Appendix E

Cargo Handling Equipment
Yard Truck Off-Road Emission Testing

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Tables and Figures

I. Summary

The Air Resources Board (ARB), along with the Port of Los Angeles, funded a demonstration program to obtain information on the baseline emissions and promising control strategies for port and intermodal rail yard trucks. Six yard trucks were tested including three in-use yard trucks equipped with mechanically controlled off-road engines (1997, 2000, and 2001 MY), a newer (2004 MY) yard truck with an electronically controlled off-road engine, a newer (2004 MY) yard truck with an electronically controlled on-road engine, and a yard truck with an LPG engine.

The test fuels included CARB diesel and emulsified diesel for the three mechanically controlled off-road engines, low-sulfur (LS) diesel for the newer electronically controlled off-road and on-road engines and liquid propane gas (LPG) for the LPG engine. All six engines were either Cummins 5.9L or 8.3L, since this make in these two engine sizes represent the largest share of the port and intermodal rail yard truck inventory. To directly compare the engine emission levels in an off-road duty cycle, all testing was done using a steady-state 8 mode test cycle, similar to the non-road C1 certification cycle. Weighted emission factors, in addition to individual modal data, are presented for each engine test.

Results of the baseline testing of the three in-use mechanically controlled engines indicate that there can be a two fold difference in emission factors for total hydrocarbon (THC) and particulate matter (PM) between the engines when tested with CARB diesel. Within the two C8.3L models, the 1997 MY engine had lower modal emissions (as shown in the individual modal data) for THC, NOx and PM than the 2001 MY.

Comparison testing using CARB diesel and emulsified diesel for the three baseline engines showed an overall increase in total hydrocarbon emission factors of 10 to 33 percent for the emulsified diesel. The reductions in NOx emission factors ranged from 18 to 22 percent for the emulsified diesel. PM emission factor reductions ranged from 17 to 53 percent.

Comparisons between the on-road certified 5.9L ISB and the off-road certified QSB using low-sulfur diesel indicated that the on-road ISB engine had lower emissions for THC, NOx and PM. Total hydrocarbons were 69 percent lower, NOx emissions were 56 percent lower and PM was 30 percent lower for the ISB compared to the QSB.

Emission testing on the Cummins liquid propane fueled yard truck indicated that both the THC emission factor and NOx emission factor were higher for the LPG engine than the diesel fueled on-road certified ISB engine. The PM levels were significantly lower for the LPG engine, compared to the ISB engine.

II. Background

Cargo handling equipment at ports is a significant contributor to diesel PM. The most common type of cargo handling equipment is a yard truck. Yard trucks are also known as yard goats, utility tractor rigs (UTRs), hustlers, yard hostlers, and yard tractors. Yard trucks are very similar to heavy-duty on-road truck tractors, but the majority are equipped with off-road engines.

Yard trucks are designed for moving cargo containers. They are used at container ports and intermodal rail yards as well as distribution centers and other intermodal facilities. Containers are loaded onto the yard trucks by other container handling equipment, such as rubber-tired gantry cranes, top picks, or side picks, and they are unloaded the same way. Yard trucks are used to move containers around a facility (yard) for moving, stacking and storing purposes.

While most yard trucks are diesel-fueled, there is limited availability of those powered by liquefied petroleum gas (LPG), compressed natural gas (CNG), and liquefied natural gas (LNG). Emulsified diesel fuel has also been used as an alternative to diesel fuel in support of voluntary emission reductions programs. Yard trucks have a horsepower (hp) range of about 150 hp to 250 hp, with most being around 175 hp to 200 hp. There are approximately 2,300 yard trucks at California's ports and intermodal rail yards.

There are a number of potentially effective emission control strategies for off-road yard trucks to reduce diesel particulate matter (PM) and nitrogen oxides (NOx). The options that have shown the most potential are

1) purchasing yard trucks with on-road certified engines;
2) using alternative fuels such as propane or natural gas;
3) using alternative diesel fuels such as emulsified diesel; and
4) installing aftertreatments such as diesel oxidation catalysts.

Diesel particulate filters may not work well for yard trucks since engine exhaust operating temperatures may not be high enough for passive diesel particulate filters.

To gather additional data on the operation of yard trucks and the emissions impacts of diesel PM control and NOx control strategies for port and intermodal yard trucks, the ARB, along with the Port of Los Angeles, funded a demonstration program. The purpose of the demonstration program was to:

- perform chassis emission testing on in use yard trucks to measure baseline emission levels;
- perform chassis emission testing to evaluate the effectiveness of promising control strategies such as on-road engines, alternative fuels and emulsified diesel;
- perform data logging to evaluate the duty cycle of yard trucks to develop typical speed, temperature and engine load profiles; and
- conduct in use emission testing for transient, container handling duty cycling.

Currently, the first two components of the study have been completed. This appendix includes an overview of the emission testing, a description of the yard truck equipment and test fuels and the test results with preliminary findings.

Emission testing was performed by University of California, Riverside, Bourns College of Engineering-Center for Environmental Research and Testing (UCR CE-CERT) under the direction of Wayne Miller, Ph.D.

