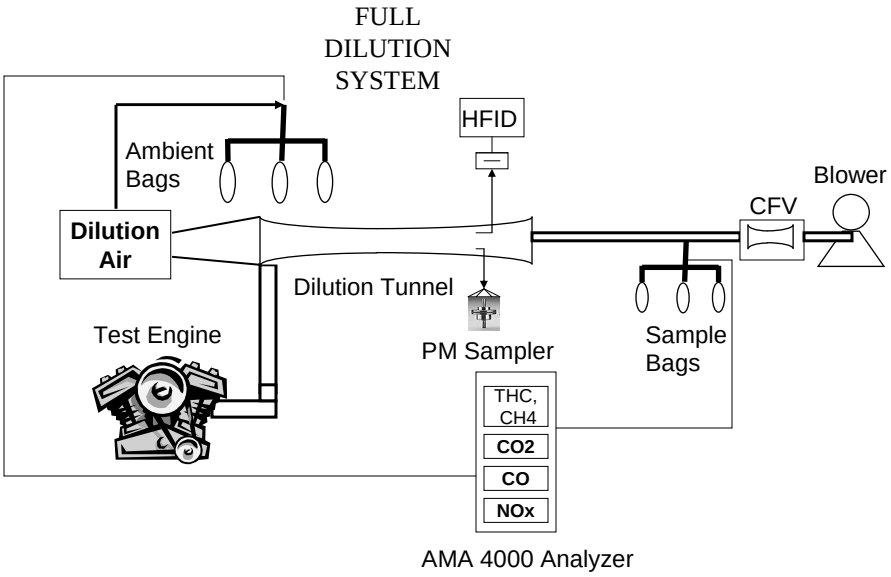
Fuel source: Stepan®Biodiesel SB-W

# Experimental Method

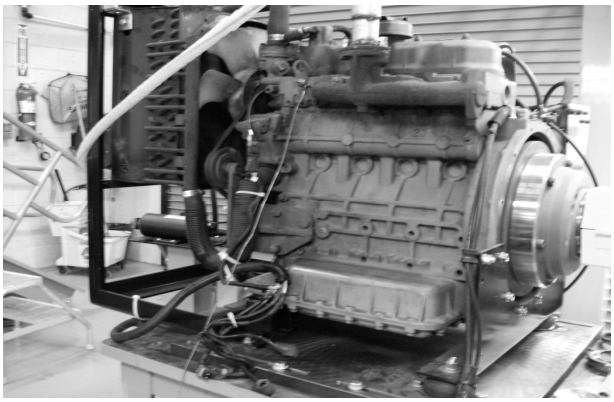
- Test cycle follows ISO 8178, Part 4 "Test Cycle Type C1 'Off-road Vehicles, Industrial and Medium/High Load.'"
- Emission measurements follow CFR Title 40, Part 89 and partially 1065 (monitoring flow and temperature at the sampling filter, and filter weighing accordingly).
- The TRU engine (Pre Tier 1 - 1998 Kubota) was operated in 8 steady-state modes on a small engine dynamometer.
- The duration of each mode was 5 min (300 sec).
- The average concentrations (ppm) of $CH_4$, CO, $CO_2$, and $NO_X$, in each mode were measured from Tedlar bags using Horiba CVS system and AVL AMA 4000 analyzer bench.
- The average THC concentration (ppmC) in each mode was measured using a Horiba CVS system and an AVL Heated FID analyzer.
- $N_2O$ was measured by GC-Electron Capture Detector (ECD) method for each mode.
- All average emission concentrations (ppm) were converted to average emission rates (g/h).
- PM was collected and weighed separately for each mode, and converted to the average emission rate (g/h).
- Weighted specific emissions (g/kWh) were calculated based on weighted factor and engine power of each mode

| 8-mode Test Parameters | | | |
|---|---|---|---|
| Mode | Speed | Torque % | Weight Factor |
| 1 | Rated* | 100 | 0.15 |
| 2 | Rated | 75 | 0.15 |
| 3 | Rated | 50 | 0.15 |
| 4 | Rated | 10 | 0.1 |
| 5 | Intermediate** | 100 | 0.1 |
| 6 | Intermediate | 75 | 0.1 |
| 7 | Intermediate | 50 | 0.1 |
| 8 | Idle | 0 | 0.15 |
| Rated speed ~ 1900 rpm<br>Intermediate speed ~ 1430 rpm<br>Idle ~ 1035 rpm | | | |

