Final Report

Study of In-Use Emissions from Diesel Off-Road Equipment

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Disclaimer

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Executive Summary

Gaseous and particle emissions from construction engines are an important fraction of the total air pollutants emitted into the atmosphere and are gaining increasing regulatory attention. Quantification of NO_x and PM is necessary to inventory the contribution of construction equipment to atmospheric loadings, particularly for those projects in non-attainment or maintenance areas. It is also important how construction emission might vary between different types of equipment or different types of operation. Although the development of portable emissions measurement systems (PEMS) has led to more studies of construction equipment emissions, these data are still much more limited than that available for on-road vehicles.

The goal of this research program was to obtain additional construction equipment emissions data from a test fleet of new construction equipment. An important element of this program was the use of one the first PEMS systems to be fully compliant with the Code of Federal Requirements (CFR) for both gaseous and PM PEMS, the AVL M.O.V.E. Gas PEMS analyzer and the AVL Micro Soot Sensor (MSS). Emissions measurements were made for 27 in-use pieces of construction equipment. The equipment included 4 backhoes, 6 wheel loaders, 4 excavators, 2 scrapers (one with 2 engines), 6 bulldozers, and 4 graders. The engines ranged in model year from 2003 to 2012, in rated horsepower from 92 to 540 hp, and from 24 to 17,149 hours of operation. The emissions measurements were made on a second-by-second basis using a portable emissions measurement system (PEMS) to develop relationships between NO_x and PM and other emissions and fuel use and engine brake horsepower.

A summary of the major findings and accomplishments of this program is provided below. It should be noted that the results presented in units of g/hp-hr are for a 'high level' comparison against the certification standards. However, it should be noted that in contrast to the 8-mode steady-state engine dynamometer certification test cycle for new diesel off-road engines, actual in-use engine/equipment operation is highly transient, with rapid and repeated changes in engine speed and load. In addition, the average engine 'load factors' (a measure of how hard the engine is working) can be different than the certification test cycle load factor. Thus, results are not expected to be directly comparable to the certification test results, but nevertheless provide an indication of how emissions from actual, in-use diesel engines compare against their new engine certification standards.

Overall Summary

- The NO_x emissions showed generally lower emissions for the Tier 4i units on a g/kg fuel and g/hp-hr basis. The NO_x emissions for the Tier 2 and 3 units do not show strong trends as a function of certification model year, however, for any of the units of comparison. Engine load appeared to be an important factor for NO_x emissions, with equipment with low average percentage engine loads showing generally higher NO_x emissions on a g/hp-hr basis and lower emissions on a g/hr basis.
- The bsPM emissions for twenty of the 26 units with measured brake specific emissions showed bsPM emissions lower than the certification levels. The Tier 4 units with DPFs all showed significant reductions in PM in comparison with those units without aftertreatment. The six units that showed higher bsPM emissions may be a result of operation at lower power and high engine hours. One of the units (#17 a 2010 grader) was equipped with an aftermarket DPF. The bsPM emissions from this unit averaged

0.029 g/hp-h overall and ranged from 0.101 to 0.002 g/hp-h depending on the activity mode.

- The THC emissions ranged from 0.01 to 63 g/hr, 0.18 to 3.5 g/kgfuel, and 0.04 to 0.68 g/hp-h. Two units (#1 and #5 both 410 Deere backhoes) showed relatively high THC emissions of greater than 0.63 g/hp-h, which is almost two times more than the other units tested. The Tier 4i THC emissions were considerably lower than those for most of the other older units.
- CO emissions did not show a trend of increases with older MY engines. The CO emissions ranged from 518 to -15.6 g/hr, 19.1 to -0.7 g/kgfuel, and 3.39 to -0.15 g/hp-h. Three units in the 175 to 600 hp range had average emissions that were higher than the 2.6 g/hp-h standard. Two units in lower power categories (50 hp to 175 hp) also had average CO emissions in the same range, but they were below the 3.7 g/hp-h standard for the smaller engine category. One unit was a wheel loader and the other was a grader. The CO emissions for the Tier 4i units were essentially at the limits of detection of the PEMS, as indicated by the negative CO emissions values for some of the units.
- CO_2 emissions on a time specific basis do not show a trend with MY since time specific CO_2 is heavily dependent on sample length and engine load. The fuel specific CO_2 ($fsCO_2$) emissions were fairly constant at 3140 g/kgfuel, as expected since CO_2 emissions are a surrogate for fuel consumption and represents the vast majority of the carbon released from fuel combustion. The $bsCO_2$ for all but 5 pieces of equipment were in the range from 520 to 650 g/hp-h, which is in a good range for medium speed diesel engines from 6-15 liters. The engines with lower $bsCO_2$ were in a bulldozer, and the two engines in a scraper. One of the scraper engines had the largest displacement, highest rated power, and highest measured power relative to the other units tested. The two high $bsCO_2$ showed relatively low percent loads, of 40% on average, but 10 other pieces of equipment also had loads of 36% or less.
- The overall in-use brake power average load was between 20 and 60% for nearly all units, with only 7 units having average loads >50%, and only one unit having an average load of >70%.
- The newer engines tended to have lower hours, although some older engines had lower hours then newer ones. This indicates that the number of hours really depends on the unit type and the fleet.

Power-Based Results

- The best correlations for the linear and polynomial regressions between emissions and power were found for CO_2 and NO_x. More than 60% of the units had R^2>0.8 for CO_2 emissions, while NO_x emissions had R^2>0.8 for 6 of 27 units.
- CO, NMHC, and PM showed relatively poor correlations with power, with only 1 unit for PM having R^2 >0.8 and no units for NMHC or CO having R^2 >0.8.
- NO_x emissions on a g/hr basis at selected 50% and 80% power levels showed some trends of higher emissions for higher horsepower engines, due to the higher amount of work they would be doing at their respective 50% and 80% power levels, and lower emissions for Tier 4 engines. Differences across categories and Tiers also indicated that activity was likely an important factor for NO_x emissions on a g/hr basis.
- Differences in real-time NO_x emissions vs. power figures showed differences that could be attributed to differences in operation for specific units.

- PM emissions on a g/hr basis at selected 50% and 80% power levels showed higher emissions for higher horsepower engines and significantly lower emissions for Tier 4 vehicles.
- PM emissions did not show a strong correlation with power on a real-time basis, with only two units showing R^2>0.6 and no units having R^2>0.8. The regression curves to PM vs. power showed considerably scatter above the best fit line for both the polynomial and linear fit lines. The degree of scatter was dependent on differences in operation between different units.
- On a g/hr basis, there are not strong trends in THC emissions as a function of hp category, indicating that the activity of the different pieces of equipment plays an important role in determining overall emissions.
- THC emissions showed some correlation with power on a real-time basis, with seven units showing R^2>0.6 and no units having R^2>0.8. The real-time THC vs. power plots showed some differences that were not related to data scatter, but rather strong trends differences between units relating to differences in operation.
- On a g/hr basis, the highest CO emissions were found for the Tier 2 175-300 hp category, and for the Tier 2/3 450-600 hp category, which is probably due to this equipment having higher overall loads. CO emissions for the Tier 4i were statistically indistinguishable from 0.
- CO emissions showed a relatively poor correlation with power on a real-time basis, with only one unit showing R^2>0.8 and no units other units having R^2>0.6. The CO trends as a function of engine power were similar to those for PM, in that the data tend to show more scatter than the other pollutants.
- On a g/hr basis the CO_2 emissions tended to increase with increasing engine horsepower independent of the engine tier, consistent with greater fuel use for the larger engines.
- CO_2 emissions showed the best correlation with power on a real-time basis, with more than 60% of the units with R^2 >0.8.
- The correlation between power and emissions was a function of different operational modes. Emissions were particularly sensitive to power take off (PTO) operation, where hydraulic pressure is used to power and manipulate attachments such as blades, shovels, hammers, and other systems, vs. non-PTO.

1.0 Introduction

Off-road equipment is one of the most significant sources of nitrogen oxides (NO_x) and particulate matter (PM), both nationally and within California. Within California, in-use off-road diesel equipment is estimated to be the 6th largest source of PM emissions and the 8th largest source of NO_x emissions, representing 7% and 4% of PM and NO_x emissions, respectively (CARB, 2010). Although increasingly more stringent engine standards are being implemented for off-road engines, there is a still some lag between the implementation of the standards compared to similar standards for on-road vehicles. Off-road engine also have relatively long lifespans, due to their inherent durability, and can sometimes remain in use for several decades. It is anticipated that the relative contribution of these sources will continue to increase as on-road emissions continue to be reduced. These factors make the control of emissions from off-road equipment one of the more critical areas in terms of reducing emissions inventories and protecting public health.

Developing emissions factors and emissions inventories for off-road equipment has inherently been more challenging than for on-road vehicles. Off-road engines are typically certified via engine dynamometer tests that are not necessarily representative of the engine's in-use operation. Prior to about 2000, emissions from off-road engines were quantified based on steady-state engine dynamometer tests, which do not represent real-world activity. Vehicles, on the other hand, are operated on chassis dynamometers over test cycles designed to represent different types of driving conditions. Although a number of studies have measured emissions from in-use off-road equipment, the available data for off-road equipment is still considerably more limited compared to on-road mobiles sources, which have been studied extensively for decades. Additionally, there is still very limited data available on activity patterns for in-use off-road equipment to understand the conditions under the equipment is typically operated and what types of operation lead to the greatest sources of emissions.

The California Air Resources Board has put considerable effort into updating and improving its emissions inventory estimates for off-road equipment over the past few years. This included a major overhaul of the EMFAC emissions inventory program for off-road equipment from 2007 to 2010 (CARB, 2010). Comparisons of the earlier 2007 estimates with other approaches, for example, indicated that there could be as much as factor of 3 difference between the EMFAC2007 emissions inventories compared with inventories derived based on fuel-based methods (Millstein and Harley, 2009). Additional considerations included the impact of the recession of 2008-2009 on the construction industry in California. This comprehensive effort included reviews of estimates of equipment population, hours of use, load factors, and growth forecasts. The resulting inventory was considerable reduced for both NO_x and PM. This led to a postponement of the implementation of some of CARB's in-use regulations for off-road diesel vehicles.

The development of accurate emissions factors for off-road equipment under in-use conditions remains and important factor in improving emissions inventories. The continuing development of Portable Emissions Measurement Systems (PEMS) has greatly enhanced the potential for characterizing in-use emissions for off-road equipment. A number of studies of construction equipment have been carried out over the years with different generations of PEMS technology. Gautam, et al. (2002) measured the CO_2 emissions from a street sweeper, a rubber-tired front end loader, an excavator, and a track type tractor in the field to develop cycles for subsequent testing of the engines on a dynamometer. They also measured all the gas phase emissions from the track type tractor in the field. Scora, et al. (2007) and Barth, et al., (2008, 2012) measured the gas phase and PM emissions from a number of pieces of heavy-duty construction equipment. The EPA and its collaborators have also conducted an extensive study of construction emissions in EPA region 7 (Kishan et al. 2010, Giasnnelli et al. 2010, Warila et al. 2013). Frey and coworkers have conducted a number of studies looking that the emissions of construction equipment and how to model their emissions impact (Abolhasani [2008,2013], Frey et al. [2003,2008a, 2008b, 2010], Lewis et al. [2009a, 2009b, 2011, 2012], Pang et al. [2009], Rasdorf et al. [2010]). Huai et al. (2005) have also measured the activity for different fleets of off-road diesel construction equipment.

Over the past few years, there has been a considerable effort to standardize PEMS systems to meet regulatory requirements for making in-use compliance measurements for on-road vehicles and off-road equipment. Much of this work was done as part of the Measurement Allowance program, which included extensive laboratory testing at Southwest Research Institute (SwRI) and in-use testing using CE-CERT's Mobile Emission Laboratory (MEL), which conforms to Code of Federal Regulations (CFR) requirements for emission measurements (Durbin, et al. (2007, 2009a, 2009b), Fiest et al. (2008), Johnson, et al. (2008, 2009, 2010, 2011a, 2011b), Khalek et al. (2010), Khan, et al. (2012), and Miller, et al. (2006)). Under this program, the accuracy of various PEMS systems was extensively evaluated to characterize the accuracy of the PEMS relative to more conventional laboratory regulatory measurements. This program was done in two separate phases to characterize gas-phase and PM PEMS. The PEMS systems meeting the US EPA Part 40 CFR 1065 developed through the Measurement Allowance program represent the latest generation of PEMS, and the first such PEMS whose performance is traceable back to regulatory requirements.

The primary purpose of this project was to obtain gaseous and PM emissions from high use off-road construction equipment using CFR 1065 compliant PEMS instruments to provide more accurate estimates of emissions from off-road construction equipment used in California. A secondary goal was to sample a wide enough range of hours of use to permit estimates of the deterioration of emissions with hours of use. The gas phase and PM exhaust emissions and the engine work (E-Work) were measured on a second-by-second basis for 27 pieces of construction equipment. The 27 pieces of equipment include 7 pieces of Tier 2 equipment with model years ranging from 2003 to 2007, with horsepower's ranging from 92 to 540 and engine hours ranging from 946 to 17,149. The other 13 pieces of equipment are Tier 3 with model years ranging from 2006 to 2011, horsepower's ranging from 99 to 520 and engine hours ranging from 242 to 5,233. Videotaping and on-site observation was used to determine the type of construction activity, i.e., digging, pushing, idling, moving, etc. (called A-Work), that the equipment was performing at specific time intervals. The results of this study will be used in conjunction with the results of several other related studies with Caltrans (Barth et al. 2012) and CARB (Johnson et al., 2013) to provide a framework for better understanding emissions from construction equipment under typical operating conditions.

2.0 Experimental Procedures

2.1 Emissions measurement systems

Over the course of the test program, three different analyzers were utilized for the measurement of the emissions.

For the first ten pieces of equipment, the gaseous emissions were measured with a Semtech DS analyzer. This system measures NO_x using a UV analyzer, total hydrocarbons (THC) using a heated flame ionization detector (HFID), and carbon monoxide (CO) and carbon dioxide (CO_2) using a non-dispersive infrared (NDIR) analyzer. THC emissions are collected through a line heated to 190°C consistent with the conditions for regulatory measurements. The analyzer provides measurements of the concentration levels in the raw exhaust. Figure 2-1 shows the Semtech DS unit.

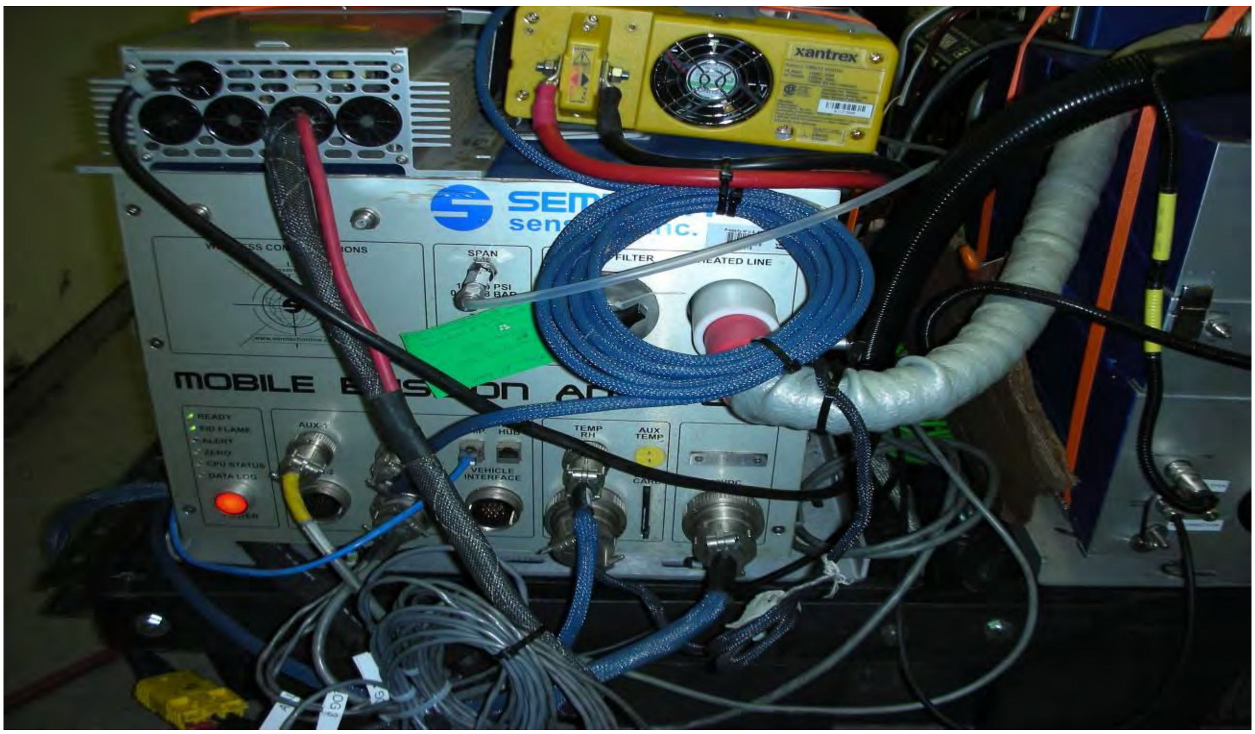


Figure 2-1: Picture of Semtech DS PEMS

For the last seventeen pieces of equipment the gaseous emissions were measured with an AVL M.O.V.E. Gas PEMS analyzer. This PEMS meets the requirements of 1065 Subpart A, B, and C, as described in the AVL user manual. This system measures NO and NO_x using a UV analyzer, THC using a HFID, and CO and CO_2 using a NDIR analyzer. THC emissions are collected through a line heated to 190°C consistent with the conditions for regulatory measurements. The analyzer provides measurements of the concentration levels in the raw exhaust. Figure 2-2 shows the AVL M.O.V.E. Gas PEMS analyzer unit. The gaseous PEMS comprises the PEMS 493 hardware with a system controller, post processor, and exhaust flow meter, for more details see [17].

Figure 2-2: Picture of AVL M.O.V.E. Gas Phase PEMS

The PM analyzer was a prototype AVL Micro Soot Sensor (MSS) with a gravimetric filter box. The MSS measures the soot concentration on a second by second basis by a photo-acoustic principle. The gravimetric filter box extends the soot measurement to a combination of time resolved soot and integral PM measurement based upon a simple gravimetric span method. The accumulated soot signal from the MSS is compared with the total mass from the filter. The ratio of the difference is multiplied by the soot signal to get the total PM measured. The range of calibration factors varied from 1.15 to 1.25 for this off-road testing project. The stored data has to be post processed by the AVL Concerto software to determine PM emissions equivalent to the PM emissions determined by the traditional method of capturing the PM on a filter. Figure 2-3 is a picture of the MSS and gravimetric filter unit.

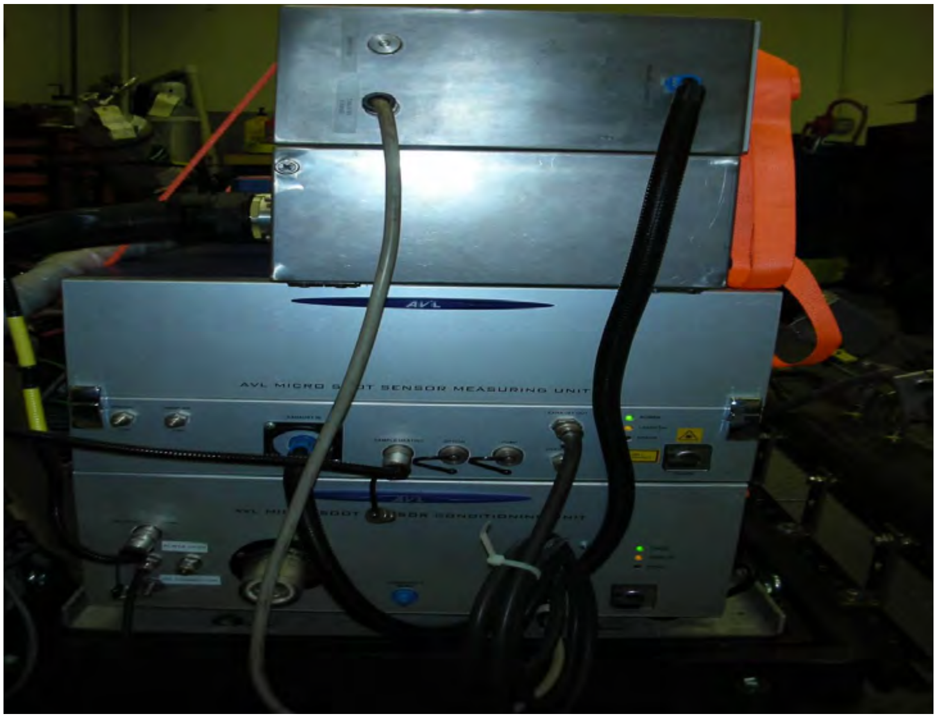


Figure 2-3: Picture of AVL Micro Soot Sensor with Gravimetric Filter Box on Top

For these analyzers the samples were extracted using a Sensors flow rate meter. The flow meter uses a pitot tube to measure exhaust flow rates. The flow meter is housed in a 3”, 4”, or 5” diameter pipe that is placed in line with the engine tailpipe exhaust for the equipment being tested. Figure 2-4 is a picture of the exhaust flow meter. The exhaust flow rates are multiplied by the concentration levels for the various emission components to provide emission rates in grams per second.

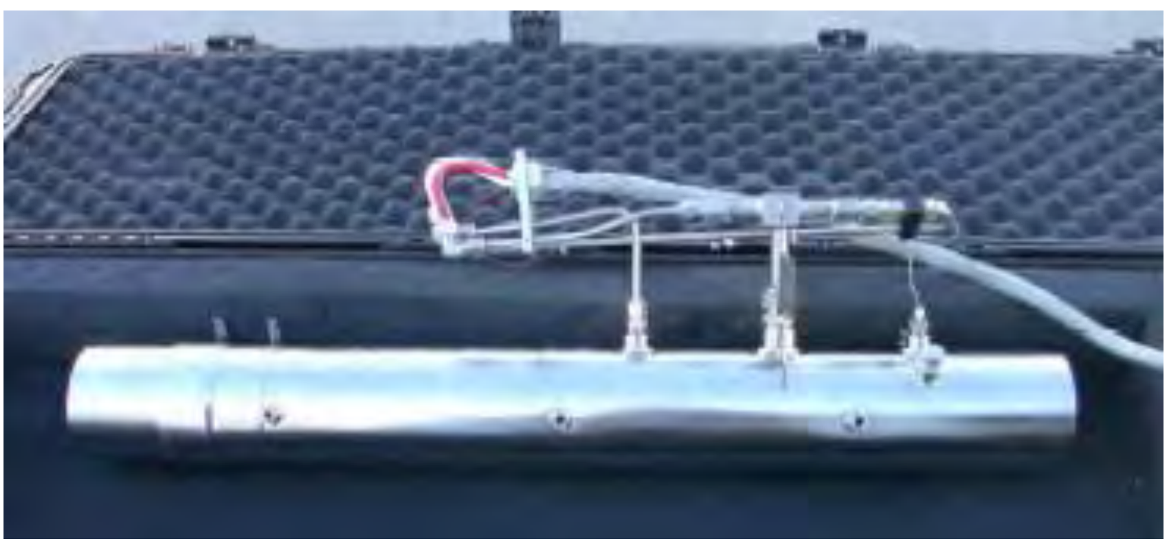


Figure 2-4: Picture of Semtech DS Exhaust Flow Meter

2.2 Test set-up

The test setup included the emissions analyzers (and associated exhaust flow meter), and a gasoline powered Yamaha EF2800 generator to power the AC emission analyzers. The generator has a built in inverter to power DC equipment, such as the PC for logging data. Figure 2-5 is a picture of the generator.

Figure 2-5: Yamaha EF2800 generator for powering equipment

The emissions analyzers were initially secured by straps to a 4 drum plastic pallet as shown in Figure 2-6 below. However, because of concerns expressed by the City of Riverside about placing a 4 foot by 4 foot pallet on the roof of their construction equipment, the equipment was removed from the pallet and the pallet cut in half. For the first ten tests all the emission measurement equipment was mounted on the 2 foot by 4 foot pallet with the generator mounted in a separate location on the construction equipment. Having the emission equipment securely fastened to the pallet, and the pallet placed on a 6 inch thick foam and securely fastened to the construction equipment, ensures the analyzers are stable over the course of a test day.

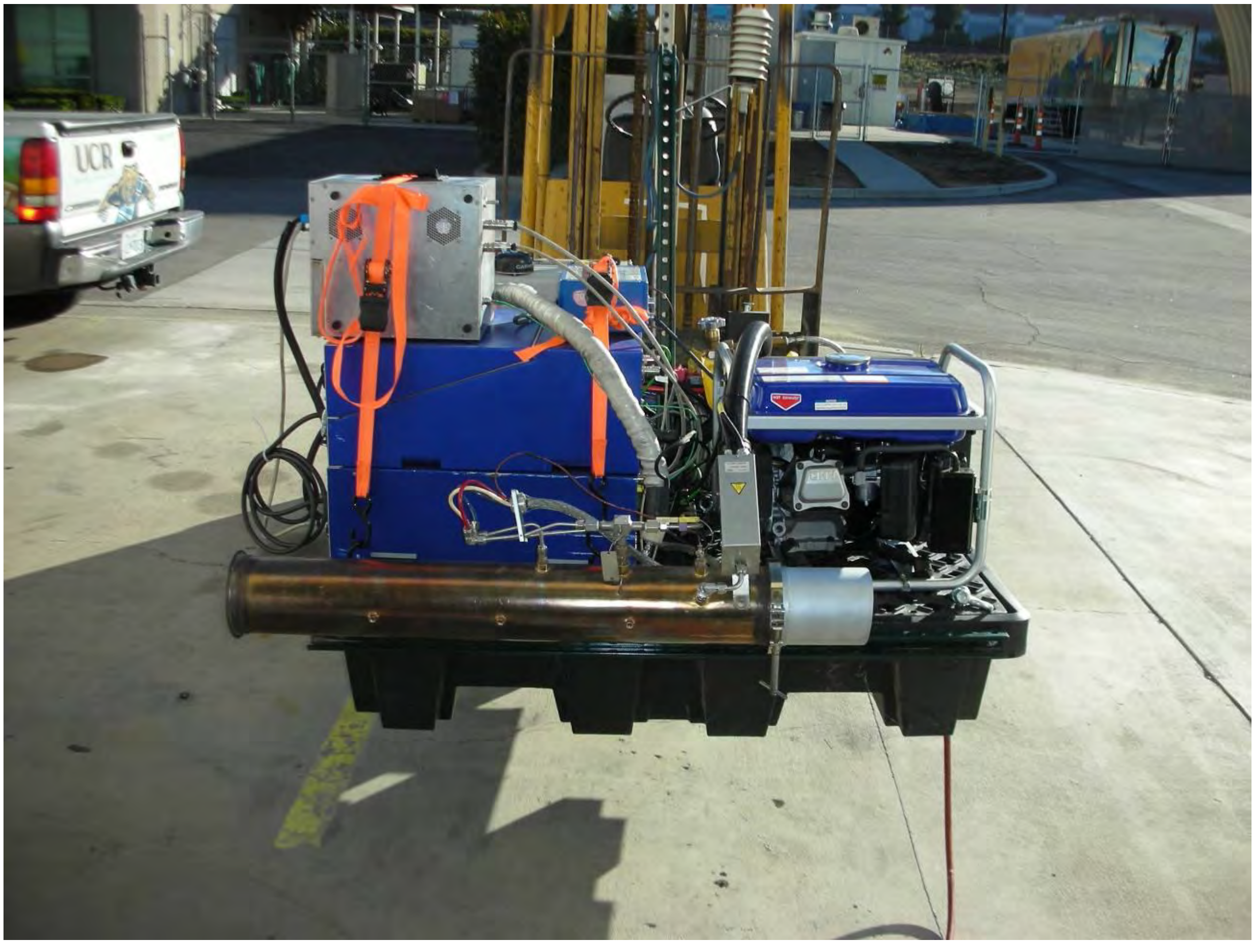


Figure 2-6: Emission analyzers, generator, and flow meter on a 4' by 4' Plastic Pallet

For the last seventeen tests a platform was built from scratch to contain all of the equipment needed for the emissions measurement, except for the Honda generator. Figure 2-7 is of the new platform.

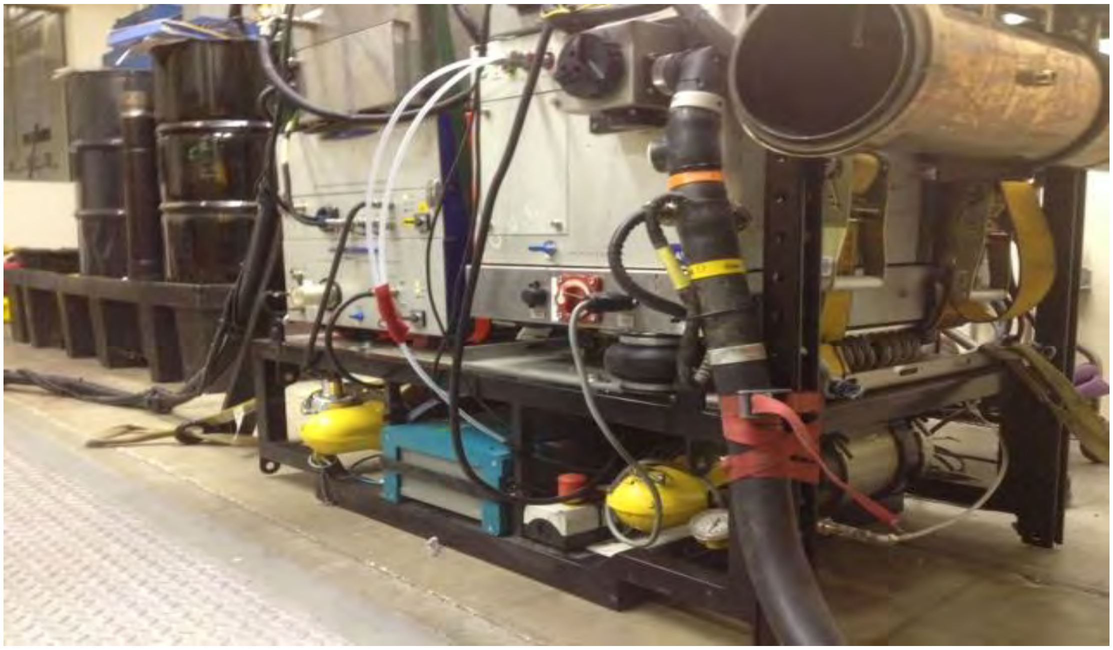


Figure 2-7: Platform with emission measurement equipment used for the last ten tests

Pictures of some of the tested equipment, with the emission measurement analyzers in place, are presented in Figure 2-8 through Figure 2-12.

Figure 2-8: John Deere Backhoe 410J on Vacant Lot in Riverside, California

Figure 2-9: John Deere wheel loader 644J on vacant Lot in Riverside, California

Figure 2-10: John Deere backhoe 410G on vacant lot in Riverside, California

Figure 2-11: Komatsu WA470-6 wheel loader at quarry in Thermal, California

Figure 2-12: Caterpillar D8R Bulldozer in El Sobrante Landfill

2.3 Preliminary Validation Testing

The use of a PEMS system that was complaint with the specification in 40 CFR Part 1065 was an important element of this program. For a PEMS to qualify for use as part of the U.S. Federal Heavy Duty In-Use Testing (HDIUT) program, it must first be approved according to the standards of the U.S. Environmental Protection Agency (EPA). According to the U.S. EPA, all new PEMS must meet various specifications of 40 CFR Part 1065. As part of the preliminary work for this program CE-ERT performed a 40 CFR Part 1065 Subpart D and Subpart J comprehensive audit and evaluation of the AVL's M.O.V.E gas PEMS 493 system. Table 2-1 provides a list of the equipment, serial numbers, firmware, and software evaluated as part of this audit. This audit and evaluation included laboratory audits, comparisons against NIST traceable sources, and engine dynamometer correlation testing, compared against a reference laboratory. In addition, UCR performed two unique in-use comparisons between the PEMS and its mobile reference laboratory utilizing a high NO_x (4.0 g/hp-h) and a low NO_x (< 0.20 g/hp-h) heavy duty on-road vehicle.

Table 2-1: List of instruments evaluated as part of this PEMS 1065 audit and correlation

Manufacturer	Model Name	Description	Serial Number	Firmware Version [1]	Software Version [2]
AVL	M.O.V.E Gas PEMS 493	THC NO/NO_2, CO/CO_2, O_2	008	V1.1.3.371	N/A
AVL	M.O.V.E System Control	Embedded PEMS controller and ECM interface	118	N/A	V2.4 B358 SP2
AVL	Concerto PEMS	PEMS post processing software	N/A	N/A	V4.4b
Sensors Inc.	EFM-HS 5”	High speed exhaust flow meter	E10-SF02/E10-ST06	2012	N/A

[1] The firmware for gaseous PEMS and EFM varied during this project. See upgrades section for description of version changes. The table reflects the latest version as of this writing.
[2] The software versions varied for Concerto and System Control during this project. See upgrades section for description of version changes. The table reflects the latest version as of this writing.

Table 2-2 shows a list of the verifications, checks, and correlations performed on the AVL PEM's system. The Subpart D laboratory verifications included system accuracy, repeatability, linearity, response time, dryer verification, interference checks, and other details. The M.O.V.E.'s PEMS, met all the requirements of Subpart D, as shown by the "PASSED" status in Table 2-2. The successful completion of 1065 Subpart D demonstrates that the AVL PEMS system conforms to the CFR and is in good agreement with traditional CVS laboratory measurements.

In Table 2-2 the numbers in the column labeled Ref# are the sections in 40 CFR Part 1065 subpart D or subpart J. Subpart D (numbers in the 300's) contains instructions and requirements for Calibrations and Verifications. Subpart J (numbers in the 900's) contains instructions and requirements for Field Testing and Portable Emission Measurement Systems. The last two entries in this column, UCR, are for the two unique in-use comparisons noted above. The column labeled Description describes what is being verified, checked, or correlated. The column labeled 1065 Limit provides the standard which must be met. The column labeled Status indicates whether the 1065 Limit was met (PASSED) or was not met (FAILED).

Table 2-2: AVL's M.O.V.E gas PEMS 493 1065 audits and verification results

Ref #	Description	1065 Limit	Status
305	Verifications for accuracy, repeatability, and noise.	< 1.0% - 2.0 %[1]	PASSED
307	Linearity verification	< 1.0% SEE[2]	PASSED
309	Continuous gas analyzer system-response and updating-recording verification—for gas analyzers continuously compensated for other gas species.	Rise/Fall Time < 10 sec	PASSED
315	Pressure, temperature, and dew point calibration	See 1065.307[1]	PASSED
342	Sample dryer verification	$T_{dew,meas} < T_{dew,spec} + 2.0$ °C	PASSED
345	Vacuum-side leak verification	< 0.5 %	PASSED
350	H_2O interference verification for CO_2 NDIR analyzers	0 ± 0.02%	PASSED
355	H_2O and CO_2 interference verification for CO NDIR	0 ± 1.0% of Std.	PASSED
360	FID optimization and verification	0 ± 5.0% of CH_4 RF	PASSED
362	Non-stoichiometric raw exhaust FID O_2 interference	0 ± 2.0% of Ref	PASSED
372	NDUV analyzer HC and H_2O interference verification	0 ± 1.0% of Std.	PASSED
376	Chiller NO_2 penetration	Penetration > 95.0%	PASSED
920,925, 935,940	Engine dyno testing 2.0 g/hp-h NO_x (drift check, NTE check, methods 1,2,3 check)	Valid NTE Point >91%	PASSED
UCR	In-use 4.0 g/hp-h NO_x testing (drift check, NTE check)	Valid NTE Point >91%	PASSED
UCR	In-use 0.20 g/hp-h NO_x testing (drift check, NTE check)	Valid NTE Point >91%	PASSED

[1] Accuracy 2.0% of pt., repeatability 1.0% of pt., Noise 1.0% of Max

[2] more linearization parameters apply

Part 1065 also recommends performing a Part 1065.920 verification. This verification involves engine dynamometer correlation testing with a 1065 approved reference CVS laboratory. The purpose of this test is to audit a new PEMS and compare it to a reference laboratory with an overall "end-to-end" type of check. The reference laboratory used for the correlation was UCR's Mobile Emissions Laboratory (MEL). The MEL is a qualified mobile reference laboratory suitable for performing the gas PEMS comparison validations. The MEL successfully completed a 40 CFR Part 1065 audit for the gaseous and CVS related measurements prior to performing the correlation testing with the AVL PEMS. The MEL was also the validation laboratory used during the federal PEMS MA program, making this correlation directly comparable to previous PEMS studies.

Three correlation exercises were performed as part of this PEMS audit evaluation. One utilized UCR's engine dynamometer (satisfying the 1065.920 test) with a 10.8L 2006 Cummins ISM diesel engine equipped with exhaust gas recirculation (EGR). The bsNO_x certification of this engine is 2.68 g/kWh (2.0 g/hp-h) and represents the same $bsNO_x$ level used during validation of previous PEMS. The other two correlations were conducted on road with the MEL, utilizing a UCR's in-house 2001 Freightliner heavy duty truck and a 2010 compliant SCR equipped low NO_x heavy duty on-road truck. Table 2-3 shows a list of the engines and vehicles tested and their certification ratings. The range of engines tested includes high $bsNO_x$ emissions level at 4 g/hp-h and low $bsNO_x$ at <0.2 g/hp-h. The designed comparisons provide a comprehensive evaluation of the PEMS behavior over a wide range of NO_x operating conditions.

Table 2-3: Engine dynamometer and in-use vehicle test matrix

Test Units	Location	Test Engine	Power Torque	ATS [1]	NO_x Certif. g/hp-h	Number NTE Points
1	Engine Lab	2006 Cummins ISM 10.8L	370 hp 1450 ft-lb	EGR	2.0	150
2	In-Use	2000 Caterpillar C15 15.0L	475 hp 1650 ft-lb	CRT-retrofit	4.0	145
3	In-Use	2011 Cummins ISX 11.9L	425 hp 1650 ft-lb	OEM DOC, DPF, SCR	0.2	174

[1] Diesel oxidation catalyst (DOC), diesel particulate filter (DPF), original equipment manufacturer (OEM), selective catalytic reduction (SCR), exhaust gas recirculation (EGR), continuously regenerative trap (CRT)

The engine dynamometer testing was conducted using a 40 minute duration test cycle where 30 distinct not-to-exceed (NTE) events were generated. This cycle is similar to those used during previous PEMS correlation studies. The NTE cycle was repeated a total of five times for a total of 150 valid NTE test points.

The in-use testing was conducted on three routes similar to those used in Measurement Allowance program. This includes a trip in the local Riverside, CA area, a trip from Riverside, CA to the Coachella Valley, CA and back, and a trip from Riverside, CA to the Coachella Valley, CA and back. Each route was performed once for each vehicle tested, generating around 150 NTE's for each vehicle. The routes represent typical coastal, desert, and city in-use conditions.

The results of these correlations tests were in good agreement with UCR's MEL.

3.0 Data Analysis

3.1 Time alignment

The gaseous emissions and available ECM data were recorded on one computer and the real-time raw PM data was recorded on another computer, so time alignment of the different data streams was an important element of the data analysis. The first step in the data analysis was to determine a reliable method to time align the data. Time alignment was done through an iterative process involving comparisons between the different data streams on a time basis. Initially, alignment was done from a gross perspective by comparing revolutions per minute (RPM) [representing the ECM data], NO (representing the gaseous emissions), and PM raw data. This initial alignment was done by looking for long breaks where PM and other emissions are very low (idle) and then identifying transitions from idle to periods of acceleration. This rough estimate typically provided time alignment that was within 5 seconds or so. Following this initial alignment, further time alignment was done by comparing exhaust flow, RPM, NO, and PM more closely. Other pollutants such as CO and THC were also compared if their concentrations were high enough to provide sufficiently sharp and notable peaks. Once this alignment was completed, the exhaust flow rate was determined based on engine parameters, such as RPM, and this calculated exhaust flow rate was evaluated against the measured exhaust flow rate to ensure they were comparable. Once this was done, the excess AVL data from the bottom of the file was trimmed off. The real-time PM data was then merged into the gaseous emissions data file with the rows merged based upon time alignment. Plots were then made of the raw PM (in mg/m^3) versus the CO (in ppm), NO (ppm), RPM, and exhaust flow rate (scfm) to verify that the time alignment is reasonable. Figure 3-1 through Figure 3-4 show the time alignment for the testing of the John Deere 410J backhoe loader. CO versus raw PM is plotted in Figure 3-4 on a smaller time scale to more clearly show the time alignment obtained using this methodology.