III. Emission Testing

Emission Measurements

Emissions were tested for PM, total hydrocarbons (THC), CO_2, CO, and NOx per International Organization for Standardization Reciprocating Internal Combustion Engines-Exhaust Emission Measurement (ISO 8178) Parts 1, 2, and 4. (ISO 8178, 1996). Exhaust analysis of the gaseous components was performed using the continuous measurement methods listed in Table E-1.

Table E-1. ISO 8178 Recommended Continuous Gaseous Sampling Analyzers

Gaseous Pollutant	Ambient Level Sampling Per ISO 8178
NOx	Chemiluminescence
CO	Non-dispersive infrared (NDIR)
CO2	Non-dispersive infrared (NDIR)
Total Hydrocarbons	Flame ionization detector (FID)

Emission testing was performed using full-flow constant volume sampling (CVS) per ISO 8178. In the CVS method, the engine exhaust is diluted with air to maintain a constant total flow rate (air + exhaust) under all running conditions. Total exhaust (full-flow) is collected and mixed with air in the full-flow primary dilution tunnel. Particulate matter sampling is done from diluted exhaust gas. This is achieved by turbulent mixing of exhaust gases with air in a dilution tunnel. A sample for particulate measurement is drawn from that tunnel into a small secondary dilution tunnel, further mixed with air and collected on particulate filters maintained 52 ºC, maximum. Samples for continuous gas phase measurements are drawn from the primary dilution tunnel. The volumetric flow rate of the dilution air and diluted exhaust gas are measured along with temperatures and pressures, allowing computation of the total mass flow rate of exhaust and mass emission rates of the sampled components.

Test Cycles

Mass emission rates were measured at steady-state conditions for specified speeds and loads developed for off-road engine applications as listed in ISO 8178 Part 4. A test cycle includes a set of modes with a specified torque, speed and weighting value designed for specific engine uses. For a given test cycle, a weighted emission factor was calculated using weighted modal emission mass rates and divided by a weighted load value. For this testing, the 8-mode C1 test cycle was selected since it is the same test cycle used for non-road EPA engine certification. The chassis testing was performed using a vehicle chassis dynamometer, leased from Johnson Power Equipment, Riverside, CA.

Table E-2. Weighting Factors for C1 Type ISO 8178 Test Cycles

Mode number	1	2	3	4	5	6	7	8	9	10	11
Torque, %	100	75	50	25	10	100	75	50	25	10	0
Speed	Rated speed					Intermediate speed					Low idle
Type C1	0.15	0.15	0.15	-	0.10	0.10	0.10	0.10	-	-	0.15

Although EPA non-road certification is performed using direct engine testing, vehicle chassis testing was used for this phase of the program. The chassis dynamometer has distinct advantages for testing in-use vehicles, the most important of which is that we did not have to remove the engine from the vehicle. However, with chassis testing there will be additional variables (such as driveline losses) influencing the results. With vehicle chassis testing on a dynamometer, the load is applied and measured at the wheel instead of directly at the engine. Due to power losses in the drive train, the engine load will be higher than the wheel load. The brake specific emission factors, in g/hp-hr, presented in this report are calculated using the load at the wheel (wHp) instead of the engine load (Hp). Therefore, the emission factors measured in vehicle chassis testing are typically higher than those measured in equivalent engine testing. These losses may be different for each of the vehicles, depending on the vehicle design and drivetrain components.

In addition, modifications were made to the C1 intermediate test points (modes 6, 7 and 8) because the dynamometer requires a minimum wheel speed to produce sufficient wheel loading. Because off-road yard trucks are governed to run at a maximum speed of 18 to 20 mph, at lower wheel speeds (corresponding lower engine speeds, 1500 to 1600 rpm), the wheel speed was too low for the dynamometer to generate some test loads. Therefore, the yard trucks had to be operated at a higher wheel speed range to achieve some of the intermediate load points specified in the C1 cycle. This resulted engine speeds which were higher than those intermediate speed points required in the C1 cycle for modes 6, 7 and 8. In general, the intermediate engine speed points were increased from specified speed points of 1500 and 1600 rpm to 1800 and 1900 rpm (See Table E-7). The weighed emission factors were calculated using the modified intermediate speed points.

IV. Yard Truck Test Matrix

Emission testing was performed on six yard trucks. The test matrix was designed to represent the makeup of the existing fleet, evaluate the effectiveness of using emulsified diesel, compare currently available certified on-road and off-road engines, and test alternatively fueled propane yard trucks.