# Schematic of Engine Testing



## Test Engine Specification



Manufacturer: Kubota
Year & Model: 1998 V2203-DIB
Displacement: 2197 cc
Power Rating: 37.8 HP (actual power ~ 27.6 HP)
Speed Rating: 2200 RPM (actual rated speed ~ 1900 RPM)
Engine Type: In-line 4 cylinders, 4 stroke (Pre-Tier 1)

## Data Collection and Analysis

The average weighted emissions (g/kWh) of each pollutant was calculated based on eight 8-mode tests per fuel. Series 1 was run from October 2009 to mid January 2010 and Series 2 from late January to July 2010. Each replicate was run sequentially in order of baseline and increasing percent biodiesel.

Series 1: ULSD=B0, B50, and B100
Series 2: ULSD=B0, B5, B20, and B100

A t-test was performed between each specific blend and their series baseline (ULSD=B0). In addition the two series were standardized to the specific baseline to assess overall trends using regression.

Series 1: ULSD=B0, B50, and B100

| | Bio Percent | THC(HFID) g/kW-hr | $CH_4$ g/kW-hr | CO g/kW-hr | $CO_2$ g/kW-hr | $NO_X$ g/kW-hr | PM g/kW-hr | $N_2O$* g/kW-hr |
|---|---|---|---|---|---|---|---|---|
| Avg | 0 | 1.87 | 0.084 | 7.47 | 821.1 | 12.24 | 1.94 | 0.0153 |
| Avg | 50 | 1.44 | 0.052 | 5.79 | 832.5 | 13.44 | 1.62 | 0.0143 |
| Avg | 100 | 0.80 | 0.026 | 3.81 | 845.4 | 14.83 | 1.22 | 0.0134 |
| SD | 0 | 0.10 | 0.011 | 0.42 | 3.0 | 0.38 | 0.08 | 0.0008 |
| SD | 50 | 0.13 | 0.008 | 0.33 | 3.0 | 0.52 | 0.11 | 0.0005 |
| SD | 100 | 0.18 | 0.004 | 0.28 | 3.6 | 0.63 | 0.16 | 0.0005 |
| n | 0 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| n | 50 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| n | 100 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| % Diff | 50-0 | **-23** | **-38** | **-22** | **1** | **10** | **-17** | **-6** |
| % Diff | 100-0 | **-57** | **-69** | **-49** | **3** | **21** | **-37** | **-13** |

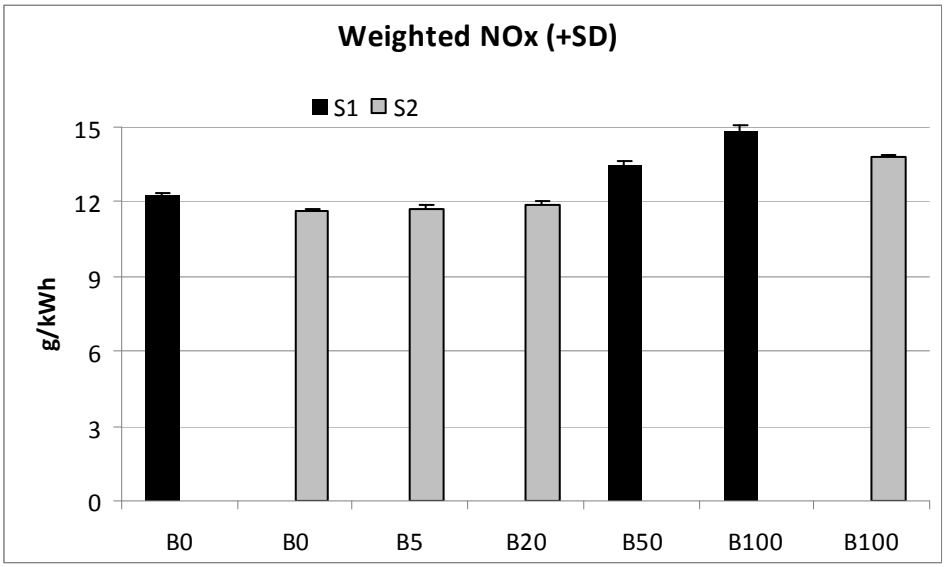
**Bold: Statistically significant** *Italic: Statistically non-significant*

