

# Effect of Soy-Based B20 Biodiesel on Fuel Use and Emissions of Onroad and Nonroad Vehicles Based on In-Use Measurements

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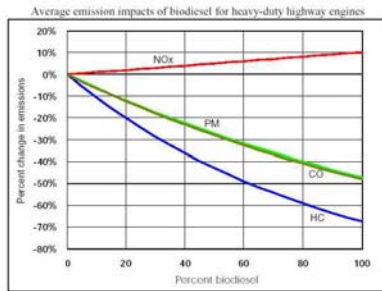
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## Research Objectives

- Measure real-world, in-use duty cycles in North Carolina for specific types of vehicles, including dump trucks, backhoes, front-end loaders, and motor graders.
- Simultaneously measure real-world, in-use emissions.
- Compare B20 versus petroleum diesel based on real-world data.

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## Emissions Impact of Biodiesel Versus Diesel (EPA, 2002)



Source: EPA (2002) "A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions."

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## Dump Trucks Tested

Vehicle Type	Number Tested
Single – Tier 1	4
Single – Tier 2	2
Tandem – Tier 1	4
Tandem – Tier 2	2

All vehicles are part of NCDOT Division 5

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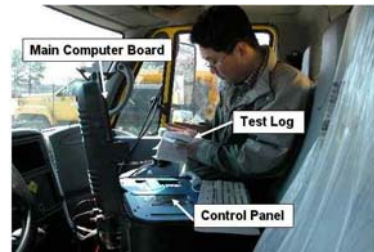
## Portable Emission Measurement System (PEMS)

- Montana System
  - Clean Air Technologies International, Inc.
  - Carry-on Luggage shape
  - Weight: 35 lbs.
  - 13.8 volt with 5-18 amps.
- 2 Gas Analyzers
  - NO and O<sub>2</sub> measured with electro-chemical sensors
  - HC, CO, and CO<sub>2</sub> measured using non-dispersive infrared (NDIR)
- 1 Particulate Matter Analyzer (based on light scattering)
- Global position system (GPS)
- Engine scanner to obtain engine RPM, manifold air pressure, and intake air temperature from diagnostic link



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## Setting Up the Instrument



### Vehicle in Motion with Instrumentation



### Dump Truck Study Region: Wake County, North Carolina



### Nonroad Vehicles Tested

- Study Location : Division 4 (Nash County) and Division 5 (Wake County)
- Data Collection Scheduling
  - 15 Tests with Petroleum Diesel and 15 Tests with B20 Biodiesel
  - Based on Regular NCDOT Duty Schedule

Vehicle Type	Number of Vehicles Tested			
	Tier 0	Tier 1	Tier 2	Tier 3
Backhoes	1	2	2	
Front-End Loaders		3	1	
Motor Graders	2	2	1	1

### Procedure for PEMS Installation and Field Measurement



### Nonroad Vehicles: B20 Biodiesel vs. Petroleum Diesel

Vehicle	NO (as NO <sub>2</sub> ) <sup>a</sup>	Opacity-based PM	HC	CO
Backhoe (5)	-4.1	-17	-27	-17
Front-End Loader (4)	-1.0	-19	-35	-42
Motor Grader (6)	-0.16	-18	-17	-17
<b>Overall Average (15)</b>	<b>-1.8</b>	<b>-18</b>	<b>-26</b>	<b>-25</b>

<sup>a</sup> NO emissions were corrected based on the ambient temperature and humidity  
<sup>b</sup> This results are based on the average of two duty cycles

### Biodiesel vs. Diesel: Results from Real-World Tests of 35 Vehicles

Type	Vehicle	NO <sup>a</sup>	Opacity	HC	CO
Onroad	Dump Truck (12)	-10	-10	-21	-11
	Cement Mixer (8)	-0.25	-20	-27	-27
	<b>Average</b>	<b>-5.1</b>	<b>-15</b>	<b>-24</b>	<b>-19</b>
Nonroad	Backhoe (5)	-4.1	-17	-27	-17
	Front-End Loader (4)	-1.0	-19	-35	-42
	Motor Grader (6)	-0.16	-18	-17	-17
	<b>Average</b>	<b>-1.8</b>	<b>-18</b>	<b>-26</b>	<b>-25</b>
<b>Overall (35)</b>		<b>-3.5</b>	<b>-16</b>	<b>-25</b>	<b>-22</b>

<sup>a</sup> NO emissions were corrected based on ambient temperature and humidity

### Emissions Reductions for Higher Tier vs. Lower Tier

Vehicle	Engine Tiers	NO (as NO <sub>2</sub> ) <sup>a</sup>	Opacity-based PM	HC	CO
Backhoe	Tier 1 vs Tier 0	-7.0	0	-36	-49
	Tier 2 vs Tier 0	-8.0	-48	-46	-86
	Tier 2 vs Tier 1	-1.0	-48	-15	-72
Front-End Loader	Tier 2 vs Tier 1	-23	-15	-57	-23
Motor Grader	Tier 1 vs Tier 0	-18	-15	-3.8	-51
	Tier 2 vs Tier 0	-25	-37	-33	-60
	Tier 3 vs Tier 0	-49	-42	-63	-74
	Tier 2 vs Tier 1	-8.9	-26	-30	-18
	Tier 3 vs Tier 1	-39	-31	-61	-47
	Tier 3 vs Tier 2	-33	-6.8	-48	-35

<sup>a</sup> NO emissions were corrected based on the ambient temperature and humidity