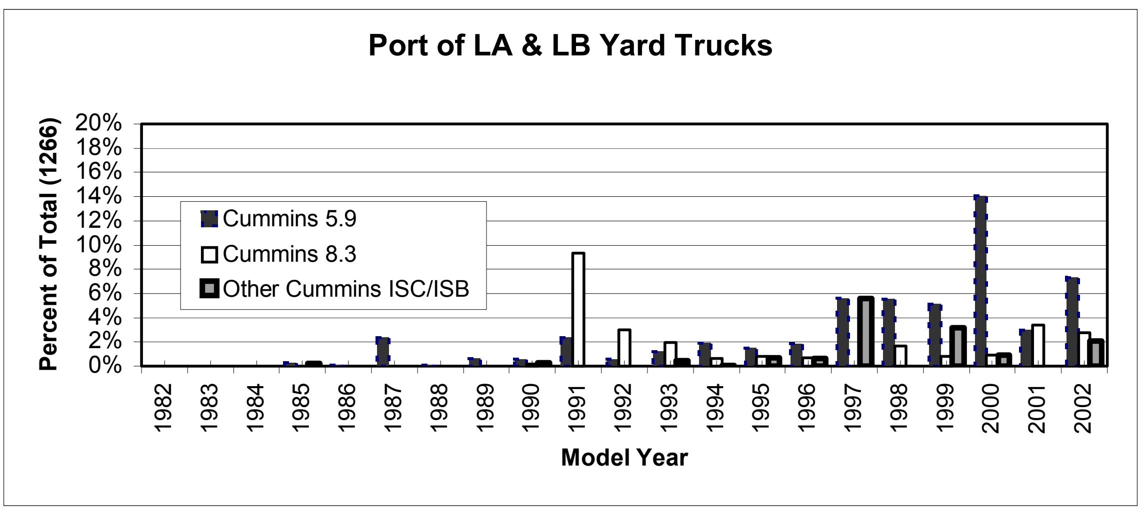
Selection of Yard Trucks for Testing

In order to develop a representative baseline for the yard truck test plan, the combined population of engines in the 2002 Port of Los Angeles and 2001 Port of Long Beach Baseline Emission Inventories were analyzed to determine the dominant engine make, model and model year groupings. (Starcrest, 2004a and Starcrest, 2004b) The inventories contain a total of 1266 yard trucks. Cummins engines represented approximately 94 percent of the inventory. Since Cummins represented the largest manufacturer grouping by far, model year distributions were developed for the two largest Cummins engine size groups, 5.9L and 8.3L.

Table E-3. Engine Make and Size Breakdown

Yard Truck Engine Make/Size	Total Number	Percent of Total
Cummins 5.9 liter	687	54%
Cummins 8.3 liter	331	26%
Other Cummins	180	14%
Cat (all models)	3	<1%
Detroit Diesel (all models)	57	5%
Other Makes	8	1%
Total	1266	100%

Figure E-1. Cummins Model Years Breakdown



Based on the model year (MY) breakdown for the Cummins 5.9L engines, MY 2000 is the most common model year at 14 percent of the total. Model Year 2002 is the next most common 5.9L engine size at 9 percent of the total. These two model years capture approximately 21 percent of the total yard truck inventory for the two ports. The Cummins 8.3L engine group represents the second largest engine category at 26 percent of the yard truck inventory. Model Year 1991 is the most common Cummins 8.3L engine at 9 percent of the total inventory. Model Year 2001 is the second most common Cummins 8.3L engine at approximately 5 percent of the inventory. These four engine makes and model years represent 37 percent of the total inventory.

Table E-4. Dominant Inventory Groupings for Baseline Selection

Cummins Engine	Model Year	Percent of Yard Truck Inventory
5.9 L	2000	14
5.9 L	2002	9
8.3 L	1991	9
8.3 L	2001	5

While the model year information shown in Table E-4 was used to guide the selection of the test vehicles, two changes were made in developing the final test matrix. First, a 1997 model year was substituted for the 1991 yard truck, since 1991 trucks were no longer available. Second, since the 2002 model year 5.9L was within the same tier (Tier 1) and similar in design to a 2000 model, only the 2000 model year was tested. The final test matrix, along with test fuels, is shown in Table E-5.

Table E-5. Yard Truck Test Matrix

Equipment (Rated speed/HP)	Model Year	Baseline Diesel	ULSD	Emulsified Diesel	Alternative Fuel (Propane)
Cummins 5.9L 6BT (2200 rpm/174 Hp)	2000	1		1	
Cummins 8.3L 6CT (2200 rpm/210 Hp)	1997	1		1	
Cummins 8.3L 6CT (2200 rpm/215 Hp)	2001	1		1	
2004 Off-Road Engine Cummins QSB - no aftertreatment (2500 rpm/173 Hp)	2004		1		
2004 On-Road Engine Cummins ISB - no aftertreatment (2300 rpm/245 Hp)	2004		1		
Cummins 5.9L Propane Fueled Engine with OEM-3 way Catalyst (2600 rpm/185 Hp)	2004				1

<u>In-use Yard Trucks Testing with CARB Diesel and Emulsified Diesel</u>

All baseline engine tests were performed using currently available CARB Diesel fuel that meets the specifications defined in Title 13, CCR sections 2281-2282. (CCR Title 13, Sections 2281, 2282) The baseline yard trucks were also tested with water emulsified diesel, developed to reduce both NOx and PM, to evaluate the impact of voluntary emission reduction programs.

The emulsified diesel, Chevron Proformix fuel, is a water emulsified diesel fuel that consists of a blend of water, conventional diesel fuel and an additive package, utilizing Lubrizol's PuriNOx technology. Small amounts of the additive package are added to the fuel to maintain the emulsion, enhance cetane and lubricity, inhibit corrosion, protect against freezing and prevent foaming. The water is suspended in droplets within the fuel lowering PM emissions by creating a leaner fuel environment in the engine. Also, the emulsified fuel creates a cooling effect in the combustion chamber, thereby, decreasing NOx emissions.