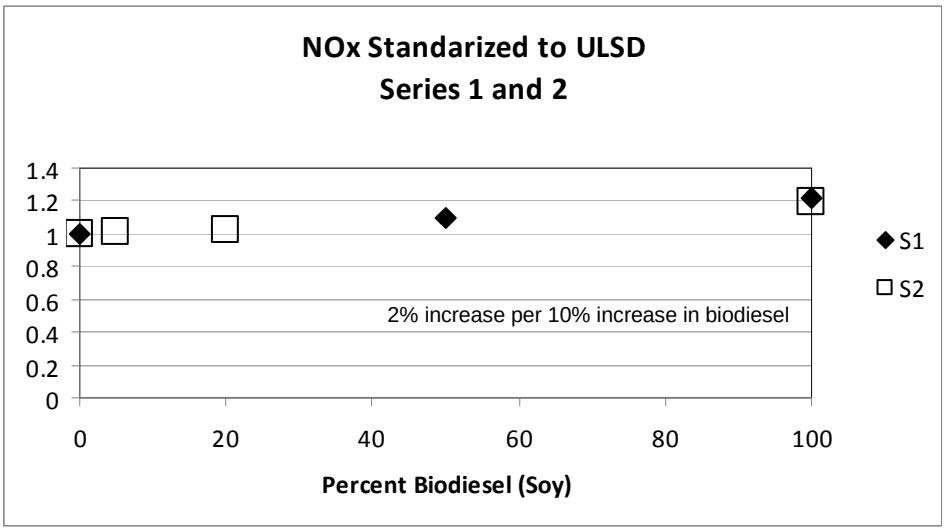
*N2O was only tested in this series

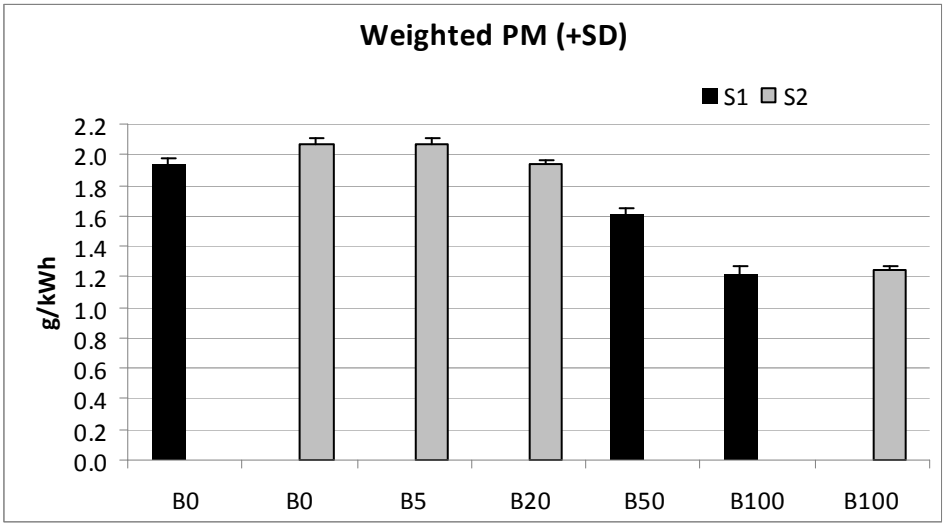
Series 2: ULSD=B0, B5, B20, and B100

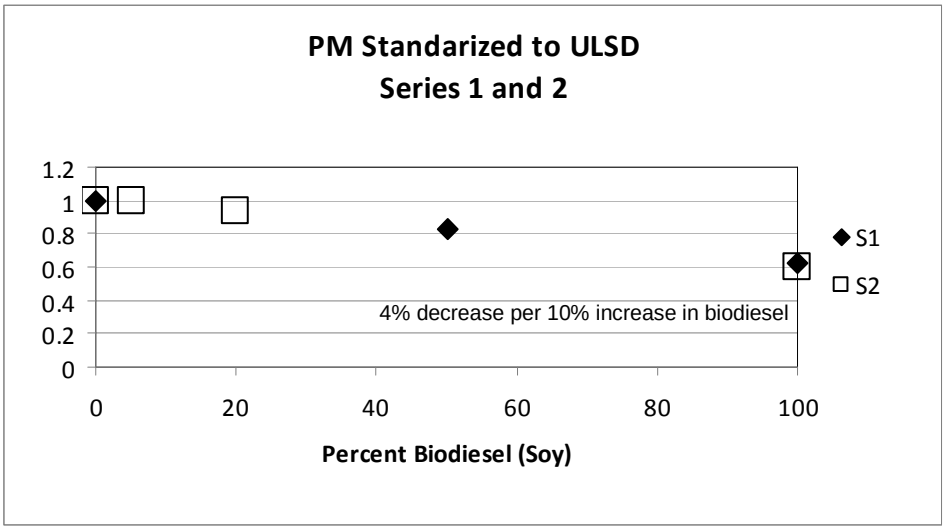
| | Bio Percent | THC(HFID) g/kW-hr | $CH_4$ g/kW-hr | CO g/kW-hr | $CO_2$ g/kW-hr | $NO_X$ g/kW-hr | PM g/kW-hr |
|---|---|---|---|---|---|---|---|
| Avg | 0 | 1.72 | 0.110 | 8.30 | 837.6 | 11.62 | 2.08 |
| Avg | 5 | 1.77 | 0.105 | 8.18 | 836.9 | 11.74 | 2.07 |
| Avg | 20 | 1.62 | 0.095 | 7.63 | 841.4 | 11.89 | 1.93 |
| Avg | 100 | 0.71 | 0.032 | 4.13 | 854.9 | 13.82 | 1.24 |
| SD | 0 | 0.14 | 0.014 | 0.51 | 5.1 | 0.30 | 0.13 |
| SD | 5 | 0.13 | 0.012 | 0.33 | 5.7 | 0.27 | 0.10 |
| SD | 20 | 0.15 | 0.009 | 0.38 | 5.1 | 0.34 | 0.09 |
| SD | 100 | 0.08 | 0.003 | 0.22 | 2.7 | 0.19 | 0.07 |
| n | 0 | 11 | 11 | 11 | 11 | 11 | 11 |
| n | 5 | 8 | 8 | 8 | 8 | 8 | 8 |
| n | 20 | 9 | 9 | 9 | 9 | 9 | 9 |
| n | 100 | 5 | 5 | 5 | 5 | 5 | 5 |
| % Diff | 5-0 | *3* | *-4* | *-1* | *-0.1* | *1* | *-0.1* |
| % Diff | 20-0 | *-6* | **-14** | **-8** | *0.5* | *2* | **-7** |
| % Diff | 100-0 | **-59** | **-70** | **-50** | **2** | **19** | **-40** |