3.2 Correcting PM data

The emissions for THC, CO, NO, and CO_2, the emissions values in gram per second were calculated automatically by the AVL Concerto program using standard calculations based on the pollutant concentration, density, and the exhaust flow rate. For PM, it was important to have total PM mass in units of grams, as PM is generally quantified as mass collected on a filter over the duration of an emissions test for regulatory purposes. The MSS measures the soot concentration in mg/m^3, so these measurements must be converted to total PM mass. Soot is just black carbon, while total PM includes black carbon and heavy organic compounds. The filter in the gravimetric filter box collects an integrated sample of the total PM. The mg/m^3 of the soot can be converted to an integrated soot mass in mg by summing the mg/m^3 and multiplying the sum by the total m^3 of exhaust gases. The soot concentration per second is then multiplied by the ratio of the weight of the PM on the gravimetric filter to the integrated soot mass to obtain PM in mg/m^3•sec.

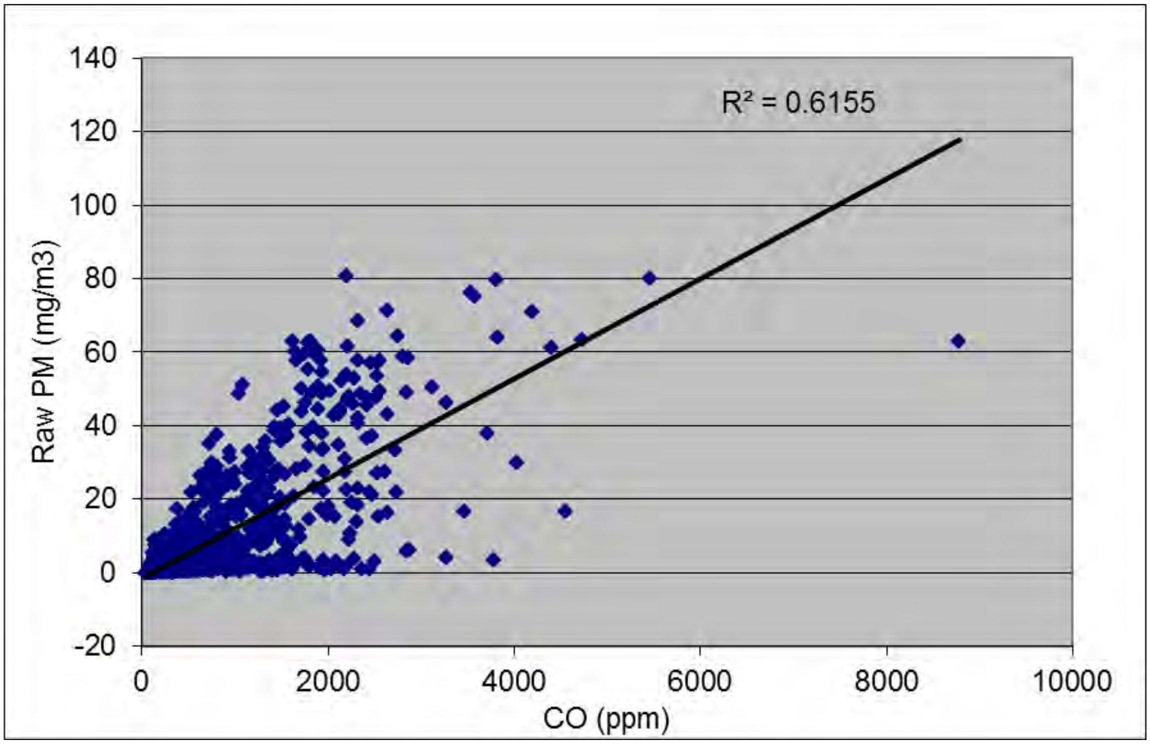


Figure 3-1: Plot of time aligned raw PM versus CO for John Deere 410J

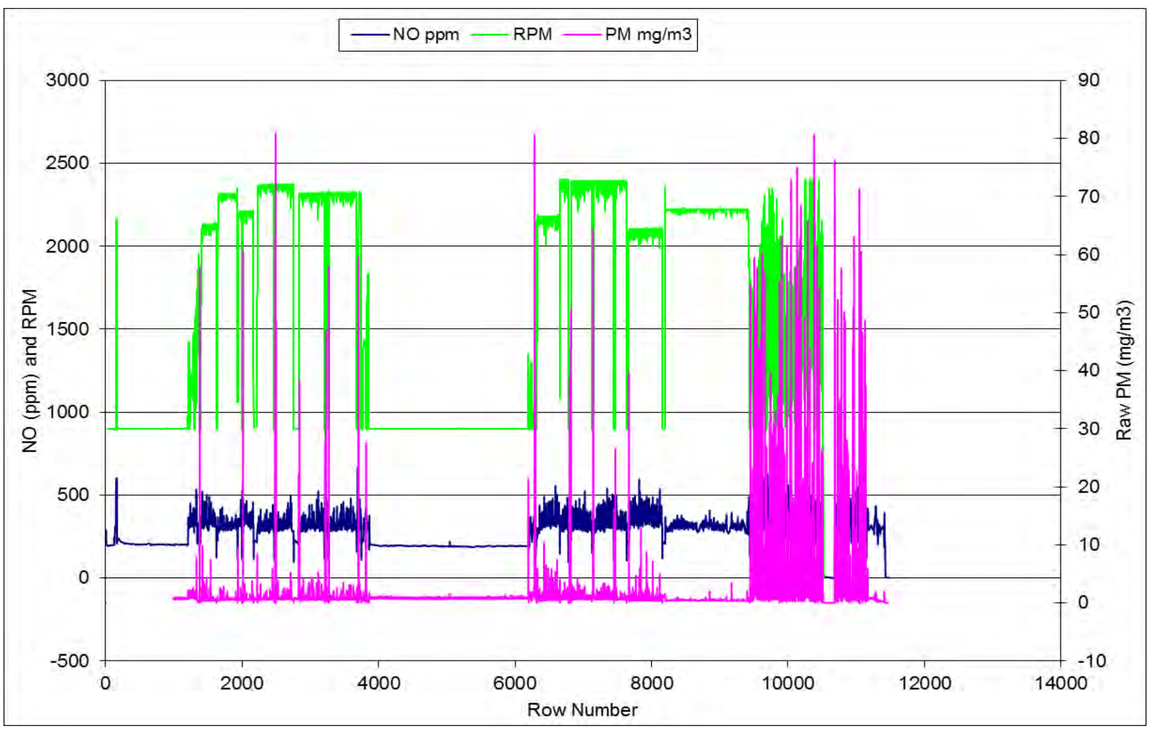


Figure 3-2: Plot of NO, RPM, and PM versus Row Number for John Deere 410J

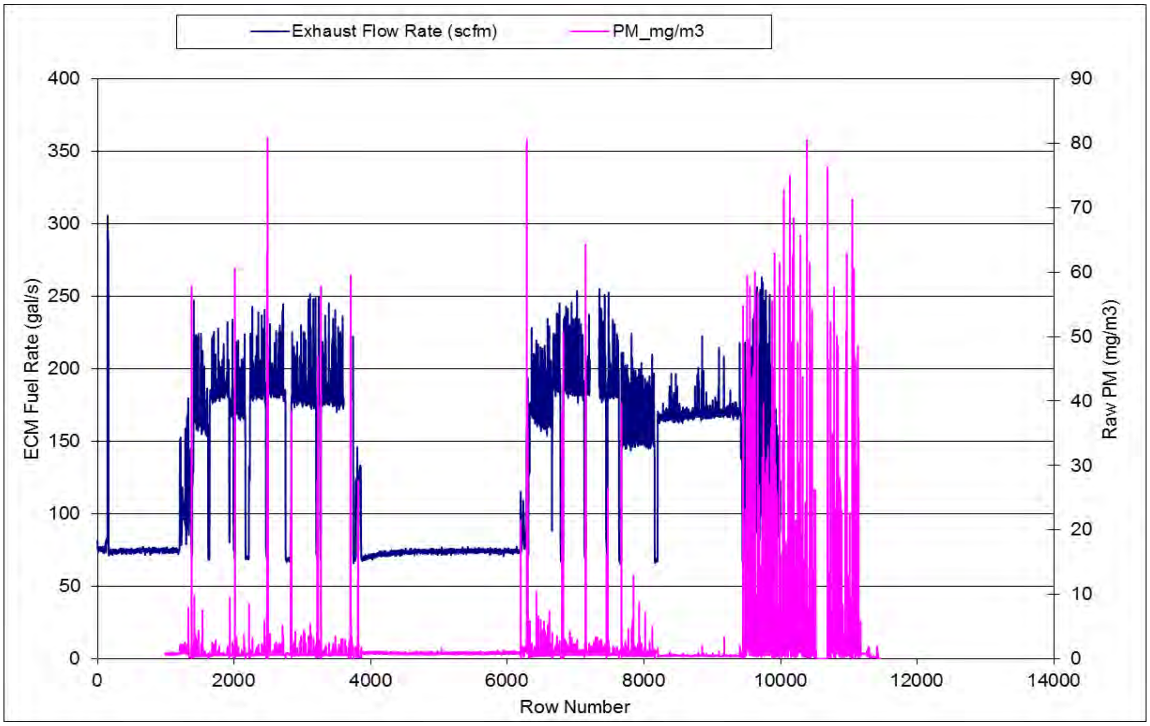


Figure 3-3: Modal exhaust flow rate and raw PM concentration for John Deere 410J

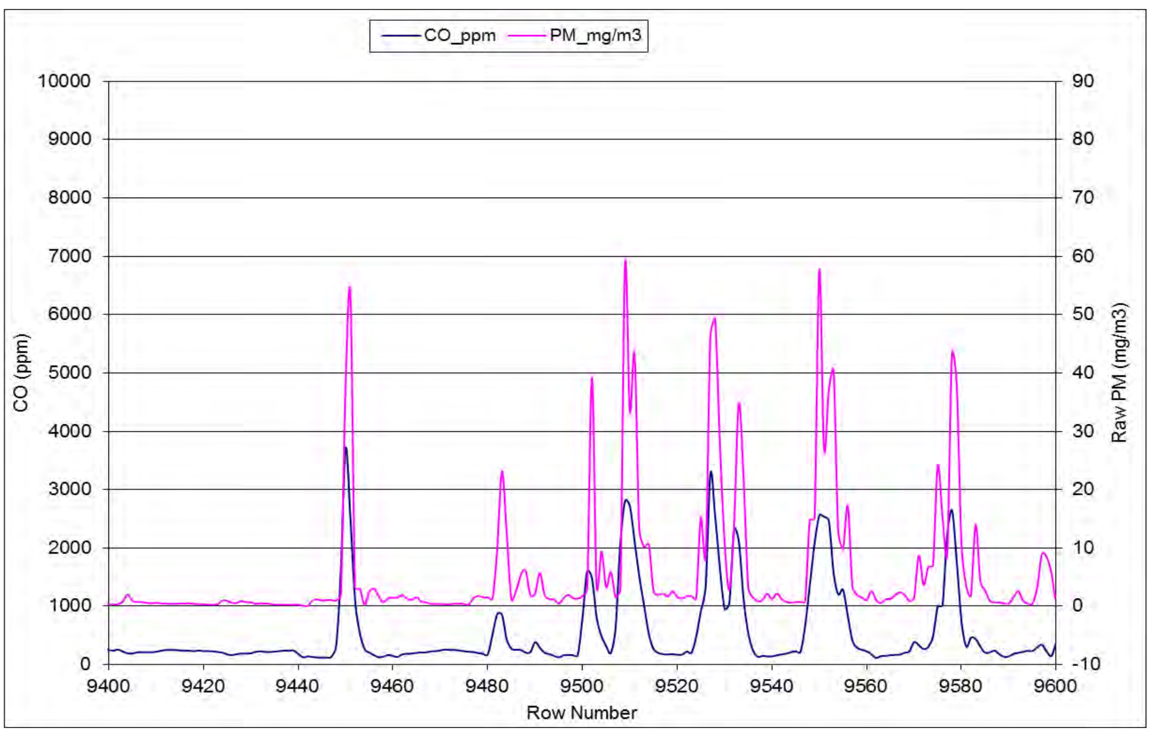


Figure 3-4: Plot of CO and Raw PM versus Row Number for John Deere 410J

3.3 Fuel flow rate

The fuel flow rate can be determined by the carbon balance method from the Sensors and AVL PEMS data and from the ECM, if the latter is available. Past experience has shown there is a high correlation between these two measurements. Figure 3-5 plots the correlation for the John Deere 410J. For consistency the carbon balance fuel flow rate is used for all further calculations. The gal/s fuel flow rate was converted to kg/hr by multiplying the gal/s by 3.221 kg/gal and 3600 sec/hr.

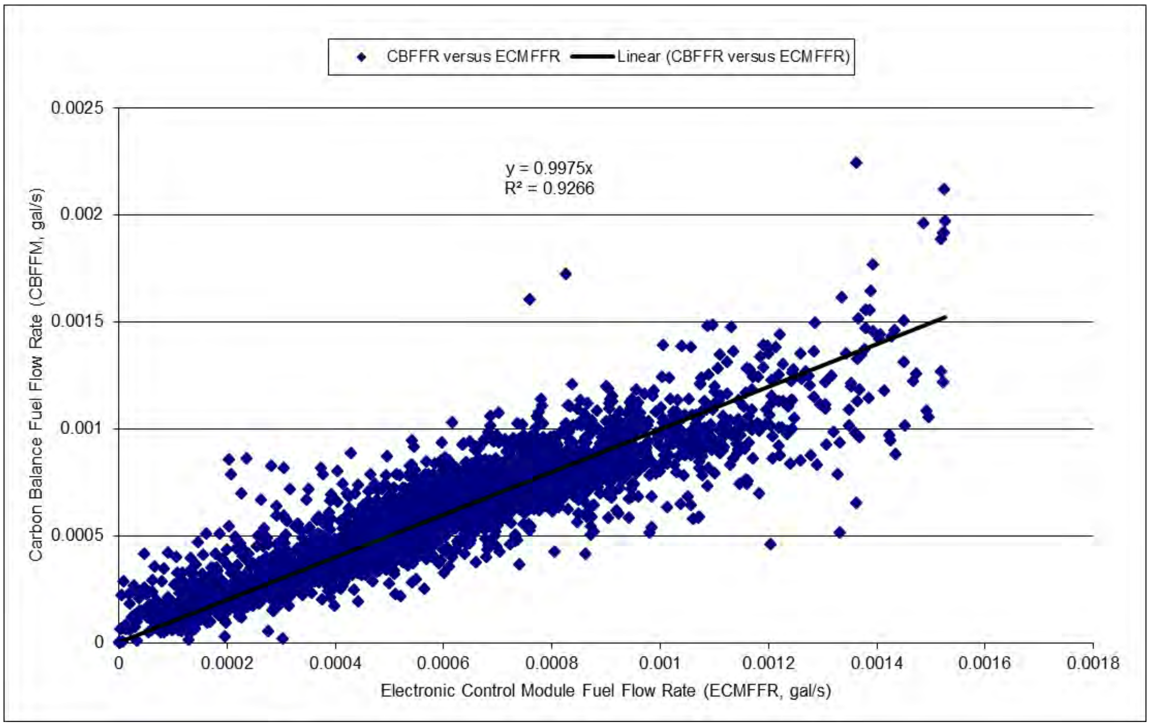


Figure 3-5: Correlation of carbon balance and ECM fuel rate for the John Deere 410J

3.4 Lug curves

To convert the measured emissions to g/hp-h it is necessary to have a lug curve or a brake specific fuel consumption curve and the RPM and the engine load in %. Attempts were made to obtain lug curves for all of the engines tested, but these attempts were not successful in all cases. Since lug curves tend to have a similar shape, a lug curve was estimated for engines where it was not available based on the reported engine rated brake power and rated maximum torque for a given rpm. If engine load was not available on a unit, then engine power was estimated from brake specific fuel consumption. In general, manufacturers report hp and torque from ~1000 or 1200 rpm to ~300 to 400 rpm above the rpm that generates the maximum horsepower. Therefore, the hp was estimated for the rpm's from idle to 1000 or 1200 rpm. All the tests reported in this document utilized a published lug curve and measured percent load and RPM, except for units #6 and #8. Unit 6 was a Komatsu wheel loader that did not report % load and #8 was a Caterpillar excavator that did not have ECM data.

3.4.1 Estimating lug curve from published lug curve

When a lug curve is available, the following method was used to estimate the lug curve for the entire rpm range of the engine:

1. Download the lug curve
    a. Use only brake power values, as other values may be incorrect (e.g., net power, gross power, flywheel power…)
2. Estimate lug curve data from a picture (if digital data not available)
    a. Print out the lug curve as large as possible
    b. Extend the curve from the lowest rpm to the rpm at idle
    c. Use straight edge and right triangle to translate points from RPM to power
    d. Use ruler and divisions to determine HP at each RPM
3. Linearly interpolate between RPM increments using measured RPM
4. Incorporate lug curve into the real-time spreadsheet
5. Verify rated power and peak torque are correctly represented by the lug curve

Figure 3-6 shows a lug curve obtained from the John Deere website, as an example, which applies to the engine in unit #1, a 410J backhoe. A ruler was added to this figure, as shown by the highlighted yellow section of the figure. Figure 3-7 shows the lookup table that was developed for this engine following the above procedure. The blue points in Figure 3-7 represent points that were extrapolated. The highest two points in Figure 3-7 were estimated via extrapolation from the official curve in Figure 3-6.

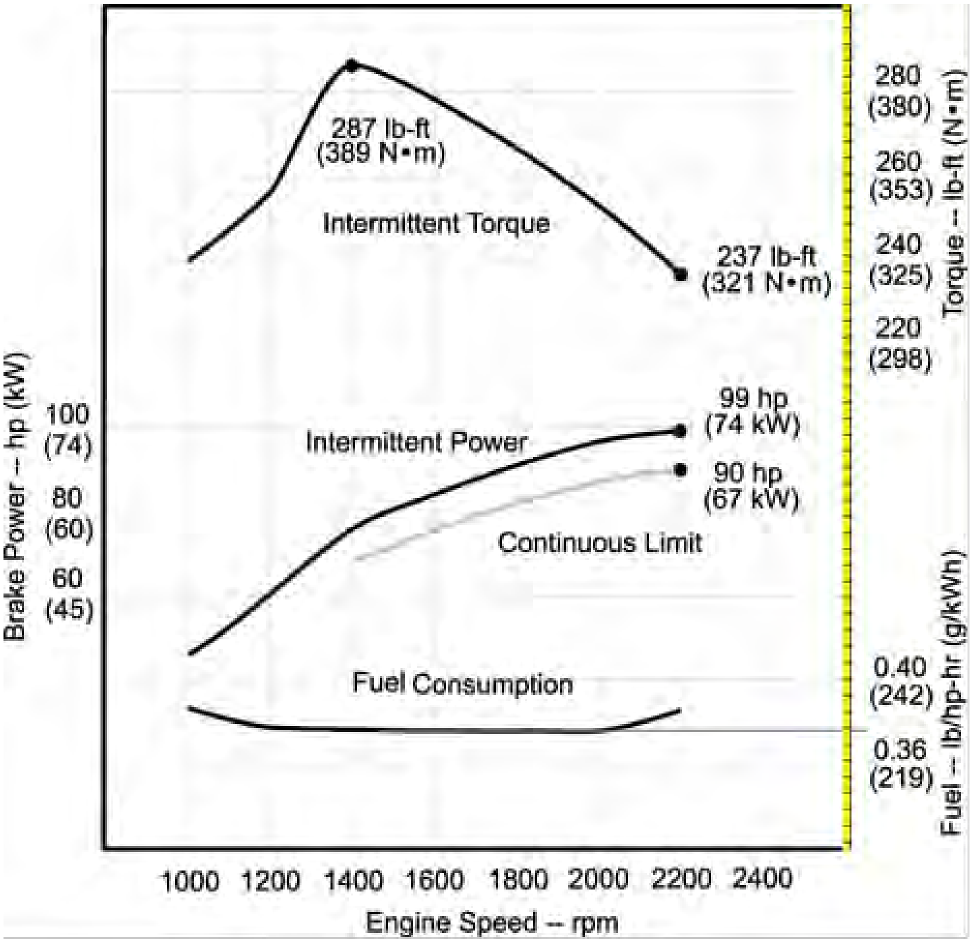
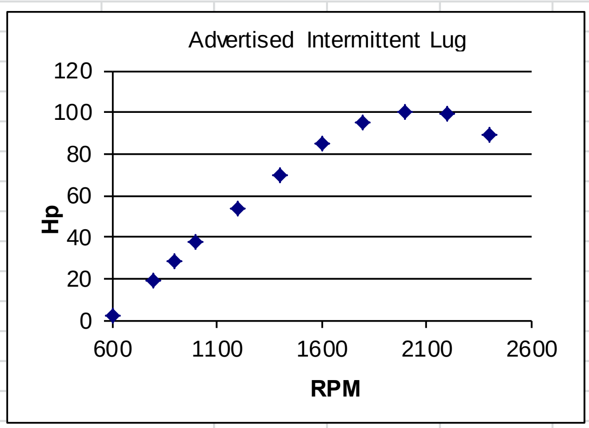


Figure 3-6: Lug curve for the John Deere engine unit #1

RPM	Hp	slope	intercept	% peak
0	0	0.0190	-1.9	0.0%
600	2	0.0864	-49.9	2.0%
800	19	0.0900	-53.0	19.2%
900	28	0.1000	-62.0	28.3%
1000	38	0.0800	-42.0	38.4%
1200	54	0.0800	-42.0	54.5%
1400	70	0.0750	-35.0	70.7%
1600	85	0.0500	5.0	85.9%
1800	95	0.0250	50.0	96.0%
2000	100	-0.0050	110.0	101.0%
2200	99	-0.0500	209.0	100.0%
2400	89	-0.0900	305.0	89.9%
2500	80			



[1] real time data is interpolated from this lug curve using a linear regression betw een RPM's

[2] colored data is estimed due to limitations of provided lug curves

Figure 3-7: Lookup table for determining power of a John Deere 410J engine[1,2]

For each RPM value, the Vlookup function was used to determine the maximum Hp from the table in Figure 3-7. This value was multiplied by the engine %load divided by 100 to determine the actual power for the given RPM and engine %load.

The published bsFC curve provided for unit #1 allows the accuracy of using a lug curve to calculate power to be evaluated. The measured bsFC, via carbon balance and the lug curve, showed a bsFC rate of 256 to 252 g/kWhr for the two working activities and 384 g/kWhr for idle, see Appendix 8.0, Table 1 through Table 27. The manufacturers maximum power rated bsFC is 228 g/kWhr from 1200 to 2000 RPM, see Figure 3-6. Idle bsFC was not available from the published curve. The in-service measured bsFC was 10% higher than the published maximum load bsFC curve. The higher measured bsFC is reasonable given the published value is based on ideal steady state maximum power conditions, while the measured bsFC is based on in-use transient behavior. This shows an independent check that the published lug curve approach is reasonable for estimating brake specific emissions.

The engine in units 13 through 20 utilized the CAT ACERT 6.6 liter engine. Three lug curves were available for this engine, as shown in Figure 3-8. Unfortunately, for these engines the ECM down loads did not provide details on the actual rated power and peak torque to verify the correct curve to use. The curves were selected based on reported rated power. The lug curve used for units 13 through 18 was #hP2 and 19 and 20 used #hP3. All the final $bsCO_2$ numbers were between 550 and 650 g/kWhr, see Appendix 8.0, Table 1 through Table 27. The idle emissions were mostly high > 800 g/kWhr. As such, the reasonable $bsCO_2$ results suggest the selected lug curves are reasonable.

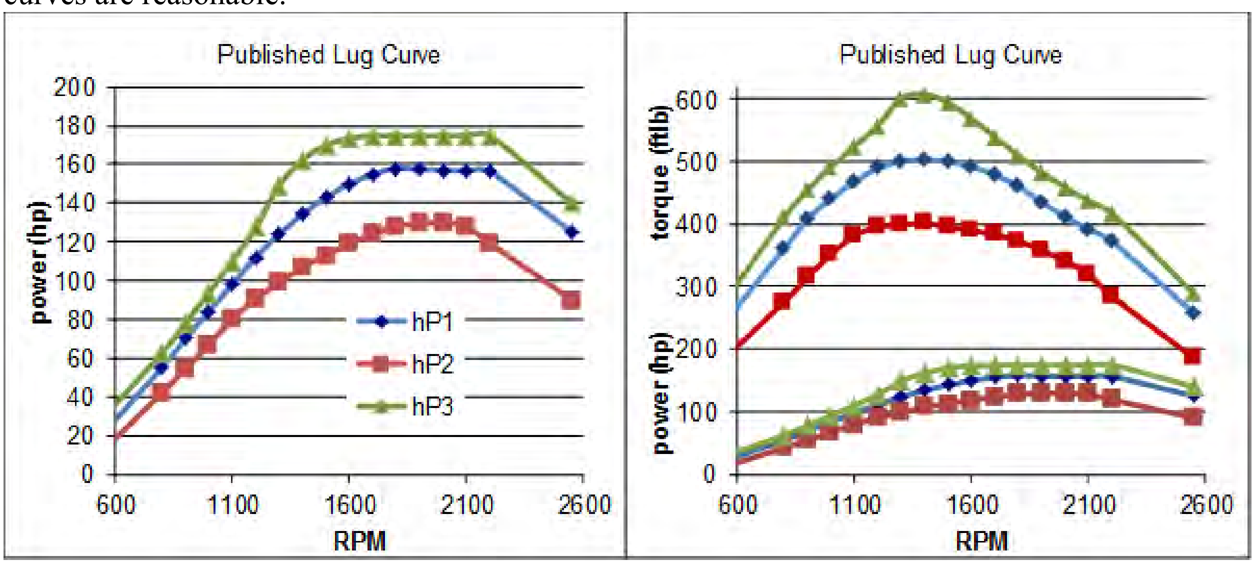


Figure 3-8 Caterpillar ACERT 6.6 liter engine published lug curve.

3.4.2 Estimating lug curve from rated power and peak torque

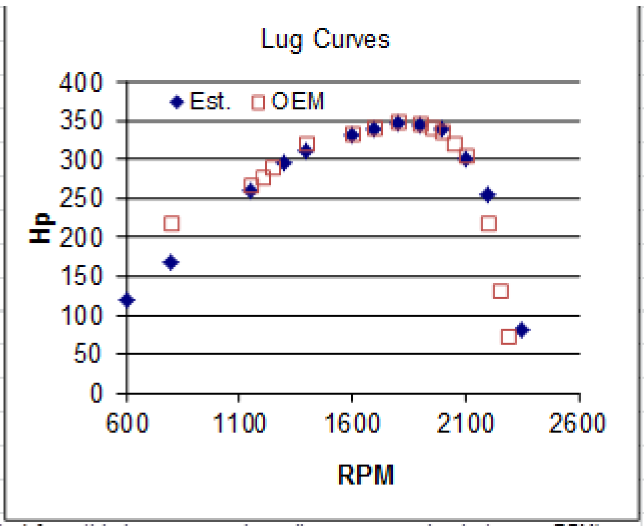
When a lug curve is not available, the following method is used to estimate the lug curve from engine rated power and peak torque at specific engine speeds (RPM):

1. Acquire brake power and break peak torque at specific RPM's
   a. 1st choice is to get the ratings from the ECM due to calibration variations
   b. 2nd choice is to get this from the engine name plate
   c. 3rd choice is to get the results from published material on the engine

   d. 4th choice is to get the results from the equipment brochures (being careful of values described as gross, net, flywheel, or peak terms)
2. Calculate power at maximum brake torque and engine speed
3. Use rated power and maximum torque power for two points to start the lug curve
4. Utilize the shape of a lug curve from a different engine, but a similar mfg. and application
5. Fill in the points to get a curve that has a reasonable shape
6. Evaluate the bsFC or $bsCO_2$ of the curve

A lug curve was prepared for the D8R (unit #12) and compared to the published curve to evaluate the accuracy of the estimated lug curves. Figure 3-9 shows the published lug curve and the lug curve estimated from rated power and peak torque power. The published and estimated lug curves are nearly identical for the range of RPM from 1100 to 2100, where rated power was at 2100 RPM and peak torque was at 1300 rpm. The close agreement provides support for the UCR estimated lug curve approach. The published lug curve was used for the results presented in this document.

RPM	Hp	Torque
0	0	
600	118	1032.9
800	168	1102.9
1150	259	1182.8
1300	297	1199.9
1400	310	1162.9
1600	332	1089.8
1700	338	1044.2
1800	348	1015.4
1900	345	953.7
2000	338	887.6
2100	300	750.3
2200	255	608.8
2350	80	178.8



[1] real time data is interpolated from this lug curve using a linear regression between RPM's

[2] colored data is estimed due to limitations of provided lug curves

Figure 3-9 Lug curve used for the Caterpillar D8R bulldozer 3406E engine (unit #12)

3.4.3 Estimating lug curve from brake specific fuel consumption

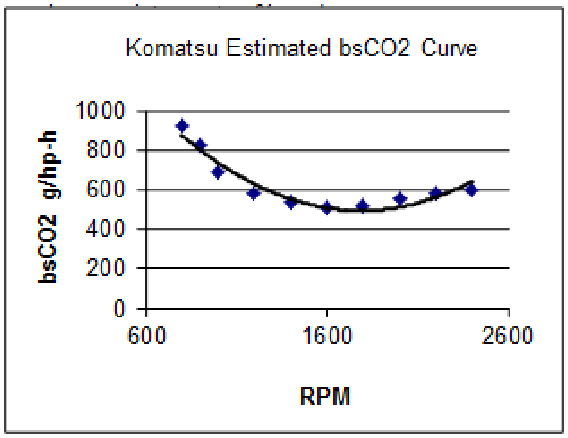
For the Komatsu WA470 wheel loader (unit #6) a manufacturer's lug curve could not be obtained and we were not successful in reading the engine percent load. To provide brake specific emissions, the power was calculated from estimated brake specific CO_2 values. The approach was as follows:

1. Acquire a reasonable maximum brake specific fuel consumption versus RPM curve
   a. Typically this is not easy to find and this needs to be estimated
   b. Next, if possible, get maximum bsFC from the engine name plate or ECM
   c. If maximum bsFC is not available, then utilize a nominal value, such as 230 g/kWhr bsFC for a Tier 3 200 to 300 hp engine

   d. A shape was applied to the curve, whereby the bsFC at 800 RPM was twice the value at the rated speed and the bsFC at the max speed was 50% greater than the value at rated speed.
2. Calculate the mass of fuel used from the carbon balance method
3. Linearly interpolate max load bsFC between 1000 RPM increments using measured RPM
4. Divide the measured carbon balance fuel rate by the interpolated max load bsFC to get brake power
5. Evaluate the resulting carbon balance bsFC and $bsCO_2$ results

For step 1, a reasonable bsFC curve looks like the one in Figure 3-10, where the bsFC is lowest from peak torque speed to rated power speed (1200 to 2000 rpm) then increases above rated speed and below peak torque.

RPM	bsCO2
0	0
600	1100
800	920
900	820
1000	690
1200	580
1400	540
1600	510
1800	520
2000	550
2200	580
2400	600
2500	700



[1] real time data is interpolated from this bsFC curve using a linear regression between RPM's
[2] all data is provided with good engineering judgetment for minimum bsCO2 at each RPM point

Figure 3-10: Fuel based $bsCO_2$ curve for Komatsu WA470 2009 Tier 3 engine[1,2]

An estimated lug curve from this bsFC method was utilized for the Komatsu engine. This approach was evaluated and the resulting $bsCO_2$ varied from 549 to 579 g/hp-h with an average of 565 g/hp-h while loading material and around 838 g/hp-h for idle, see Appendix 8.0, Table 1 through Table 27. The measured bsFC varied from 235 to 240 g/kWhr, which is a reasonable result for diesel engines. These are in good agreement with previous tests suggesting the estimated bsFC curve in Figure 3-10 provides a good approximation.

It should be noted that brake specific emissions are not as accurate as the time specific or fuel specific emissions. The brake specific emissions are based on ECM percent load and available lug curves. The percent load and lug curves are not based on NIST traceable measurements like emissions and exhaust flow. The percent load and lug curves have associated uncertainties that vary by unit tested. The brake specific emissions should be relatively accurate and are probably within 10% to 20% of a laboratory measurement (depending on load percent), where the gaseous emissions are expected to be within 5% of the standard and PM within 10% of the standard based on UCR's comparison analysis and the remainder of the uncertainty is due to the inaccuracy in the load percent (Johnson et al. 2010; Miller et al. 2007, 2008). For more details on the PEMS accuracy relative to a reference laboratory see Section 2.3.

3.5 Work

For construction equipment, two different types of work were defined: (1) the work which the equipment is performing, i.e., digging, moving, idling, pushing, etc., which we designate as A-work and (2) the work which the engine is performing, which we designate as E-work, which is expressed as horsepower. During the emission measurements, CE-CERT personnel were always on-site videotaping the construction equipment as it performed its tasks and taking notes. From this information we were subsequently able to assign start and stop times for specific A-work within segments of the continuous emission and engine data. For these specific segments, the fuel consumption in kg/hr, engine work in hp, the emissions in g/hr, the emissions in g/kg-fuel, and the emissions in g/hp-h could then be calculated.

3.6 Data collection and reduction

The integrated analysis presented in Section 4.0 is based on the total available valid data. Some data was eliminated such as during PEMS hourly zero's, spans, issues with the ECM drop out or connection loss. All reported data has been validated and is presented in its calibrated and audited form using good engineering practices for calibrations, drift validations, and post-test calibration checks.

This section describes the data collected for each unit. Each testing campaign was targeted to collect the maximum amount of data. Typically CE-CERT would start at 4:00 AM for the installation and then start sampling by around 7:00 AM. The team would collect data through lunch and into the end of the shift at around 3:00 PM. The sample collection time varied, but was typically around five to six hours.

Table 3-1 lists the total valid data utilized for the integrated real-time regression analysis. The data collection durations varied from six hours to just under one hour with an average of about 3.5 hours for the 27 units tested, see Table 3-1.

Table 3-1 Total data used in the integrated and modal regression analysis

Unit ID	Total Data		Unit ID	Total Data	
	rows	hrs		rows	hrs
1_410J	9882	2.75	14_928Hz	14048	3.90
2_310SJ	11601	3.22	15_120M	15146	4.21
3_644J	11431	3.18	16_120M	13352	3.71
4_310SG	12141	3.37	17_120M_DPF	12198	3.39
5_410G	14125	3.92	18_928Hz	12221	3.39
6_WA470-6	7598	2.11	19_613G	11755	3.27
7_928G	11353	3.15	20_928Hz	12283	3.41
8_345D	n/a	n/a	21_D6T_JM	11779	3.27
9_637E	5957	1.65	22_D7E_WM	10332	2.87
10_637E	2440	0.68	23_D8T-JM	19391	5.39
11_EC360B	11019	3.06	24_D6T_OC	15911	4.42
12_D8R	20917	5.81	25_D7E_OC	7370	2.05
13_120M	15622	4.34	26_PC200	17462	4.85
			27_HB215	15811	4.39

Results – Section 4 and 5

Introduction

The presentation of project results is divided into two main sections:

Section 4 - Overall summary results and discussion

Section 5 - Power-based data analyses results and discussion

Section 4 contains summary results for each of the 26 units tested, with results presented on a by-unit basis, using three different metrics (described in Section 4), while Section 5 contains results from a 'power-based' emissions data analysis that compares real-time (second-by-second) pollutant emissions against real-time engine power.

4.0 Results and Discussion – Overall Summary

4.1 Introduction – Reporting Emissions Results

Results from emissions testing off-road equipment are usually expressed in units of grams of pollutant per horsepower-hour (or per kilowatt-hour) of work done by the engine - the reporting units for certification purposes. But emissions can also be expressed in units of grams of pollutant per hour (g/hour), or, in units of grams of pollutant per kilogram of fuel consumed (g/kg-fuel). In this report, for comparative purposes, emissions results will be reported using all three metrics.

The results presented in units of g/hp-hr are for a 'high level' comparison against the certification standards. However, it should be noted that in contrast to the 8-mode steady-state engine dynamometer certification test cycle for new diesel off-road engines, actual in-use engine/equipment operation is highly transient, with rapid and repeated changes in engine speed and load. In addition, the average engine 'load factors' (a measure of how hard the engine is working) can be different than the certification test cycle load factor. Thus, results are not expected to be directly comparable to the certification test results, but nevertheless provide an indication of how emissions from actual, in-use diesel engines compare against their new engine certification standards.

4.2 Fleet Description

Emission measurements were made for the following equipment: four backhoes, six wheel loaders, four excavators, three scrapers (one with two engines tested), six bulldozers, and four graders. Properties of the tested equipment are listed in Table 4-2.

The operation of the backhoe that was tested included digging with the backhoe and/or the front end shovel, filling in the holes with the front end shovel, idling, and general moving around from place to place. For the wheel loaders, the primary activity for 3 was to load gravel or rocks into a truck bed, while 2 were primarily digging (one also did some filling), and 1 was primarily cleaning and smoothing the shoulder of a road, much like a road grader. The wheel loaders also had periods of idling or moving around. One excavator had emissions measured during digging, moving around, and idling, one had limited emission data for loading and idling, and the last two were part of a designed study including travel, trenching with various arm swings, backfilling, dressing, and idling. The emissions data for the second excavator was limited because the boot connecting the exhaust stack to the Sensors flow meter failed so the emissions were not captured after the first 90 minutes of operation and UCR's team was unable to gain access to the equipment due to in-revenue service operation.

Three scrapers were tested for this program. One scraper was working near a landfill scraping up dirt to cover the trash. This scraper had a front engine that is used to move the machine around and a back engine that operates the machinery that scrapes the dirt up into the bowl. The second scraper had a single engine and a hopper that is lowered so that the front edge cuts into the soil like a plane forcing the soil into the hopper. The bulldozers tested were working in a landfill or in a riverbed so their operation included idling and pushing trash and/or dirt. The graders were all used for grading (scraping) dirt roads so their operations included idling, moving, and grading.

Table 4-1 shows the off-road certification values as a function of model year (MY), Tier, and power rating. NMHC represents the non-methane hydrocarbon measurements, which are obtained by subtracting CH_4 from THC, as per CFR Part 1065. Most PEMS do not measure CH_4 (as done here), so NMHC is calculated as 0.98*THC per 1065 PEMS testing. The NMHC+NO_x certification value was reduced between Tier 2 and Tier 3 engines. NMHC represent as small part of the NMHC+NO_x standard. The split between Tier 2 and 3 occurs roughly around MY 2007. Seven of the 27 units tested were Tier 2, 15 were Tier 3, and 5 were Tier 4 interim (or Tier 4i). Four of the units tested were 50 to 100 hp, ten were 100 to 175 hp, nine were 175 to 300 hp, two were 300 to 450 hp, and two were 450 to 600 hp. The CO emission standard doesn't change between Tier levels, but changes between power ratings from 3.7 g/hp-h to 2.6 g/hp-h. The Tier 4i units were all equipped with diesel particle filters (DPFs). Note that no Tier 1 or Tier 0 engines were tested in this program.