On-road and Off-road Engine Comparisons

A direct comparison between a current (MY 2004) electronically controlled off-road engine (QSB 5.9L) and a current (MY 2004) electronically controlled on-road engine (ISB 5.9L) was conducted. While both these engines are certified, the on-road engine is certified with a transient on highway test procedure. The off-road engine is certified using a non-road 8 mode (C1) steady state test procedure. To directly compare the emission levels of both engines in an off-road application, both engines were tested using the modified non-road 8 mode (C1) steady state test procedure described above. Low-sulfur diesel (15 ppm) was used for this component of the testing to best represent proposed regulatory control strategies.

Liquid Propane Yard Tractors

Alternative fuels, such as liquid propane gas, are options available to reduce emissions from compression ignition engines. Cargo handling equipment applications, specifically yard tractors, are typically using LPG as an alternative to diesel fuel at some terminals. Engines using alternative fuel have emission levels than are comparable or lower than new diesel engines operating on CARB diesel fuel. Currently the Port of Los Angeles has 53 LPG yard tractors in service. The test plan included one 2004 Cummins LPG fueled yard tractor. As with the diesel fueled Cummins ISB engine, this engine is certified with an on highway transient test procedure. To directly compare to the other yard trucks tested in this program, the LPG yard truck was tested using the modified non-road 8 mode (C1) steady state test procedure described above.

V. Results and Discussion

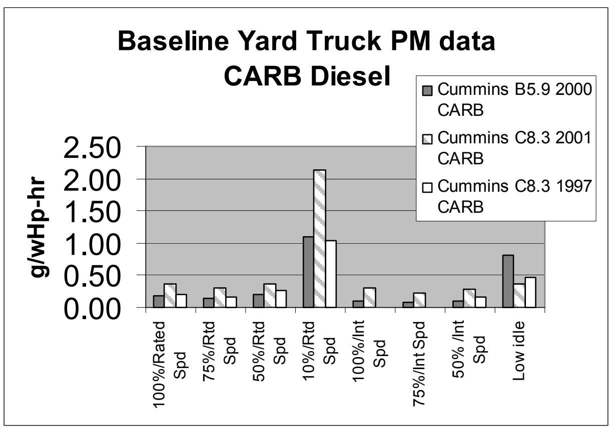
In-use Yard Trucks with CARB Diesel (baseline) and Emulsified Diesel
Three in-use yard trucks were tested with both CARB diesel and Proformix emulsified diesel. The yard trucks tested were a 2000 MY Cummins B5.9L, a 2001 MY Cummins C8.3L and a 1997 MY Cummins C8.3L. We were not able to test the 1997 MY Cummins C8.3L engines in modes 6 and 7 due to automatic shifting of the transmission. Therefore, we were not able to calculate corresponding C1 (modified) weighted emission factors for that engine. To compare emissions between the three in-use trucks, modal values are shown in Figure E-2. Comparison of the 2000 MY B5.9L and the 2001 MY C8.3L baseline weighted emission factors show significantly different emission levels. As shown in Table E-6 and Figure E-3, the C1 weighed emissions for the 2000 MY B5.9L engine was 2.8 g/wHp-hr, 7.13 g/wHp-hr and 1.5 g/wHp-hr,

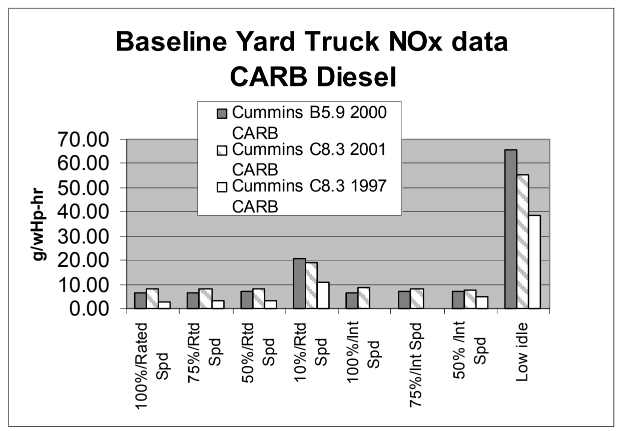
respectively, for THC, NOx and PM. The C1 weighed emissions for the 2001 MY C8.3L engine was 0.48 g/wHp-hr, 8.49 g/wHp-hr and 0.35 g/wHp-hr respectively for THC, NOx and PM.

Emission testing of the 2000 MY B5.9L with emulsified diesel shows an increase in THC of 33 percent with reductions in NOx of 18 percent and reductions in PM of 17 percent. Emission testing of the 2001 MY C8.3L with emulsified diesel shows an increase in THC of 10 percent with reductions in NOx of 22 percent and reductions in PM of 53 percent.

The variations in reductions indicate that the levels of reductions may be dependent on engine design and baseline engine emission levels. Results also show that for certain engine types, emulsified fuel is very effective technology to reduce PM significantly, while also providing reductions in NOx.