<sup>b</sup> This results are based on the average of two fuels

### NCDOT Inventory of Backhoes, Front-End Loaders, and Motor Graders (Based on Engine Tier)

		Vehicles (Each)
Backhoes	Tier 0	119
	Tier 1	116
	Tier 2	52
	<b>Total</b>	<b>287</b>
Front-End Loaders	Tier 0	107
	Tier 1	76
	Tier 2	55
	<b>Total</b>	<b>238</b>
Motor Graders	Tier 0	185
	Tier 1	255
	Tier 2	60
	<b>Total</b>	<b>500</b>
<b>TOTAL</b>		<b>1,025</b>

### Current Estimated Average Annual Emissions for Selected Nonroad Vehicles (Based on Fuel Type)

	NO (tons/yr)			OPACITY (tons/yr)			CO (tons/yr)			HC (tons/yr)		
	B20	PD	Total	B20	PD	Total	B20	PD	Total	B20	PD	Total
Backhoes	4.1	18	22	0.04	0.21	0.25	2.1	10	12	0.4	2.2	2.6
Front-End Loaders	3.1	19	22	0.02	0.13	0.15	0.3	2.3	2.6	0.2	2.0	2.2
Motor Graders	15	81	96	0.09	0.60	0.69	2.1	13	15	1.7	11	13
<b>TOTAL</b>	<b>22</b>	<b>118</b>	<b>140</b>	<b>0.15</b>	<b>0.94</b>	<b>1.1</b>	<b>4.5</b>	<b>25</b>	<b>30</b>	<b>2.3</b>	<b>15</b>	<b>18</b>

### Current Estimated Average Annual Emissions for Selected Nonroad Vehicles (Based on Engine Tier)

		NO (tons/yr)	OPACITY (tons/yr)	CO (tons/yr)	HC (tons/yr)
Backhoes	Tier 0	9.2	0.10	7.4	1.3
	Tier 1	10	0.13	4.4	1.0
	Tier 2	2.9	0.02	0.4	0.3
Front-End Loaders	Tier 0	6.7	0.04	0.8	0.8
	Tier 1	9.0	0.06	1.1	1.1
	Tier 2	6.5	0.04	0.7	0.4
Motor Graders	Tier 0	23	0.16	5.6	2.9
	Tier 1	57	0.42	7.5	8.2
	Tier 2	16	0.10	1.9	1.9
<b>TOTAL</b>		<b>140</b>	<b>1.1</b>	<b>30</b>	<b>18</b>

### Change in Estimated Average Annual Emissions from All Backhoes, Front-End Loaders, and Motor Graders

(Based on Fuel Type)

	Current Fuel Mix (tons/yr)	Petroleum Only (tons/yr)	B20 Only (tons/yr)	Current vs. Petroleum (% Change)	B20 vs. Current (% Change)	B20 vs. Petroleum (% Change)
NO	140	141	137	-0.7	-2.1	-2.8
OPACITY	1.1	1.12	0.91	-1.8	-17.3	-18.8
CO	18	18.5	14.1	-2.7	-21.7	-23.8
HC	30	30.7	25.4	-2.3	-15.3	-17.3

### Change in Estimated Average Annual Emissions from All Backhoes, Front-End Loaders, and Motor Graders

(Based on Engine Tier)

	Current Engine Tiers (tons/yr)	Replace Tier 0 & Tier 1 with Tier 2	
		Total Emissions (tons/yr)	Change (%)
NO	140	125	-10.7
OPACITY	1.1	0.79	-28.2
CO	18	13	-27.8
HC	30	15	-50.0

### Change in Estimated Average Annual Emissions from All Motor Graders

(Based on Engine Tier)

	Current Engine Tiers (tons/yr)	Replace Tier 0 & Tier 1 with Tier 2		Replace Tier 0, Tier 1, & Tier 2 with Tier 3	
		Total Emissions (tons/yr)	Change (%)	Total Emissions (tons/yr)	Change (%)
NO	96	85	-11.5	58	-39.6
OPACITY	0.7	0.52	-25.7	0.48	-31.4
CO	13	9.7	-25.4	5.2	-60.0
HC	15	10	-33.3	7.2	-52.0

### Change in Estimated Average Annual Emissions from All Backhoes, Front-End Loaders and Motor Graders

(Based on Using B20 Only & Highest Engine Tier)

	Current Fuel Mix & Tiers (tons/yr)	B20 Only & Highest Tier		
		Total Emissions (tons/yr)	Change in Emissions (tons/yr)	Change (%)
NO	140	97	-43	-30.7
OPACITY	1.1	0.6	-0.5	-45.5
CO	18	6.4	-11	-64.4
HC	30	8.5	-21	-71.7

### Key Findings & Conclusions

- B20 biodiesel vs. petroleum diesel:
  - As expected, little change in overall fuel and CO<sub>2</sub> mass rates
  - NO (as NO<sub>2</sub>) emission rates slightly lower
  - Opacity- based PM, HC and CO emission rates are lower
- B20 vs. current fuel mix: NCDOT fleet-wide emissions reductions would be 11 to 37 percent for CO, HC, and PM, and 2 to 5 percent for NO<sub>x</sub>
- New vs. Older vehicles: If NCDOT replaced older tier engines (Tier 0 or Tier 1) with newer tier engines (Tier 2 or higher), fleet-wide total annual emissions reductions would be 14 to 78 percent for CO, HC, and PM, and 4 to 39 percent for NO<sub>x</sub>.

### Recommendations

- Measure a larger number of vehicles of each tier to develop refined comparisons of emission rates among different tiers;
- Further evaluate alternative fuels, e.g., different suppliers of B20, different proportions of biofuel blend stock (e.g., B30);
- Evaluate future vehicles as they become available (e.g., Tier 3 for backhoes and front end loaders, Tier 4 for all vehicles); and
- Evaluate additional types of onroad and nonroad vehicles.

### Acknowledgements and Disclaimer

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#### Disclaimer

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