Table 4-1 Off-road certification standards for selected tier and engine power ratings [1]

			CERT Standards (g/hp-h)		
hp	Tier	Year	CO	NMHC+NO_x	PM
75 to 101	2	2004 - 2007	3.7	5.6	0.30
75 to 101	3	2008+	3.7	3.5	0.30
101 to 174	2	2003 - 2006	3.7	4.9	0.22
101 to 174	3	2007+	3.7	3.0	0.22
174 to 302	2	2003 - 2005	2.6	4.9	0.15
174 to 302	3	2006+	2.6	3.0	0.15
174 to 302	4i	2011 or 2012	2.6	3.0	0.015
302 to 449	2	2001 - 2005	2.6	4.8	0.15
302 to 449	4i	2012	2.6	3.0	0.015
449to 603	2	2001 - 2005	2.6	4.8	0.15
449 to 603	3	2006+	2.6	3.0	0.15

[1] Certification standards as per 40 CFR

Table 4-2: Off-road equipment tested during in-use operation

Test Count	Date Tested	UCR Name ID	Equipment Owner	Equipment Type	Engine Mfg	Model	Year	Tier	Engine Family	Engine Model	Rated Power (bhp)	Rated Speed (RPM)	Engine Hours	Lug Curve	Percent Load
1	12/03/10	1_410J	RDO	Backhoe	Deere	410J	2007	2	7JDXL04.5062	4045TT095	99	2200	1182	Published	yes
2	12/07/10	2_310SJ	RDO	Backhoe	Deere	310SJ	2010	3	AJDXLO6.8106	4045HT054	99	2250	242	Published	yes
3	12/08/10	3_644J	RDO	Wheel loader	Deere	644J	2007	3	7JDXL06.8101	6068HDW69	225	2200	1735	Published	yes
4	12/09/10	4_310SG	RDO	Backhoe	Deere	310SG	2006	2	6JDXL04.5062	4045TT089	92	2300	2599	Published	yes
5	12/10/10	5_410G	RDO	Backhoe	Deere	410G	2006	2	6JDXL04.5062	4045TT093	99	2200	946	Published	yes
6	02/09/11	6_WA470-6	Riverside County	Wheel loader	Komatsu	WA470-6	2009	3	9KLXL11.0DD6	SAA6D125E-5	273	2000	900	bsFC Curve	no
7	02/10/11	7_928G	Riverside County	Wheel loader	Caterpillar	928G	2004	2	n/a	3056E	156	2300	2294	Published	yes
8	3/17/2011	8_345D	Sukut	Excavator	Caterpillar	345D	2008	3	n/a	C13	520	2100	tbd	none	no
9	4/20/2011	9_637E	Riverside County	Scraper	Caterpillar	637E	2006 (Rebuild)	2	n/a	C9 637D	280	2200	>10000	Published	yes
10	04/21/11	10_637E	Riverside County	Scraper	Caterpillar	637E	2006 (Rebuild)	2	n/a	C15 IND (LHX14568)	540	2100	>10000	Published	yes
11	05/04/12	11_EC360B	Waste Management	Excavator	Volvo	EC360B	2006	3	6VSXL12 .1CE3	D12DEBE3	269	1700	5233	Published	yes
12	05/14/12	12_D8R	Waste Management	Bulldozer	Caterpillar	D8R	2003	2	3CPXL14.6ESK	3406E	338	2000	17149	Published	yes
13	10/16/12	13_120M	Riverside County	Grader	Perkins	120M	2008	3	8PKXL06.6PJ1	C6.6	163	2200	3815	Published	yes
14	10/17/12	14_928Hz	Riverside County	Wheel loader	Caterpillar	928Hz	2011	3	APKXL06.6PJ2	C6.6	171	2200	289	Published	yes
15	10/18/12	15_120M	Riverside County	Grader	Caterpillar	120M	2010	3	APKXL06.6PJ1	C6.6	163	2200	1308	Published	yes
16	10/22/12	16_120M	Riverside County	Grader	Perkins	120M	2008	3	8PKXL06.6PJ1	C6.6	163	2200	2706	Published	yes
17	10/23/12	17_120M_DPF	Riverside County	Grader	Caterpillar	120M_DPF	2010	3	APKXL06.6PJ1	C6.6	168	2200	952	Published	yes
18	10/29/12	18_928Hz	Riverside County	Wheel loader	Caterpillar	928Hz	2011	3	APKXL06.6PJ2	C6.6	171	2200	345	Published	yes
19	10/30/12	19_613G	Riverside County	Scraper	Caterpillar	613G	2010	3	APKXL06.6PJ1	C6.6	193	2200	439	Published	yes
20	10/31/12	20_928Hz	Riverside County	Wheel loader	Caterpillar	928Hz	2011	3	APKXL06.6PJ2	C6.6	171	2200	242	Published	yes
21	11/13/12	21_D6T_JM	Johnson Machinery	Bulldozer	Caterpillar	D6T	2012	4i	CCPXL0903HPB	ACERT C9.3	223	2000	24	Estimated	yes
22	12/04/12	22_D7E_WM	Waste Management	Bulldozer	Caterpillar	D7E	2011	4i	BCPXL09.3HPA	ACERT C9.3	296	2200	296	Estimated	yes
23	12/06/12	23_D8T-JM	Johnson Machinery	Bulldozer	Caterpillar	D8T	2012	4i	CCPXL15.2HPA	ACERT C15	316	2000	32	Estimated	yes
24	12/11/12	24_D6T_OC	Orange County	Bulldozer	Caterpillar	D6T	2012	4i	CCPXL0903HPB	ACERT C9.3	223	2000	44	Estimated	yes
25	12/12/12	25_D7E_OC	Orange County	Bulldozer	Caterpillar	D7E	2011	4i	BCPXL09.3HPA	ACERT C9.3	296	2200	589	Estimated	yes
26	03/01/13	26_PC200	Diamond D	Excavator	Komatsu	PC200	2007	3	7KLXL0409AAC	SAA6D107E-1	155	2000	2097	Published	yes
27	02/28/13	27_HB215	Diamond D	Excavator	Komatsu	HB215	2012	3	BKLXL0275AAG	SAA4D107E-1	148	2000	245	Published	yes

4.3 Fleet Summary Results

The overall results for the 27 units tested are presented in Table 4-3 and a detailed summary with A-work analysis for each unit is tabulated in Appendix 8.0, Table 1 through Table 27. The results in Table 4-3 are sorted by model year (MY) where oldest is first. The first four columns of Table 4-3 list the engine MY, engine tier, engine hours, and a unique test ID. The unique test ID allows one to cross reference engine and equipment specific information provided in Table 4-2. Note that the unit number from the unique test ID is based on the chronological order in which the unit was tested. Columns 5 through 8 contain the average carbon balance fuel rate in kg/hr, the engine power in bhp, the engine percent load in %, and the engine speed in RPM, respectively. Columns 9 thru 13 contain time specific emissions in g/hr. Columns 14 thru 18 contain fuel specific emissions in g/kg-fuel. Columns 19 thru 23 contain brake specific emissions in g/hp-h.

Six sub sections are presented that provide a combined analysis of the 27 units tested on three different emissions basis. In each section there are three figures showing the time specific, fuel specific, and brake specific emission factors between each unit tested. The data in the figures are sorted by MY to allow direct comparison to emissions certification year. The older MY units are to the left and the newer MY units are to the right.

It should be noted that valid work values were not obtained for unit 8_345D, as such no brake specific emission values are available for that unit for any of the emissions components. There also was an issue with the connection to the exhaust flow meter, so only approximately 30 minutes of data are available on this unit. Nevertheless, observation of the unit throughout the work day indicated that this unit was repeating the same operation throughout the full work day, so the data on a g/hr and g/kg of fuel represent valid measurements.

It should be noted that all comparisons to certification standards do not include in-use compliance margins, allowances, or engine aging factors. While these factors have been developed for on-road vehicles, compliance margins and allowances are still being developed for off-road engines. Additionally, these factors may not be applicable to pre-2011 off-road engines. As such, comparisons of the data in this report were made to certification values based on engine dynamometer tests.

Table 4-3 Overall emissions summary for each of the 27 units tested (sorted by MY)

MY	Tier	Hours	Unit ID	Fuel [2]	Power [3]	eLoad	eSpeed	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel)					Brake Specific Emissions (g/hp-h)				
	Level		#	kg/hr	bhp	%	RPM	kg CO2	CO	NOx	THC	PM [5]	CO2	CO	NOx	THC	mg PM [5]	CO2	CO	NOx	THC	mg PM [5]
2003	2	17149	12_D8R	29.6	214.5	72.8	1744	93.3	145	798	20.8	28.4	3152	4.9	27.0	0.70	961	435	0.68	3.72	0.10	133
2004	2	2294	7_928G	8.3	42.4	29.8	1377.2	26.5	90.1	205	11.9	5.6	3192	10.9	24.7	1.4	670	624	2.12	4.8	0.28	131
2006	2	2599	4_310SG	5.9	33.7	40.4	2066	18.8	51.0	175	10.8	4.2	3184	8.7	29.7	1.84	719	557	1.51	5.19	0.32	126
2006	2	946	5_410G	7.3	38.8	44.2	1865	23.1	76.6	193	24.9	4.9	3188	10.6	26.7	3.43	677	596	1.97	4.99	0.64	126
2006	2	10000	9_637E[1]	25.9	161.3	61.1	1596	81.8	493	288	45.7	20.7	3164	19.1	11.1	1.77	804	507	3.06	1.78	0.28	129
2006	2	10000	10_637E[1]	38.3	274.6	54.5	1631	121.2	518	535	27.0	38.1	3164	13.5	14.0	0.71	996	441	1.88	1.95	0.10	139
2006	3	5233	11_EC460B	25.1	134.5	55.0	1650	78.9	124	384	28.8	36.9	3142	5.0	15.3	1.15	1515	587	0.93	2.86	0.21	274
2007	2	1182	1_410J	5.0	25.8	32.6	1712	15.9	64.9	138	17.5	4.0	3167	12.9	27.4	3.50	794	615	2.51	5.33	0.68	154
2007	3	1735	3_644J	14.6	81.2	41.0	1665	46.4	236	365	6.6	10.4	3181	16.2	25.0	0.45	713	572	2.91	4.50	0.08	128
2007	3	2097	26_PC200	12.0	69.0	49.2	1663	37.8	69.3	183	11.7	7.5	3150	5.8	15.3	0.98	628	547	1.00	2.65	0.17	109
2008	3	tbd	8_345D[4]	28.4				90.0	502	487	18.3	63.4	3169	17.7	17.1	0.64	2230					
2008	3	3815	13_120M	10.6	51.8	34.1	1668	33.2	108	220	15.3	18.9	3141	10.2	20.8	1.45	1792	641	2.08	4.24	0.29	365
2008	3	2706	16_120M	8.4	45.0	32.2	1525	26.1	137	162	11.8	22.1	3123	16.3	19.3	1.41	2649	581	3.04	3.59	0.26	491
2009	3	900	6_WA470-6	15.5	87.1		1296	49.4	296	450	9.7	7.3	3182	19.1	29.0	0.63	4731	567	3.39	5.16	0.11	84.2
2010	3	242	2_310SJ	8.6	45.3	52.3	1718	27.4	62.2	152	10.9	4.4	3178	7.2	17.6	1.26	5064	606	1.37	3.35	0.24	97.0
2010	3	1308	15_120M	7.4	38.6	28.2	1353	23.2	96.2	146	11.6	18.4	3128	13.0	19.6	1.57	2493	601	2.49	3.78	0.30	478
2010	3	952	17_120M_dpf	12.1	68.4	42.8	1774	38.0	131	198	11.1	2.0	3133	10.8	16.3	0.92	165	555	1.91	2.89	0.16	29.1
2010	3	439	19_613G	19.9	100.7	58.4	1638	62.6	137	315	5.0	14.3	3142	6.9	15.8	0.25	718	622	1.36	3.13	0.05	142
2011	3	289	14_928Hz	5.8	31.9	26.0	1159	18.3	85.1	182	9.6	10.3	3134	14.6	31.3	1.64	1774	573	2.67	5.71	0.30	324
2011	3	345	18_928Hz	16.0	89.9	56.1	1650	50.2	130	282	13.4	15.8	3138	8.1	17.6	0.84	989	558	1.45	3.14	0.15	175
2011	3	242	20_928Hz	11.3	56.1	36.0	1625	35.6	97.7	191	13.9	18.7	3136	8.6	16.8	1.22	1655	634	1.74	3.39	0.25	333
2011	3	245	27_HB215	9.3	55.6	43.9	1347	30.1	52.9	175	4.0	8.7	3235	5.7	18.8	0.43	930	541	0.95	3.15	0.07	156
2011	4i	2528	22_D7E_WM	19.9	106.7	35.3	1466	62.9	45.4	201	9.7	0.04	3157	2.3	10.1	0.49	1.91	590	0.43	1.89	0.09	0.36
2011	4i	589	25_D7E_OC	14.4	82.2	27.6	1466	45.6	-7.1	140	3.1	0.01	3162	-0.5	9.7	0.21	1.01	555	-0.09	1.70	0.04	0.18
2012	4i	24	21_D6T_JM	19.1	90.7	40.6	1553	60.3	-6.8	145	3.4	0.03	3162	-0.4	7.6	0.18	1.57	665	-0.08	1.60	0.04	0.33
2012	4i	32	23_D8T_JM	23.4	104.0	39.4	1548	74.1	-15.6	222	6.0	0.73 [6]	3162	-0.7	9.5	0.26	31.2 [6]	712	-0.15	2.14	0.06	7.03 [6]
2012	4i	48	24_D6T_OC	14.2	74.5	34.5	1370	45.0	-10.5	121	3.3	0.02	3162	-0.7	8.5	0.23	1.37	605	-0.14	1.62	0.04	0.26

[1] Rebuilt engine

[2] Fuel calculated from carbon balance method

[3] Power estimated from lug curve work sheet

[4] No ECM information was collected

[5] Total PM using gravimetric span method and not the model alpha methods

[6] DPF regen occurred for about 50 mins, if remove DPF regen data, PM emissins will be 116.8 mg/hr, 5.51 mg/kg fuel, and 1.21 mg/hp-h gaseous emissions would reduce only slightly (< 5%)

4.4 Idle Emissions

This section describes the idle emissions for each unit tested. Idle emissions are considered separately since idle emissions represents a large fraction of all equipment usage and load specific emissions at idle are not representative because load is near zero and thus load specific emissions become infinite and un-realistic.

The idle emissions for each pollutant are presented in Table 4-4 in g/hr and g/hr-L, where L is the engine displacement in liters. Overall, the idle emissions for CO_2 correlate with engine displacement.

Table 4-4 Low RPM idle emissions for each unit tested vs. engine displacement

			Idle Emissions (g/hr)					Idle Emissions (g/hr-L)				
Unit ID	% Idle	Disp (L)	CO2	CO	NOx	THC	PM	CO2	CO	NOx	THC	PM
1_410J	31.7	4.5	4234	18.9	47.4	7.03	1.082	941	4.21	10.53	1.56	0.240
2_310SJ	25.3	6.8	4740	15.8	52.3	3.62	0.522	697	2.33	7.69	0.53	0.077
3_644J	28.4	6.8	7815	38.5	93.2	4.24	0.903	1149	5.66	13.71	0.62	0.133
4_310SG	11.1	4.5	6486	32.9	129.8	6.73	0.274	1441	7.31	28.84	1.49	0.061
5_410G	21.5	4.5	4328	36.6	44.2	5.76	0.650	962	8.14	9.83	1.28	0.145
6_WA470-6	22.4	11.04	10832	56.8	119.0	6.53	1.226	981	5.15	10.78	0.59	0.111
7_928G	23.0	6.6	7734	30.2	99.0	4.13	0.699	1172	4.58	15.00	0.63	0.106
8_345D		12.5	17528	160.8	199.4	8.05	n/a	1402	12.86	15.95	0.64	n/a
9_637E	18.3	8.8	7322	32.8	111.5	13.98	0.906	832	3.72	12.67	1.59	0.103
10_637E	16.5	15.2	21352	85.7	162.9	9.30	1.825	1405	5.64	10.71	0.61	0.120
11_EC360B	18.8	12.1	9590	8.2	90.0	3.48	1.227	793	0.67	7.44	0.29	0.101
12_D8R	13.1	14.8	11978	6.0	146.2	5.55	1.248	809	0.40	9.88	0.38	0.084
13_120M	17.7	6.6	7335	30.2	130.1	4.54	0.853	1111	4.57	19.72	0.69	0.129
14_928Hz	39.2	6.6	6276	27.0	120.1	4.60	2.128	951	4.09	18.19	0.70	0.322
15_120M	28.4	6.6	6645	23.9	101.1	5.73	0.278	1007	3.63	15.33	0.87	0.042
16_120M	23.6	6.6	5693	29.5	86.9	4.00	0.179	863	4.48	13.17	0.61	0.027
17_120M_DPF	14.2	6.6	7028	30.1	106.9	3.38	0.029	1065	4.56	16.19	0.51	0.004
18_928Hz	10.4	6.6	6524	22.1	100.6	4.38	1.040	989	3.35	15.24	0.66	0.158
19_613G	28.9	6.6	7060	12.7	111.9	1.98	0.761	1070	1.92	16.96	0.30	0.115
20_928Hz	14.3	6.6	6707	17.6	112.7	4.43	0.895	1016	2.66	17.07	0.67	0.136
21_D6T_JM	27.5	9.3	10643	-3.7	98.0	0.86	0.009	1144	-0.39	10.54	0.09	0.001
22_D7E_WM	18.6	9.3	9027	4.3	89.1	2.83	0.006	971	0.46	9.58	0.30	0.001
23_D8T-JM	29.5	15.3	11412	-6.6	97.4	0.74	0.013	746	-0.43	6.37	0.05	0.001
24_D6T_OC	44.5	9.3	9548	1.6	98.5	3.71	0.005	1027	0.17	10.59	0.40	0.001
25_D7E_OC	31.2	9.3	6933	-5.0	83.7	0.74	0.005	746	-0.54	9.00	0.08	0.001
26_PC200	32.6	6.7	6589	16.4	53.8	5.55	1.112	983	2.45	8.02	0.83	0.166
27_HB215	28.5	4.5	3735	4.4	55.4	1.21	0.156	830	0.98	12.31	0.27	0.035

4.5 NO_x emissions

The overall NO_x emissions results for each of the units tested are provided in Figure 4-1. The top figure shows the time specific results, the middle figure shows the fuel specific results, and bottom figure shows the brake specific results. The results are sorted by MY where the leftmost results represents the older MYs tested. The NMHC+NO_x certification value decreased between Tier 2 and Tier 3 engines. The split occurred roughly around MY 2007 in the presented data. 7 of the 27 units tested were Tier 2, 15 were Tier 3, and 5 were Tier 4i.

The NO_x emissions showed generally lower emissions for the Tier 4i units on a g/kg fuel and g/hp-hr basis. The NO_x emissions for the Tier 2 and 3 units do not show a trend that correlates with certification MY, however, where one would expect higher emissions for older MY units and lower emissions for newer MY units. In fact, the highest fuel specific NO_x ($fsNO_x$) and $bsNO_x$ emissions were from a 2011 wheel loader (#14 based on the first two numbers of the equipment ID). This can probably be attributed to the differences in the type of work being done by the different units. In this regard, it should be noted that this unit also had the lowest emissions on a Two other wheel loaders (#18 and #20) have similar engine hours, MYs, and engine displacements, but showed almost 50% less $bsNO_x$ and $fsNO_x$ emissions. The average power over the time of operation was 56% and 36%, respectively, for the two units with lower NO_x emissions compared to the average percent load of 26% for unit #14, see Table 4-3.

These three units (#14, #18, and #20) were tested during in-service operation and, thus, represent real NO_x emission factors. The percent load was below 30% for #14, but higher than 30% for #18 and #20. The percent engine load threshold for NTE in-use compliance testing is 30%, thus, operation below 30% is excluded from compliance testing. Operation below 30% occurs during in-service operation and can even represent the overall average for some in-service operations, as shown by unit #14. This suggests activity for off-road equipment is very important to the emissions inventory.

The oldest MY tested (#12) did not show the highest load specific emissions, but did show the highest time specific emissions. The oldest MY unit had an average of 798 g/hr, 20.3 kg/kgfuel, and 3.72 g/hp-h NO_x emissions. The lowest $fsNO_x$ and $bsNO_x$ emissions, for units with more than 250 hours of operation, were for the front engine on a 2006 rebuilt scraper (#9). The $fsNO_x$ and $bsNO_x$ emissions were 11.1 g/kgfuel and 1.78 g/hp-h, respectively. The actual hours were not available on unit #9 due to an engine rebuild, but the hours were estimated at more than 10,000 due to typical rebuild recommendations.

The 2006 scraper (#9) was one of seven engines tested with power ratings over 275 hp, and also one of seven engines with an average percent load over 50%. The fsNOx and bsNOx on the engines with percent loads over 50% averaged 16.9 g/kgfuel and 2.8 g/hp-h. The $fsNO_x$ is 10% lower and the $bsNO_x$ is 20% lower than the average for the less than 50% average power tests, and both are as much as 100% lower than the lowest percent load test from unit #14. The higher power operation appears to have a more significant effect on the emission factors on a work basis than engine hours or MY. Again, this suggests the type of work being performed is critical in characterizing and understanding the emission impacts from construction equipment.

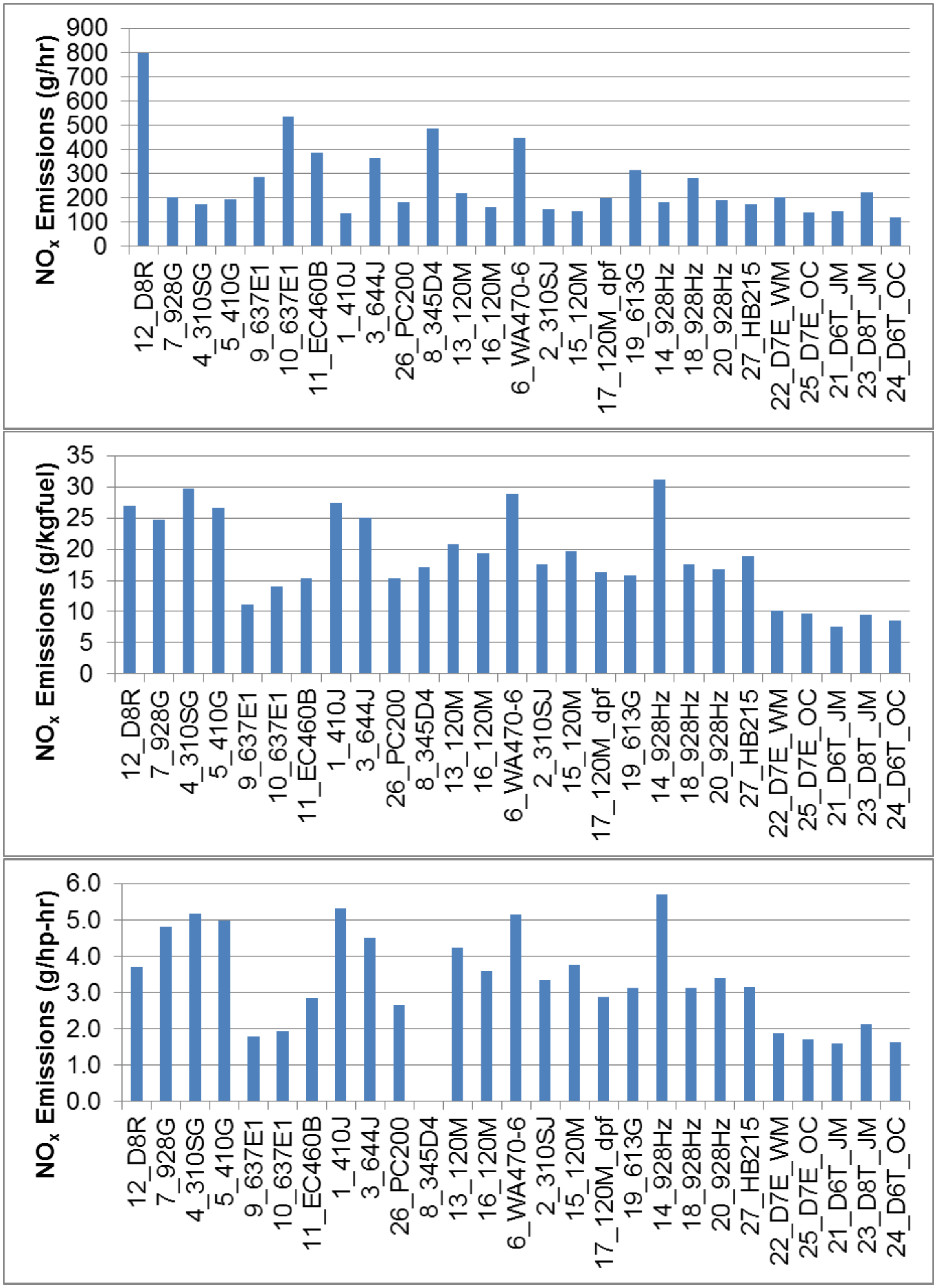


Figure 4-1 Overall average NO_x emissions [1]

[1] (Top – g/hr; Middle – g/kgfuel; Bottom – g/hp-h)

4.6 PM emissions

The overall PM emissions results for each of the units tested are provided in Figure 4-2. The top figure shows the time specific results, the middle figure shows the fuel specific results, and bottom figure shows the brake specific results.

The units with DPFs all showed significant reductions in PM in comparison with those units without aftertreatment. There is a slight trend of lower bsPM emissions for older MYs when comparing units without aftertreatment, see Figure 4-2, although any such trend would be complicated by differences in the operational work between units, such as the lower power for some units like #14, as discussed previously. It is also possible that the engine calibration differences needed to achieve $bsNO_x$ emissions for the newer equipment could lead to increases in brake specific PM (bsPM).

Comparisons with certification limits can provide a rough estimate of how the emissions from different equipment compare. The PM certification limits are 300 mg/hp-h for Tier 2 and 3 in the 50-100 hp category, 220 mg/hp-h for Tier 2 and 3 in the 100 to 175 hp category, 150 mg/hp-h for Tier 2 and 3 for the 175 to 600 hp category, and 15 mg/hp-h for Tier 4i. It should be emphasized that the PM certification limits are based on engine dynamometer measurements over a specific test cycle, so any comparisons with emissions from the real-world operation are not meant to imply that an individual piece of equipment may or may not be operating within certification limits. 21 of the 27 units with measured brake specific emissions showed bsPM emissions lower than the certification levels. The six units that showed higher bsPM emissions may be a result of operation at lower power and high engine hours. All but two of the tier 2 and tier 3 units with bsPM emissions of less than 200 mg/hp-h had power levels over 36% load, indicating that higher power levels were generally associated with lower emissions. The one unit that showed emissions greater than 200 mg/hp-h bsPM with a relatively high load was the 328 hp excavator (#11). The excavator (#11) showed an average percent load of 55% and a bsPM emissions of 274 mg/hp-h, see Table 4-3.

One of the units (#17 a 2010 grader) was equipped with an aftermarket DPF. The bsPM emissions from this unit averaged 29.1 mg/hp-h overall and ranged from 100.8 to 2.4 mg/hp-h depending on the activity mode, see Table 4-3 and the information in Appendix 8.0. The bsPM Tier4 interim standard for off-road engines is 15 mg/hp-h, suggesting unit #17 is exceeding standard for some modes.

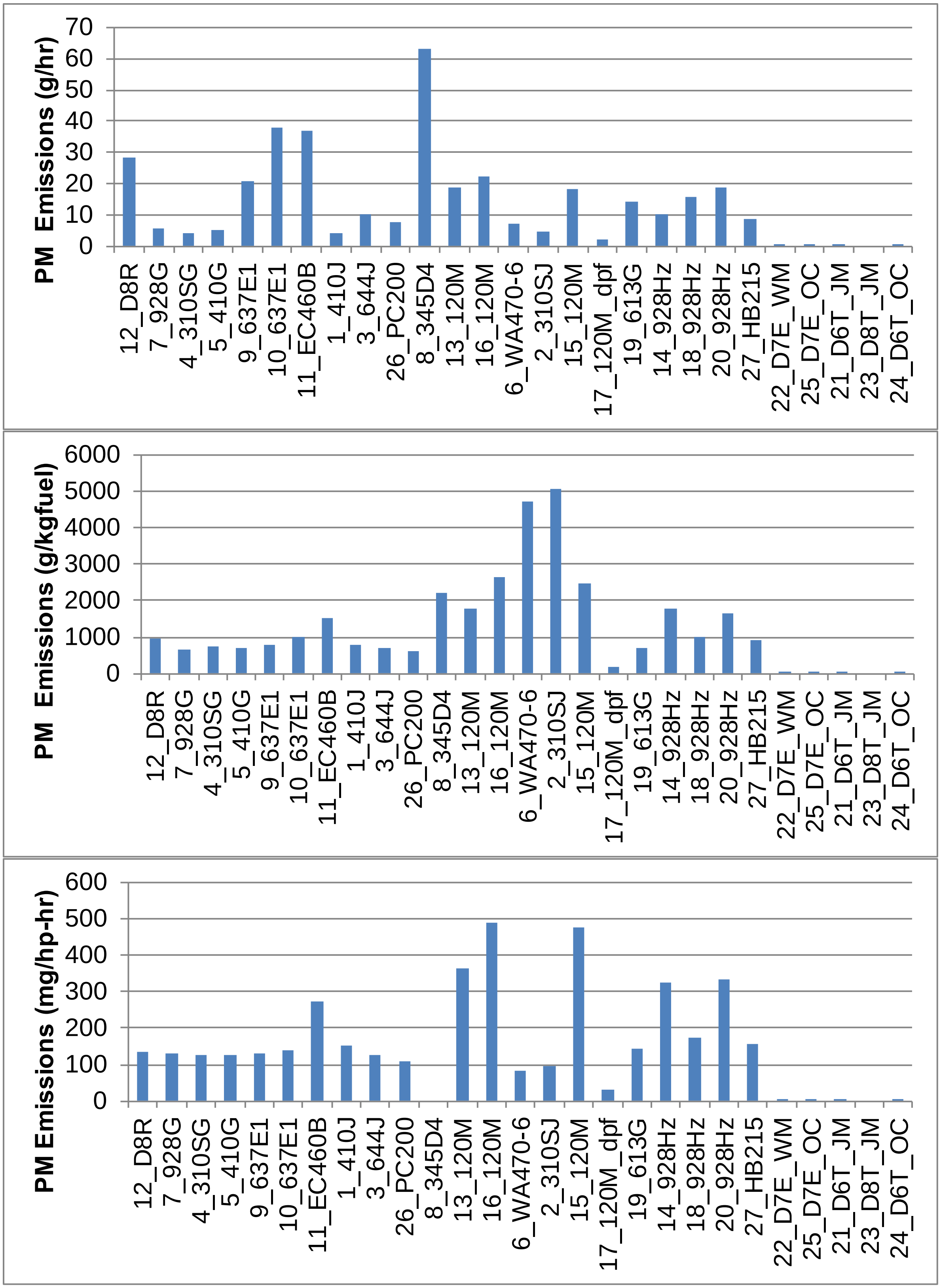


Figure 4-2 Overall average PM emissions [1]

[1] **(Top – g/hr; Middle – g/kgfuel; Bottom – g/hp-h)**

4.7 THC and NMHC emissions

The overall THC emissions results for each of the units tested are provided in Figure 4-3. The top figure shows the time specific results, the middle figure shows the fuel specific results, and bottom figure shows the brake specific results. The THC certification levels are tied to the NMHC+NO_x, and are thus not easy to directly compare to. One would expect the brake specific NMHC (bsNMHC) emissions to be less than 1 g/hp-h and they are typically less than 0.1 g/hp-h. Since CH_4 is typically not measured with a PEMS, NMHC is calculated as 0.98* THC as per 40 CFR Part 1065.

The THC emissions ranged from 0.01 to 63 g/hr, 0.18 to 3.5 g/kgfuel, and 0.04 to 0.68 g/hp-h. Two units (#1 and #5 both 410 Deere backhoes) showed relatively high THC emissions of greater than 0.63 g/hp-h, which is almost two times more than the other units tested. The average percent loads for unit #1 and #5 were greater than 32%. This suggests the high THC is not necessarily due to light load operation. A similar Deere backhoe model 310 used over a very similar duty cycle, for example, showed about half the emissions as those for the 410 backhoe, as listed in Table 2 and Table 4 in Appendix 8.0. It is unclear what caused the higher THC emissions for the 410 backhoe compared to the 310 backhoe. The Tier 4i THC emissions were considerably lower than those for most of the other older units.

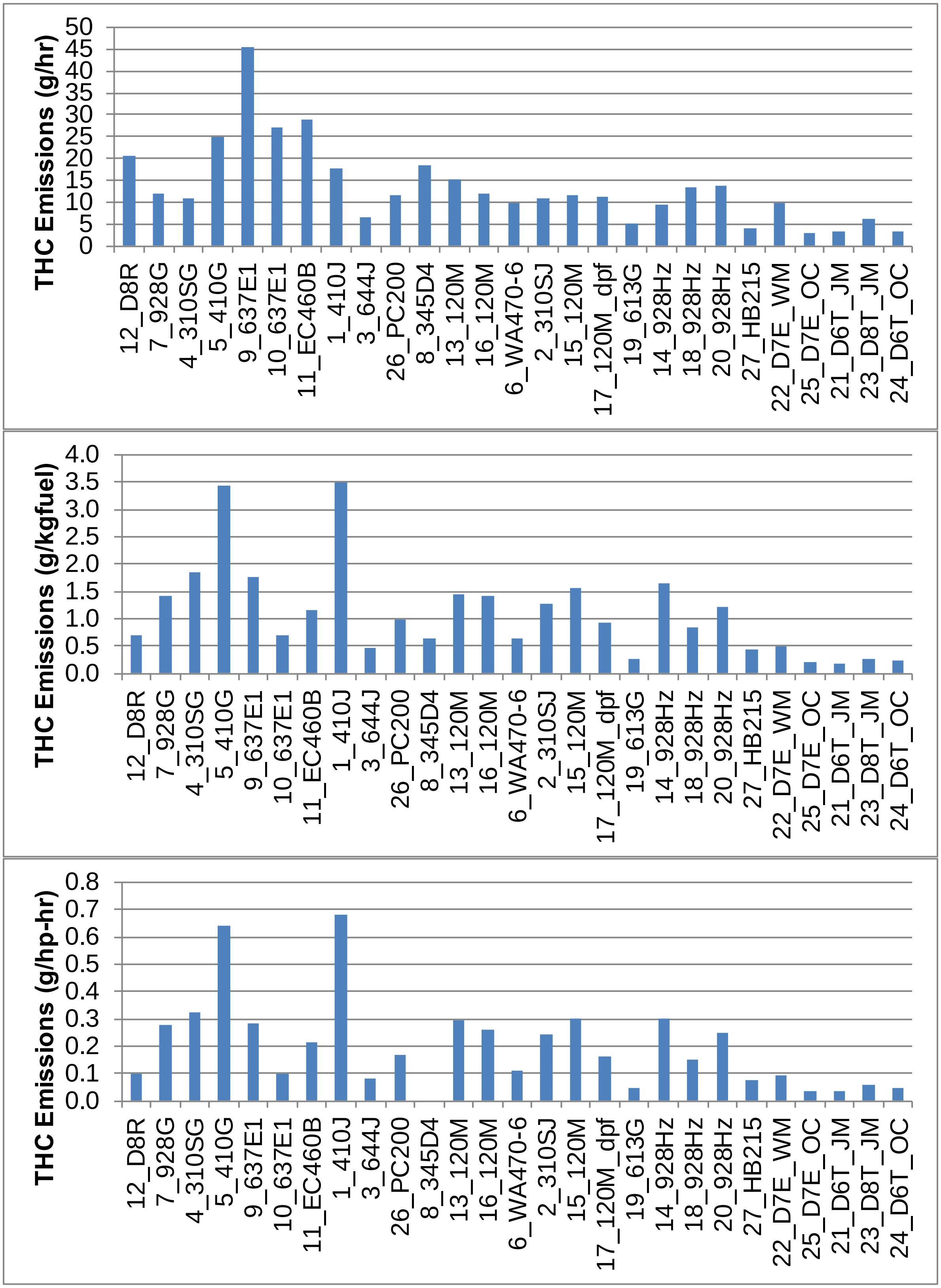


Figure 4-3 Overall average THC emissions [1]

[1] **(Top – g/hr; Middle – g/kgfuel; Bottom – g/hp-h)**

4.8 CO emissions

The overall CO emissions results for each of the units tested are provided in Figure 4-4. The top figure shows the time specific results, the middle figure shows the fuel specific results, and bottom figure shows the brake specific results. The CO emission standard doesn't change between Tier levels, but changes from 3.7 g/hp-h for hp less than 175 to 2.6 g/hp-h for hp greater than 175. The certification standard for fourteen of the units is 3.7 g/hp-h (50 hp to 175 hp) and is 2.6 g/hp-h (175 to 600 hp) for the other thirteen units.

The CO emissions ranged from 518 to -15.6 g/hr, 19.1 to -0.7 g/kgfuel, and 3.39 to -0.15 g/hp-h. Three units in the 175 to 600 hp had average CO emissions above 2.6 g/hp-h certification level, including units #9, #3, and #6. Unit #9 was a scraper and units #3 and #6 were wheel loaders. Two units (units #14 and #16) in lower power categories (50 hp to 175 hp) also had average CO emissions in the same range, but they were below the 3.7 g/hp-h standard for the smaller engine category. One unit was a wheel loader and the other was a grader. The CO emissions for the Tier 4i units were essentially at the limits of detection of the PEMS, as indicated by the negative CO emissions values for some of the units.

Figure 4-4 shows there is not a trend in the CO emissions that increases with older MY engines. There is a strong trend in CO emissions as a function of % load, with lower % loads leading to the higher bsCO and fsCO emissions, with the exception of unit #9, the 2006 rebuilt scraper engine. This unit showed a relatively high % load, but also a high fsCO and bsCO emission of 19.1 g/kgfuel and 3.06 g/hp-h, respectively.

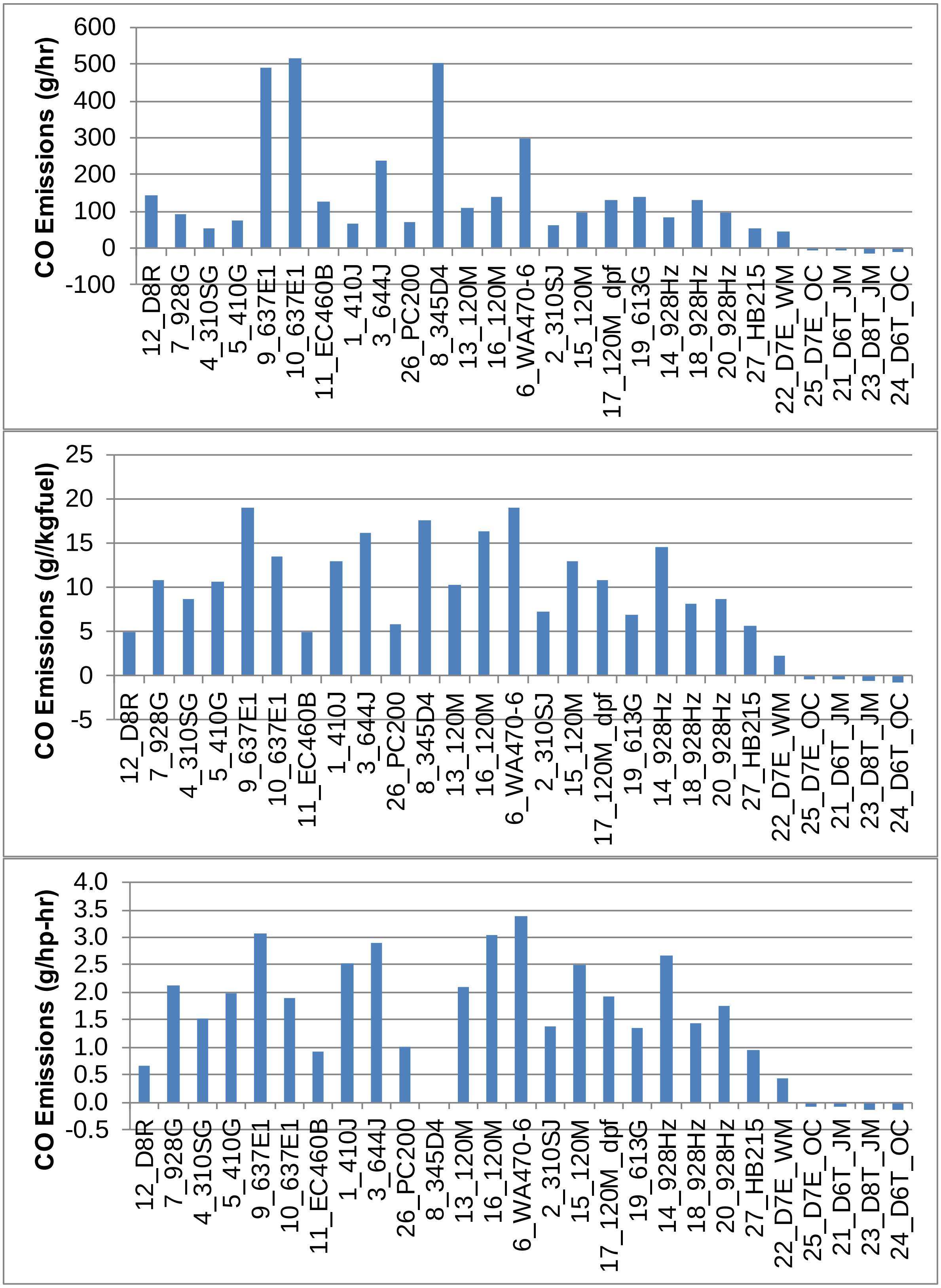


Figure 4-4 Overall average CO emissions [1]

[1] **(Top – g/hr; Middle – g/kgfuel; Bottom – g/hp-h)**

4.9 CO_2 emissions

The overall CO_2 emissions results for each of the units tested are provided in Figure 4-5. The top figure shows the time specific results, the middle figure shows the fuel specific results, and bottom figure shows the brake specific results.