**Bold: Statistically significant** *Italic: Statistically non-significant*

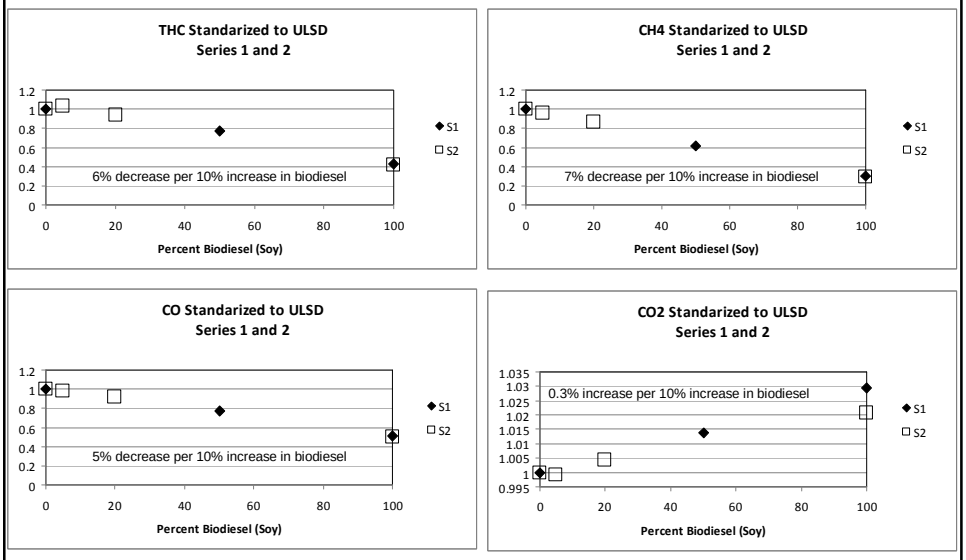

Weighted NOx (+SD)
S1
S2
g/kWh
15
12
9
6
3
0
B0
B0
B5
B20
B50
B100
B100


NOx Standarized to ULSD
Series 1 and 2
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
Percent Biodiesel (Soy)
2% increase per 10% increase in biodiesel
S1
S2

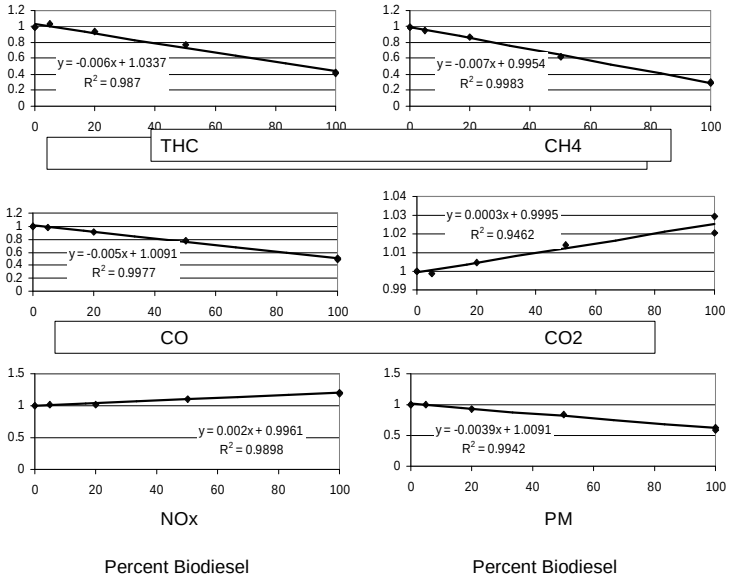

Weighted PM (+SD)
S1
S2
g/kWh
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
B0
B0
B5
B20
B50
B100
B100