Figure E-2. Modal Emission Factors for Baseline Yard Truck Engine Testing with CARB Diesel





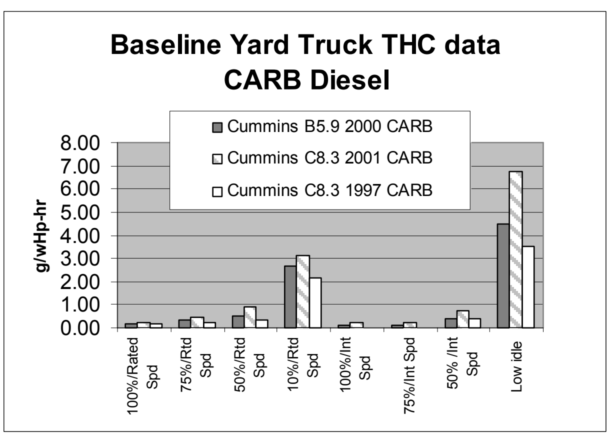
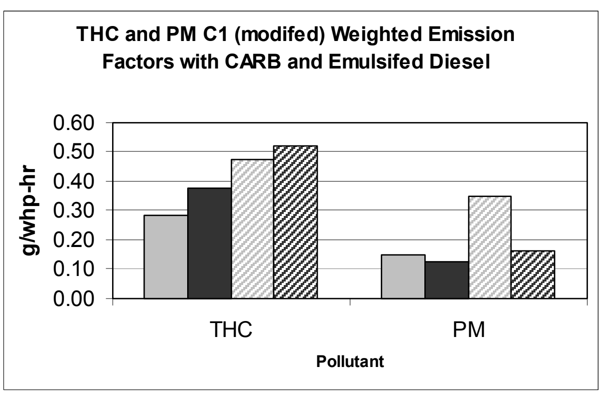


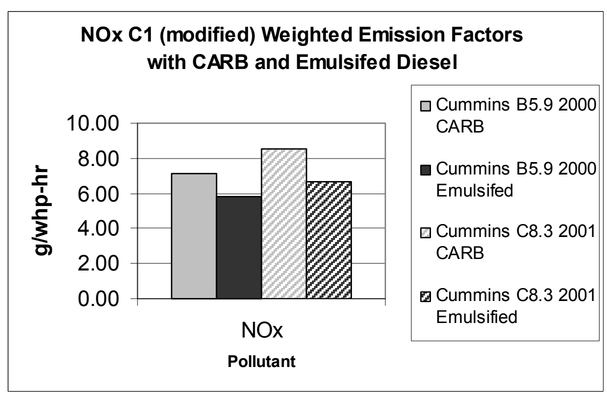
Table E-6. Average Modified C1 Weighted Emissions Factors for Yard Truck Engine Testing with CARB Diesel and Emulsified Diesel

Engine Type	Cummins 5.9L 6BT 2000 MY	Cummins 5.9L 6BT 2000 MY	Cummins 8.3L 6CT 2001 MY	Cummins 8.3L 6CT 2001 MY	Cummins 8.3L 6CT 1997 MY	Cummins 8.3L 6CT 1997 MY
Fuel	CARB Diesel	Emulsified Diesel	CARB Diesel	Emulsified Diesel	CARB Diesel	Emulsified Diesel
	g/wHp-hr	g/wHp-hr	g/wHp-hr	g/wHp-hr	g/wHp-hr	g/wHp-hr
THC	0.28	0.38	0.48	0.52	N/A See Note 2	N/A See Note 2
THC % reduction See Note 1		-33 See Note 1		-10 See Note 1		N/A See Note 2
NOx	7.13	5.85	8.49	6.64	N/A See Note 2	N/A See Note 2
NOx % Reduction		18		22		N/A See Note 2
PM	0.15	0.12	0.35	0.16	N/A See Note 2	N/A See Note 2
PM % Reduction		17		53		N/A See Note 2

Note 1. Negative number indicates Increase in Total Hydrocarbon
Note 2. A weighted C1 emission factor could not be calculated because modes 6 and 7 were not performed due to automatic transmission shifting.

Figure E-3. Average Modified C1 Weighted Emissions Factors for Yard Truck Engine Testing with CARB Diesel and Emulsified Diesel





On-road and Off-road Engine Comparisons

Emission testing was performed on an electronically controlled 2004 off-road certified engine (QSB 5.9L) and an electronically controlled 2004 on-road certified engine (ISB 5.9L) using low-sulfur diesel fuel (<15 ppm sulfur). The modified C1 weighed emissions for the 2004 QSB engine was 0.16 g/wHp-hr, 5.54 g/wHp-hr and 0.14 g/wHp-hr respectively for THC, NOx and PM. The C1 weighed emissions for the

2004 ISB engine was 0.05 g/wHp-hr, 2.45 g/wHp-hr and 0.10 g/wHp-hr respectively for THC, NOx and PM.

Comparisons between the QSB and ISB on low-sulfur diesel show that the ISB has 69 percent lower THC, 56 percent lower NOx levels and 30 percent lower PM. These results indicate that the emission levels for the on-road certified ISB engine are significantly lower than the QSB, when tested under the same off-road modified C1 test cycle.