The CO_2 emissions provide a direct comparison to the fuel consumption of diesel engines and their impact on greenhouse gas (GHG) emissions. The time specific CO_2 emissions do not show a trend with MY, since time specific CO_2 is heavily dependent on the specific operation of the equipment. The fuel specific CO_2 ($fsCO_2$) emissions, in Figure 4-5 middle, are fairly constant at 3140 g/kgfuel, as expected since CO_2 emissions are a surrogate for fuel consumption and represents the vast majority of the carbon released from fuel combustion. The fsCO2 should come out as a constant scaling factor, which is a useful tool to verify the emissions are calculated properly.

The brake specific CO_2 ($bsCO_2$) values are a good reference tool for a properly operating diesel engine. The $bsCO_2$ for medium speed 6 – 15 L diesel engines is expected to have $bsCO_2$ from 520 to 650 g/hp-h, based on our experience with various types of testing. Five units tested had $bsCO_2$ values outside these bounds. Three were lower and two were higher than that range. The engines with lower $bsCO_2$ were in a bulldozer, and the two engines in a scraper. One of the scraper engines had the largest displacement, highest rated power, and highest measured power relative to the other units tested. The low $bsCO_2$ for unit #10 was investigated for anomalies and none were found. The two high $bsCO_2$ showed relatively low percent loads, 40% on average, but 10 other pieces of equipment also had loads of 36% or less. The higher bsCO2 may be from the fraction of time at idle. One way to determine the impact of idle is to evaluate the idle fraction for each of the units tested.

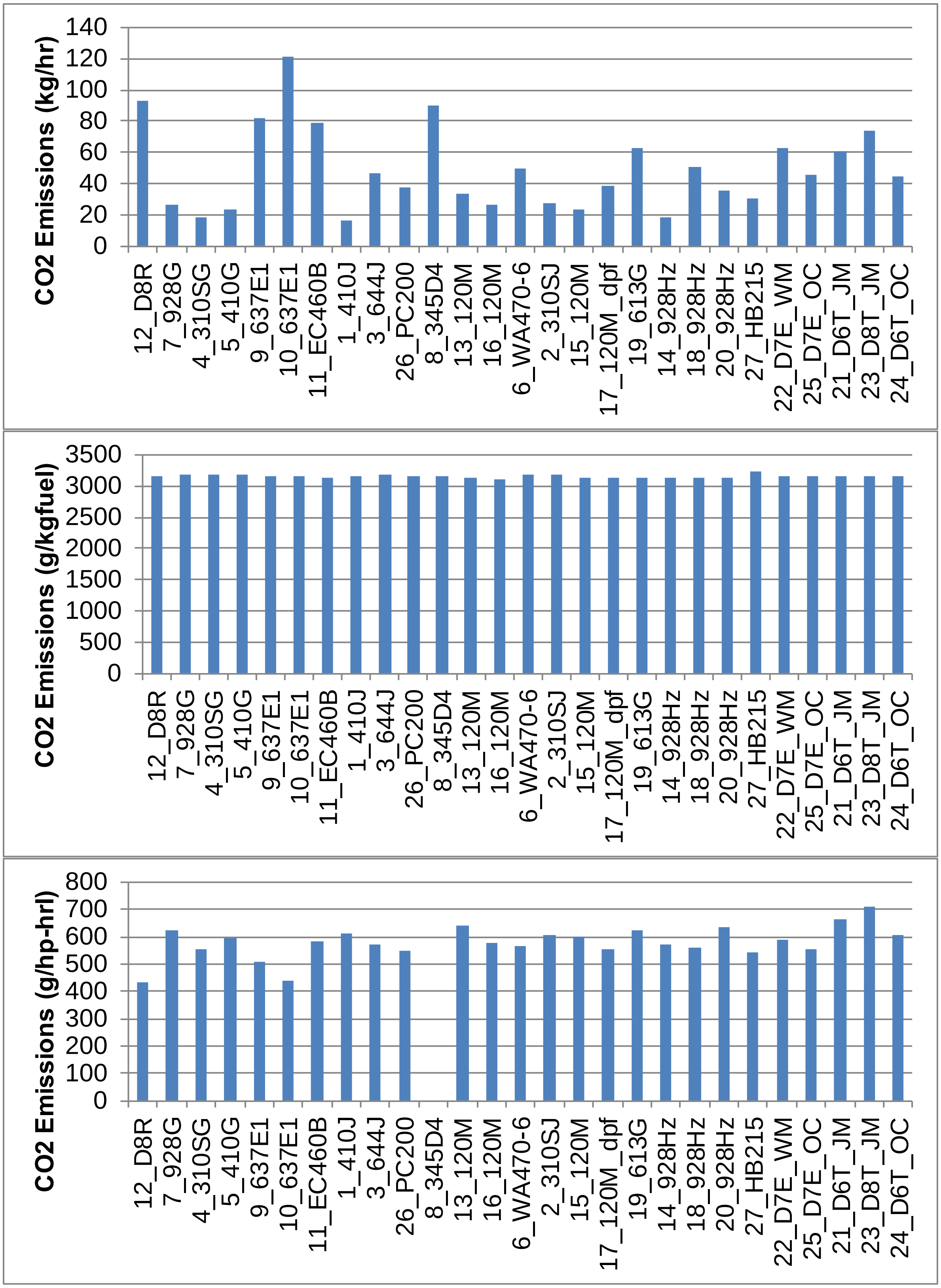


Figure 4-5 Overall average CO_2 emissions [1]

[1] **(Top – g/hr; Middle – g/kgfuel; Bottom – g/hp-h)**

4.10 Engine information

The overall selected engine results for each of the units tested are provided in Figure 4-6 through Figure 4-10. Figure 4-6 shows the total engine hours for each unit, Figure 4-7 shows the average engine brake power, Figure 4-8 shows the average fuel consumption based on carbon balance, Figure 4-9 shows the average ECM percent load, and Figure 4-10 shows the average engine speed results.

The total engine hours in Figure 4-6 are shown in logarithmic scale, since the engine run time hours varied from a few hundred to over 17,000 hours. The high engine hours for the bulldozer (unit #12) includes an engine rebuild around the 10,000 hr time frame. Two other engines tested were rebuilt and had hours over 10,000. The newer engines tended to have lower hours, as shown in Figure 4-6, but some older engines had lower hours then newer ones (#7 and #4). This indicates that the number of hours really depends on the unit type and the fleet. In other testing by UCR, for example, a 2011 bulldozer was found to have over 2200 hours as of the end of 2012 due to its heavy use in its application.

The overall in-use brake power was typically light: 9 units with rated hp's between 97 to 171 had average in-use hp's <50 with average engine loads between 26.0 to 52.3%, 11 units with rated hp's between 148 to 296 had average in-use hp's between 50 to 100 with average engine loads between 27.6 to 56.1%, 5 units with rated hp's between 193 to 316 had average in-use hp's between 100 to 150 with average engine loads between 35.3 to 66.1%, and 3 units with rated hp's between 280 to 540 had average in-use hp's between 161 to 275 with average engine loads between 54.5 to 72.8. Higher power emission factors can be found by looking at the A-work in Table 1 through Table 27 in Appendix 8.0.

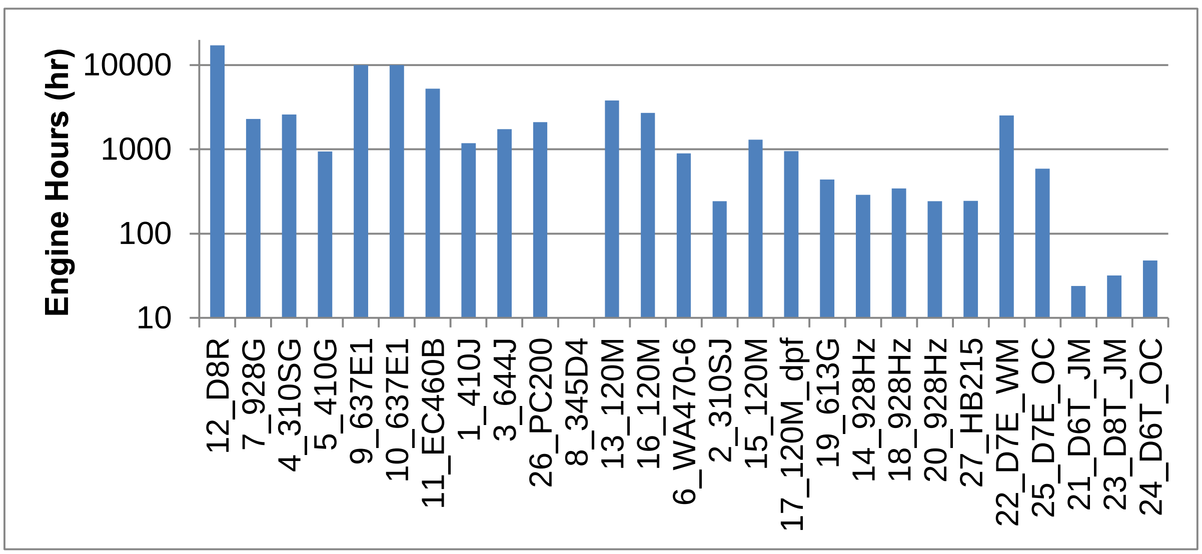


Figure 4-6 Engine hours for all units tested

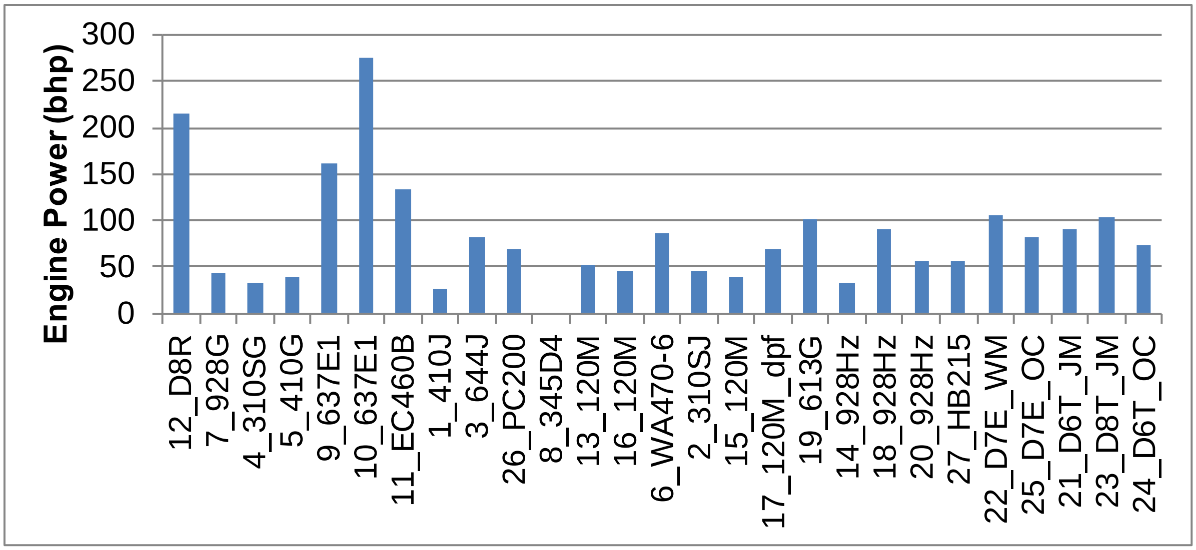


Figure 4-7 Overall average calculated engine power for all units tested

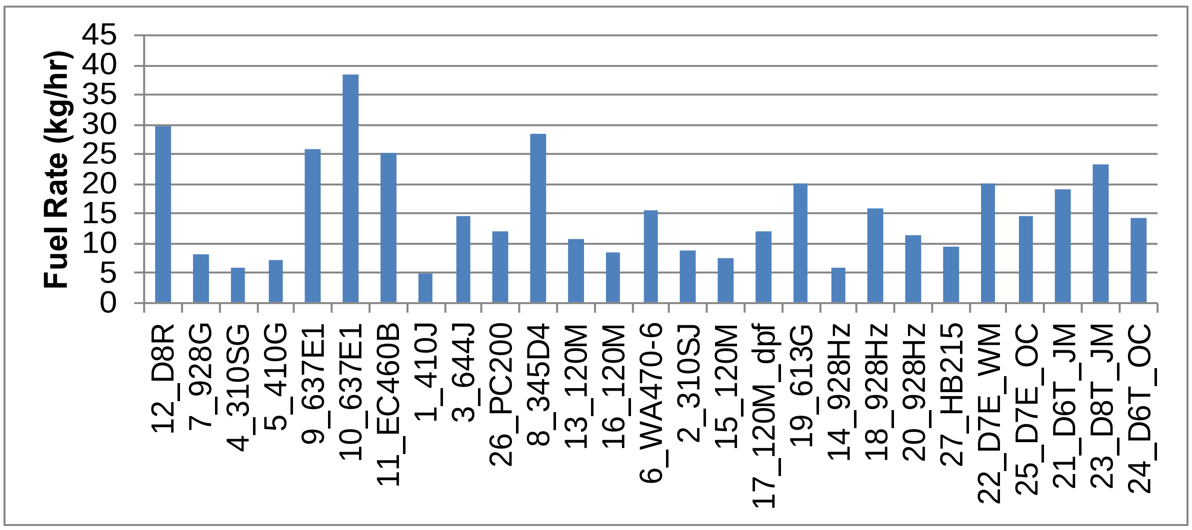


Figure 4-8 Overall fuel consumption rate for all units tested

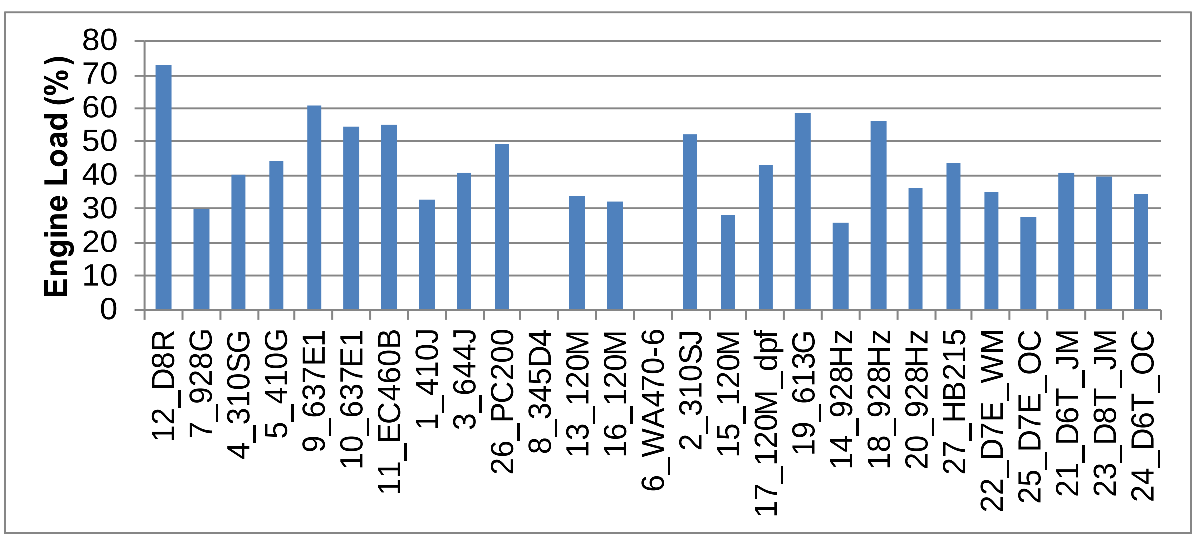


Figure 4-9 Overall average ECM engine percent load for all units tested

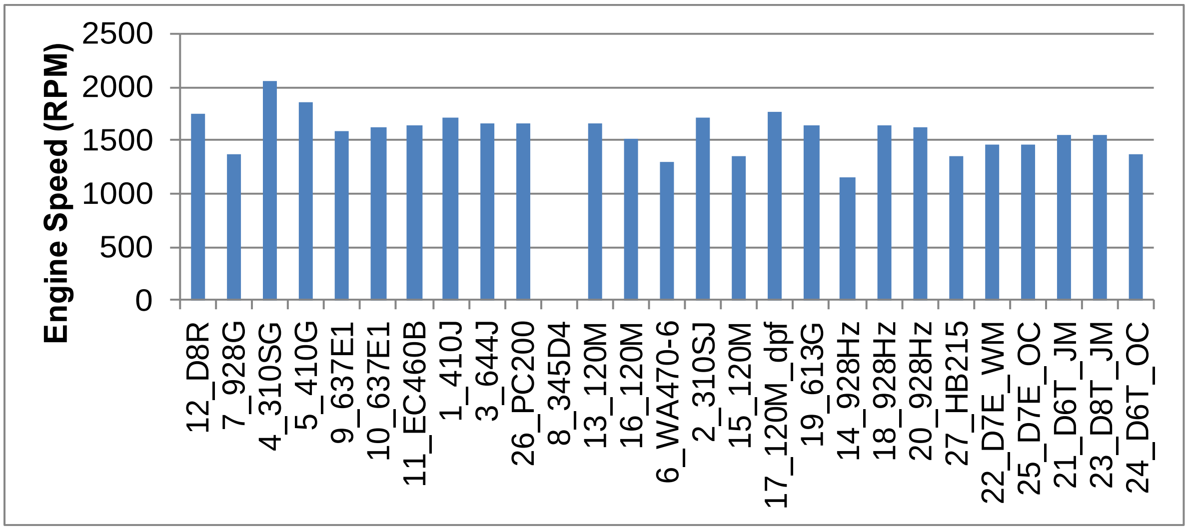


Figure 4-10 Overall average engine speed for all units tested

5.0 Results and Discussion – Power Based Results

5.1 Introduction

As part of this project, engine load data and pollutant emissions data were collected and reported on a second-by-second basis. These data can be used to explore relationships between instantaneous engine power and instantaneous mass/time pollutant emissions, as a possible new method for calculating and utilizing emissions factors for emissions inventory development. This section describes data processing and data analysis methods, the preliminary regression analyses, and then presents results.

5.2 Data Analysis

A polynomial and linear least squared regression analysis was performed on the modal data to model the emissions as a function of power for each unit tested. Prior to performing the linear regression a three second moving averaged was performed on the real-time power and emissions data to prevent time alignment issues from influencing the ratio of emissions to power for brake specific emission calculations. It was determined that the three second running average was sufficient for preventing time alignment issues. A description of the different elements of the data analysis is provided below.

5.2.1 Idle data in regression

Idle emissions typically cause unreasonably high brake specific emissions due to the work term being very low and hard to estimate at idle. As such, brake specific analyses can be inconsistent when idle is included. Similar issues with idle emissions are not seen on a time specific basis. For the analyses described below, it was decided to keep the idle emissions in the regression analysis. This is supported by the improvement to the goodness of fit statistics for the regression analysis.

The idle emissions improved the goodness of fit statistics and trend line shape for several units. An idle analysis based on the 01_410J backhoe is provided here. This unit was operated with and without PTO. For NO_x emissions, it was found that R^2 improved from 0.7 to greater than 0.92 with the idle was included. Similar improvements were also seen for THC, CO_2 and FC. Even PM and CO showed significant improvement, but the overall R^2 was still less than 0.5. Similar trends were found for other units tested.

As such, the idle emissions are included in the final regression analysis of the modal data sets presented in this final report. They are treated separately for the g/hr analyses in Section 4.0 due to the significance of idle emissions.

5.2.2 Moving average

Time alignment between power and emissions is difficult due to the response time of the engine compared to the response time of the instruments. The engine response is on the order of 100 ms where the emissions response time is around 1-2 seconds. One solution is to implement a running average or a filter on the real time data to improve the relationship between power and emissions. Too little filtering and the data are very noisy. Too much filtering and you lose the relationship between power and emissions. This section discusses the calculation method and different moving average times evaluated. The moving average analysis is based on the 01_410J backhoe. This unit was operated with and without PTO.

A moving average of three seconds was implemented in MATLAB using the function called "MEDFILT1". MEDFILT1 is a one dimensional median filter function in MATLAB (see MATLAB user manual). The filter uses the median calculation between the points not an average. The three second median filter was used (n=3) for all the real-time gaseous, PM and ECM measurements.

A running average (not a median filter) comparison was performed in EXCEL to visually see the difference between 1 second, 3 second and 21 second running average. Figure 5-1 shows the real-time moving average for 1 second (no averaging), 3 second, and 21 seconds. The difference between no averaging and 3 second averaging is subtle, where only slight differences in the emissions spikes are visible. The 21 second averaging, on the other hand, shows a significant reduction in the transient nature of the NO_x emissions.

Moving averages were also compared with a correlation plot of emissions versus power to show the impact for the presented regression analysis. Figure 5-2 shows NO_x emissions versus power at the different averaging times of 1 second (no averaging), 3 seconds, and 21 seconds. Figure 5-2 shows that the scatter reduces as we increase averaging time from the 1 second to the 21 seconds. The data show a good improvement in data spread in going from 1 second to 3 seconds. In general, the 3 second averaged data seems to be well behaved with a reasonable slope, $R^2 >$ 0.9 and low data spread.

A moving median filter of three seconds using the MEDFILT1 function in Matlab was used for all the data presented in the regression analysis of this report. Regression analysis graphs for each of the emissions components for each unit tested is presented in Appendix 9.0. Additional comparisons of the modal power vs. RPM are also provided in Appendix 10.0.

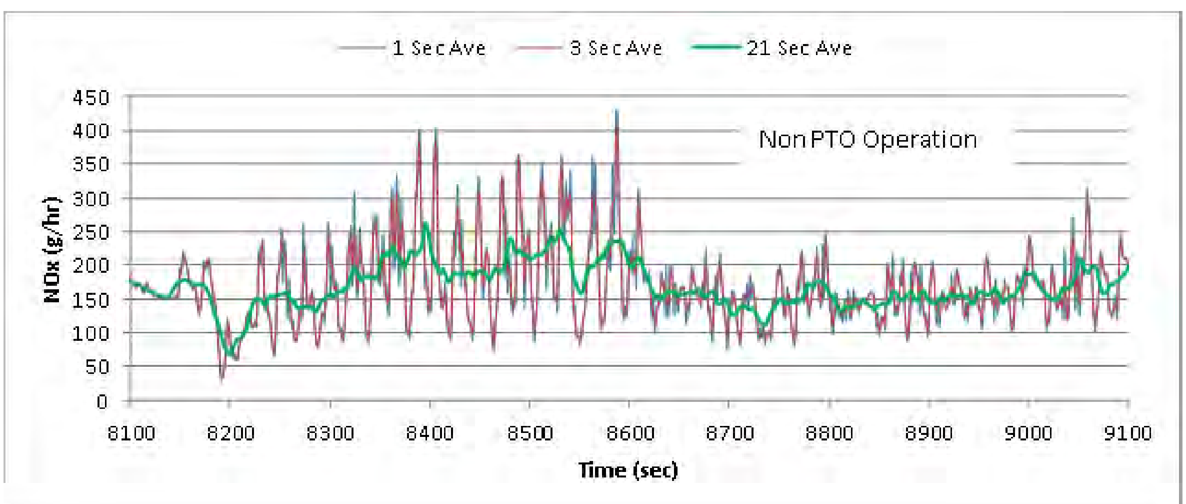


Figure 5-1 Real time moving averages of 1 second (none), 3 second, and 21 seconds

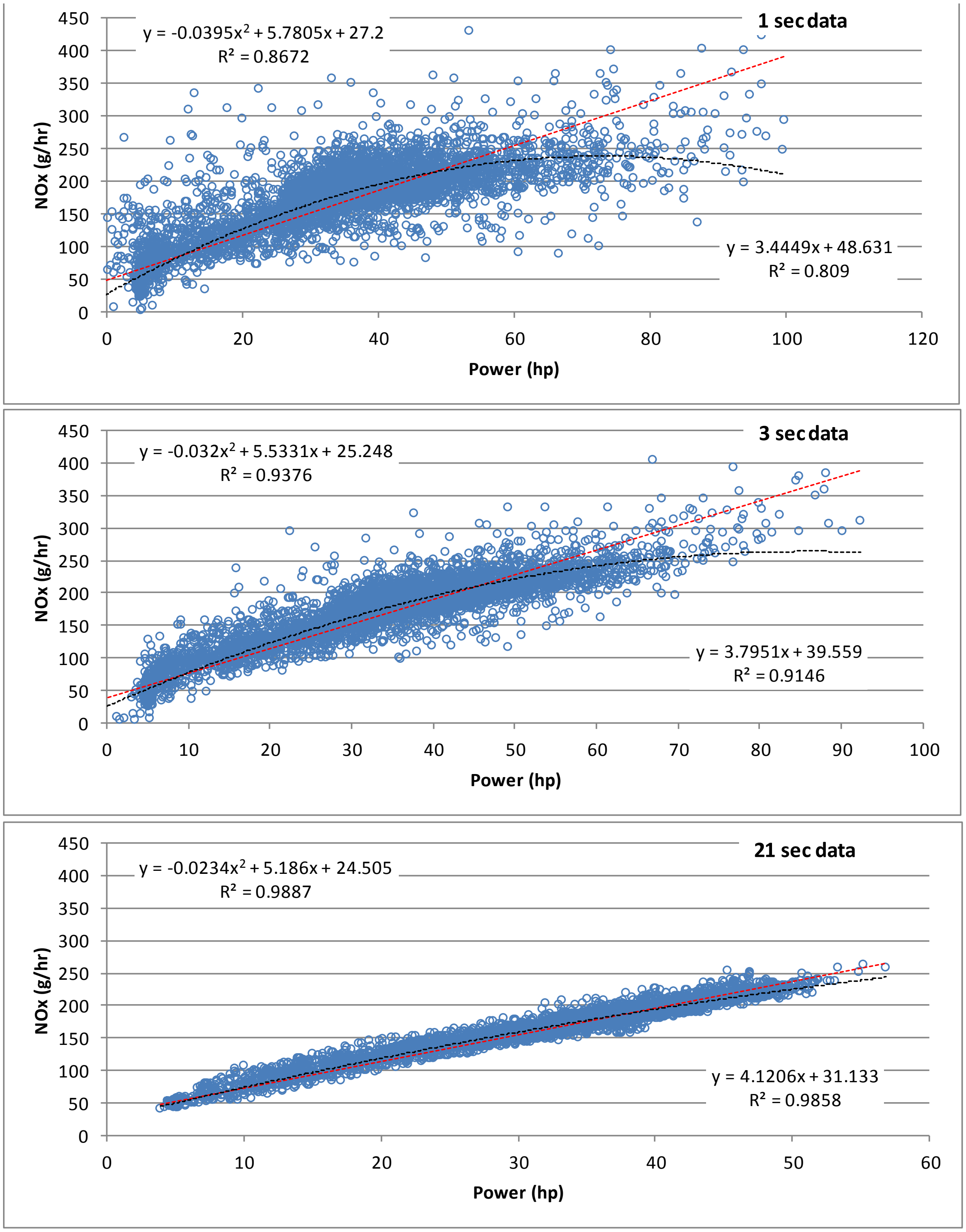


Figure 5-2 Correlation moving averages of 1 second (none), 3 second, and 21 seconds

5.2.3 Regression function

The least squared regression best fit coefficients were analyzed using MATLAB's "polyfit" command. The Polyfit command finds the coefficients of a polynomial P(X) of degree N that fits the data Y best in a least-squares sense. P is a row vector of length N+1 containing the polynomial coefficients in descending powers, P(1)*X^N + P(2)*X^(N-1) +...+ P(N)*X +

P(N+1) (MATLAB user manual). For this analysis the order of the coefficients used were N = 1 and N = 2, representing a linear and polynomial fit, respectively.

5.3 Overview of Regression Results

5.3.1 Goodness of fit

In Table 5-1 the number of units (out of a total of 27 units) having R^2 values within the ranges of 0 to 0.4, 0.4 – 0.6, 0.6 – 0.8, and 0.8 – 1.0 for each pollutant is summarized. For regressions with a large number of points, an R^2 of greater than 0.8 indicates a reasonable correlation; R^2 from 0.6 to 0.8 indicates a moderate correlation; R^2 from 0.4 to 0.6 is a poor correlation; and R^2 from 0 and 0.4 indicates the variables are not correlated. Another possibility is that there is some correlation between emissions and power for a particular pollutant, but that other variables would need to be included to achieve a reasonable correlation. In Table 5-1, only CO_2 has more than 60% of the units with R^2 in the reasonable correlation range (i.e., >0.8). NO_x showed 6 of the 27 units with R^2 >0.8, while CO, NMHC, and PM had either 1 or no units with R^2 >0.8. Clearly, the emissions showing very low correlation are dependent upon one or more other variables in addition to horsepower.

Table 5-1 Number of units tested with R square in the given range

Pollutant	Number in R^2 range for Polynomial Equation				Number in R^2 range for Linear Equation			
	0 to 0.4	0.4 - 0.6	0.6 - 0.8	0.8 - 1.0	0 to 0.4	0.4 - 0.6	0.6 - 0.8	0.8 - 1.0
CO	22	4	0	1	23	3	0	1
CO_2	0	1	9	17	0	2	8	17
NMHC	15	5	7	0	17	4	6	0
NO_x	7	7	7	6	7	8	6	6
PM	24	1	2	0	24	1	2	0

The relatively good fits for NO_x, CO_2, and Fuel Consumption (FC), suggest these species correlated well to power. The strong relationships with power for NO_x, CO_2 and FC are expected based on the typical compression ignition combustion process. NO_x is formed from the conversion of nitrogen in the presence of excess oxygen at high temperatures, which are more common during high power events. Higher FC is also needed during higher power events. CO_2 is formed from the braking of fuels H-C bonds, and is a basic measure of fuel consumption, with ~99% of the carbon in fuel engine up as CO_2. In general, it is expected that the linear regression will provide a reasonable correlation for NO_x, CO_2 and FC.

The poor regression fits for PM and CO, suggest these species do not correlate well to power. This can be attributed to the fact that PM emissions are formed from transient fueling related issues when RPM and load change quickly, whereas the formation of NO_x, and CO_2 is more directly related to power. This suggests PM and CO emissions cannot be directly correlated with power. More analysis is needed to determine what additional variables would need to be considered to find a better correlation for PM and CO under transient conditions.

THC showed a relatively low correlation to power compared to NO_x, CO_2 and FC, but a better correlation than PM and CO. This may be a result of hydrocarbons sticking to the walls of the analytical tubing and therefore having a long tail as they pass through the detector.

The regression statistics for the individual units are shown in Table 5-2 through Table 5-7, where the values labeled “2nd” are for the polynomial fit and the values labeled “1st” are for the linear fit.

Table 5-2 NO_x (g/hr) vs. Power Regression Analysis Statistics for Individual Units

Unit ID	1stCoef_1	1stCoef_0	1stR2	1stSEE	2ndCoef_2	2ndCoef_1	2ndCoef_0	2ndR2	2ndSEE
08_345D_V01	1.8	83.9	0.911	105.2	0.005	-0.9	233.6	0.964	67.1
07_928G_V01	3.3	65.8	0.858	47.2	0.004	2.8	75.8	0.859	47.0
12_D8R_V01	3.5	39.7	0.831	146.1	0.007	1.2	154.8	0.848	138.5
05_410G_V01	4.3	24.7	0.834	39.3	0.005	3.8	30.7	0.838	38.9
02_310SJ_V01	2.5	40.5	0.816	24.1	0.008	1.8	47.3	0.818	24.0
27_HB215_DD	2.2	48.1	0.806	47.0	0.003	1.8	54.4	0.817	45.7
09_637E_V01	1.8	32.6	0.713	211.1	0.005	-0.9	244.2	0.792	179.6
04_310SG_v01	2.4	95.0	0.79	21.1	0.012	1.6	106.6	0.79	21.1
18_928Hz_V01	1.5	145.2	0.753	48.8	0.001	1.4	149.2	0.764	47.7
11_EC460B_V01	2.3	77.2	0.719	86.7	-0.003	3.1	47.0	0.736	84.1
01_410J_V01	3.8	41.1	0.656	21.9	-0.034	5.6	25.2	0.668	21.5
26_PC200_DD	2.2	26.0	0.659	35.0	-0.002	2.4	21.8	0.659	35.0
15_120M_V01	1.3	94.9	0.591	39.3	0.002	1.1	98.9	0.603	38.8
09_637E_V01	1.2	77.7	0.556	93.3	0.003	0.2	117.5	0.59	89.7
03_644J_v01	3.4	86.8	0.543	135.5	-0.009	5.2	38.5	0.58	129.9
19_613G_V01	2.1	103.9	0.533	75.5	-0.003	2.6	93.6	0.534	75.4
22_D7E_WM	0.8	112.3	0.509	79.6	0.002	0.2	128.3	0.53	77.8
21_D6T_WM	0.5	95.2	0.484	34.0	0.001	0.3	100.5	0.501	33.5
20_928Hz_V02	1.1	131.7	0.407	41.7	-0.002	1.4	124.2	0.407	41.7
17_120M_V01	1.0	125.4	0.403	49.2	-0.001	1.3	117.8	0.403	49.2
16_120M_V01	1.4	97.1	0.338	49.9	-0.001	1.6	93.4	0.338	49.9
24_D6T_OC	0.4	90.5	0.314	42.1	0.001	0.2	93.7	0.337	41.4
23_D8T_WM	0.8	136.9	0.327	101.6	-0.002	1.2	127.8	0.33	101.4
06_WA470_V01	2.7	209.0	0.252	240.2	-0.015	6.2	79.2	0.294	233.4
13_120M_V01	1.6	138.5	0.256	57.6	-0.002	1.9	131.9	0.26	57.5
14_928Hz_V01	1.3	145.5	0.217	58.6	-0.008	2.3	128.2	0.217	58.6
25_D7E_OC	0.5	101.5	0.095	77.6	-0.002	0.9	91.7	0.098	77.5

Notes: Columns labeled "1st" correspond to linear regression and those labeled "2nd" correspond to polynomial regression. Coef_2, Coef_1, and Coef_0 correspond to the A, B, and C values of the regression equation. R2 is the regression coefficient. SEE is the standard error estimate.

Table 5-3 PM (g/hr) vs. Power Regression Analysis Statistics for Individual Units

Unit ID	1stCoef_1	1stCoef_0	1stR2	1stSEE	2ndCoef_2	2ndCoef_1	2ndCoef_0	2ndR2	2ndSEE
08_345D_V01	0.3	-6.6	0.707	37.8	-0.001	1.0	-43.2	0.787	32.3
27_HB215_DD	0.1	0.1	0.71	3.9	-0.001	0.3	-1.4	0.752	3.6
14_928Hz_V01	0.4	-3.8	0.546	12.5	0.001	0.3	-2.6	0.546	12.5
24_D6T_OC	0.0	0.0	0.351	0.0	0.000	0.0	0.0	0.399	0.0
16_120M_V01	0.4	3.8	0.228	11.2	-0.004	0.8	-7.0	0.355	10.3
15_120M_V01	0.3	5.7	0.161	15.1	-0.004	0.9	-5.0	0.338	13.4
20_928Hz_V03	0.2	5.1	0.209	12.4	-0.003	0.6	-4.0	0.289	11.8
21_D6T_WM	0.0	0.0	0.272	0.0	0.000	0.0	0.0	0.272	0.0
26_PC200_DD	0.1	0.8	0.059	3.3	-0.002	0.3	-3.0	0.23	3.0
11_EC460B_V01	0.2	3.9	0.217	19.2	-0.001	0.3	-1.2	0.223	19.1
03_644J_v01	0.1	-1.3	0.162	14.4	0.000	0.1	-0.9	0.166	14.4
18_928Hz_V01	0.1	7.1	0.047	14.1	-0.002	0.5	-4.9	0.163	13.3
01_410J_V01	0.1	0.1	0.103	5.1	0.003	-0.1	1.6	0.146	5.0
07_928G_V01	0.1	2.0	0.134	5.8	0.000	0.1	0.9	0.143	5.8
05_410G_V01	0.1	0.4	0.13	5.4	0.000	0.1	0.6	0.131	5.4
09_637E_V01	0.1	10.3	0.112	24.8	0.000	0.2	-1.6	0.114	24.7
23_D8T_WM	0.0	0.2	0.024	2.6	0.000	0.0	-0.3	0.099	2.5
12_D8R_V01	0.1	13.6	0.006	24.9	-0.001	0.4	-1.9	0.086	23.9
09_637E_V01	0.0	8.4	0.008	17.3	-0.001	0.3	-0.6	0.075	16.7
13_120M_V01	0.2	6.5	0.044	10.1	-0.002	0.5	-0.5	0.047	10.1
06_WA470_V01	0.0	1.2	0.046	12.7	0.000	0.0	1.4	0.046	12.7
04_310SG_v01	0.1	0.6	0.035	7.3	0.001	0.0	1.9	0.045	7.3
17_120M_V01	0.0	1.3	0	2.2	0.000	0.1	-0.2	0.037	2.2
02_310SJ_V01	0.1	0.8	0.026	3.1	-0.001	0.2	-0.3	0.035	3.1
25_D7E_OC	0.0	0.0	0.005	0.1	0.000	0.0	0.0	0.01	0.1
19_613G_V01	0.1	2.5	0.003	17.8	-0.001	0.3	-1.4	0.006	17.8
22_D7E_WM	0.0	0.0	0.003	0.2	0.000	0.0	0.0	0.004	0.2

Notes: Columns labeled "1st" correspond to linear regression and those labeled "2nd" correspond to polynomial regression. Coef_2, Coef_1, and Coef_0 correspond to the A, B, and C values of the regression equation. R2 is the regression coefficient. SEE is the standard error estimate.

Table 5-4 NMHC (g/hr) vs. Power Regression Analysis Statistics for Individual Units

Unit ID	1stCoef_1	1stCoef_0	1stR2	1stSEE	2ndCoef_2	2ndCoef_1	2ndCoef_0	2ndR2	2ndSEE
08_345D_V01	1.7	115.2	0.886	117.5	0.00	3.7	6.6	0.918	99.9
27_HB215_DD	0.8	6.4	0.589	26.9	0.00	0.9	4.7	0.589	26.9
09_637E_V01	1.5	112.5	0.524	185.3	0.00	2.0	68.1	0.524	185.2
14_928Hz_V01	2.7	-0.6	0.456	93.1	0.00	2.6	1.1	0.456	93.0
09_637E_V01	2.2	138.4	0.358	185.6	-0.01	5.6	5.3	0.427	175.4
06_WA470_V01	2.7	0.3	0.293	258.6	-0.01	4.1	-53.3	0.322	253.2
15_120M_V01	1.4	31.5	0.16	96.6	-0.01	3.1	-0.1	0.203	94.1
11_EC460B_V01	0.9	-1.6	0.199	103.6	0.00	1.0	-5.8	0.199	103.6
05_410G_V01	0.8	42.8	0.108	27.6	-0.02	2.3	22.0	0.178	26.4
04_310SG_v01	1.1	8.4	0.116	50.2	0.04	-1.4	42.5	0.176	48.5
18_928Hz_V01	0.4	88.7	0.013	108.0	-0.02	4.5	-23.3	0.176	98.6
16_120M_V01	1.7	43.2	0.158	77.4	-0.01	3.0	15.2	0.165	77.0
07_928G_V01	0.8	47.9	0.12	61.5	-0.01	1.9	25.7	0.156	60.2
23_D8T_WM	-0.1	-6.9	0.049	11.5	0.00	-0.3	-1.4	0.131	11.0
03_644J_v01	1.6	38.4	0.097	179.3	-0.01	2.9	-0.1	0.116	177.5
13_120M_V01	1.3	38.3	0.072	78.1	0.00	1.3	38.4	0.113	76.4
20_928Hz_V04	0.9	50.4	0.062	81.0	-0.01	2.7	4.5	0.107	79.0
02_310SJ_V01	0.9	21.2	0.054	26.9	-0.02	2.6	4.5	0.095	26.4
01_410J_V01	1.5	16.6	0.07	40.5	-0.02	2.4	9.0	0.071	40.5
17_120M_V01	0.5	83.4	0.006	83.2	-0.01	2.6	19.5	0.057	81.0
22_D7E_WM	0.1	34.7	0.02	59.6	0.00	-0.2	41.8	0.032	59.2
24_D6T_OC	-0.1	-4.7	0.008	22.7	0.00	-0.3	-1.8	0.03	22.4
12_D8R_V01	0.5	35.1	0.013	195.6	0.00	1.4	-9.1	0.028	194.1
26_PC200_DD	0.7	20.2	0.023	28.3	-0.01	1.6	3.4	0.023	28.3
25_D7E_OC	0.0	-6.2	0.011	14.6	0.00	-0.1	-3.0	0.014	14.6
19_613G_V01	0.8	23.8	0.009	173.8	-0.01	2.0	1.8	0.01	173.8
21_D6T_WM	0.0	-4.5	0	18.8	0.00	-0.1	-2.4	0.007	18.8

Notes: Columns labeled “1st” correspond to linear regression and those labeled “2nd” correspond to polynomial regression. Coef_2, Coef_1, and Coef_0 correspond to the A, B, and C values of the regression equation. R2 is the regression coefficient. SEE is the standard error estimate.

