

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

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**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<sub>x</sub>) emissions.
- This presentation includes quantitative emission data for: THC, CO, CO<sub>2</sub>, CH<sub>4</sub>, NO<sub>x</sub>, N<sub>2</sub>O and PM for soy-based biodiesel blends B5, B20, B50 and B100 compared to California ultralow sulfur diesel (ULSD/B0).

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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

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## 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<sub>4</sub>, CO, CO<sub>2</sub>, and NO<sub>x</sub> 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<sub>2</sub>O 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

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### 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  
 Intermediate speed ~ 1430 rpm  
 Idle ~ 1035 rpm

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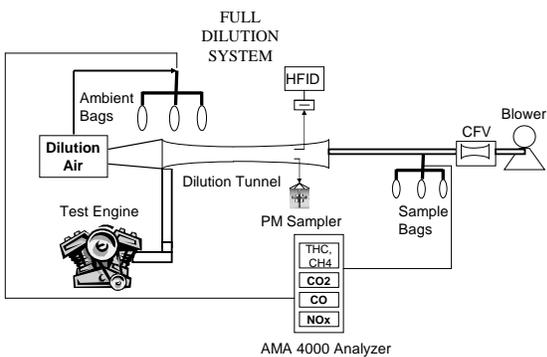
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## Schematic of Engine Testing




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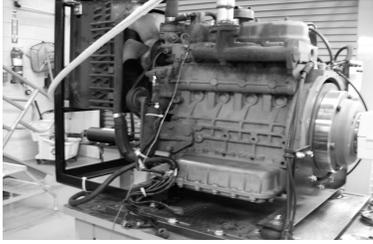
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## Test Engine Specification



Manufacturer: Kubota  
 Year & Model: 1998 V2203-D1B  
 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)

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## 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.

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Series 1: ULSD=B0, B50, and B100

Bio Percent	THC(HFID) g/kW-hr	CH <sub>4</sub> g/kW-hr	CO g/kW-hr	CO <sub>2</sub> g/kW-hr	NO <sub>x</sub> g/kW-hr	PM g/kW-hr	N <sub>2</sub> O* 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	<b>-23</b>	<b>-38</b>	<b>-22</b>	<b>1</b>	<b>10</b>	<b>-17</b>	<b>-6</b>
% Diff 100-0	<b>-57</b>	<b>-69</b>	<b>-49</b>	<b>3</b>	<b>21</b>	<b>-37</b>	<b>-13</b>