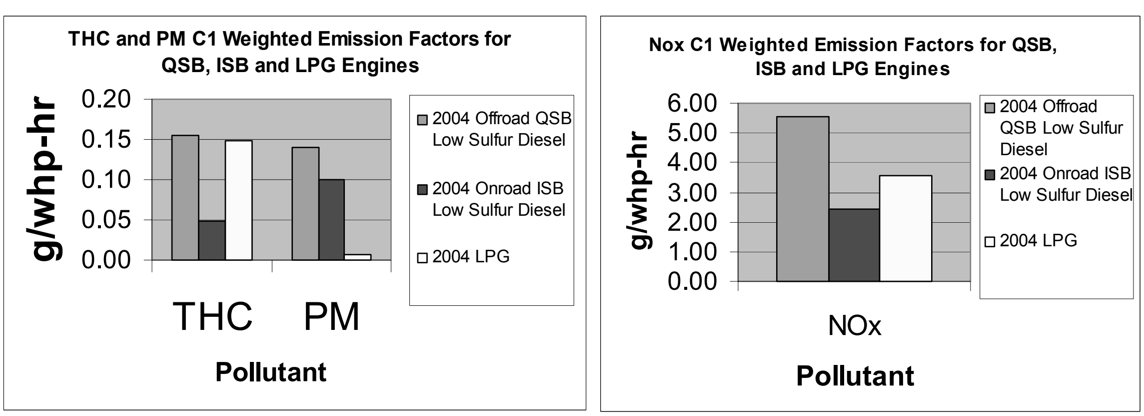
Liquid Propane Yard Tractors

Emission testing was performed for a 2004 on-road certified Cummins LPG engine. The C1 (modified) weighed emissions were 0.15 g/wHp-hr, 3.58 g/wHp-hr and 0.007 g/wHp-hr respectively for THC, NOx and PM. These results indicate that both the THC and NOx are higher for the LPG engine, compared to the 2004 MY on-road certified ISB engine. PM is significantly lower for the LPG than either the ISB or QSB engines. Modal data for all the tests is included in Table E-7.

Table E-7. Average Modified C1 Weighted Emissions Factors for Current Off-road, On-road and LPG Yard Truck Engines

Pollutant	Cummins 2004 QSB 5.9L Low-Sulfur Diesel	Cummins 2004 5.9L ISB Low-Sulfur Diesel	Cummins 2004 5.9L LPG
	g/wHp-hr	g/wHp-hr	g/wHp-hr
THC	0.16	0.05	0.15
NOx	5.54	2.45	3.58
PM	0.14	0.10	0.007

Figure E-4. Average Modified C1 Weighted Emissions Factors for Off-road, On-road and LPG Yard Truck Engines



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(CCR Title 13, Sections 2281, 2282) Standards for Diesel Fuel, Title 13, California Code of Regulations, sections 2281, and 2282.

(ISO 8178, 1996) International Organization for Standardization. *RIC Engines-Exhaust emission measurement* ISO/DP 8178 Test Procedure, Part 1, August 15, 1996, Part 2, August 15, 1996, and Part 4, August 15, 1996.

(Starcrest, 2004a) Starcrest Consulting Group, LLC. *The Port of Los Angeles, Final Draft, Port-Wide Baseline Air Emission Inventory*; June 2004.

(Starcrest, 2004b) Starcrest Consulting Group, LLC. *2002 Baseline Emissions Inventory, Cargo Handling Equipment, Rail Locomotives, and Heavy-Duty Vehicles*; March 2004.

Table E-8. All Yard Truck Modal Data

Cummins 2004 QSB 5.9L (Capacity) Low-Sulfur Diesel — Eng Hr/Odometer: Not Available

Test Mode			g/bhp-hr	g/bhp-hr	g/bhp-hr	gm/bhp-hr	g/bhp-hr
Percent Load/Speed	Load (Hp)	RPM	THC	CO	NOx	CO2	PM
100%/Rated Spd	122.50	2507.00	0.12	0.41	5.49	827.83	0.14
75%/Rtd Spd	90.50	2492.00	0.14	0.56	4.90	944.40	0.16
50%/Rtd Spd	61.50	2501.50	0.18	0.87	4.89	1117.43	0.18
10%/Rtd Spd	12.00	2500.50	1.30	4.31	18.11	3344.00	0.42
100%/Int Spd	134.00	2202.50	0.08	0.36	5.76	730.10	0.12
75%/Int Spd	102.00	2202.00	0.14	0.39	5.11	765.07	0.09
50% /Int Spd	68.50	2200.00	0.17	0.58	4.83	878.16	0.09
Low idle	1.23	750.00	2.65	12.89	41.70	3591.49	0.23
C1 Emfac			0.16		5.54		0.14

Extra Data Points

Int load/IS	42.50	1500.00	0.23	0.32	7.27	805.84	0.04

Cummins 2004 5.9L ISB (Ottawa) Low-Sulfur Diesel — Eng Hr/Odometer: Not Available