Table 5-5 CO (g/hr) vs. Power Regression Analysis Statistics for Individual Units

Unit ID	1stCoef_1	1stCoef_0	1stR2	1stSEE	2ndCoef_2	2ndCoef_1	2ndCoef_0	2ndR2	2ndSEE
08_345D_V01	1.7	115.2	0.886	117.5	0.00	3.7	6.6	0.918	99.9
27_HB215_DD	0.8	6.4	0.589	26.9	0.00	0.9	4.7	0.589	26.9
09_637E_V01	1.5	112.5	0.524	185.3	0.00	2.0	68.1	0.524	185.2
14_928Hz_V01	2.7	-0.6	0.456	93.1	0.00	2.6	1.1	0.456	93.0
09_637E_V01	2.2	138.4	0.358	185.6	-0.01	5.6	5.3	0.427	175.4
06_WA470_V01	2.7	0.3	0.293	258.6	-0.01	4.1	-53.3	0.322	253.2
15_120M_V01	1.4	31.5	0.16	96.6	-0.01	3.1	-0.1	0.203	94.1
11_EC460B_V01	0.9	-1.6	0.199	103.6	0.00	1.0	-5.8	0.199	103.6
05_410G_V01	0.8	42.8	0.108	27.6	-0.02	2.3	22.0	0.178	26.4
04_310SG_v01	1.1	8.4	0.116	50.2	0.04	-1.4	42.5	0.176	48.5
18_928Hz_V01	0.4	88.7	0.013	108.0	-0.02	4.5	-23.3	0.176	98.6
16_120M_V01	1.7	43.2	0.158	77.4	-0.01	3.0	15.2	0.165	77.0
07_928G_V01	0.8	47.9	0.12	61.5	-0.01	1.9	25.7	0.156	60.2
23_D8T_WM	-0.1	-6.9	0.049	11.5	0.00	-0.3	-1.4	0.131	11.0
03_644J_v01	1.6	38.4	0.097	179.3	-0.01	2.9	-0.1	0.116	177.5
13_120M_V01	1.3	38.3	0.072	78.1	0.00	1.3	38.4	0.113	76.4
20_928Hz_V04	0.9	50.4	0.062	81.0	-0.01	2.7	4.5	0.107	79.0
02_310SJ_V01	0.9	21.2	0.054	26.9	-0.02	2.6	4.5	0.095	26.4
01_410J_V01	1.5	16.6	0.07	40.5	-0.02	2.4	9.0	0.071	40.5
17_120M_V01	0.5	83.4	0.006	83.2	-0.01	2.6	19.5	0.057	81.0
22_D7E_WM	0.1	34.7	0.02	59.6	0.00	-0.2	41.8	0.032	59.2
24_D6T_OC	-0.1	-4.7	0.008	22.7	0.00	-0.3	-1.8	0.03	22.4
12_D8R_V01	0.5	35.1	0.013	195.6	0.00	1.4	-9.1	0.028	194.1
26_PC200_DD	0.7	20.2	0.023	28.3	-0.01	1.6	3.4	0.023	28.3
25_D7E_OC	0.0	-6.2	0.011	14.6	0.00	-0.1	-3.0	0.014	14.6
19_613G_V01	0.8	23.8	0.009	173.8	-0.01	2.0	1.8	0.01	173.8
21_D6T_WM	0.0	-4.5	0	18.8	0.00	-0.1	-2.4	0.007	18.8

Notes: Columns labeled "1st" correspond to linear regression and those labeled "2nd" correspond to polynomial regression. Coef_2, Coef_1, and Coef_0 correspond to the A, B, and C values of the regression equation. R2 is the regression coefficient. SEE is the standard error estimate.

Table 5-6 CO_2 (g/hr) vs. Power Regression Analysis Statistics for Individual Units

Unit ID	1stCoef_1	1stCoef_0	1stR2	1stSEE	2ndCoef_2	2ndCoef_1	2ndCoef_0	2ndR2	2ndSEE
08_345D_V01	411.4	-245.6	1	272.4	0.01	407.4	-26.2	1	242.4
06_WA470_V01	514.5	4482.0	0.99	3128.4	0.20	466.8	6260.2	0.991	2985.9
05_410G_V01	560.6	1351.9	0.979	1719.0	0.01	559.4	1369.1	0.979	1702.8
02_310SJ_V01	566.8	1806.0	0.97	1882.2	-0.21	585.4	1620.2	0.97	1869.7
04_310SG_v01	503.6	1817.7	0.968	1375.0	1.00	433.9	2774.2	0.968	1372.4
17_120M_V01	459.6	6352.1	0.93	5112.5	-0.21	496.7	5244.2	0.93	5106.4
18_928Hz_V01	483.4	6811.3	0.922	8093.5	-0.13	509.1	6107.2	0.922	8084.1
15_120M_V01	484.4	4371.8	0.912	5253.0	-0.22	515.0	3801.6	0.912	5242.9
07_928G_V01	516.9	4527.1	0.882	6516.9	-0.01	517.6	4513.9	0.882	6516.6
12_D8R_V01	419.1	2951.4	0.863	13875.2	0.09	386.5	4589.9	0.864	13800.5
27_HB215_DD	497.5	1619.1	0.862	8712.0	0.00	497.6	1617.6	0.862	8709.3
09_637E_V01	454.3	7627.3	0.857	14525.8	-0.21	518.7	5102.3	0.857	14504.8
01_410J_V01	555.4	1607.3	0.853	2639.8	-0.24	568.8	1494.5	0.854	2629.5
20_928Hz_V06	522.6	6706.1	0.836	7704.9	-1.31	710.9	2024.4	0.847	7441.1
24_D6T_OC	463.4	10458.4	0.836	12022.4	-0.71	611.6	8075.3	0.836	12021.6
22_D7E_WM	438.6	15628.5	0.831	18335.2	-0.73	634.2	10394.2	0.835	18126.2
21_D6T_WM	513.8	13242.9	0.823	11876.2	-1.00	724.4	7902.7	0.831	11608.5
03_644J_v01	510.9	4663.0	0.786	11994.8	-0.55	615.2	1773.3	0.79	11872.8
09_637E_V01	403.7	8080.5	0.769	34839.7	0.27	247.2	20523.9	0.786	33559.8
14_928Hz_V01	507.1	4384.6	0.783	8386.2	0.36	462.3	5155.1	0.785	8351.9
25_D7E_OC	428.8	10444.9	0.772	15056.5	-0.33	506.6	8381.4	0.785	14636.8
11_EC460B_V01	571.0	3453.6	0.776	19266.1	-0.01	574.0	3344.1	0.776	19266.2
16_120M_V01	483.0	4132.8	0.773	6451.2	-0.28	519.3	3312.4	0.775	6428.8
13_120M_V01	546.3	7795.3	0.758	6625.9	-1.50	736.5	3302.4	0.764	6554.4
23_D8T_WM	480.6	24297.6	0.743	23130.1	-1.01	752.0	18202.6	0.746	22986.4
26_PC200_DD	524.4	2209.5	0.585	6660.7	-4.35	1080.8	-7833.6	0.705	5615.5
19_613G_V01	559.4	5991.0	0.578	17294.2	-1.38	831.6	744.9	0.58	17254.6

Notes: Columns labeled "1st" correspond to linear regression and those labeled "2nd" correspond to polynomial regression. Coef_2, Coef_1, and Coef_0 correspond to the A, B, and C values of the regression equation. R2 is the regression coefficient. SEE is the standard error estimate.

Table 5-7 Fuel Consumption (kg/hr) vs. Power Regression Analysis Statistics

Unit ID	1stCoef_1	1stCoef_0	1stR2	1stSEE	2ndCoef_2	2ndCoef_1	2ndCoef_0	2ndR2	2ndSEE
08_345D_V01	129.5	0.0	1	0.0	0.00	129.5	0.0	1	0.0
06_WA470_V01	161.6	1408.8	0.991	965.9	0.06	147.6	1931.1	0.991	929.5
05_410G_V01	175.8	430.7	0.979	540.7	0.00	176.1	426.2	0.979	534.9
02_310SJ_V01	178.5	563.8	0.969	597.0	-0.07	185.0	498.8	0.97	592.9
04_310SG_v01	158.6	556.3	0.967	435.9	0.34	135.1	878.5	0.967	434.5
17_120M_V01	145.7	2056.6	0.93	1623.0	-0.07	158.6	1671.5	0.93	1621.5
18_928Hz_V01	153.2	2205.4	0.921	2574.0	-0.05	163.4	1923.1	0.921	2572.1
15_120M_V01	154.0	1405.4	0.912	1663.8	-0.08	164.7	1207.3	0.912	1661.3
07_928G_V01	161.3	1442.1	0.882	2030.1	-0.01	162.3	1422.5	0.883	2029.9
12_D8R_V01	132.8	960.7	0.861	4426.5	0.03	123.1	1450.5	0.863	4401.4
27_HB215_DD	157.8	517.2	0.862	2759.7	0.00	157.9	515.4	0.862	2758.8
09_637E_V01	143.5	2438.2	0.856	4604.6	-0.07	166.1	1553.5	0.856	4595.6
01_410J_V01	174.8	519.2	0.852	829.2	-0.09	180.0	475.3	0.854	825.7
20_928Hz_V07	165.8	2152.1	0.835	2448.6	-0.42	226.4	645.2	0.847	2362.8
24_D6T_OC	146.5	3308.0	0.836	3801.7	-0.23	193.3	2555.6	0.836	3801.5
22_D7E_WM	138.7	4970.8	0.831	5804.4	-0.23	200.6	3317.0	0.835	5738.7
21_D6T_WM	162.5	4188.4	0.823	3755.6	-0.32	229.1	2499.9	0.831	3671.0
03_644J_v01	160.0	1488.1	0.786	3741.3	-0.18	193.7	554.3	0.791	3700.6
09_637E_V01	126.8	2636.9	0.769	10909.4	0.08	78.6	6468.9	0.786	10510.3
25_D7E_OC	135.6	3302.5	0.772	4762.0	-0.10	160.2	2650.1	0.785	4629.3
14_928Hz_V01	147.6	1198.2	0.78	2474.4	0.11	133.7	1437.2	0.782	2464.5
11_EC460B_V01	175.8	1103.6	0.777	5918.1	-0.01	177.5	1041.2	0.777	5918.2
16_120M_V01	153.8	1334.5	0.774	2048.2	-0.09	166.0	1058.2	0.775	2041.5
13_120M_V01	160.9	2249.8	0.76	1949.8	-0.44	216.1	945.1	0.765	1928.8
23_D8T_WM	151.9	7685.7	0.742	7318.2	-0.32	237.7	5760.4	0.746	7272.8
26_PC200_DD	166.3	715.9	0.585	2108.3	-1.38	343.0	-2473.8	0.705	1777.1
19_613G_V01	177.4	1909.4	0.58	5455.7	-0.44	264.1	238.1	0.582	5442.954

Notes: Columns labeled "1st" correspond to linear regression and those labeled "2nd" correspond to polynomial regression. Coef_2, Coef_1, and Coef_0 correspond to the A, B, and C values of the regression equation. R2 is the regression coefficient. SEE is the standard error estimate.

5.3.2 Estimated emission factors

The polynomial and linear least squared regression fit lines for the individual pieces of equipment were used to predict emissions at the 50% and 80% hp level. Table 5-8 shows the horsepower categories, average horsepower in each category, number of units in each horsepower category, the number in each tier, the selected hp for estimation of the 50% and 80% loads, and the corresponding 50% hp and 80% hp levels. Note that the "selected" hp values were chosen to be very similar to the average hp in the category. Figures of predicted emissions at 50% and 80% of load for various horsepower categories and emission Tiers are presented in the subsections below on a g/hr basis. Additional figures of predicted emissions at 50% and 80% of load for various horsepower categories and emission Tiers are presented in Appendix 11 on a g/hr basis.

Table 5-8 Determination of emission estimates from polynomial and linear fits

hp Category	Average hp in category	Number of hp's averaged	Number in Tier 2	Number in Tier 3	Number in Tier 4i	Selected hp	50% hp	80% hp
50 -100	97	4	3	1	0	100	50	80
100 - 175	162	10	1	9	0	160	80	128
175 - 300	253	9	1	4	4	255	128	204
300 - 450	327	2	1	0	1	330	165	264
450 - 600	530	2	1	1	0	530	265	424

5.3.3 Multi modal analysis

Many of the regressions analyses did not show a good correlation to power as discussed earlier. For NO_x and CO_2, only a few units showed a poor correlation. For CO and PM, on the other hand, most of the correlations were poor <0.5 R^2. This subsection discusses possible affects due to modes of operation unique to off-road equipment.

One common element on off-road equipment is the power take off (PTO) system. This system provides hydraulic pressure to different attachments, and manipulates other parts of the equipment such as blades, shovels, hammers, and other systems. PTO operation is associated with high engine speed that is nearly constant compared to non-PTO operation. Thus only load varies in the PTO-on mode compared to PTO-off mode.

Figure 5-3 shows the real-time PM and CO emissions for a backhoe in PTO and non-PTO operating modes. The early part of the in-use testing was with the PTO on and for the latter part of the testing the PTO was off. The change in the emissions between the two can be seen by the much higher PM emissions for the mode without the PTO compared to with the PTO.

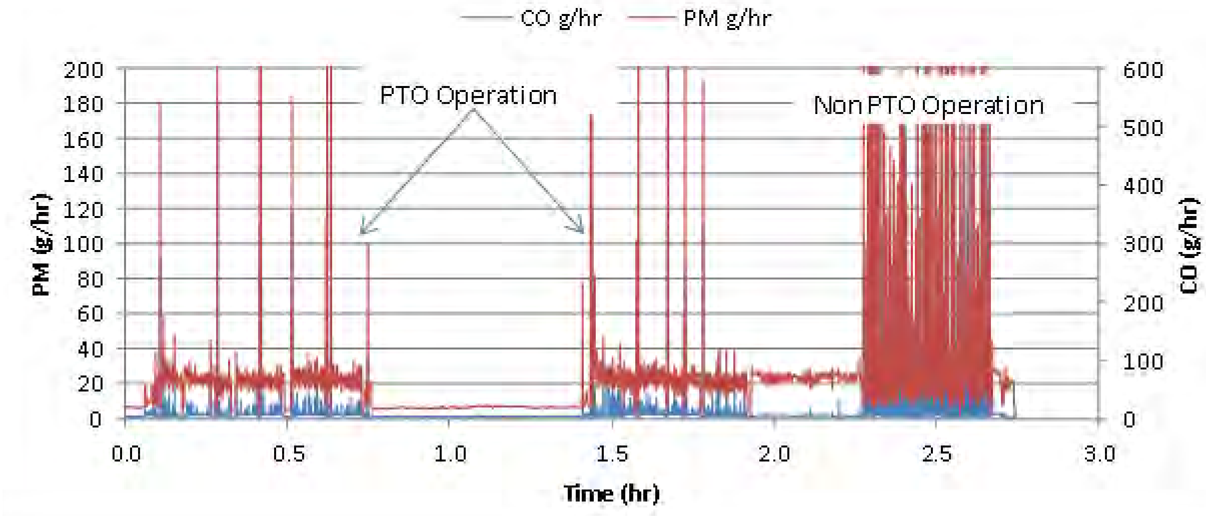


Figure 5-3 Real-time PM emissions for a backhoe operating in two different modes

Figure 5-4 shows more detailed analysis with regression correlations between PM and power while filtering out the different modes. The top figure is the full data set, the middle figure is the data set with the PTO off (transient RPM and load), and the bottom figure is with the PTO on (transient load only RPM is constant).

To reflect these differences in operation, PM emissions at 50 hp can be calculated using the different linear regression equations for each different mode of operation. The prediction of PM emissions from the 410J backhoe at 50 hp varies from 3.42 g/hr to 21.4 g/hr, depending on whether the operation is in a non-PTO or PTO modes. This is a factor of six difference in emission factors between modes. This suggests a simple overall data regression analysis may not be sufficient for off-road units. An analysis for the individual units is beyond the scope of the current study, however.

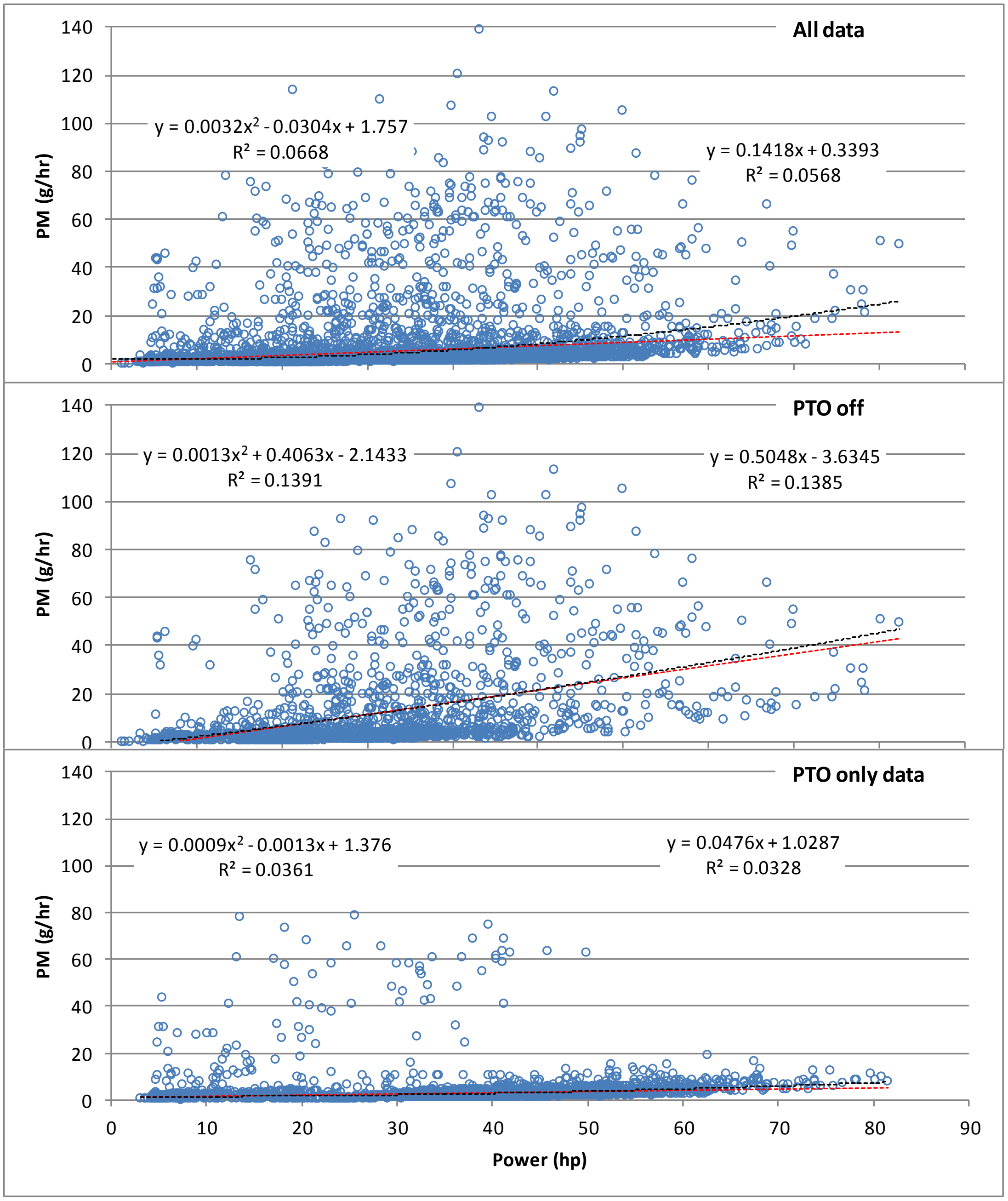


Figure 5-4 All data versus stabilized PTO operation data for a backhoe

5.4 NO_x emissions

The predicted emissions at 50% and 80% of load for various horsepower categories and emission Tiers (i.e., 2, 3, and 4i) are presented in Figure 5-5 on a g/hr basis. For these plots, the predicted values for all pieces of equipment within each category are averaged for each bar. The error bars represent the standard deviation of the average values for all equipment within each category. On a g/hr basis, there were some trends of higher emissions for the higher hp equipment categories, but this was not true for all the different categories. This could be due to differences in activity between the different categories, which in turn would impact the amount of power used over a given testing period.

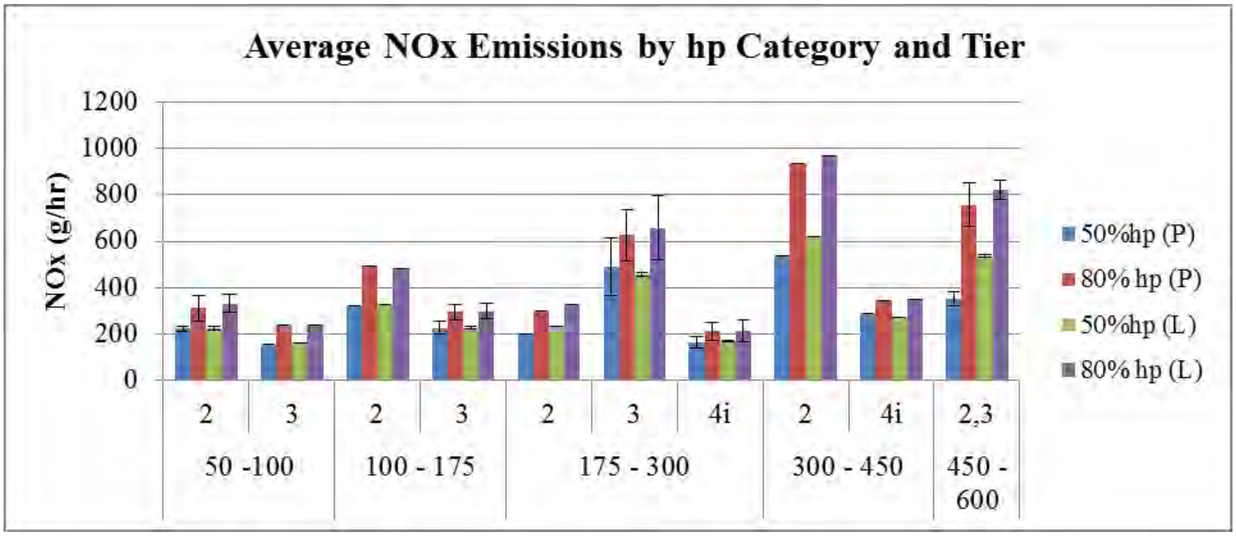


Figure 5-5 Average estimated NO_x emissions in g/hr

Two representative plots of real-time emissions as a function of power for NO_x are provided in Figure 5-6 and Figure 5-7. This includes a plot for a Volvo excavator and a plot for a Komatsu wheel loader. It should be noted that these figures were selected to provide examples of behavior seen throughout the larger data set. The behavior of other individual pieces of equipment will be different based on the specific task the equipment is doing and the characteristics of the equipment in terms of hp level and emissions Tier. The plots for both pieces of equipment show least square best fits to the data using a polynomial fit and a linear fit.

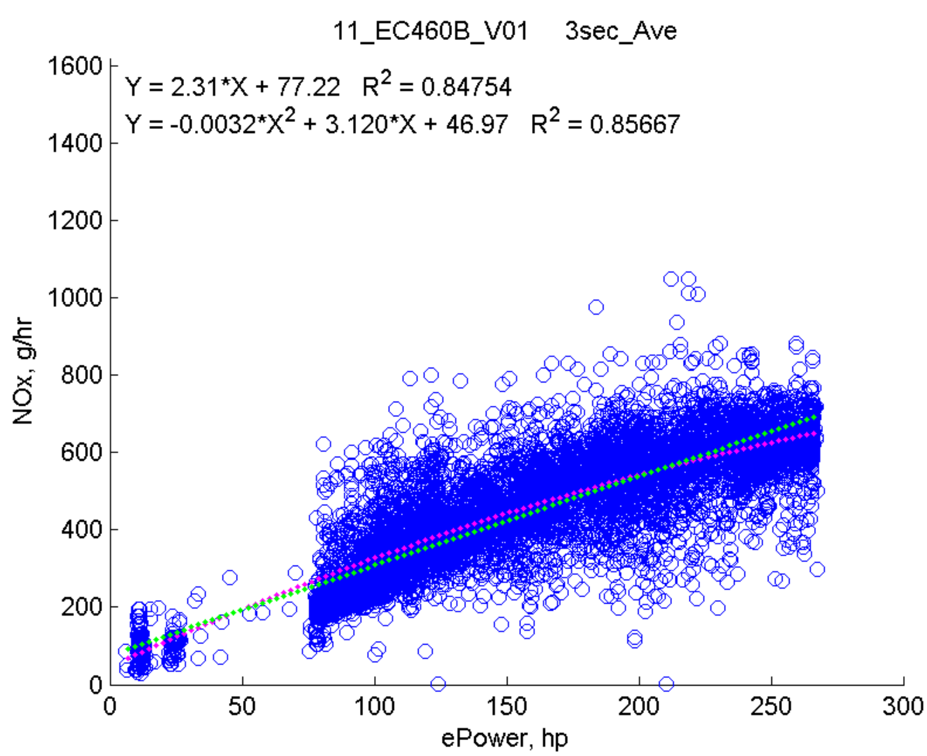


Figure 5-6 Real time NO_x emissions compared to engine power for the Volvo excavator

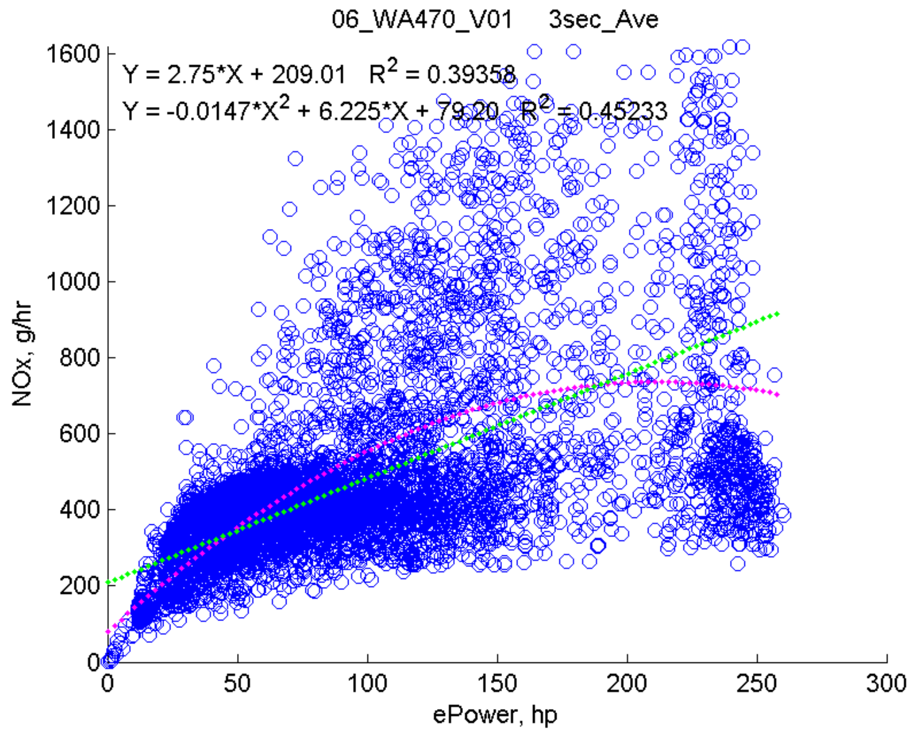


Figure 5-7 Real time NO_x emissions compared to engine power for the Komatsu wheel loader

The real-time NO_x emissions vs. power figures show differences that can be related to differences in the operation of the specific piece of equipment. Figure 5-6 shows a relatively consistent trend of NO_x emissions increasing with hp. Figure 5-7, on the other hand, shows much greater scatter above the trend lines. If the scatter was removed from Figure 5-7, the comparison between these two pieces of equipment would be much closer. The additional scatter is likely due to additional modes of operation that are seen for the wheel loader that are not seen for the excavator, whose operation is more consistent. More detailed investigations of the trends in the data could be performed for data on all equipment, but this is outside the current scope of work.

5.5 PM emissions

The average predicted PM emissions at the 50% and 80% hp levels for the various hp and emission Tier categories in the fleet are presented in Figure 5-8 on a g/hr basis. On a g/hr basis, the emissions show an increase in emissions with increasing hp level, as might be expected for the bigger engines doing more work.

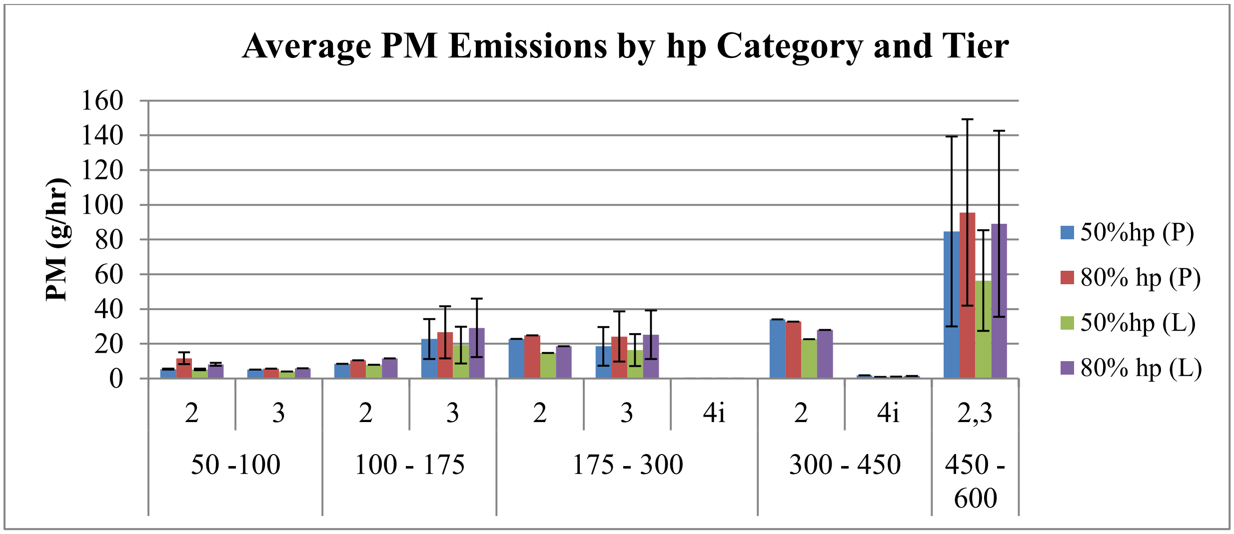


Figure 5-8 Average estimated PM emissions in g/hr

Two example plots of real-time PM emissions as a function of power are provided in Figure 5-9 and Figure 5-10. This includes a plot for a backhoe and a plot for a wheel loader. The data show different degrees of scatter and are chosen to represent the different levels of data scatter found throughout the larger data set of equipment in different power and operating categories, rather than to provide definitive comparisons between different power categories.

The real-time emissions vs. power plots can be examined more closely to better understand the trends within the data. For both pieces of equipment, the data show scatter above the best fit line for both the polynomial and linear fit lines. The PM emissions for the backhoe appear to be more consistent than those for the wheel loader. For the backhoe, the plot shows the polynomial curve trends upward. The linear fit tends to stay in the bulk of the data points. It appears the polynomial line is over predicting the high power emissions where the linear line seems to be a good fit and maybe slightly over predicting. A more detailed analysis of the real-time data for the backhoe is provided in section 5.2, showing that differences between the PTO and non-PTO operation lead to variations by a factor of 6 in PM emissions.

The figure for the wheel loader shows a slightly different PM behavior where PTO operation was not available. This figure show PM concentrated at peak power and moved up and down at peak power in addition to a steep trend line. The polynomial trend line appears to be under reporting at the high power conditions and the linear trend line may be over predicting the lower power conditions. Additional analysis is needed to further investigate unique modes of operation for this wheel loader. The modes of operation are provided in the tables in Appendix 8.0 for digging, scraping and such.

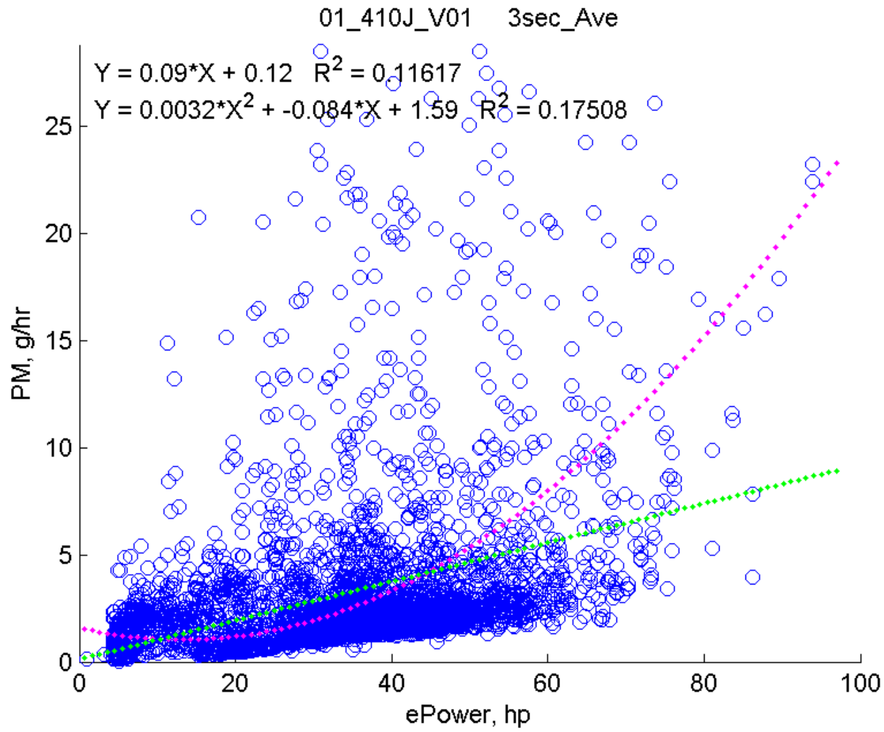


Figure 5-9 Real time PM emissions compared to engine power for a Backhoe

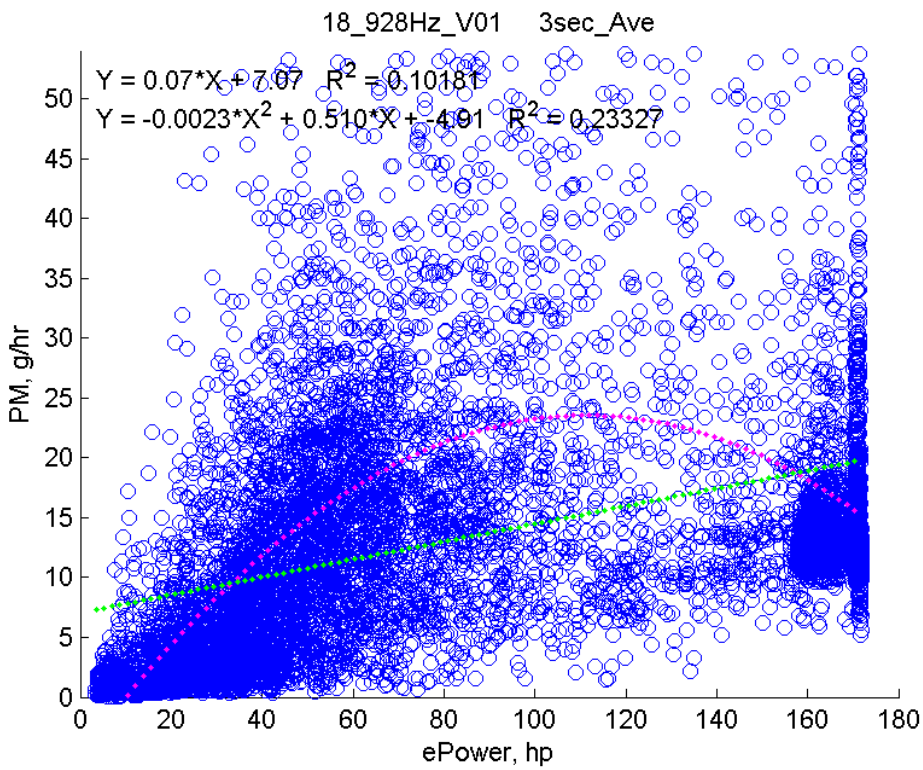


Figure 5-10 Real time PM emissions compared to engine power for a Wheel Loader

5.6 THC and NMHC emissions

The average predicted THC emissions at the 50% and 80% hp levels for the various hp and emission Tier categories in the fleet are presented in Figure 5-11 on a g/hr basis. On a g/hr basis, there are not strong trends in THC emissions as a function of hp category, indicating that the activity of the different pieces of equipment plays an important role in determining overall emissions.

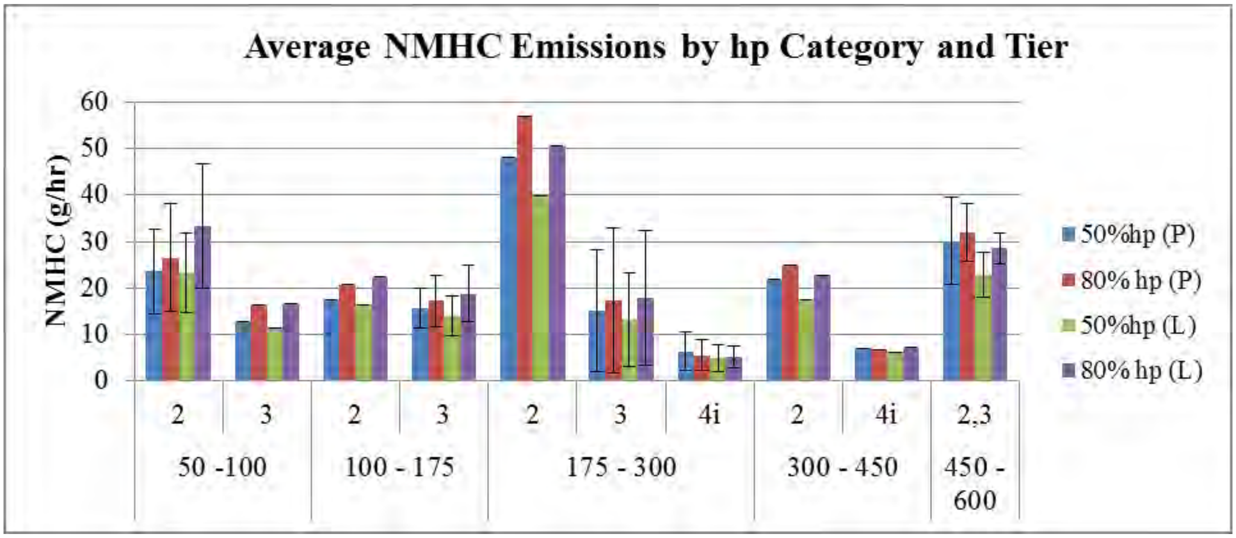


Figure 5-11 Average estimated NMHC emissions in g/hr

The predicted values for NMHC were more consistent for the 100-175 hp category and more variable for the 50-100 hp category. When looking at the real time data it appears the difference is not due to data scatter, but strong trend differences between units. Figure 5-12 shows a representative NMHC power response of one of the off road units for the 175-300 hp category, and Figure 5-13 and Figure 5-14 show NMHC measurements for two backhoes in the 50-100 hp category. Figure 5-13 and Figure 5-14 have significantly different regression line slopes, 0.15 in Figure 5-13 and 0.4 in Figure 5-14. The data show a strong correlation for individual units, but the correlation itself varies between units. The variation between units is the reason for the difference in the predicted value for the NMHC category 50-100 compared to 175 to 300.