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

\*N2O was only tested in this series

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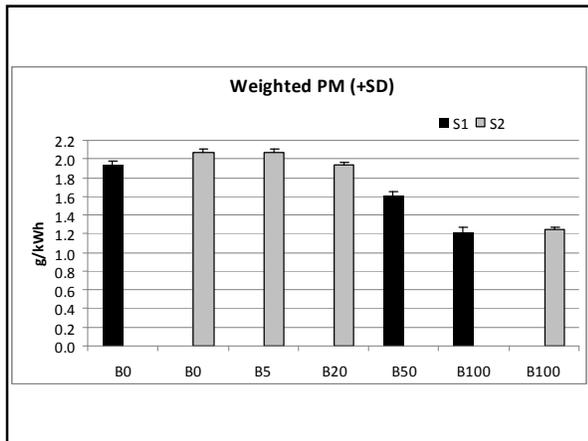
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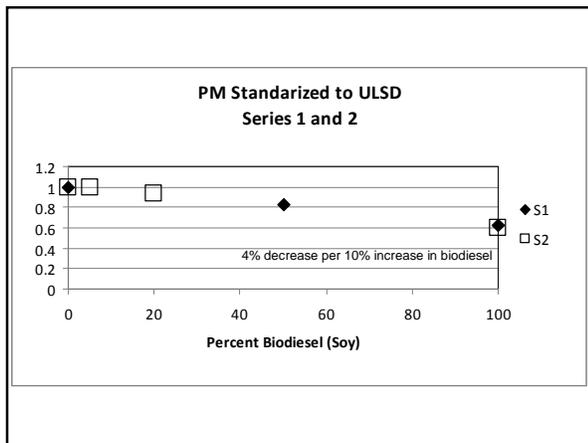
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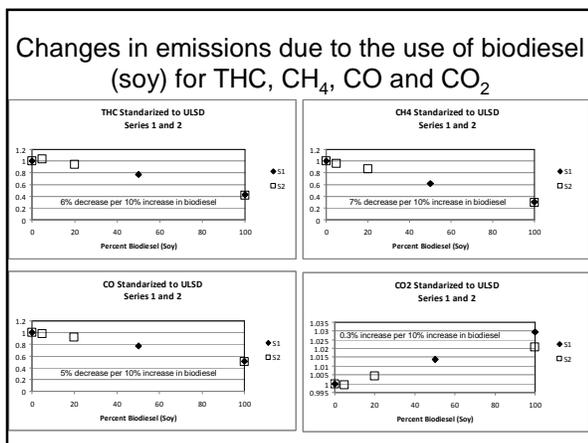
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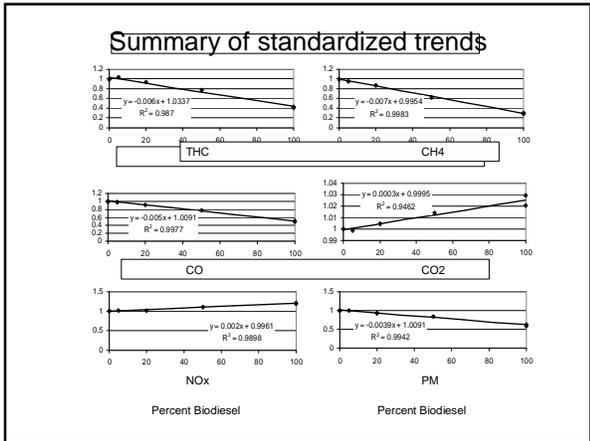
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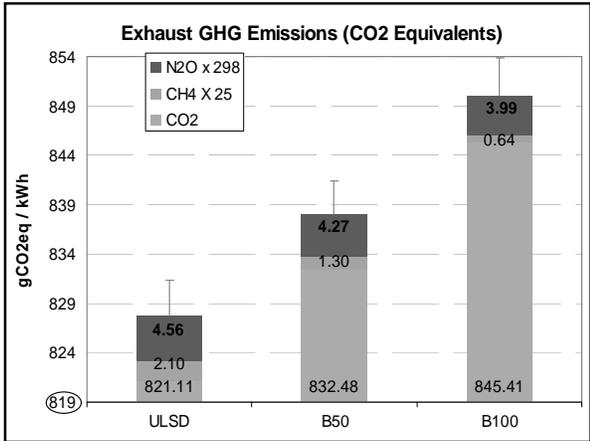
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### Conclusions

- Emission reductions were observed with the use of biodiesel for THC, CH<sub>4</sub>, CO and PM which increased with the percent usage of biodiesel.
- Slight emission increases for NO<sub>x</sub> and CO<sub>2</sub> 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<sub>x</sub> and CO<sub>2</sub> for B20.
- Emission reductions were observed between ULSD and B50 and B100 for N<sub>2</sub>O.
- Both N<sub>2</sub>O and CH<sub>4</sub> accounted for less than 1% of the total CO<sub>2</sub> equivalent greenhouse gas emissions.

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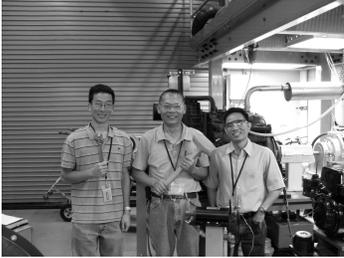
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## Acknowledgements



The TRU team wants to thank all the other ARB employees that supported this project

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