Test Mode			g/bhp-hr	g/bhp-hr	g/bhp-hr	gm/bhp-hr	g/bhp-hr
Percent Load/Speed	Load (Hp)	RPM	THC	CO	NOx	CO2	PM
100%/Rated Spd	164.50	2298.00	0.03	0.56	2.11	785.53	0.11
75%/Rtd Spd	123.50	2301.50	0.04	0.43	2.27	832.49	0.07
50%/Rtd Spd	82.50	2304.50	0.05	0.56	2.65	958.43	0.09
10%/Rtd Spd	16.50	2308.50	0.47	3.54	6.65	2815.44	0.32
100%/Int Spd	133.50	2006.50	0.04	0.51	2.06	787.58	0.09
75%/Int Spd	101.00	2003.50	0.04	0.46	2.14	810.43	0.10
50% /Int Spd	67.00	2001.50	0.06	0.62	2.46	931.81	0.12
Low idle	1.65	700.50	0.53	3.17	45.49	2697.01	0.10
C1 Emfac			0.05		2.45		0.10

Extra Data Points

Int load/IS	79.50	1501.00	0.04	0.40	2.62	764.06	0.06

Cummins 2004 5.9L LPG (Yalmar)	Eng Hr/Odometer	1199.00					
Test Mode			g/bhp-hr	g/bhp-hr	g/bhp-hr	gm/bhp-hr	g/bhp-hr
Percent Load/Speed	Load (Hp)	RPM	THC	CO	NOx	CO2	PM
100%/Rated Spd	133.90	2600.00	0.20	0.01	6.18	814.65	0.016
75%/Rtd Spd	99.42	2598.00	0.06	0.01	2.41	862.27	0.008
50%/Rtd Spd	65.95	2601.00	0.20	0.01	2.11	1069.87	0.005
10%/Rtd Spd	12.98	2601.50	0.31	0.04	9.14	3436.44	0.009
100%/Int Spd	116.41	1798.00	0.16	0.01	3.20	675.49	0.002
75%/Int Spd	85.93	1814.50	0.06	0.03	1.92	703.78	0.001
50% /Int Spd	54.95	1808.00	0.30	0.01	2.09	861.34	0.001
Low idle	1.34	750.50	0.90	20.38	3.54	5355.75	0.034
C1 Emfac			0.15		3.58		0.007

Cummins B5.9 2000 (Ottawa) CARB Diesel — Eng Hr/Odometer 12380.00

Test Mode			g/bhp-hr	g/bhp-hr	g/bhp-hr	gm/bhp-hr	g/bhp-hr
Percent Load/Speed	Load (Hp)	RPM	THC	CO	NOx	CO2	PM
100%/Rated Spd	100.92	2201.50	0.15	0.48	6.55	851.02	0.18
75%/Rtd Spd	68.95	2201.00	0.35	0.64	6.64	938.15	0.15
50%/Rtd Spd	45.96	2197.50	0.51	0.96	7.32	1113.45	0.19
10%/Rtd Spd	8.99	2201.50	2.68	7.99	20.56	3749.73	1.09
100%/Int Spd	126.40	1899.50	0.13	0.46	6.70	704.12	0.10
75%/Int Spd	101.42	1901.00	0.10	0.32	6.93	721.70	0.08
50% /Int Spd	67.95	1899.00	0.39	0.42	6.99	794.08	0.09
Low idle	1.01	642.50	4.50	8.78	65.57	3001.99	0.82
C1 Emfac			0.28		7.13		0.15

Extra Data Points

Int load/IS	110.42	1552.50	0.09	0.68	7.51	656.83	0.11
<100/RS-match lubrizol	79.94	2199.50	0.37	0.52	6.89	916.10	0.16
<100/IS-match lubrizol	116.41	1898.00	0.16	0.37	6.93	722.75	0.09

Cummins B5.9 2000 (Ottawa) Emulsified Diesel — Eng Hr/Odometer 12374.00

Test Mode			g/bhp-hr	g/bhp-hr	g/bhp-hr	gm/bhp-hr	g/bhp-hr
Percent Load/Speed	Load (Hp)	RPM	THC	CO	NOx	CO2	PM
100%/Rated Spd	81.94	2198.50	0.44	0.65	5.28	901.69	0.17
75%/Rtd Spd	68.95	2202.50	0.26	0.82	5.35	936.97	0.14
50%/Rtd Spd	45.96	2200.00	0.65	1.33	6.02	1102.62	0.18
10%/Rtd Spd	9.49	2199.50	2.72	14.56	17.11	3455.66	0.84
100%/Int Spd	112.41	1899.00	0.20	0.37	5.69	725.27	0.06
75%/Int Spd	101.92	1897.50	0.10	0.34	5.51	720.00	0.05
50% /Int Spd	67.95	1902.00	0.32	0.44	5.71	788.78	0.07
Low idle	0.82	634.50	12.59	32.98	61.20	4015.34	0.96
C1 Emfac			0.38		5.85		0.12