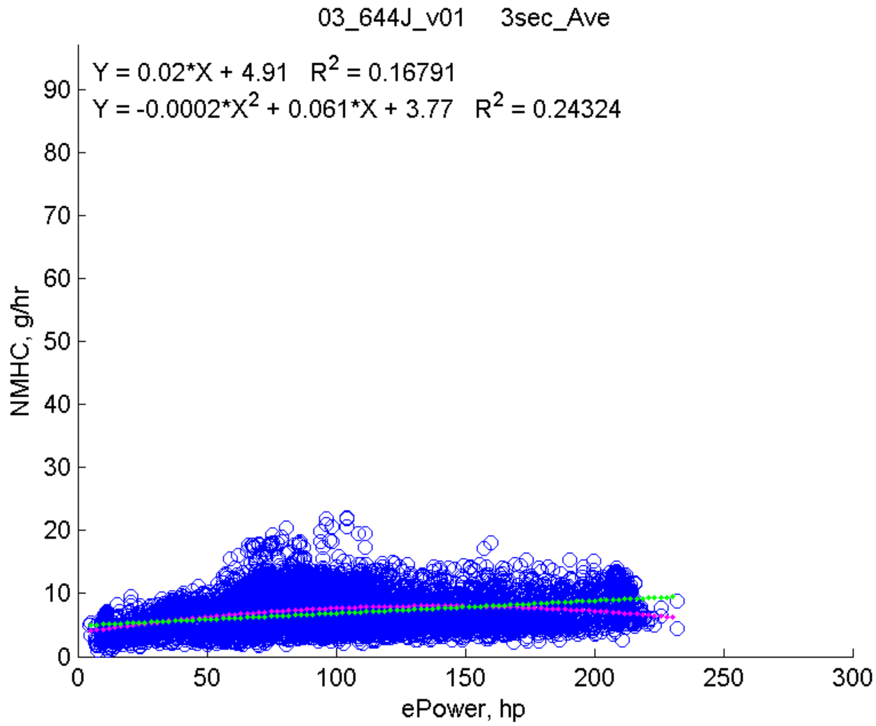


Figure 5-12 Real time NMHC emissions compared to engine power for a Wheel Loader

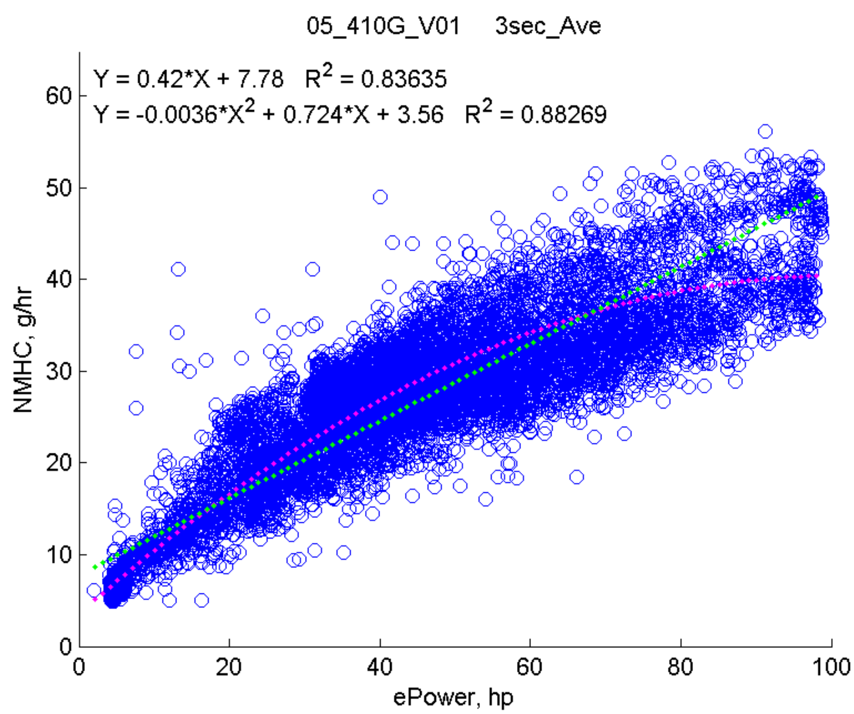


Figure 5-13 Real time NMHC emissions compared to engine power for a Backhoe

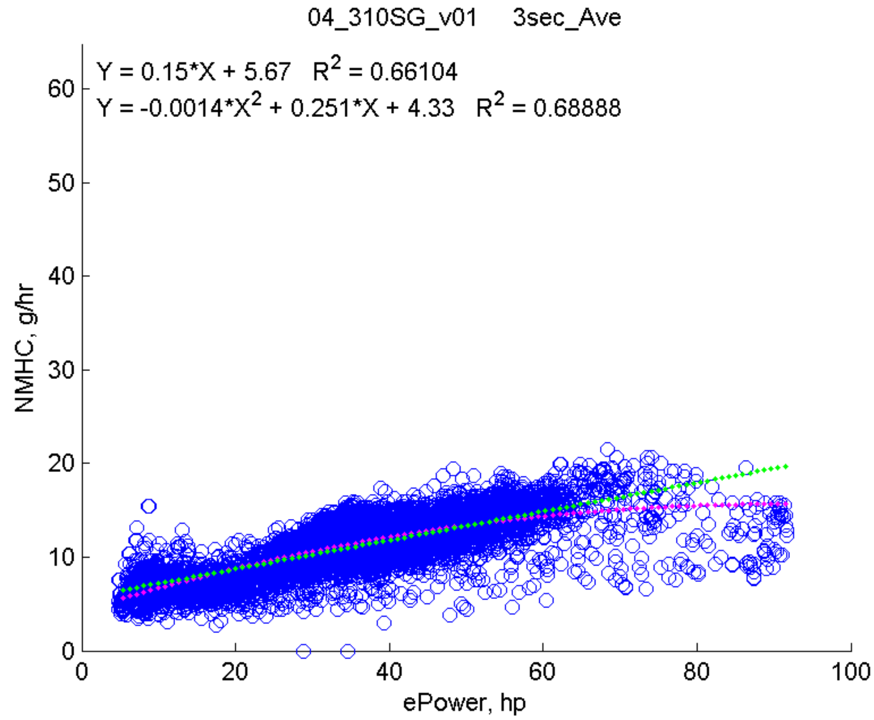


Figure 5-14 Real time NMHC emissions compared to engine power for a Backhoe

5.7 CO emissions

The average predicted CO emissions at the 50% and 80% hp levels for the various hp and emission Tier categories in the fleet are presented in Figure 5-15 on a g/hr basis. On a g/hr basis, the highest CO emissions were found for the Tier 2 175-300 hp category, and for the Tier 2/3 450-600 hp category, which is probably due to this equipment having higher overall loads. As was the case for PM, the CO emissions for the Tier 4i are statistically indistinguishable from 0.

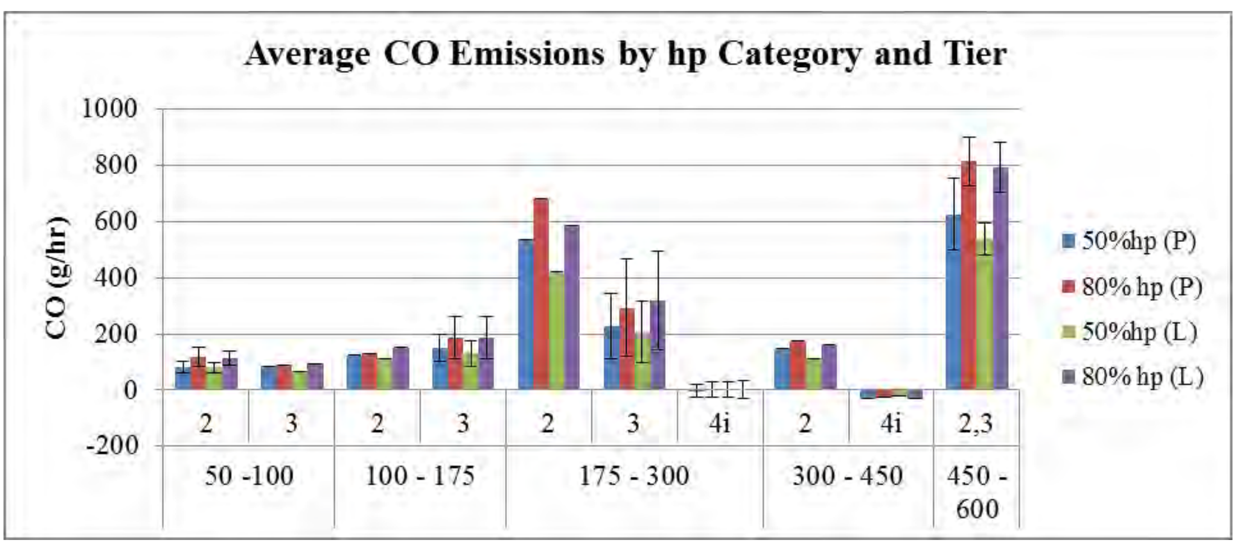


Figure 5-15 Average estimated CO emissions in g/hr

The CO trends as a function of engine power were similar to those for PM, in that the data tend to show more scatter than the other pollutants. Figure 5-16 and Figure 5-17 show real-time emissions as a function of power for a backhoe and a grader, respectively. The first figure shows the CO emissions has a noticable trend where the data flattens out at 100 g/hr from 60 to 100 hp. The poly trend lines somewhat captures this and the linear over estimates from 60 hp to 100 hp. There is a signficnant amount of data that is above the trend line that represents real data from non-PTO operation as discussed previously. This pattern was noticed on several units and was somewhat typical for CO emissions.

Figure 5-17 shows a slighly different trend with a signficant amount of scatter above and below the least fit prediction line. The figure also shows a cluster of data near low power, a large cluster between 40 and 199 hp, and another cluster at max power. Most of the data for this unit appears to be collected at 40-100% load, and these data would be more heavily weighted in the overall emissions factor in the summary tables in the Appendix.

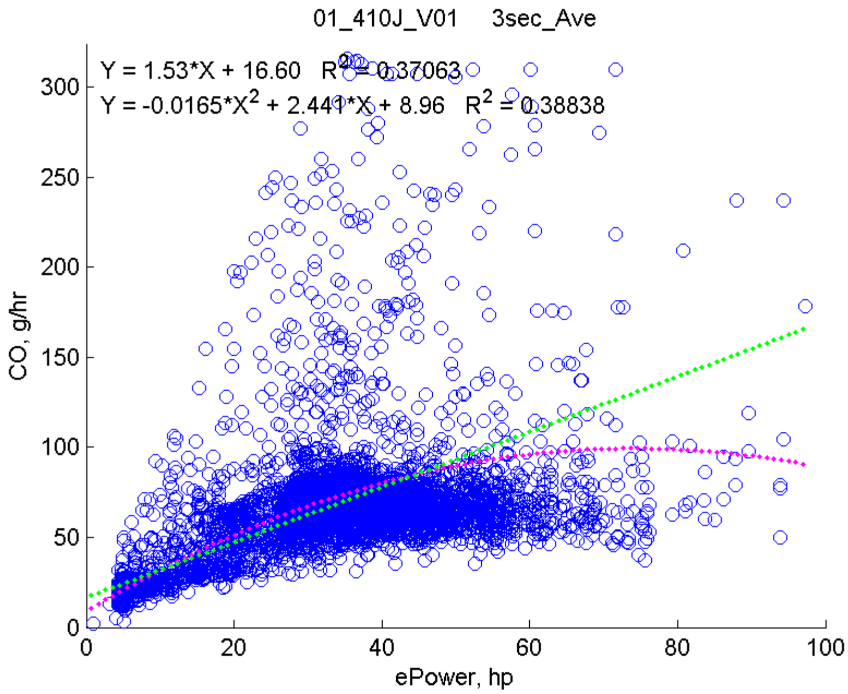


Figure 5-16 Real time CO emissions compared to engine power for a Backhoe

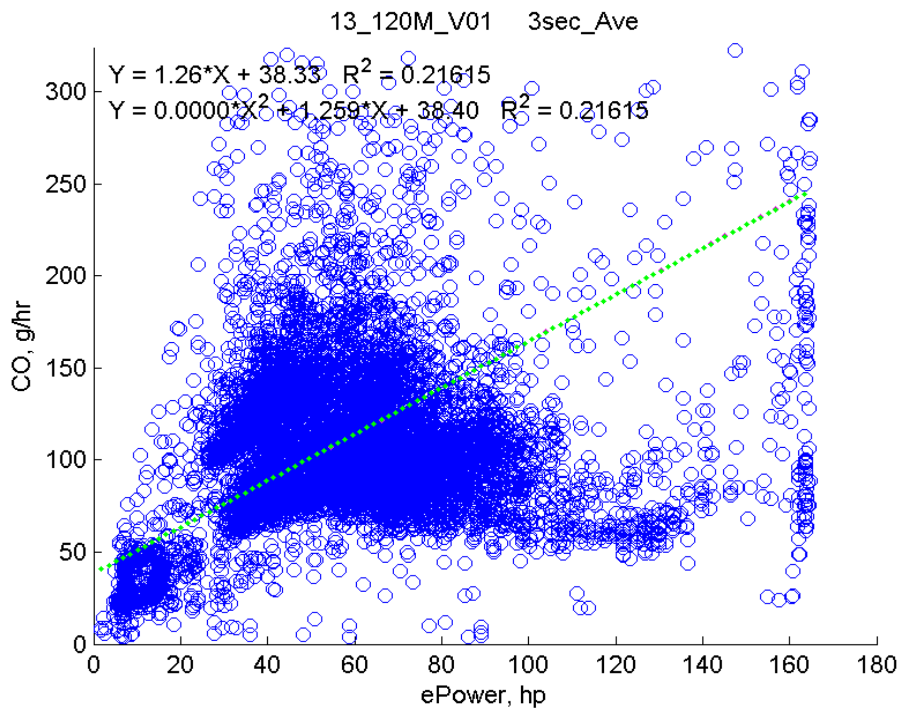


Figure 5-17 Real time CO emissions compared to engine power for a Grader.

5.8 CO_2 emissions

The average predicted CO_2 emissions and FE at the 50% and 80% hp levels for the various hp and emission Tier categories in the fleet are presented in Figure 5-18 and Figure 5-19, respectively, on a g/hr basis. On a g/hr basis the CO_2 emissions tended to increase with increasing engine horsepower independent of the engine tier. Because FE is closely related to CO_2 in the exhaust, the trends for FE are similar to those seen for CO_2 emissions.

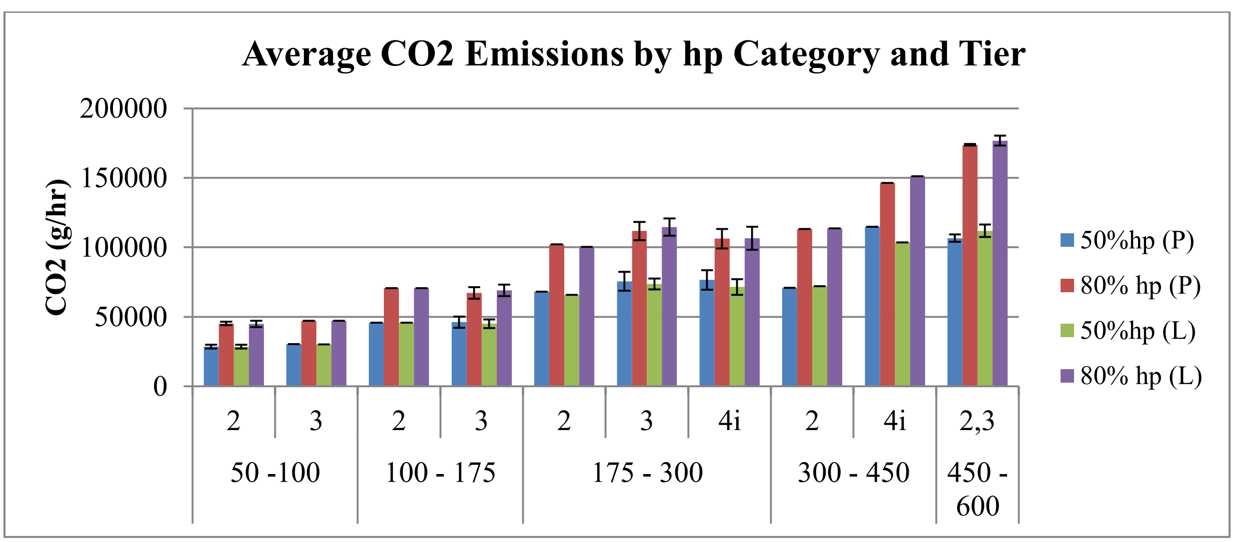


Figure 5-18 Average estimated CO_2 emissions in g/hr

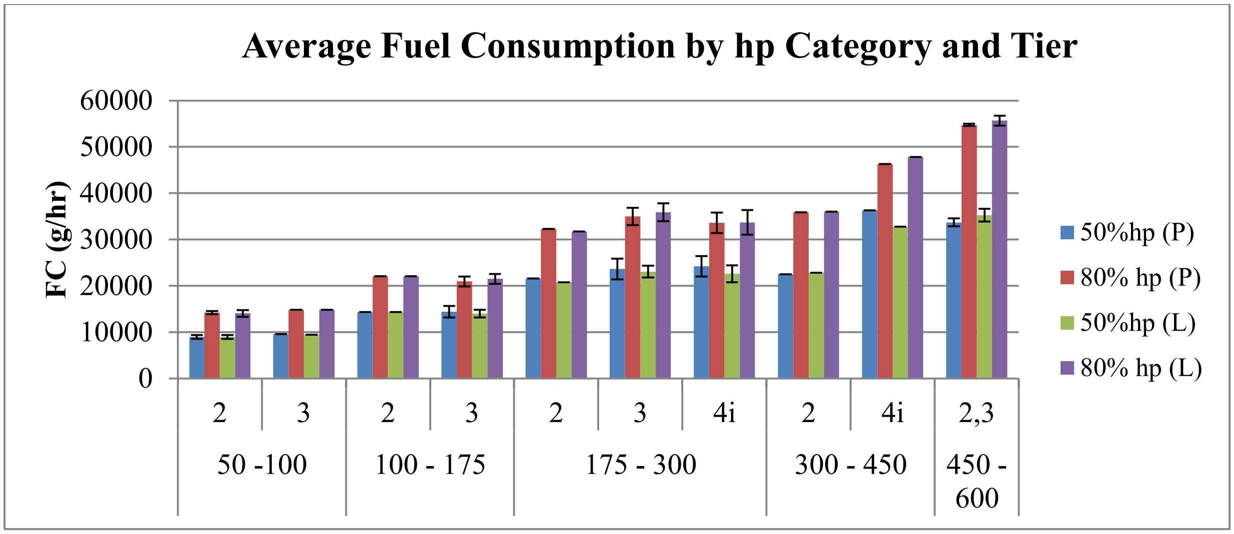


Figure 5-19 Average estimated Fuel Consumption in g/hr

Figure 5-20 through Figure 5-23 shows the CO_2 and FC real-time vs. power for a grader and an excavator, respectively. CO_2 and FC were grouped together since the primary component for the FC calculations is CO_2 emissions. The CO_2 and FC figures are very similar with similar scatter and trends concentrating at max power. The data show a strong correlation with power, which is to be expected. The data has an R^2 greater than 0.9 and is typical for most diesel engine tests. This suggests these measurements are in good agreement with other researchers and industry.

The figures for the grader show a nice linear relationship with power while the figures for the excavator show a slight curve at high load. This excavator is unique in that the other excavators tested did not show this trend of emissions. Additional analysis is needed to determine why the difference exists for this particular excavator.

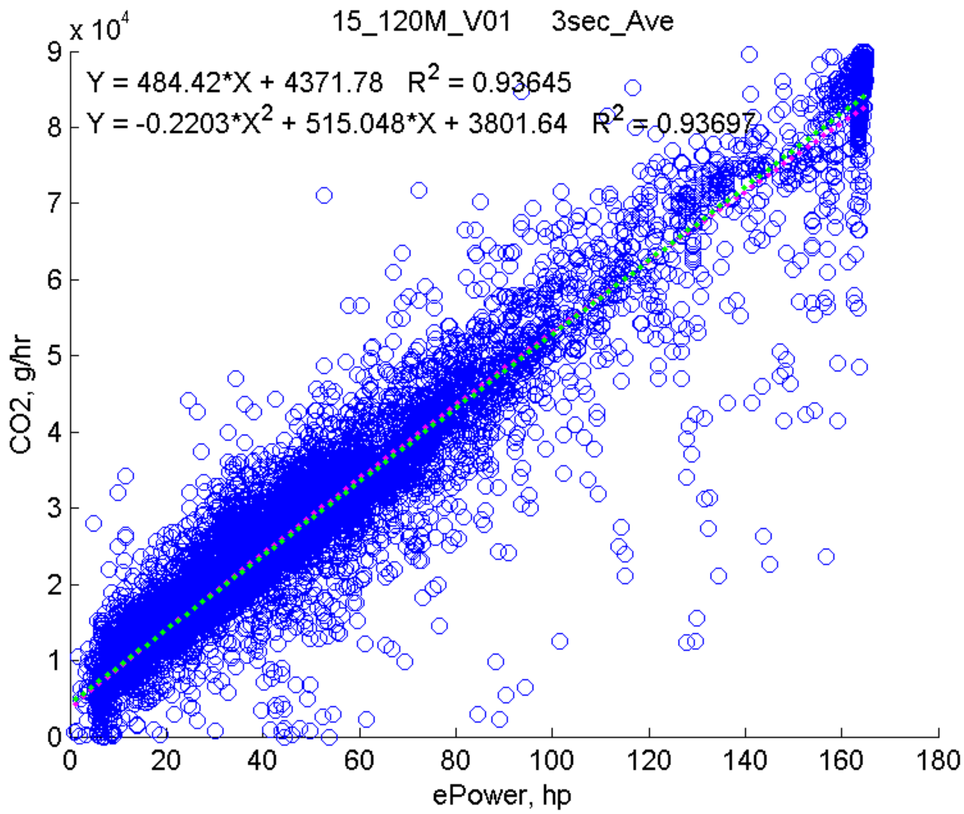


Figure 5-20 Real time CO_2 emissions compared to engine power for a Grader

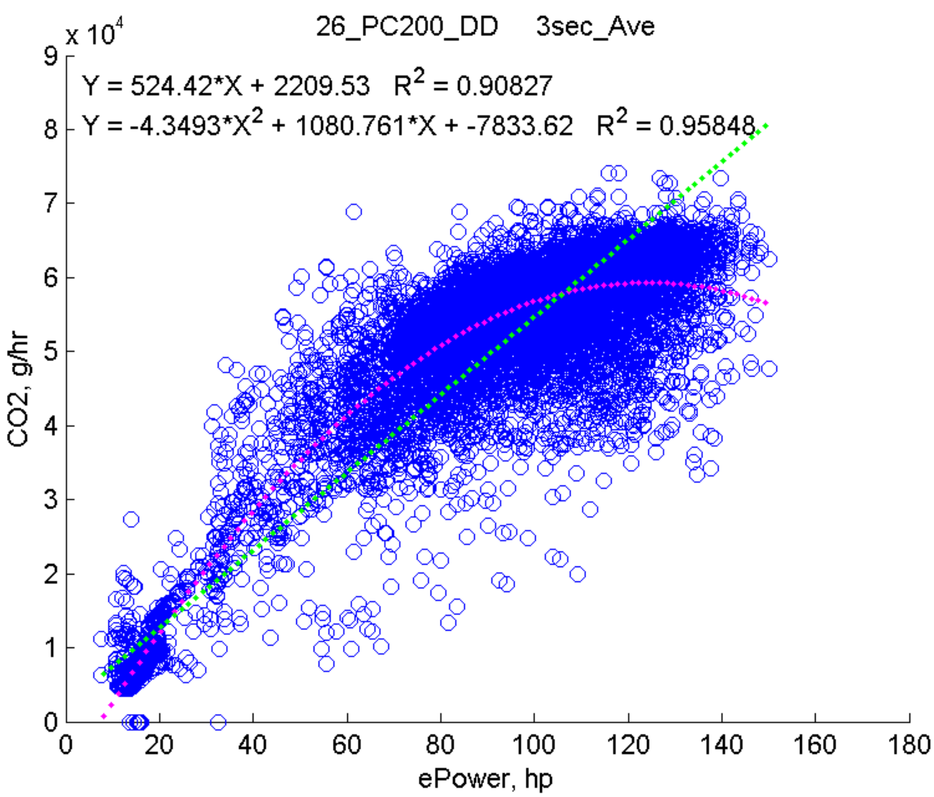


Figure 5-21 Real time CO_2 emissions compared to engine power for an Excavator.

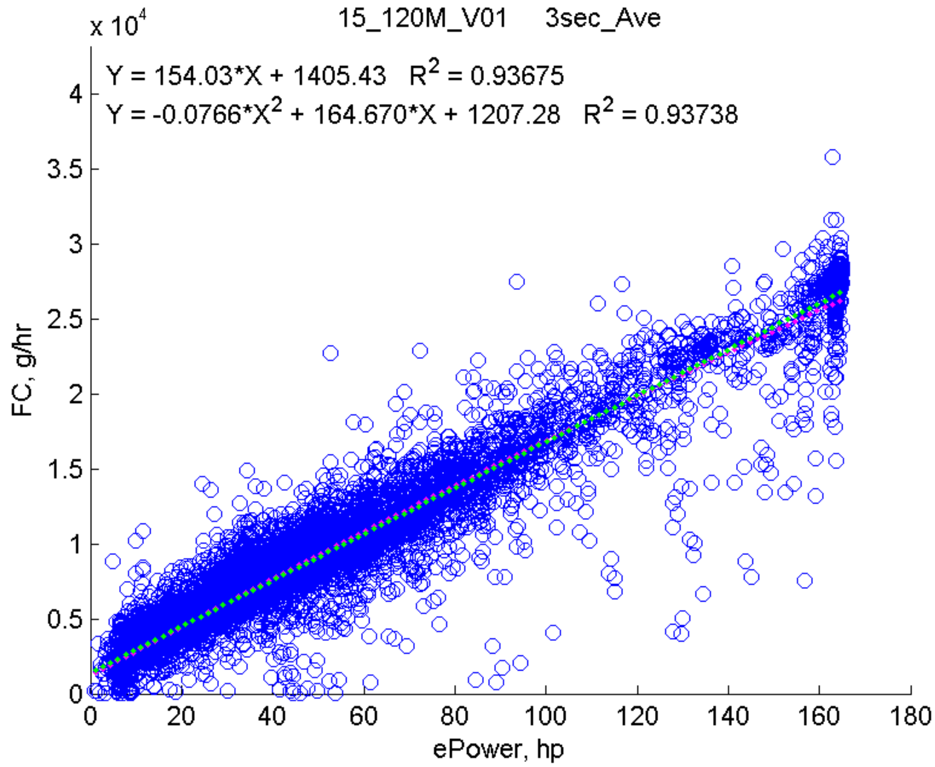


Figure 5-22 Real time FC compared to engine power for a Grader.

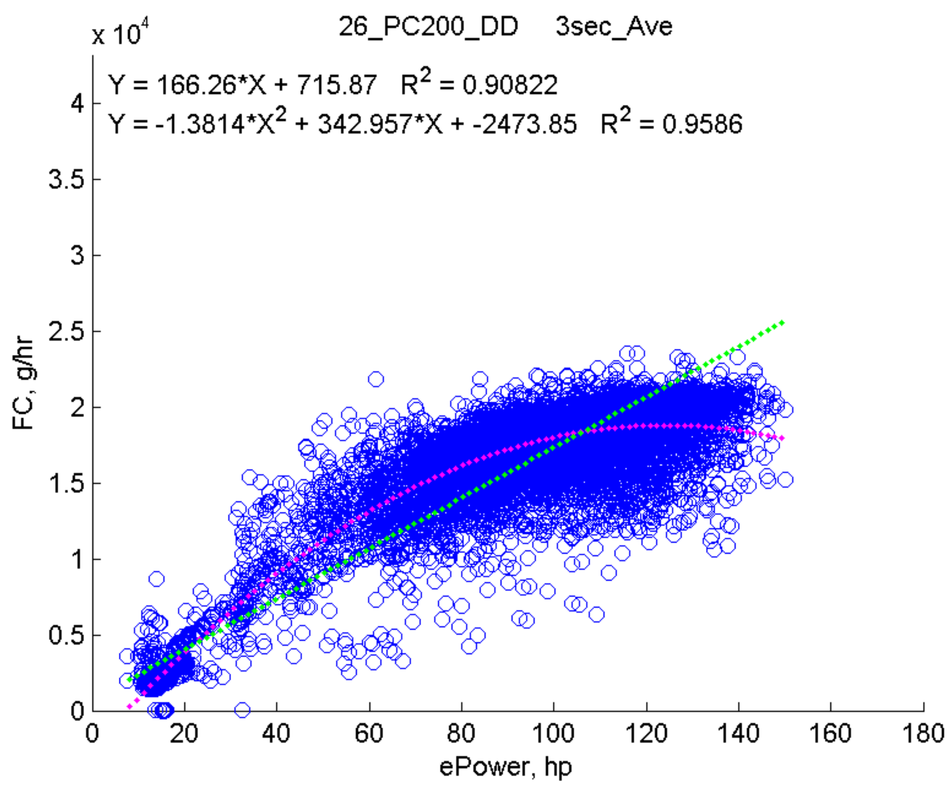


Figure 5-23 Real time FC compared to engine power for an Excavator.

6.0 Summary and Conclusions

Emissions measurements were made for 27 in-use pieces of construction equipment. The equipment included 4 backhoes, 6 wheel loaders, 2 excavators, 2 scrapers (one with 2 engines), 1 bulldozer, and 4 graders. The engines ranged in model year from 2003 to 2011, in rated horsepower from 92 to 540 hp, and from 242 to 17,149 hours of operation. The emissions measurements were made with an the AVL M.O.V.E. Gas PEMS analyzer for gaseous emissions and an AVL Micro Soot Sensor (MSS) for PM. Emissions rates were obtained for each of the 27 pieces of equipment on a g/hr, g/kg of fuel, and g/hp-h basis.

A summary of the major findings and accomplishments of this program is provided below. It should be noted that the results presented in units of g/hp-hr are for a 'high level' comparison against the certification standards. However, it should be noted that in contrast to the 8-mode steady-state engine dynamometer certification test cycle for new diesel off-road engines, actual in-use engine/equipment operation is highly transient, with rapid and repeated changes in engine speed and load. In addition, the average engine 'load factors' (a measure of how hard the engine is working) can be different than the certification test cycle load factor. Thus, results are not expected to be directly comparable to the certification test results, but nevertheless provide an indication of how emissions from actual, in-use diesel engines compare against their new engine certification standards.

Overall Summary

- The NO_x emissions showed generally lower emissions for the Tier 4i units on a g/kg fuel and g/hp-hr basis. The NO_x emissions for the Tier 2 and 3 units do not show strong trends as a function of certification model year, however, for any of the units of comparison. Engine load appeared to be an important factor for NO_x emissions, with equipment with low average percentage engine loads showing generally higher NO_x emissions on a g/hp-hr basis and lower emissions on a g/hr basis.
- The bsPM emissions for twenty of the 26 units with measured brake specific emissions showed bsPM emissions lower than the certification levels. The Tier 4 units with DPFs all showed significant reductions in PM in comparison with those units without aftertreatment. The six units that showed higher bsPM emissions may be a result of operation at lower power and high engine hours. One of the units (#17 a 2010 grader) was equipped with an aftermarket DPF. The bsPM emissions from this unit averaged 0.029 g/hp-h overall and ranged from 0.101 to 0.002 g/hp-h depending on the activity mode.
- The THC emissions ranged from 0.01 to 63 g/hr, 0.18 to 3.5 g/kgfuel, and 0.04 to 0.68 g/hp-h. Two units (#1 and #5 both 410 Deere backhoes) showed relatively high THC emissions of greater than 0.63 g/hp-h, which is almost two times more than the other units tested. The Tier 4i THC emissions were considerably lower than those for most of the other older units.
- CO emissions did not show a trend of increases with older MY engines. The CO emissions ranged from 518 to -15.6 g/hr, 19.1 to -0.7 g/kgfuel, and 3.39 to -0.15 g/hp-h. Three units in the 175 to 600 hp range had average emissions that were higher than the 2.6 g/hp-h standard. Two units in lower power categories (50 hp to 175 hp) also had average CO emissions in the same range, but they were below the 3.7 g/hp-h standard for the smaller engine category. One unit was a wheel loader and the other was a grader. The

CO emissions for the Tier 4i units were essentially at the limits of detection of the PEMS, as indicated by the negative CO emissions values for some of the units.

- CO_2 emissions on a time specific basis do not show a trend with MY since time specific CO_2 is heavily dependent on sample length and engine load. The fuel specific CO_2 ($fsCO_2$) emissions were fairly constant at 3140 g/kgfuel, as expected since CO_2 emissions are a surrogate for fuel consumption and represents the vast majority of the carbon released from fuel combustion. The $bsCO_2$ for all but 5 pieces of equipment were in the range from 520 to 650 g/hp-h, which is in a good range for medium speed diesel engines from 6-15 liters. The engines with lower $bsCO_2$ were in a bulldozer, and the two engines in a scraper. One of the scraper engines had the largest displacement, highest rated power, and highest measured power relative to the other units tested. The two high $bsCO_2$ showed relatively low percent loads, of 40% on average, but 10 other pieces of equipment also had loads of 36% or less.
- The overall in-use brake power average load was between 20 and 60% for nearly all units, with only 7 units having average loads >50%, and only one unit having an average load of >70%.
- The newer engines tended to have lower hours, although some older engines had lower hours then newer ones. This indicates that the number of hours really depends on the unit type and the fleet.

Power-Based Results

- The best correlations for the linear and polynomial regressions between emissions and power were found for CO_2 and NO_x. More than 60% of the units had R^2>0.8 for CO_2 emissions, while NO_x emissions had R^2>0.8 for 6 of 27 units.
- CO, NMHC, and PM showed relatively poor correlations with power, with only 1 unit for PM having R^2 >0.8 and no units for NMHC or CO having R^2 >0.8.
- NO_x emissions on a g/hr basis at selected 50% and 80% power levels showed some trends of higher emissions for higher horsepower engines, due to the higher amount of work they would be doing at their respective 50% and 80% power levels, and lower emissions for Tier 4 engines. Differences across categories and Tiers also indicated that activity was likely an important factor for NO_x emissions on a g/hr basis.
- Differences in real-time NO_x emissions vs. power figures showed differences that could be attributed to differences in operation for specific units.
- PM emissions on a g/hr basis at selected 50% and 80% power levels showed higher emissions for higher horsepower engines and significantly lower emissions for Tier 4 vehicles.
- PM emissions did not show a strong correlation with power on a real-time basis, with only two units showing R^2>0.6 and no units having R^2>0.8. The regression curves to PM vs. power showed considerably scatter above the best fit line for both the polynomial and linear fit lines. The degree of scatter was dependent on differences in operation between different units.
- On a g/hr basis, there are not strong trends in THC emissions as a function of hp category, indicating that the activity of the different pieces of equipment plays an important role in determining overall emissions.
- THC emissions showed some correlation with power on a real-time basis, with seven units showing R^2>0.6 and no units having R^2>0.8. The real-time THC vs. power plots

showed some differences that were not related to data scatter, but rather strong trends differences between units relating to differences in operation.

- On a g/hr basis, the highest CO emissions were found for the Tier 2 175-300 hp category, and for the Tier 2/3 450-600 hp category, which is probably due to this equipment having higher overall loads. CO emissions for the Tier 4i were statistically indistinguishable from 0.
- CO emissions showed a relatively poor correlation with power on a real-time basis, with only one unit showing R^2>0.8 and no units other units having R^2>0.6. The CO trends as a function of engine power were similar to those for PM, in that the data tend to show more scatter than the other pollutants.
- On a g/hr basis the CO_2 emissions tended to increase with increasing engine horsepower independent of the engine tier, consistent with greater fuel use for the larger engines.
- CO_2 emissions showed the best correlation with power on a real-time basis, with more than 60% of the units with R^2 >0.8.
- The correlation between power and emissions was a function of different operational modes. Emissions were particularly sensitive to power take off (PTO) operation, where hydraulic pressure is used to power and manipulate attachments such as blades, shovels, hammers, and other systems, vs. non-PTO.

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Appendix A. Detailed Emission Summary by Unit

This Appendix describes the results for each individual piece of equipment. This includes a brief description of the piece of equipment, where it was tested, and the different types of operation that the equipment did during testing.

The average A-work and overall results for the 27 units tested are presented in Table 1 through Table 27. The first column of the tables indicates the length of time that the data was averaged over. For example, in row one of Table 1 the digging operation was 11.6 minutes, but the overall test was 174.8 minutes (row 10). Thus, the digging operation represents a small snapshot of the full test day. Column 2 is a description for the type of work being performed such as digging, moving, pushing, and lifting. Columns 3 through 6 contain engine related details such as fuel use in kg/hr, engine power in bhp, engine percent load in %, and engine speed in RPM, respectively. Columns 7 thru 11 contain time specific emissions in g/hr. Columns 12 thru 16 contain fuel specific emissions in g/kg-fuel. Columns 17 thru 21 contain brake specific emissions in g/hp-h. For these latter three groupings the emissions are presented in the following order: CO2, CO, NOx, THC, and PM.

Following the results of the individual segments are the overall statistics for the full data set on each piece of equipment. The averages, standard deviations, and coefficient of variations (COV's) for the individual types of A-work are then given. The averages, standard deviations, and COV's for all of the listed A-work without regard to the type of A-work are then given. If for every hour of data recorded specific A-work had been identified and tabulated in these tables then the "A-work Ave" should be approximately equal to the "Overall". The standard deviation and COV of the "A-Work" provides an estimate of the range of results for the "Overall".

Figure 1 through Figure 27 show the second-by-second NOx, PM, and engine speed results for the 27 units tested. NOx and PM are in units of g/s and engine speed is in units of RPM. The figures show test comments for the specific A-work being performed. The A-work was labeled from video analysis and other details noted in hand logs as the test was being performed. The figures in combination with the tabulated data provide a good picture of the variability of the emissions over the course of the testing. These tables and figures are ideal for future analysis of the raw data.

01_410J: 2010.12.03

This 2007 Tier 2 John Deere 410J backhoe is a rental unit owned by RDO equipment. The test location was at the vacant lot next to RDO equipment at the corner of S Iowa Ave and W Main St in Riverside, CA. The equipment was operated by CE-CERT operators and doing mostly digging and backfilling dirt work. The PEMS equipment used was the Semtech DS gaseous PEMS, the AVL 483 MSS, and the 5 inch Semtech EFM. There was about 4 hours of valid test data collected.