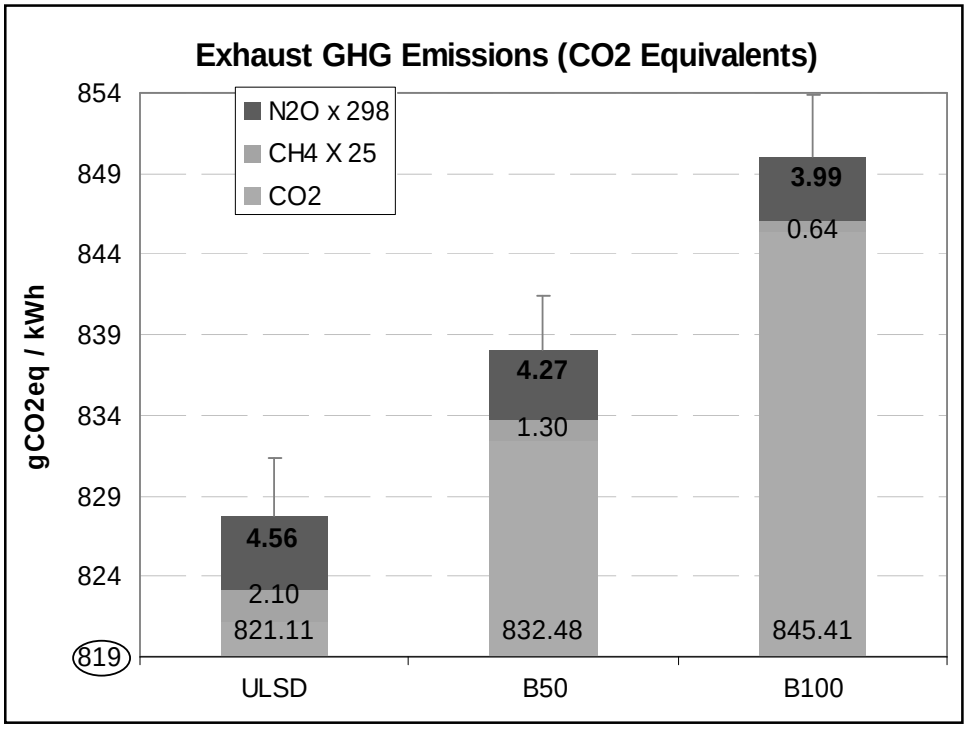

PM Standarized to ULSD
Series 1 and 2
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
Percent Biodiesel (Soy)
S1
S2
4% decrease per 10% increase in biodiesel

# Changes in emissions due to the use of biodiesel (soy) for THC, $CH_4$, CO and $CO_2$




# Summary of standardized trends

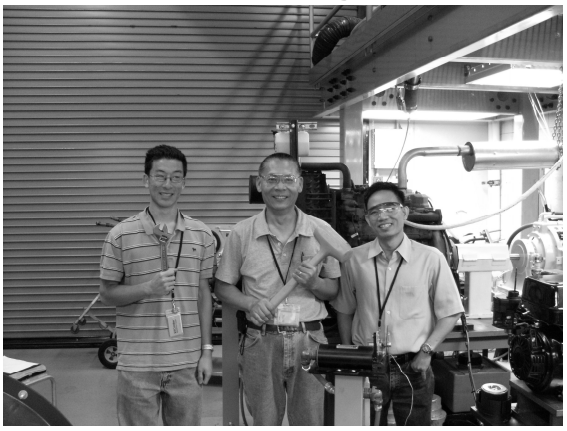





# Conclusions

- Emission reductions were observed with the use of biodiesel for THC, $CH_4$, CO and PM which increased with the percent usage of biodiesel.
- Slight emission increases for $NO_x$ and $CO_2$ were observed which increased with the percent usage of biodiesel.
- For this sample size, statistically non-significant changes were observed between ULSD emissions and B5 for all parameters and for THC, $NO_x$, and $CO_2$ for B20.
- Emission reductions were observed between ULSD and B50 and B100 for $N_2O$.
- Both $N_2O$ and $CH_4$ accounted for less than 1% of the total $CO_2$ equivalent greenhouse gas emissions.

# Acknowledgements



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