Extra Data Points

Int load/IS	93.43	1502.00	0.11	0.38	6.58	641.82	0.03

Cummins C8.3 2001 (Ottawa) CARB Diesel	Eng Hr/Odometer	8195.00					
Test Mode			g/bhp-hr	g/bhp-hr	g/bhp-hr	gm/bhp-hr	g/bhp-hr
Percent Load/Speed	Load (Hp)	RPM	THC	CO	NOx	CO2	PM
100%/Rated Spd	106.92	2203.50	0.22	1.37	8.38	981.54	0.37
75%/Rtd Spd	81.44	2202.50	0.47	0.99	7.98	1011.25	0.29
50%/Rtd Spd	54.46	2201.00	0.88	1.24	8.14	1172.24	0.37
10%/Rtd Spd	10.99	2201.00	3.10	5.96	18.96	3764.49	2.13
100%/Int Spd	104.92	1899.00	0.24	1.15	8.55	904.76	0.30
75%/Int Spd	77.44	1902.00	0.24	0.67	8.02	912.57	0.22
50% /Int Spd	52.46	1900.00	0.71	0.95	7.54	995.84	0.28
Low idle	1.07	592.00	6.77	11.51	55.46	3048.79	0.37
C1 Emfac			0.48		8.49		0.35

Extra Data Points

Int load/IS	63.95	1602.00	0.31	0.52	8.46	866.40	0.23
<100/RS-match lubrizol	89.43	2198.00	0.61	1.15	8.35	1035.70	0.33
<100/IS-match lubrizol	97.43	1899.50	0.28	1.04	8.31	916.53	0.29

Cummins C8.3 2001 (Ottawa) Emulsified Diesel	Eng Hr/Odometer	9999.00					
Test Mode			g/bhp-hr	g/bhp-hr	g/bhp-hr	g/bhp-hr	g/bhp-hr
Percent Load/Speed	Load (Hp)	RPM	THC	CO	NOx	CO2	PM
100%/Rated Spd	90.43	2195.00	0.52	0.72	6.11	991.86	0.15
75%/Rtd Spd	81.44	2200.50	0.33	0.75	6.22	1001.94	0.15
50%/Rtd Spd	53.46	2201.50	0.74	1.08	6.71	1170.14	0.20
10%/Rtd Spd	11.49	2202.00	2.26	6.60	15.96	3468.46	0.78
100%/Int Spd	98.92	1902.00	0.41	0.64	6.63	905.22	0.13
75%/Int Spd	77.44	1899.00	0.27	0.60	6.15	909.89	0.13
50% /Int Spd	52.46	1899.50	0.49	0.84	6.17	989.54	0.13
Low idle	0.90	625.50	14.55	38.40	60.49	4043.04	0.40
C1 Emfac			0.52		6.64		0.16

Extra Data Points

Int load/IS	63.95	1600.00	0.30	0.60	6.33	875.45	0.15

Cummins C8.3 1997 (Capacity) CARB Diesel

Not all modes were done due to transmission shifting

Modal Average | Eng Hr/Odometer | 451.00

Test Mode			g/bhp-hr	g/bhp-hr	g/bhp-hr	g/bhp-hr	g/bhp-hr
Percent Load/Speed	Load (Hp)	RPM	THC	CO	NOx	CO2	PM
100%/Rated Spd	124.41	2403.50	0.15	0.31	2.90	1028.80	0.20
75%/Rtd Spd	92.93	2398.50	0.24	0.35	3.03	1093.36	0.17
50%/Rtd Spd	61.95	2398.00	0.33	0.66	3.38	1257.92	0.26
10%/Rtd Spd	11.99	2403.50	2.15	6.84	10.62	4033.58	1.04
100%/Int Spd	N/A	N/A	N/A	N/A	N/A	N/A	N/A
75%/Int Spd	N/A	N/A	N/A	N/A	N/A	N/A	N/A
50% /Int Spd	41.47	1800.50	0.41	0.34	4.91	1181.09	0.15
Low idle	1.24	701.00	3.54	2.81	38.29	4722.73	0.46
C1 Emfac			N/A		N/A		N/A

Cummins C8.3 1997 (Capacity) Emulsified Diesel

Not all modes were done due to transmission shifting

Modal Average | Eng Hr/Odometer | 453.00

Test Mode			g/bhp-hr	g/bhp-hr	g/bhp-hr	gm/bhp-hr	g/bhp-hr
Percent Load/Speed	Load (Hp)	RPM	THC	m CO	m NOx	CO2	PM
100%/Rated Spd	101.42	2402.00	0.19	0.35	2.55	1094.28	0.13
75%/Rtd Spd	92.93	2398.00	0.21	0.43	2.59	1109.79	0.13
50%/Rtd Spd	61.95	2404.50	0.36	1.26	2.95	1294.14	0.21
10%/Rtd Spd	11.99	2398.00	3.53	34.47	10.04	4000.38	0.78
100%/Int Spd	N/A	N/A	N/A	N/A	N/A	N/A	N/A
75%/Int Spd	N/A	N/A	N/A	N/A	N/A	N/A	N/A
50% /Int Spd	40.96	993.50	0.48	0.97	4.05	1208.95	0.11
Low idle	1.01	700.00	6.87	32.37	36.26	5942.74	0.28
C1 Emfac			N/A		N/A		N/A