Table 1: Integrated emissions for 01_410J John Deere 2007 Tier 2 backhoe

Dur.	Test Function	Fuel [2]	Power [3]	eLoad	eSpeed	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel)					Brake Specific Emissions (g/hp-h)					g/kWhr
min	A-Work[4]	kg/hr	bhp	%	RPM	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]	bsFC
11.6	Digging #1a	6.12	31.2	36.1	1909	19394	61.6	167	22.5	2.4	3169	10.1	27.3	3.68	0.39	622	1.98	5.35	0.72	0.076	263
17.0	Digging #1b	6.34	32.5	37.3	2043	20095	68.1	166	22.6	3.2	3168	10.7	26.1	3.56	0.51	619	2.10	5.10	0.70	0.099	262
14.6	Digging #1c	6.75	35.2	39.2	2113	21396	69.3	176	23.0	3.1	3170	10.3	26.0	3.41	0.46	607	1.97	4.99	0.65	0.089	257
36.4	Idling	1.34	4.7	16.7	899	4234	18.9	47	7.0	1.1	3157	14.1	35.3	5.24	0.81	905	4.05	10.13	1.50	0.231	384
11.5	Digging #2a	6.45	33.1	37.6	1978	20452	74.7	170	22.7	3.7	3169	11.6	26.3	3.52	0.57	617	2.26	5.12	0.68	0.111	261
10.0	Digging #2b	7.80	40.0	46.3	2270	24759	78.9	192	24.0	4.1	3174	10.1	24.6	3.08	0.53	619	1.97	4.80	0.60	0.102	262
13.6	Digging #2c	6.28	34.5	36.7	2043	19931	62.8	171	21.1	2.1	3173	10.0	27.2	3.36	0.34	578	1.82	4.94	0.61	0.061	244
18.2	Digging #2d	6.18	34.1	34.7	2217	19590	70.9	171	24.2	1.4	3169	11.5	27.7	3.91	0.23	575	2.08	5.02	0.71	0.042	243
16.7	Filling and Moving a	6.06	32.2	40.4	1584	19132	131.3	169	15.6	14.8	3158	21.7	27.8	2.57	2.45	595	4.08	5.24	0.48	0.461	253
17.0	Filling and Moving b	5.68	30.2	36.1	1792	17951	108.1	155	17.4	9.6	3160	19.0	27.4	3.07	1.68	594	3.58	5.14	0.58	0.316	252
174.8	Overall[6]	5.02	25.8	32.6	1712	15884	64.9	138	17.5	4.0	3167	12.9	27.4	3.50	0.79	615	2.51	5.33	0.68	0.154	261
	Digging Ave.	6.56	34.4	38.3	2082	20802	69.5	173	22.9	2.9	3170	10.6	26.4	3.50	0.43	605	2.02	5.04	0.67	0.08	256
	Digging Stdev	0.58	2.8	3.8	128	1864	6.2	9	1.1	0.9	2	0.7	1.0	0.26	0.12	20	0.14	0.17	0.05	0.02	8.7
	Digging COV	8.9%	8.2%	10.0%	6.1%	9.0%	8.9%	5.1%	4.6%	32.7%	0.1%	6.4%	3.9%	7.5%	27.7%	3.4%	6.8%	3.4%	7.1%	29.8%	3.4%
	F&M Ave.	5.87	31.2	38.3	1688	18541	119.7	162	16.5	12.2	3159	20.3	27.6	2.82	2.06	594	3.83	5.19	0.53	0.39	252
	F&M Stdev	0.27	1.4	3.1	147	835	16.4	9	1.3	3.7	1	1.9	0.3	0.35	0.54	1	0.36	0.07	0.07	0.10	0.3
	F&M COV	4.5%	4.4%	8.0%	8.7%	4.5%	13.7%	5.8%	7.9%	30.5%	0.0%	9.2%	1.2%	12.4%	26.1%	0.1%	9.3%	1.4%	12.3%	26.3%	0.1%
	A-Work Ave.[7]	5.90	30.8	36.1	1885	18693	74.5	158	20.0	4.6	3167	12.9	27.6	3.54	0.80	633	2.59	5.58	0.72	0.16	268
	A-Work Stdev	1.70	9.6	7.6	400	5393	29.5	40	5.4	4.3	6	4.2	2.9	0.71	0.71	97	0.92	1.60	0.28	0.14	41.5
	A-Work COV	29%	31.1%	20.9%	21.2%	28.9%	39.7%	25.3%	26.8%	94.8%	0.2%	32.2%	10.5%	19.9%	89.0%	15.3%	35.7%	28.7%	39.1%	85.2%	15.5%

[1] Data filtered for ECM and EFM drop out

[2] Fuel calculated from carbon balance method using Sensors data

[3] Power estimated from lug curve work sheet

[4] Activity work for selected sections where the specific type of work is known

[5] Total PM using gravimetric span method and not the model alpha methods

[6] Average for the whole day independent of type of A-work

[7] Overall not included

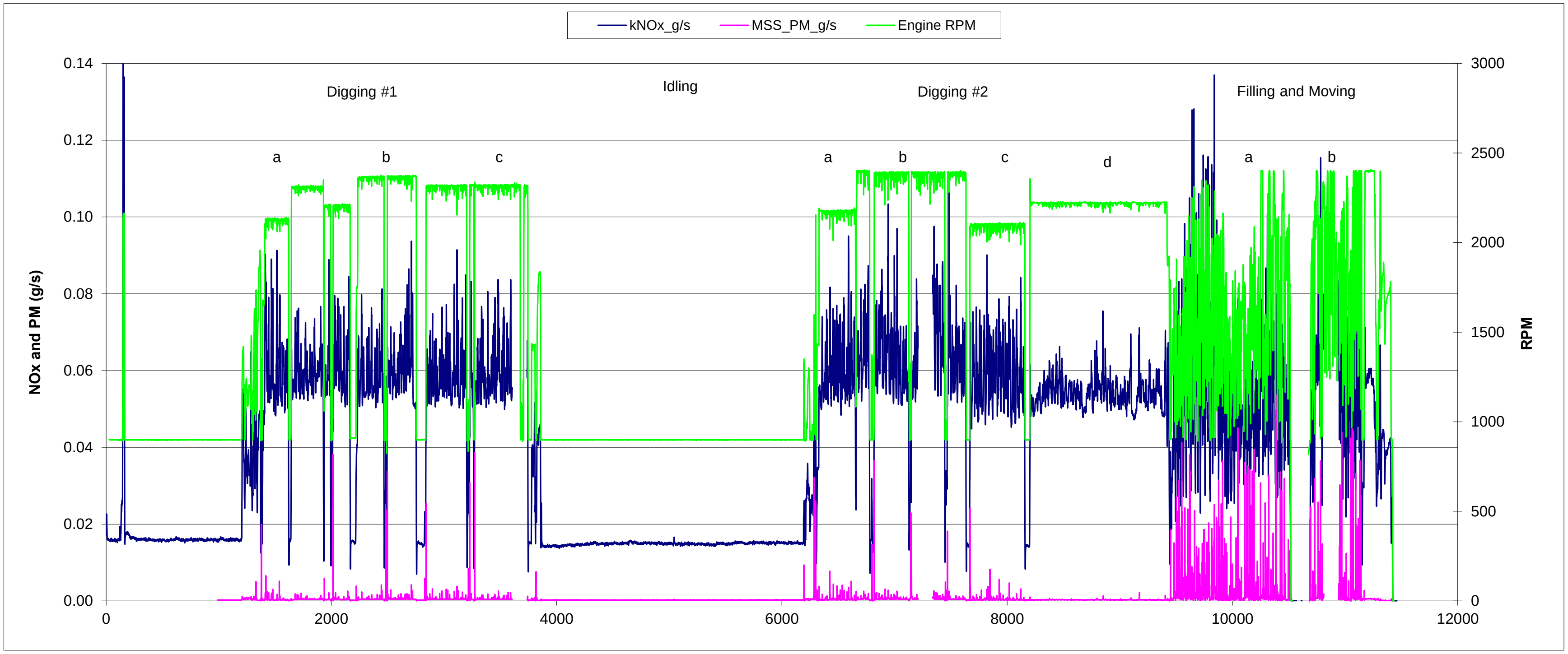

Figure 1: Modal emissions for 01_410J John Deere 2007 Tier 2 backhoe

02_310SJ: 2010.12.07

This 2010 Tier 3 John Deere 310SJ backhoe is a rental unit owned by RDO equipment. The test location was also at the RDO vacant lot in Riverside. The equipment was operated by CE-CERT operators and doing mostly digging and backfilling dirt work. The PEMS equipment was the same as the last test but the EFM was replaced by a 3 inch size tube, the new flow tube was malfunctioning thus method 2 calculation was used for exhaust flow. There was about 4 hours of valid test data collected.

Table 2: Integrated emissions for 02_310SJ John Deere 2010 Tier 3 backhoe

Dur.	Test Function	Fuel [2]	Power [3]	eLoad	eSpeed	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel)					Brake Specific Emissions (g/hp-h)					g/kWhr
Min	A-Work[4]	kg/hr	bhp	%	RPM	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]	bsFC
13.97	Moving	7.50	38.6	46.3	1671	23824	62.1	148	10.6	5.7	3176	8.3	19.8	1.42	0.77	618	1.61	3.85	0.28	0.149	261
8.083	Digging #1a	12.55	66.9	71.4	2087	39871	77.0	206	15.2	4.6	3177	6.1	16.4	1.21	0.36	596	1.15	3.08	0.23	0.068	251
10.25	Digging #1b	11.64	62.1	66.9	2029	36998	73.7	195	15.0	5.0	3177	6.3	16.8	1.29	0.43	596	1.19	3.15	0.24	0.080	251
18.33	Idling	1.49	5.4	18.0	899	4776	15.9	52	3.1	0.6	3195	10.7	34.9	2.06	0.38	887	2.96	9.69	0.57	0.105	372
15	Digging #2a	12.58	67.6	69.0	2070	39980	85.9	205	14.6	5.3	3177	6.8	16.3	1.16	0.42	591	1.27	3.03	0.22	0.079	250
16.67	Digging #2b	11.82	63.0	66.8	2172	37583	77.7	192	13.7	4.6	3178	6.6	16.2	1.16	0.39	596	1.23	3.04	0.22	0.073	252
25	Digging #2c	13.10	70.1	75.4	2201	41634	78.3	221	13.8	4.3	3179	6.0	16.9	1.05	0.32	594	1.12	3.16	0.20	0.061	250
14.33	Digging #2d	12.63	67.6	71.8	2135	40159	73.8	213	16.3	4.6	3179	5.8	16.8	1.29	0.36	594	1.09	3.14	0.24	0.067	250
44.32	idling	1.47	5.3	17.7	899	4705	15.7	52	4.2	0.5	3196	10.7	35.6	2.83	0.33	886	2.97	9.88	0.79	0.090	372
14.9	Digging #3a	13.66	73.0	75.6	2348	43395	79.4	213	20.4	5.1	3177	5.8	15.6	1.50	0.37	594	1.09	2.91	0.28	0.070	251
18.28	Filling and Moving a	9.18	48.5	55.6	1714	29127	93.0	151	9.3	6.1	3172	10.1	16.4	1.01	0.66	601	1.92	3.11	0.19	0.126	254
21.33	Filling and Moving b	10.22	54.5	59.7	1958	32437	95.5	168	11.5	6.4	3174	9.3	16.4	1.13	0.62	595	1.75	3.08	0.21	0.117	251
239.5	Overall[6]	8.63	45.3	52.3	1718	27426	62.2	152	10.9	4.4	3178	7.2	17.6	1.26	0.51	606	1.37	3.35	0.24	0.097	256
	Digging Ave.	12.57	67.2	71.0	2149	39946	78.0	206	15.6	4.8	3178	6.2	16.4	1.24	0.38	594	1.16	3.07	0.23	0.07	250.8
	Digging Stdev	0.69	3.8	3.6	106	2201	4.1	10	2.3	0.4	1	0.4	0.5	0.14	0.04	2	0.07	0.09	0.03	0.01	0.7
	Digging COV	5.5%	5.6%	5.1%	4.9%	5.5%	5.3%	5.0%	14.8%	7.7%	0.0%	6.1%	2.8%	11.3%	9.4%	0.3%	6.1%	2.8%	11.4%	9.4%	0.3%
	F&M Ave.	9.70	51.5	57.7	1836	30782	94.3	159	10.4	6.2	3173	9.7	16.4	1.07	0.64	598	1.83	3.09	0.20	0.12	252.6
	F&M Stdev	0.73	4.3	2.9	172	2341	1.8	12	1.6	0.2	2	0.6	0.0	0.08	0.03	4	0.12	0.02	0.01	0.01	1.9
	F&M COV	7.6%	8.3%	5.0%	9.4%	7.6%	1.9%	7.7%	15.1%	2.9%	0.1%	5.7%	0.1%	7.6%	4.7%	0.7%	6.4%	0.6%	6.8%	5.4%	0.8%
	A-Work Ave.[7]	9.82	51.9	57.9	1849	31207	69.0	168	12.3	4.4	3180	7.7	19.8	1.43	0.45	646	1.61	4.26	0.30	0.09	272.1
	A-Work Stdev	4.27	23.9	20.5	483	13568	26.4	59	5.0	1.9	8	2.0	7.3	0.52	0.15	113	0.69	2.59	0.18	0.03	46.7
	A-Work COV	43%	46.0%	35.5%	26.1%	43.5%	38.2%	35.2%	40.3%	43.7%	0.2%	25.6%	36.7%	36.7%	32.6%	17.5%	42.7%	60.9%	59.9%	30.7%	17.2%

[1] Data filtered for ECM and EFM drop out
[2] Fuel calculated from carbon balance method using Sensors data
[3] Power estimated from lug curve work sheet
[4] Activity work for selected sections where the specific type of work is known
[5] Total PM using gravimetric span method and not the model alpha methods
[6] Average for the whole day independent of type of A-work
[7] Overall not included

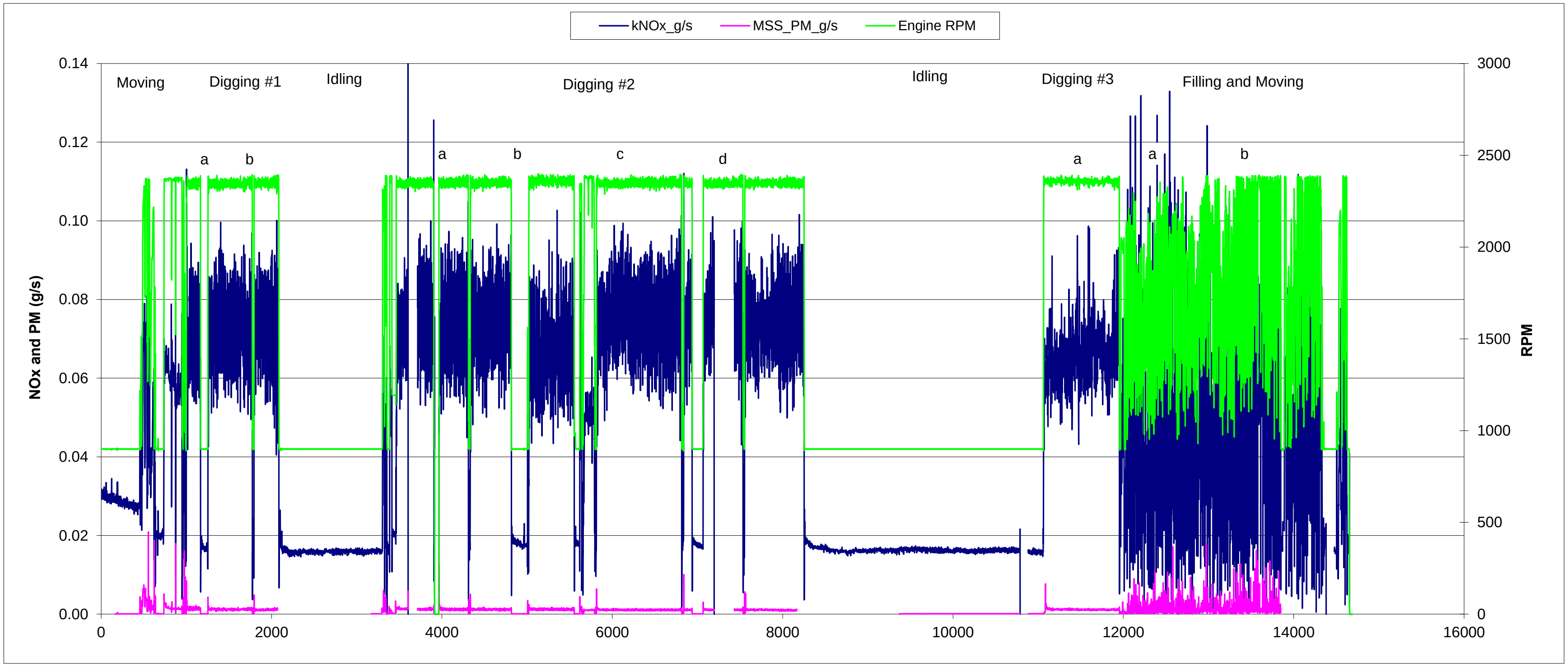

Figure 2: Modal emissions for 02_310SJ John Deere 2010 Tier 3 backhoe

03_644K: 2010.12.08

This 2007 Tier 3 John Deere 644K John Deere wheel loader is also a rental unit owned by RDO equipment. The test location was the same lot and equipment operator was also the same. The EFM was switch back to the 5 inch tube. The wheel loader was doing digging and backfill dirt work as well. There was 4 hours of valid test data collected.

Table 3: Integrated emissions for 03_644J John Deere 2007 Tier 3 wheel loader.

Dur.	Test Function	Fuel [2]	Power [3]	eLoad	eSpeed	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel)					Brake Specific Emissions (g/hp-h)					g/kWhr
Min	A-Work[4]	kg/hr	bhp	%	RPM	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]	bsFC
17.8	Digging/Moving #1a	14.1	77.8	37.2	1625	44727	197.4	327	10.3	9.2	3182	14.0	23.2	0.73	0.66	575	2.54	4.20	0.13	0.12	242
16.8	Digging/Moving #1b	19.9	113.1	52.6	1891	63450	229.5	462	9.1	11.2	3188	11.5	23.2	0.46	0.56	561	2.03	4.09	0.08	0.10	236
14.2	Digging/Moving #1c	20.5	113.8	53.6	1980	65234	267.3	487	7.8	12.7	3186	13.1	23.8	0.38	0.62	573	2.35	4.28	0.07	0.11	241
7.3	Driving #1	4.3	20.3	17.6	1050	13674	58.9	142	5.6	1.0	3180	13.7	33.1	1.29	0.24	674	2.91	7.02	0.27	0.05	284
16.0	Digging #2a	20.9	119.6	55.1	2007	66397	371.9	557	6.5	16.2	3178	17.8	26.7	0.31	0.78	555	3.11	4.66	0.05	0.14	234
19.9	Digging #2b	19.8	108.7	51.7	2070	62799	393.9	483	6.8	18.4	3174	19.9	24.4	0.35	0.93	578	3.62	4.44	0.06	0.17	244
12.7	Digging #2c	10.8	56.3	28.5	1715	34580	117.1	264	8.3	3.1	3187	10.8	24.4	0.77	0.29	614	2.08	4.69	0.15	0.05	258
15.4	Digging #2d	18.6	108.8	50.4	1857	58911	417.9	502	5.5	16.9	3172	22.5	27.0	0.30	0.91	541	3.84	4.61	0.05	0.16	229
7.5	Idling #1	2.4	10.6	14.1	899	7744	39.4	88	4.6	0.9	3176	16.1	35.9	1.88	0.38	734	3.73	8.30	0.43	0.09	310
21.8	Driving #2	4.3	20.3	22.8	939	13735	69.9	144	4.2	2.3	3180	16.2	33.4	0.98	0.53	678	3.45	7.12	0.21	0.11	286
14.3	Filling and Moving a	19.2	114.5	51.9	1893	61132	367.2	478	5.2	17.3	3179	19.1	24.9	0.27	0.90	534	3.21	4.17	0.05	0.15	225
12.9	Filling and Moving b	21.0	114.7	55.8	2115	66793	287.3	457	5.5	14.5	3187	13.7	21.8	0.26	0.69	582	2.50	3.99	0.05	0.13	245
8.3	Idling #2	2.5	10.4	13.8	900	7887	37.7	99	3.9	0.9	3179	15.2	39.9	1.57	0.35	762	3.64	9.55	0.38	0.08	321
190.4	Overall[6]	14.6	81.2	41.0	1665	46426	236.0	365	6.6	10.4	3181	16.2	25.0	0.45	0.71	572	2.91	4.50	0.08	0.13	241
	D/M Ave	18.1	101.6	47.8	1832	57804	231.4	425	9.1	11.1	3185	12.9	23.4	0.52	0.61	570	2.31	4.19	0.09	0.11	240
	D/M Stdev	3.6	20.6	9.2	185	11360	35.0	86	1.2	1.8	3	1.3	0.3	0.19	0.05	7	0.26	0.09	0.03	0.01	3
	COV	20%	20.3%	19.3%	10.1%	19.7%	15.1%	20.3%	13.7%	16.0%	0.1%	9.8%	1.3%	35.4%	7.7%	1.3%	11.1%	2.2%	36.3%	9.0%	1.4%
	Driving Ave	4.31	20.3	20.2	994	13704	64.4	143	4.9	1.7	3180	14.9	33.2	1.13	0.38	676	3.18	7.07	0.24	0.08	285
	Driving Stdev	0.01	0.0	3.7	78	43	7.8	1	0.9	0.9	0	1.8	0.2	0.22	0.21	2	0.38	0.07	0.05	0.05	1
	Driving COV	0.3%	0.0%	18.2%	7.9%	0.3%	12.1%	1.0%	19.4%	55.1%	0.0%	11.7%	0.7%	19.7%	54.8%	0.3%	12.1%	1.0%	19.4%	55.1%	0.3%
	F&M Ave	20.1	114.6	53.8	2004	63963	327.3	468	5.3	15.9	3183	16.4	23.3	0.27	0.80	558	2.86	4.08	0.05	0.14	235
	F&M Stdev	1.2	0.2	2.7	157	4003	56.5	15	0.3	2.0	6	3.8	2.1	0.00	0.15	34	0.50	0.13	0.00	0.02	14
	F&M COV	6%	0.1%	5.0%	7.8%	6.3%	17.3%	3.1%	4.8%	12.4%	0.2%	23.2%	9.2%	1.3%	18.5%	6.1%	17.4%	3.3%	4.7%	12.6%	5.9%
	Idling Ave.	2.46	10.5	14.0	899	7815	38.5	93	4.2	0.9	3177	15.7	37.9	1.72	0.37	748	3.68	8.92	0.41	0.09	316
	Idling Stdev	0.03	0.1	0.2	0	101	1.2	8	0.5	0.0	3	0.7	2.8	0.22	0.02	20	0.07	0.88	0.04	0.00	8
	Idling COV	1.2%	1.3%	1.4%	0.0%	1.3%	3.1%	8.6%	11.7%	4.8%	0.1%	4.3%	7.4%	12.9%	6.0%	2.6%	1.8%	9.9%	10.3%	3.5%	2.6%
	A-Work Ave.[7]	13.7	76.1	38.9	1611	43620	219.7	345	6.4	9.6	3181	15.7	27.8	0.73	0.60	612	3.00	5.47	0.15	0.11	258
	A-Work StDev.	7.7	45.7	17.0	480	24599	143.3	175	2.0	7.0	5	3.4	5.8	0.54	0.24	75	0.64	1.86	0.13	0.04	32
	A-Work COV	56%	60.0%	43.8%	29.8%	56.4%	65.2%	50.7%	30.8%	73.2%	0.2%	21.8%	20.7%	74.0%	39.6%	12.2%	21.4%	34.0%	86.8%	32.6%	12.3%

[1] Data filtered for ECM and EFM drop out

[2] Fuel calculated from carbon balance method using Sensors data

[3] Power estimated from lug curve work sheet

[4] Activity work for selected sections where the specific type of work is known

[5] Total PM using gravimetric span method and not the model alpha methods

[6] Average for the whole day independent of type of A-work

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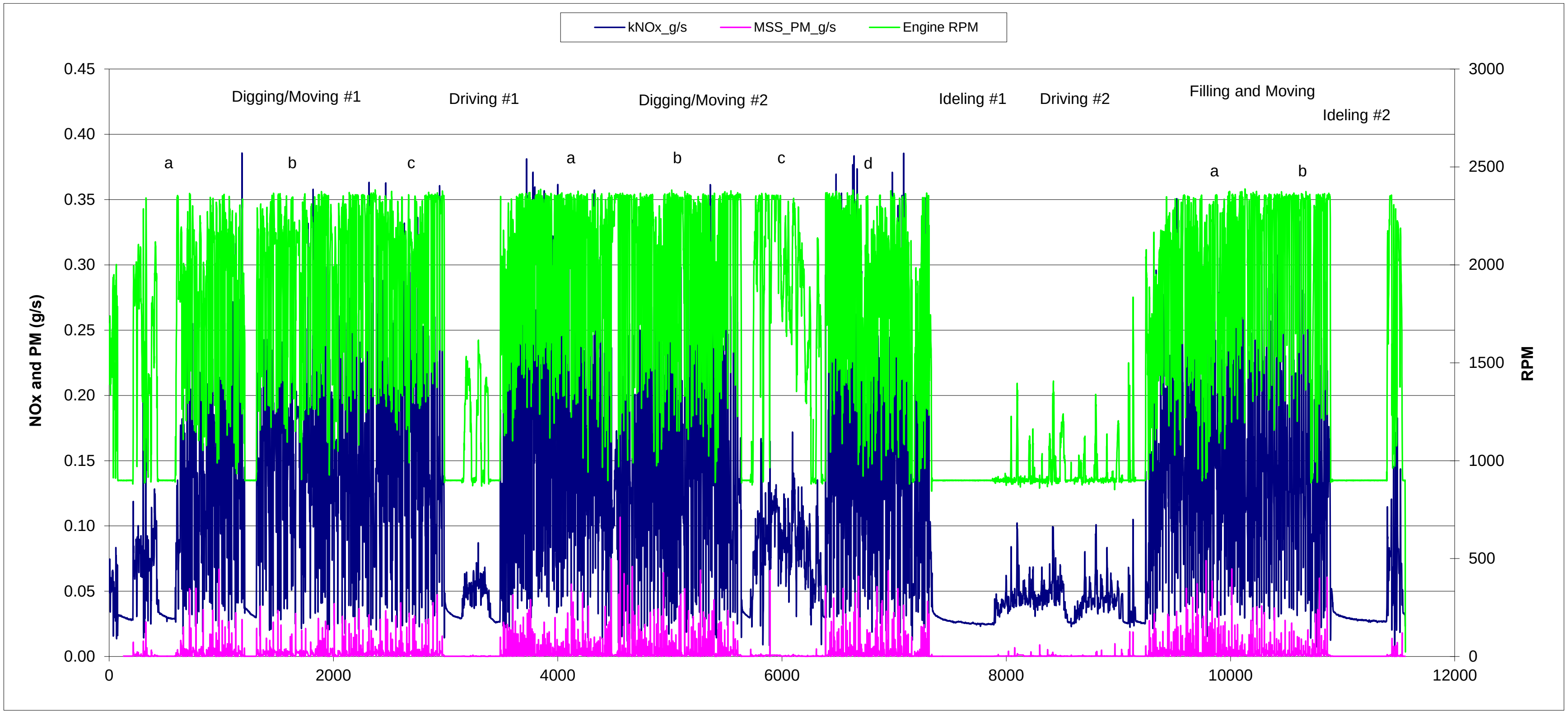


Figure 3: Modal emissions for 03_644J John Deere 2007 Tier 3 wheel loader

04_ 310SG: 2010.12.09

This 2006 Tier 2 John Deere 310SG backhoe is a rental unit owned by RDO equipment. The test location was the same and equipment operator was also the same as the last 3 tests. The work was also digging and back filling dirt. The PEMS equipment was the same as the last test and there was about 4 hours of data collected.

Table 4: Integrated emissions for 04_310SG John Deer 2006 Tier 2 backhoe

Dur.	Test Function	Fuel [2]	Power [3]	eLoad	eSpeed	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel)					Brake Specific Emissions (g/hp-h)					g/kWhr
Min	A-Work[4]	kg/hr	bhp	%	RPM	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]	bsFC
2.4	Idling	2.04	7.2	24.3	942	6486	32.9	130	6.7	0.3	3180	16.1	63.6	3.30	0.13	896	4.54	17.93	0.93	0.038	378
11.0	Moving	2.45	11.9	21.6	1295	7786	31.0	108	7.3	0.7	3182	12.7	44.0	2.98	0.27	652	2.60	9.01	0.61	0.055	275
17.2	Digging #1a	6.02	34.6	40.4	2224	19193	42.7	171	10.6	3.5	3186	7.1	28.3	1.76	0.58	555	1.23	4.93	0.31	0.101	234
32.6	Digging #1b	6.16	35.8	40.8	2288	19621	41.2	176	10.2	2.4	3187	6.7	28.5	1.66	0.39	549	1.15	4.91	0.29	0.067	231
21.3	Digging #1c	4.91	27.4	35.7	1922	15661	41.1	155	8.5	0.0	3187	8.4	31.6	1.73	0.00	571	1.50	5.66	0.31	0.000	240
14.3	idling (broken file)																				
30.8	Digging #2a	7.18	42.1	47.3	2383	22891	36.2	195	12.6	3.9	3188	5.0	27.1	1.75	0.54	543	0.86	4.63	0.30	0.092	229
8.7	Digging #2b	4.95	28.8	33.7	2033	15800	29.2	159	10.6	2.0	3189	5.9	32.1	2.14	0.40	549	1.01	5.52	0.37	0.069	231
4.5	Moving	2.62	12.3	26.0	1133	8366	23.1	142	6.8	0.9	3194	8.8	54.2	2.60	0.35	678	1.87	11.50	0.55	0.073	285
9.5	Digging #3a	5.44	30.7	38.5	2010	17338	32.7	169	10.7	2.5	3189	6.0	31.1	1.96	0.46	564	1.06	5.51	0.35	0.082	237
28.2	Digging #3b	6.12	35.4	41.5	2258	19495	37.9	173	13.0	2.6	3188	6.2	28.2	2.12	0.42	551	1.07	4.88	0.37	0.073	232
26.7	Digging #3c	7.16	41.7	47.7	2315	22819	47.3	198	13.1	4.5	3185	6.6	27.7	1.83	0.62	547	1.13	4.75	0.31	0.107	230
14.1	Digging #3d	7.44	43.4	49.3	2347	23720	39.7	198	13.7	3.3	3187	5.3	26.6	1.84	0.44	547	0.91	4.57	0.32	0.076	230
15.8	Filling and Moving a	6.73	37.8	45.9	1767	21294	134.1	211	8.7	19.3	3164	19.9	31.4	1.29	2.87	563	3.54	5.58	0.23	0.511	239
34.6	Filling and Moving b	6.72	38.3	45.6	1948	21287	120.9	201	10.2	14.1	3168	18.0	29.8	1.51	2.10	556	3.16	5.24	0.27	0.369	235
241.9	Overall[6]	5.89	33.7	40.4	2066	18761	51.0	175	10.8	4.2	3184	8.7	29.7	1.84	0.72	557	1.51	5.19	0.32	0.126	235
	Digging Ave.	6.15	35.5	41.7	2198	19615	38.6	177	11.4	2.7	3187	6.4	29.0	1.87	0.43	553	1.10	5.04	0.32	0.074	233
	Digging Stdev	0.95	5.9	5.5	166	3030	5.4	16	1.7	1.3	1.254	1.0	2.0	0.17	0.18	9	0.19	0.41	0.03	0.031	3.79
	Digging COV	15.5%	16.6%	13.1%	7.6%	15.4%	14.1%	9.2%	15.0%	47.2%	0.0%	15.6%	7.0%	9.2%	41.9%	1.6%	17.0%	8.2%	9.2%	41.9%	1.6%
	F&M Ave.	6.72	38.1	45.8	1858	21290	127.5	206	9.4	16.7	3166	19.0	30.6	1.40	2.49	559	3.35	5.41	0.25	0.440	237
	F&M Stdev	0.01	0.3	0.3	128	5	9.3	7	1.1	3.7	2.618	1.4	1.1	0.16	0.54	5	0.27	0.24	0.03	0.101	2.36
	F&M COV	0.1%	0.9%	0.6%	6.9%	0.0%	7.3%	3.6%	11.4%	22.0%	0.1%	7.2%	3.5%	11.5%	21.9%	0.9%	8.2%	4.5%	10.5%	22.9%	1.0%
	Moving Ave	2.53	12.1	23.8	1214	8076	27.0	125	7.0	0.8	3188	10.7	49.1	2.79	0.31	665	2.23	10.26	0.58	0.064	280
	Moving Stdev	0.12	0.3	3.1	115	410	5.6	24	0.3	0.2	8.85	2.7	7.2	0.27	0.06	18	0.51	1.76	0.04	0.013	6.86
	Moving COV	4.8%	2.4%	12.9%	9.5%	5.1%	20.7%	19.5%	4.9%	22.7%	0.3%	25.4%	14.7%	9.7%	18.0%	2.7%	23.0%	17.2%	7.2%	20.4%	2.5%
	A-Work Ave.[7]	5.42	30.5	38.5	1919	17268	49.3	170	10.2	4.3	3184	9.5	34.6	2.03	0.68	594	1.83	6.76	0.39	0.122	250
	A-Work Stdev	1.83	11.9	9.1	473	5823	33.8	30	2.4	5.5	8.239	5.1	11.3	0.56	0.80	96	1.17	3.76	0.19	0.140	40.5
	A-Work COV	33.8%	38.9%	23.6%	24.6%	33.7%	68.6%	17.5%	23.1%	129.3%	0.3%	53.3%	32.7%	27.7%	116.1%	16.1%	63.6%	55.7%	47.5%	114.3%	16.2%

[1] Data filtered for ECM and EFM drop out

[2] Fuel calculated from carbon balance method using Sensors data

[3] Power estimated from lug curve work sheet

[4] Activity work for selected sections where the specific type of work is known

[5] Total PM using gravimetric span method and not the model alpha methods

[6] Average for the whole day independent of type of A-work

[7] Overall not included

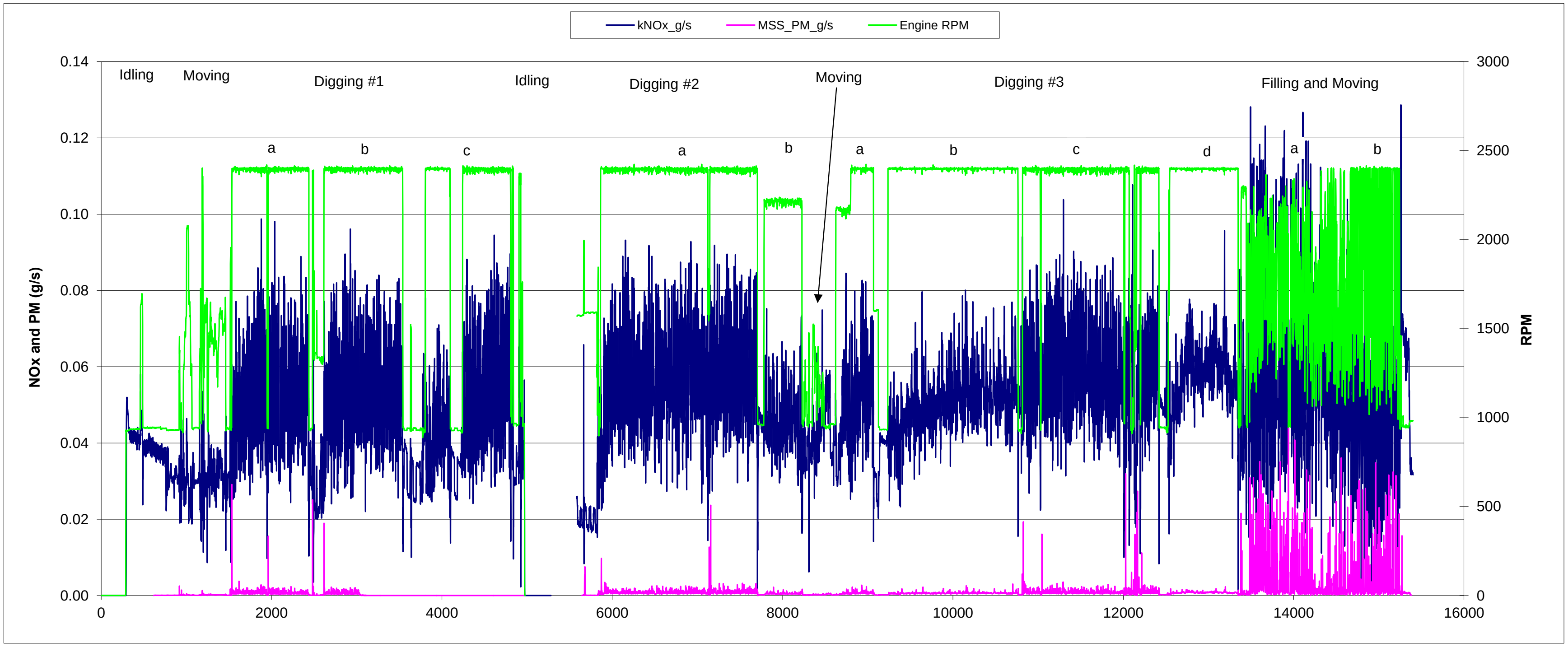


Figure 4: Modal emissions for 04_310SG John Deer 2006 Tier 2 backhoe

05_410G: 2010.12.10

This 2006 Tier 2 John Deere 410G backhoe is a rental unit owned by RDO equipment. The test location was the same and equipment operator was also the same as the last 4 tests. The work was also digging and back filling dirt. The PEMS equipment was the same as the last test and there are about 4 hours of data collected.

Table 5: Integrated emissions for 05_410G John Deer 2006 Tier 2 backhoe

Dur.	Test Function	Fuel [2]	Power [3]	eLoad	eSpeed	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel)					Brake Specific Emissions (g/hp-h)					g/kWhr
Min	A-Work[4]	kg/hr	bhp	%	RPM	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]	bsFC
12.1	Moving	3.38	17.9	26.6	1314	10732	58.0	92	18.5	1.3	3171	17.1	27.0	5.46	0.39	601	3.25	5.12	1.03	0.07	254
13.0	Digging #1a	7.50	40.2	43.7	2106	23842	82.1	172	28.6	3.9	3179	10.9	22.9	3.82	0.52	593	2.04	4.28	0.71	0.10	250
11.0	Digging #1b	8.33	44.7	47.8	2155	26500	81.0	198	27.7	4.2	3181	9.7	23.8	3.32	0.51	593	1.81	4.44	0.62	0.09	250
11.0	Digging #1c	9.63	52.2	54.5	2300	30644	81.0	240	31.0	5.2	3182	8.4	24.9	3.22	0.54	587	1.55	4.59	0.59	0.10	247
14.1	Digging #1d	9.22	49.9	53.2	2188	29343	81.2	229	29.6	5.0	3181	8.8	24.8	3.21	0.54	588	1.63	4.58	0.59	0.10	248
8.4	Digging #2a	8.68	46.6	50.0	2134	27603	86.8	201	27.4	4.3	3180	10.0	23.2	3.16	0.49	592	1.86	4.31	0.59	0.09	250
11.2	Digging #2b	9.13	49.0	52.5	2161	29039	82.2	225	28.4	5.0	3181	9.0	24.6	3.11	0.55	592	1.68	4.59	0.58	0.10	250
5.0	idling	1.27	4.4	16.5	899	4023	42.3	42	5.7	0.7	3178	33.4	33.3	4.49	0.53	906	9.52	9.51	1.28	0.15	383
5.8	idling	1.40	5.1	17.6	920	4461	41.9	45	5.6	0.9	3182	29.9	32.4	4.02	0.61	867	8.15	8.83	1.10	0.17	365
17.5	Light Digging #3a	6.92	36.6	38.5	2339	22000	93.6	156	27.3	2.8	3179	13.5	22.6	3.95	0.41	601	2.56	4.28	0.75	0.08	253
16.7	Digging #3b	9.94	53.8	56.2	2252	31623	86.7	245	30.1	5.5	3181	8.7	24.7	3.03	0.55	588	1.61	4.56	0.56	0.10	248
16.7	Digging #3c	11.46	62.4	64.6	2301	36451	86.2	292	31.7	6.5	3182	7.5	25.5	2.77	0.56	584	1.38	4.68	0.51	0.10	246
8.8	Digging #4a	11.81	64.7	66.6	2311	37837	110.6	366	44.6	n/a	3203	9.4	31.0	3.77	n/a	585	1.71	5.66	0.69	n/a	245
10.1	Digging #5a	5.66	29.4	36.0	1644	18104	61.1	164	21.4	n/a	3201	10.8	28.9	3.79	n/a	616	2.08	5.56	0.73	n/a	258
18.2	Digging #5b	9.76	52.7	56.7	2093	31280	82.8	288	34.9	6.0	3205	8.5	29.5	3.57	0.62	593	1.57	5.47	0.66	0.11	248
1.9	idling	1.41	5.7	17.4	957	4499	25.7	45	6.0	0.4	3189	18.2	31.9	4.22	0.30	793	4.53	7.95	1.05	0.08	334
17.6	Filling and moving a	7.37	40.6	48.2	1619	23586	88.6	225	23.1	10.3	3200	12.0	30.5	3.13	1.39	581	2.18	5.55	0.57	0.25	243
23.7	Filling and moving b	6.33	34.6	41.0	1694	20249	87.0	193	21.9	8.0	3197	13.7	30.4	3.46	1.26	584	2.51	5.56	0.63	0.23	245
269.8	Overall[6]	7.25	38.8	44.2	1865	23114	76.6	193	24.9	4.9	3188	10.6	26.7	3.43	0.68	596	1.97	4.99	0.64	0.13	251
	Digging Ave.	9.00	48.5	51.7	2165	28689	84.6	231	30.2	4.8	3186	9.6	25.5	3.39	0.53	593	1.79	4.75	0.63	0.10	249
	Digging Stdev	1.76	10.0	9.3	185	5640	11.2	61	5.5	1.1	10	1.6	2.8	0.38	0.05	9	0.31	0.51	0.07	0.01	4
	Digging COV	19.6%	20.7%	17.9%	8.6%	19.7%	13.2%	26.4%	18.3%	22.0%	0.3%	16.5%	10.8%	11.1%	10.3%	1.5%	17.6%	10.7%	11.8%	9.7%	1.4%
	F&M Ave.	6.85	37.6	44.6	1656	21917	87.8	209	22.5	9.1	3198	12.9	30.5	3.30	1.33	583	2.35	5.55	0.60	0.24	244
	F&M Stdev	0.73	4.2	5.1	53	2359	1.1	23	0.8	1.6	2	1.2	0.1	0.24	0.09	3	0.23	0.01	0.05	0.02	1
	F&M COV	10.7%	11.2%	11.4%	3.2%	10.8%	1.2%	11.0%	3.6%	17.6%	0.1%	9.5%	0.3%	7.2%	7.0%	0.4%	10.0%	0.2%	7.7%	6.5%	0.5%
	A-Work Ave.[7]	7.21	38.6	44.3	1813	23009	76.4	202	24.7	5.0	3192	13.2	28.8	3.57	0.71	639	2.83	5.81	0.72	0.14	269
	A-Work Stdev	3.71	21.1	17.5	542	11845	25.7	104	12.1	3.4	10	6.7	3.3	0.47	0.39	103	2.08	1.46	0.20	0.07	43
	A-Work COV	51.5%	54.6%	39.6%	29.9%	51.5%	33.7%	51.6%	49.1%	68.3%	0.3%	50.5%	11.6%	13.2%	55.4%	16.0%	73.4%	25.1%	27.5%	49.1%	16.2%

[1] Data filtered for ECM and EFM drop out

[2] Fuel calculated from carbon balance method using Sensors data

[3] Power estimated from lug curve work sheet

[4] Activity work for selected sections where the specific type of work is known

[5] Total PM using gravimetric span method and not the model alpha methods

[6] Average for the whole day independent of type of A-work

[7] Overall not included

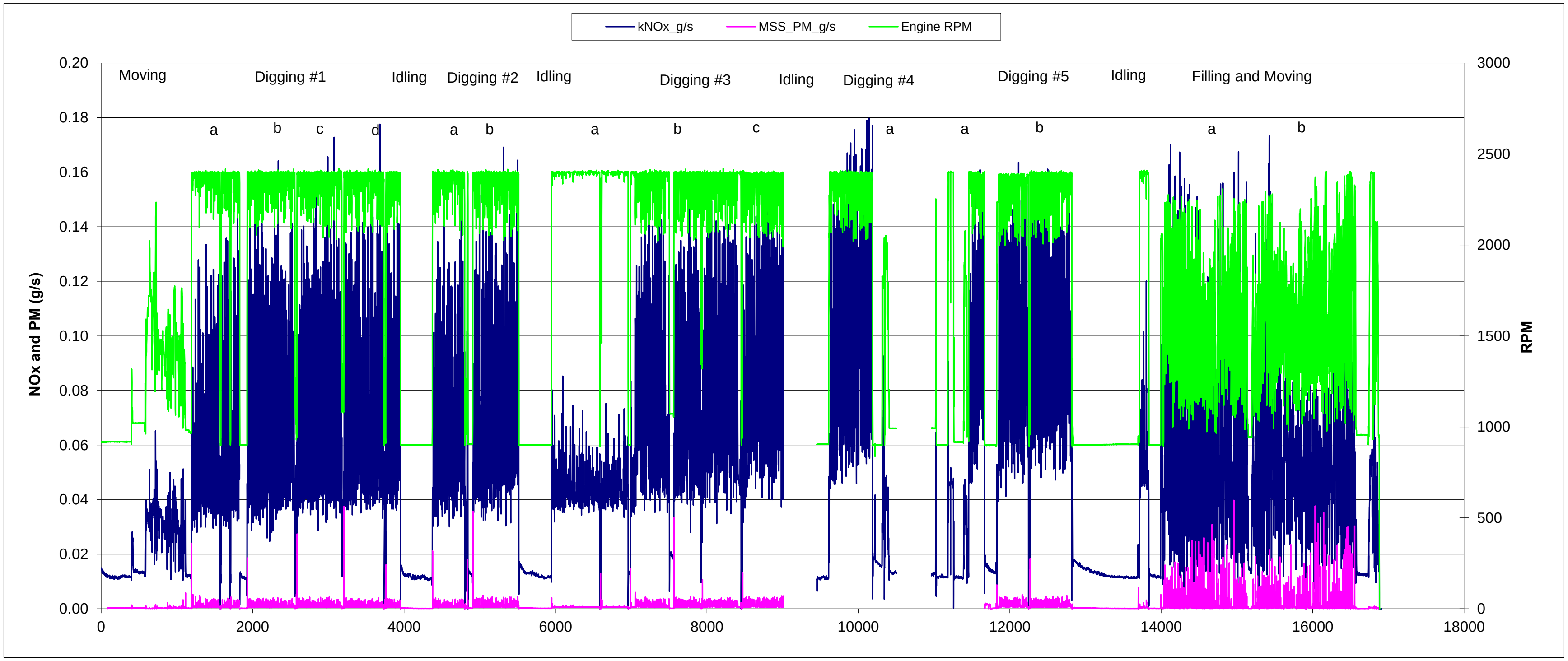


Figure 5: Modal emissions for 05_410G John Deer 2006 Tier 2 backhoe

06_WA470-6: 2011.02.09

This 2009 Tier 3 Komatsu WA470-6 wheel loader is owned and operated by County of Riverside. The test location was at the Riverside County Rock Quarry at Thermal, CA. The wheel loader was operated by Riverside County operator and was loading trucks with crushed gravel. The PEMS equipment was the same as the last tests. There was no ECM connection found, thus no ECM data collected. There was total of 3 hours of test data collected.

Table 6: Integrated emissions for 06_WA470-6 Komatsu 2009 Tier 3 wheel loader

Dur.	Test Function	Fuel [2]	Power [3]	eLoad	eSpeed	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel)					Brake Specific Emissions (g/hp-h)					g/kWhr
Min	A-Work[4]	kg/hr	bhp	%	RPM	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]	bsFC
7.3	Loading #1 a	20.3	118.8	NA	1586	64829	288.1	505	13.3	9.0	3190	14.2	24.9	0.66	0.44	546	2.43	4.25	0.11	0.076	229
15.0	Loading #1 b	13.1	72.0	NA	1208	41687	234.5	366	10.1	5.6	3183	17.9	28.0	0.77	0.43	579	3.26	5.09	0.14	0.078	244
18.8	Loading #2 a	16.6	92.4	NA	1300	52714	319.0	470	9.8	8.5	3182	19.3	28.4	0.59	0.51	570	3.45	5.08	0.11	0.092	240
2.5	Idling #1	3.4	13.0	NA	884	10842	63.1	117	6.7	1.4	3175	18.5	34.3	1.95	0.40	836	4.87	9.04	0.51	0.107	353
16.6	Loading #2 b	14.9	82.4	NA	1254	47384	294.4	439	9.8	5.8	3181	19.8	29.5	0.66	0.39	575	3.57	5.33	0.12	0.071	242
19.6	Loading #2 c	16.9	95.1	NA	1337	53618	336.1	488	9.8	9.8	3181	19.9	28.9	0.58	0.58	564	3.53	5.13	0.10	0.103	238
14.8	Loading #2 d	17.1	97.4	NA	1385	54263	322.1	529	9.7	7.7	3182	18.9	31.0	0.57	0.45	557	3.31	5.43	0.10	0.079	235
3.3	Idling #2	3.4	12.9	NA	880	10821	50.5	121	6.4	1.1	3181	14.9	35.5	1.88	0.31	838	3.91	9.35	0.49	0.083	353
16.4	Loading #2 e	19.0	110.4	NA	1414	60618	363.0	534	10.4	8.9	3183	19.1	28.1	0.55	0.47	549	3.29	4.84	0.09	0.081	231
3.7	Loading #2 f	16.95	93.0	NA	1323	53754	454.7	515	8.5	8.7	3172	26.8	30.4	0.50	0.51	578	4.89	5.54	0.09	0.093	244
217.2	Overall[6]	15.52	87.1	NA	1296	49390	295.8	450	9.7	7.3	3182	19.1	29.0	0.63	0.47	567	3.39	5.16	0.11	0.084	239
	Loading Ave.	16.85	95.2	NA	1351	53608	326.5	481	10.2	8.0	3182	19.5	28.6	0.61	0.47	565	3.47	5.09	0.11	0.08	238
	Loading Stdev	2.23	14.7	NA	115	7143	64.3	56	1.4	1.5	5	3.5	1.9	0.08	0.06	13	0.68	0.40	0.02	0.01	5.73
	Loading COV	13%	15.4%	NA	8.5%	13.3%	19.7%	11.6%	13.6%	19.1%	0.2%	17.9%	6.6%	13.7%	12.5%	2.3%	19.6%	7.9%	14.6%	12.8%	2.4%
	Idling Ave.	3.41	12.9	NA	882	10832	56.8	119	6.5	1.2	3178	16.7	34.9	1.92	0.36	837	4.39	9.20	0.50	0.09	353
	Idling Stdev	0.01	0.0	NA	3	15	8.9	3	0.2	0.2	4	2.6	0.8	0.06	0.06	1	0.67	0.22	0.01	0.02	0.06
	Idling COV	0.3%	0.3%	NA	0.3%	0.1%	15.6%	2.1%	3.1%	18.0%	0.1%	15.3%	2.4%	2.9%	17.7%	0.1%	15.4%	2.4%	2.9%	17.8%	0.0%
	A-Work Ave.[7]	14.16	78.7	NA	1257	45053	272.6	408	9.4	6.7	3181	18.9	29.9	0.87	0.45	619	3.65	5.91	0.19	0.09	261
	A-Work Stdev	6.00	37.0	NA	223	19105	127.1	160	2.0	3.2	5	3.4	3.1	0.56	0.07	115	0.75	1.77	0.17	0.01	49
	A-Work COV	42.4%	47.0%	NA	17.7%	42.4%	46.6%	39.3%	20.8%	47.5%	0.2%	18.0%	10.5%	63.8%	16.4%	18.6%	20.5%	30.0%	89.4%	13.8%	18.7%

[1] Data filtered for ECM and EFM drop out
[2] Fuel calculated from carbon balance method using Sensors data
[3] ECM % load data not available on this Komatsu vehicle. Power estimated from bsCO2 curve
[4] Activity work for selected sections where the specific type of work is known
[5] Total PM using gravimetric span method and not the model alpha methods
[6] Average for the whole day independent of type of A-work
[7] Overall not included

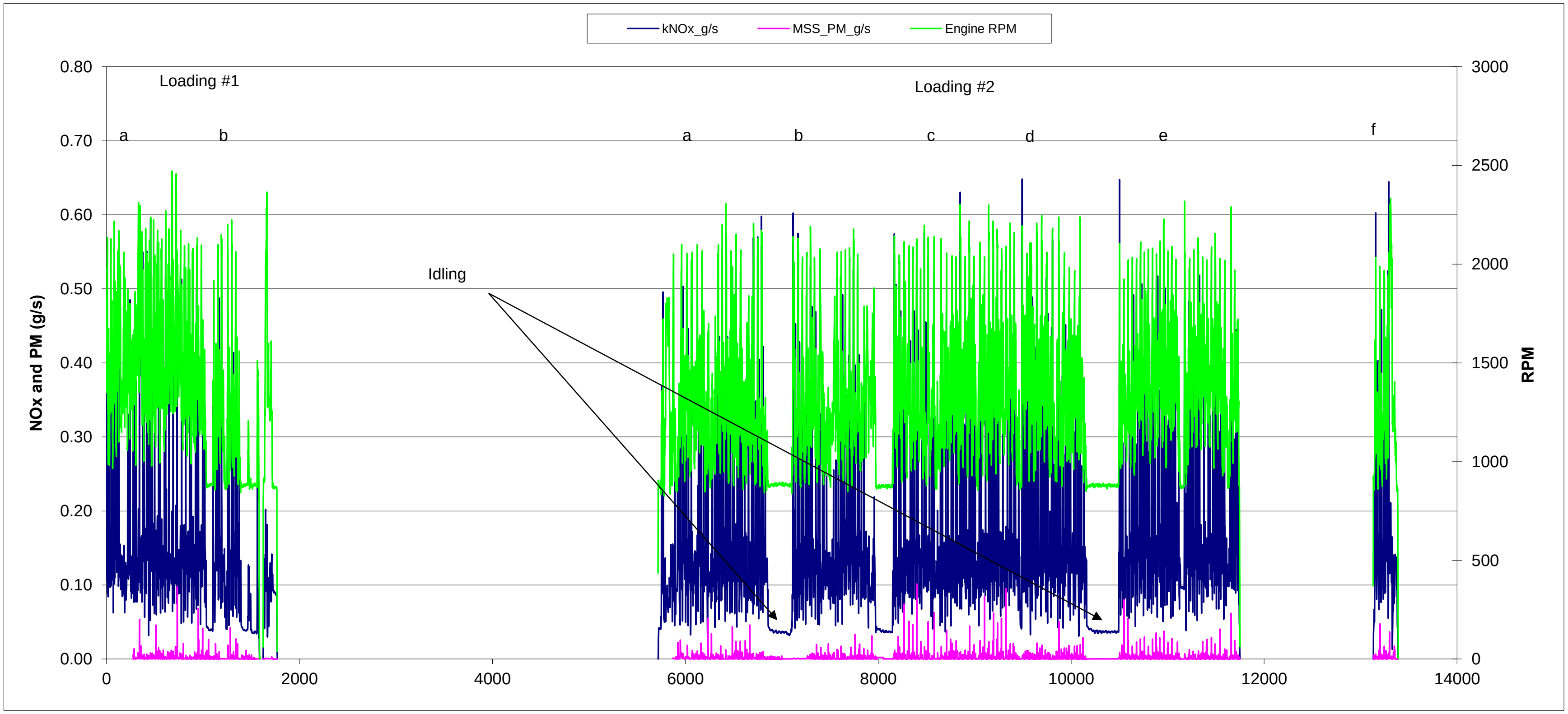


Figure 6: Model emissions for 06_WA470-6 Komatsu 2009 Tier 3 wheel loader

07_928G: 2011.02.10

This 2004 Tier 2 Caterpillar 928G wheel load is also owned and operated by County of Riverside. The test location was at the Riverside County Rock Quarry at Thermal, CA. The wheel loader was operated by Riverside County operator and was loading and smoothing asphalt. The PEMS equipment was the same and ECM was record by CAT ET. There was about 3 hours of data recorded.

Table 7: Integrated emissions for 07_928G 2004 CAT Tier 2 wheel loader

Dur.	Test Function	Fuel [2]	Power [3]	eLoad	eSpeed	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel)					Brake Specific Emissions (g/hp-h)					g/kWhr
Min	A-Work[4]	kg/hr	bhp	%	RPM	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]	bsFC
15.7	Smoothing Asphalt	8.3	46.9	34.4	1316	26309	128.4	207	12.3	n/a	3184	15.5	25.1	1.48	n/a	562	2.74	4.42	0.26	n/a	236
11.67	Drive to Quarry	10.3	48.8	33.1	1587	32781	76.6	256	14.0	4.5	3197	7.5	25.0	1.36	0.44	671	1.57	5.25	0.29	0.092	282
21.67	Drive to Quarry	17.9	97.0	62.8	2006	57231	90.9	444	17.2	6.3	3203	5.1	24.8	0.96	0.35	590	0.94	4.57	0.18	0.065	247
32.38	Staff Meeting																				
27.5	Pick up/load rock	6.9	34.0	24.9	1266	21993	78.7	175	9.4	4.5	3192	11.4	25.4	1.36	0.65	647	2.32	5.16	0.28	0.132	272
1.3	idle	2.5	5.1	6.0	829	7867	29.7	98	3.5	0.7	3190	12.0	39.8	1.41	0.30	1545	5.83	19.27	0.68	0.145	649
0.533	idle	2.4	5.2	6.1	829	7601	30.8	100	4.8	0.7	3185	12.9	41.9	2.00	0.28	1466	5.95	19.28	0.92	0.127	617
25.53	Pick up/load rock	6.2	31.2	23.1	1249	19801	80.1	155	10.3	4.1	3188	12.9	24.9	1.66	0.67	634	2.56	4.96	0.33	0.133	267
18.62	Pick up/load rock	6.7	33.4	24.8	1253	21346	86.5	167	10.6	4.4	3188	12.9	25.0	1.58	0.65	639	2.59	5.01	0.32	0.131	269
23.68	Pick up/load rock	7.0	35.2	25.6	1286	22288	91.8	174	10.7	4.5	3188	13.1	24.9	1.54	0.65	632	2.61	4.94	0.30	0.128	266
33.33	Pick up/load rock	6.1	30.1	22.0	1183	19443	85.9	159	10.8	n/a [5]	3186	14.1	26.0	1.77	n/a [5]	645	2.85	5.27	0.36	N/A [6]	271
16.67	Pick up/load rock	6.8	34.4	24.2	1267	21843	87.8	172	11.1	n/a	3189	12.8	25.0	1.62	n/a	636	2.56	4.99	0.32	N/A	267
16.67	Pick up/load rock	8.0	41.3	29.3	1351	25464	103.8	191	12.3	n/a	3189	13.0	23.9	1.54	n/a	616	2.51	4.61	0.30	N/A	259
33.33	Drive from Quarry	10.9	56.6	38.0	1627	34833	99.0	252	15.0	n/a	3195	9.1	23.1	1.37	n/a	616	1.75	4.45	0.26	N/A	258
298	Overall[7]	8.3	42.4	29.8	1377	26462	90.1	205	11.9	5.6	3192	10.9	24.7	1.43	0.67	624	2.12	4.83	0.28	0.131	262
	Driving Ave.	13.01	67.5	44.6	1740	41615	88.8	317	15.4	5.4	3198	7.2	24.3	1.23	0.39	626	1.42	4.76	0.24	0.08	262
	Driving Stdev	4.22	25.8	15.9	231	13563	11.3	109	1.6	1.3	4	2.0	1.1	0.23	0.06	42	0.43	0.43	0.06	0.02	18
	Driving COV	32%	38.3%	35.6%	13.3%	32.6%	12.7%	34.5%	10.7%	24.3%	0.1%	27.8%	4.3%	19.0%	14.7%	6.6%	30.1%	9.1%	23.8%	23.8%	6.7%
	Pick up/loadAve.	6.82	34.2	24.8	1265	21740	87.8	170	10.7	4.4	3189	12.9	25.0	1.58	0.66	636	2.57	4.99	0.32	0.13	267
	Pick up/loadStdev	0.62	3.6	2.3	50	1976	8.4	12	0.9	0.2	2	0.8	0.7	0.13	0.01	10	0.16	0.21	0.03	0.00	4
	Pick up/loadCOV	9.1%	10.5%	9.3%	4.0%	9.1%	9.5%	6.9%	8.1%	3.9%	0.1%	6.1%	2.6%	7.9%	1.3%	1.6%	6.1%	4.1%	8.2%	1.4%	1.6%
	Idle Ave	2.43	5.1	6.1	829	7734	30.2	99	4.1	0.7	3188	12.5	40.8	1.71	0.29	1505	5.89	19.27	0.80	0.14	633
	Idle Stdev	0.06	0.1	0.1	0	188	0.8	1	0.9	0.1	4	0.6	1.5	0.42	0.02	56	0.08	0.00	0.17	0.01	23
	Idle COV	2.3%	1.3%	1.2%	0.0%	2.4%	2.7%	1.3%	22.3%	8.1%	0.1%	5.0%	3.6%	24.5%	5.8%	3.7%	1.4%	0.0%	21.0%	9.4%	3.6%
	A-Work Ave.[7]	7.68	38.4	27.3	1312	24523	82.3	196	10.9	3.7	3190	11.7	27.3	1.51	0.50	761	2.83	7.09	0.37	0.12	320
	A-Work Stdev	3.91	23.0	14.2	310	12546	26.7	88	3.7	2.0	5	2.9	6.1	0.25	0.17	332	1.46	5.41	0.20	0.03	140
	A-Work COV	51%	59.9%	52.3%	23.7%	51.2%	32.4%	44.8%	34.0%	53.3%	0.2%	24.4%	22.2%	16.2%	35.0%	43.6%	51.7%	76.4%	55.0%	22.4%	43.6%

[1] Data filtered for ECM and EFM drop out
[2] Fuel calculated from carbon balance method using Sensors data
[3] Power estimated from lug curve work sheet
[4] Activity work for selected sections where the specific type of work is known
[5] Total PM using gravimetric span method and not the model alpha methods
[6] PM PEMS system turned off during in-use operation and could not access equipment until shift was over
[7] Average for the whole day independent of type of A-work
[8] Overall not included

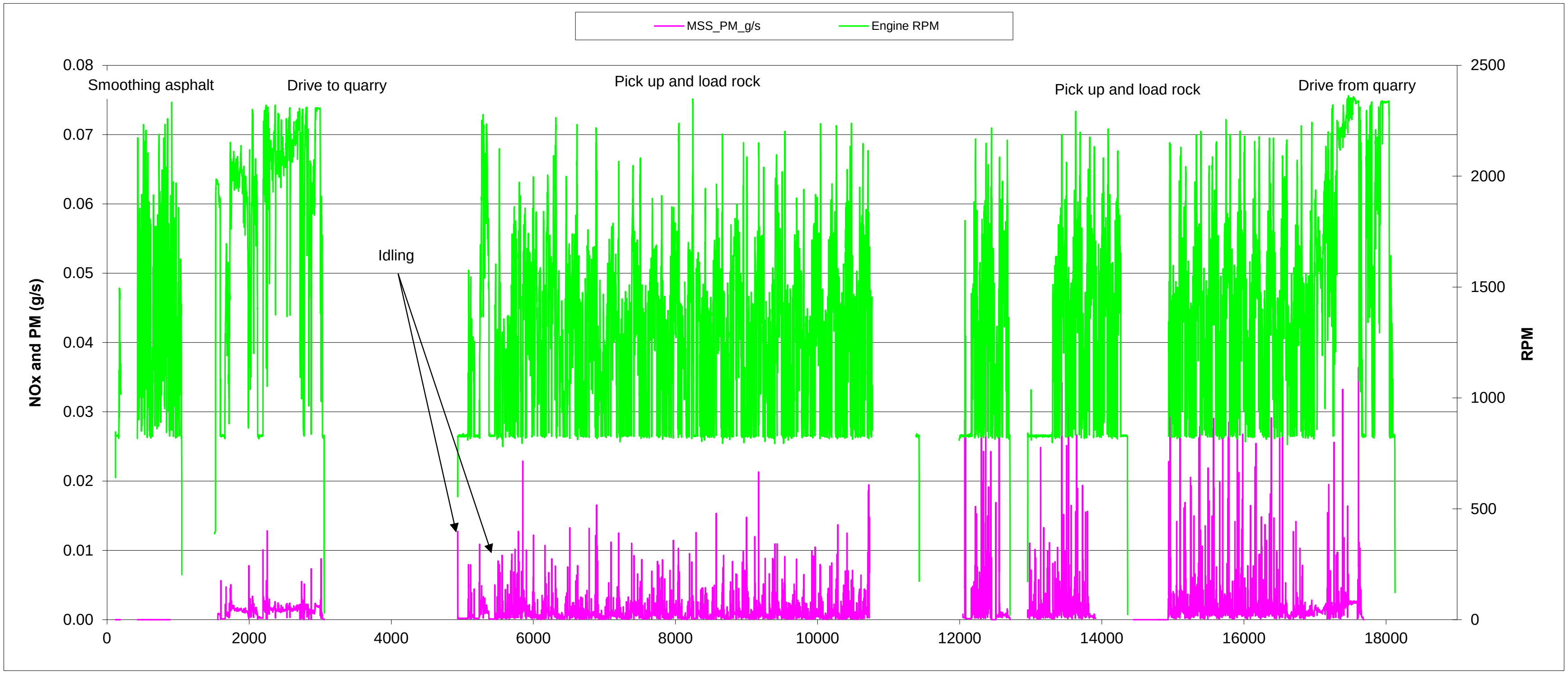


Figure 7: Modal emissions for 07_928G 2004 CAT Tier 2 wheel loader

08_345D: 2011.03.17

This 2008 Tier 3 Caterpillar 345D excavator was owned and operated by Sukut Equipment. The test location was at the Sukut dirt pit Temecula, CA. The excavator was loading trucks with dirt. The PEMS equipment was the same as last test but the main exhaust connection was connected but a rubber exhaust boot due to the strange angle of the exhaust tips. The excavator was running very high load thus the rubber boot was burned off after the first 15 min. The excavator was busy and we did not have access to it until the end of the day. There was only 15 min of emissions data collected from this unit.

Table 8: Integrated emissions for 08_345 CAT 2008 tier 3 excavator

Dur.	Test Function	Fuel [2]	Power [3]	eLoad	eSpeed	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel)					Brake Specific Emissions (g/hp-h)				
min	A-Work[4]	kg/hr	bhp	%	RPM	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]
3.0	Scraping #1	56.9	n/a	n/a	n/a	180647	874.4	934	32.7	120.4	3173	15.4	16.4	0.57	2.11	n/a	n/a	n/a	n/a	n/a
1.1	Scraping #2	35.0	n/a	n/a	n/a	111178	570.0	583	18.3	78.3	3172	16.3	16.6	0.52	2.23	n/a	n/a	n/a	n/a	n/a
3.2	Scraping #2	25.9	n/a	n/a	n/a	82055	535.6	385	17.7	82.9	3163	20.6	14.8	0.68	3.19	n/a	n/a	n/a	n/a	n/a
2.1	Scraping #2	44.0	n/a	n/a	n/a	139628	708.0	659	19.3	104.3	3173	16.1	15.0	0.44	2.37	n/a	n/a	n/a	n/a	n/a
1.0	cold idle	6.2	n/a	n/a	n/a	19466	171.6	222	12.9	n/a	3143	27.7	35.8	2.08	n/a	n/a	n/a	n/a	n/a	n/a
2.9	idle	5.6	n/a	n/a	n/a	17528	160.8	199	8.1	n/a	3145	28.8	35.8	1.44	n/a	n/a	n/a	n/a	n/a	n/a
1.3	high idle	8.6	n/a	n/a	n/a	27144	228.4	235	13.4	n/a	3148	26.5	27.2	1.55	n/a	n/a	n/a	n/a	n/a	n/a
5.8	invalid test	28.3	n/a	n/a	n/a	89657	483.1	368	16.1	53.3	3171	17.1	13.0	0.57	1.89	n/a	n/a	n/a	n/a	n/a
5.4	invalid test	32.5	n/a	n/a	n/a	103021	510.4	429	18.2	65.5	3174	15.7	13.2	0.56	2.02	n/a	n/a	n/a	n/a	n/a
14.6	Overall valid	28.4	n/a	n/a	n/a	90046	502.1	487	18.3	63.4	3169	17.7	17.1	0.64	2.23	n/a	n/a	n/a	n/a	n/a
	Scraping Ave.	40.48	n/a	n/a	n/a	128377	672.0	640	22.0	96.5	3170	17.1	15.7	0.55	2.48	n/a	n/a	n/a	n/a	n/a
	Scraping Stdev	13.22	n/a	n/a	n/a	42033	154.1	227	7.2	19.6	5	2.4	0.9	0.10	0.49	n/a	n/a	n/a	n/a	n/a
	Scraping COV	33%	n/a	n/a	n/a	32.7%	22.9%	35.5%	32.7%	20.3%	0.2%	14.1%	5.9%	18.4%	19.7%	n/a	n/a	n/a	n/a	n/a
	Idle Ave.	6.80	n/a	n/a	n/a	17528	160.8	199	8.1	n/a	3145	28.8	35.8	1.44	n/a	n/a	n/a	n/a	n/a	n/a
	Idle Stdev	1.61	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Idle COV	24%	n/a	n/a	n/a										n/a	n/a	n/a	n/a	n/a	n/a
	A-Work Ave.[7]	26.05	n/a	n/a	n/a	82521	464.1	459	17.5	96.5	3160	21.6	23.1	1.04	2.48	n/a	n/a	n/a	n/a	n/a
	A-Work Stdev	20.31	n/a	n/a	n/a	64521	282.1	277	7.8	19.6	14	5.9	9.7	0.64	0.49	n/a	n/a	n/a	n/a	n/a
	A-Work COV	78%	n/a	n/a	n/a	78.2%	60.8%	60.3%	44.6%	20.3%	0.4%	27.5%	41.9%	61.7%	19.7%	n/a	n/a	n/a	n/a	n/a

[1] Data filtered for ECM and EFM drop out

[2] Fuel calculated from carbon balance method using Sensors data

[3] Power not available since ECM not working on this data set

[4] Activity work for selected sections where the specific type of work is known

[5] Total PM using gravimetric span method and not the model alpha methods

[6] Average for the whole day independent of type of A-work

[7] Overall not included

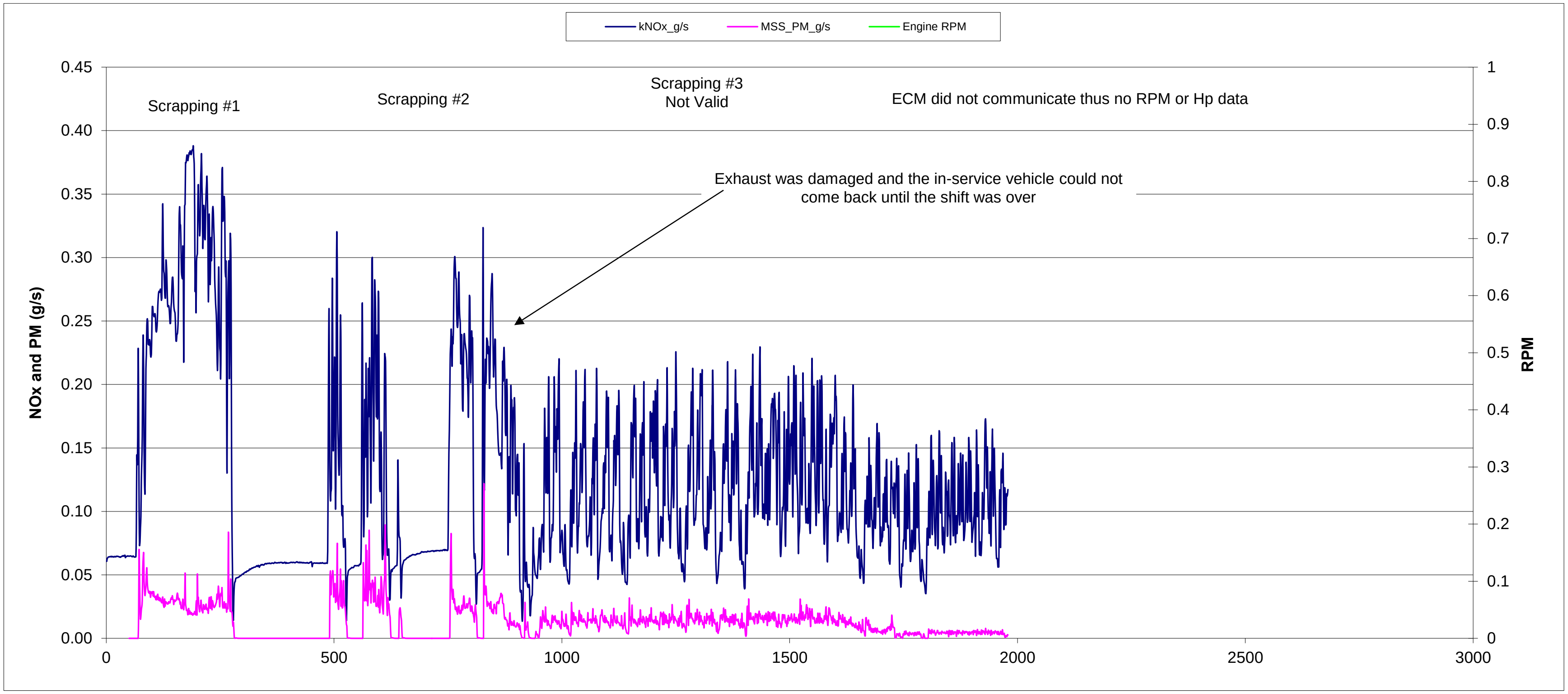


Figure 8: Modal emissions for 08_345 CAT 2008 tier 3 excavator

09_637E 2011.04.20

This twin engine 2006 Tier 2 Caterpillar 637E scrapper was owned and operated by County of Riverside. The test location was at the Riverside Bad Lands waste disposal site. The scrapper was scraping up dirt from the disposal cell and dump at another located nearby, the loop was about 1.5 miles. The PEMS equipment was testing the rear C9 engine and the PEMS had major power issue caused equipment damage after about 4000 seconds. The issue is possible cause of the turning of the scrapper itself. We couldn't watch/follow the scrapper due to safety reasons. There are about 3 hours of test data collected.

Table 9: Integrated emissions for 09_637E CAT 2006 C9 (rebuilt) tier 2 scraper

Dur.	Test Function	Fuel [2]	Power [3]	eLoad	eSpeed	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel)					Brake Specific Emissions (g/hp-h)					g/kWhr	lb/hp-h
min	A-Work[4]	kg/hr	bhp	%	RPM	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]	bsFC	bsFC
11.87	Idling	3.2	5.7	25.0	700	9927	47.9	169	21.4	1.4	3147	15.2	53.6	6.80	0.46	1737	8.4	29.6	3.75	0.247	740	1.217
13.03	Moving #1a	31.0	184.5	69.1	1779	98071	559.9	277	54.5	29.5	3165	18.1	8.9	1.76	0.95	532	3.03	1.50	0.30	0.160	225	0.370
13.33	Moving #1b	28.5	175.4	64.4	1795	90435	510.0	270	45.6	18.4	3171	17.9	9.5	1.60	0.65	516	2.91	1.54	0.26	0.105	218	0.358
12.07	Moving #1c	26.2	166.8	64.1	1669	83183	510.5	260	38.4	15.8	3169	19.4	9.9	1.46	0.60	499	3.06	1.56	0.23	0.095	211	0.347
2.233	Idling	1.5	5.3	25.0	700	4717	17.7	54	6.5	0.4	3173	11.9	36.2	4.38	0.27	883	3.31	10.08	1.22	0.074	373	0.614
14.2	Moving #1d	32.4	211.7	76.6	1914	102699	628.6	323	50.6	20.4	3169	19.4	10.0	1.56	0.63	485	2.97	1.52	0.24	0.096	205	0.337
13.87	Moving#1e	30.1	199.0	72.2	1891	95589	559.1	310	54.9	16.9	3172	18.6	10.3	1.82	0.56	480	2.81	1.56	0.28	0.085	203	0.334
13.08	Moving#2b	27.9	174.5	66.0	1721	87855	593.5	358	52.3	22.2	3146	21.3	12.8	1.87	0.79	503	3.40	2.05	0.30	0.127	215	0.353
10.13	Moving #2a	31.6	196.2	72.5	1880	99248	639.0	425	53.7	25.7	3139	20.2	13.4	1.70	0.81	506	3.26	2.16	0.27	0.129	216	0.355
176.3	Overall[6]	25.9	161.3	61.1	1596	81792	493.1	288	45.7	20.7	3164	19.1	11.1	1.77	0.80	507	3.06	1.78	0.28	0.129	215	0.353
	Idling Ave.	2.32	5.5	25.0	700	7322	32.8	111	14.0	0.9	3160	13.5	44.9	5.59	0.36	1310	5.84	19.84	2.49	0.16	557	0.92
	Idling Stdev	1.18	0.3	0.0	0	3684	21.3	82	10.6	0.7	18	2.3	12.3	1.71	0.14	604	3.58	13.80	1.79	0.12	259	0.43
	Idling COV	51%	4.8%	0.0%	0.0%	50.3%	65.1%	73.1%	75.5%	79.7%	0.6%	17.1%	27.4%	30.6%	37.5%	46.1%	61%	70%	72%	76%	46.6%	47%
	Moving Ave.	29.69	186.9	69.3	1807	93868	571.5	318	50.0	21.3	3162	19.3	10.7	1.68	0.71	503	3.06	1.70	0.27	0.11	213	0.35
	Moving Stdev	2.21	16.0	4.7	92	6948	51.8	58	6.0	4.9	14	1.2	1.7	0.15	0.14	18	0.20	0.28	0.03	0.03	8	0.01
	Moving COV	7.4%	8.6%	6.8%	5.1%	7.4%	9.1%	18.4%	12.1%	23.2%	0.4%	6.3%	16.2%	8.8%	19.8%	3.5%	6.7%	16.6%	9.9%	23.0%	3.6%	3.6%
	A-Work Ave.[7]	23.61	146.6	59.4	1561	74636	451.8	272	42.0	16.7	3161	18.0	18.3	2.55	0.64	682	3.68	5.73	0.76	0.12	290	0.48
	A-Work Stdev	12.23	81.2	19.9	494	38657	241.9	108	17.1	10.0	13	2.9	15.8	1.83	0.20	415	1.77	9.37	1.17	0.05	177	0.29
	A-Work COV	52%	55.4%	33.6%	31.7%	51.8%	53.5%	39.7%	40.8%	59%	0.4%	15.9%	86.2%	71.8%	32%	60.9%	48%	164%	153%	43%	61.2%	61%

[1] Data filtered for ECM and EFM drop out

[2] Fuel calculated from carbon balance method using Sensors data

[3] Power estimated from lug curve work sheet

[4] Activity work for selected sections where the specific type of work is known

[5] Total PM using gravimetric span method and not the model alpha methods

[6] Average for the whole day independent of type of A-work

[7] Overall not included

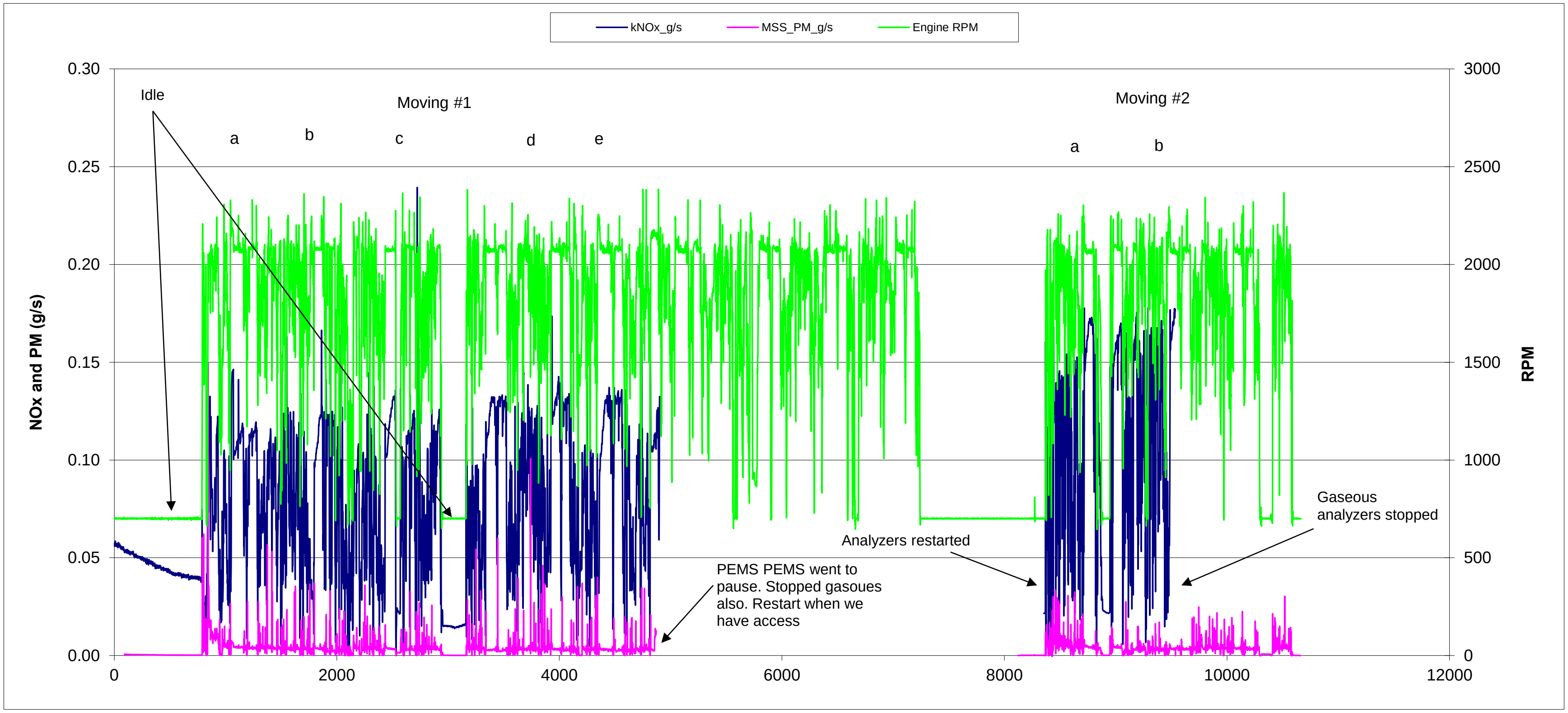


Figure 9: Modal emissions for 09_637E CAT 2006 C9 (rebuilt) tier 2 scraper

10_637E 2011.04.21

This twin engine 2006 Tier 2 Caterpillar 637E scrapper was owned and operated by County of Riverside. The test location was at the Riverside Bad Lands waste disposal site. The scrapper was scraping up dirt at the disposal cell. The PEMS equipment was testing the main C15 engine and PEMS still have some issues due to yesterday's power issue. The scrapper was running very high and exhaust connection was broken after about 1 hours of testing. The scrapper turn too hard and struck the Semtech after 3 hours of testing, equipment was damaged and taken off at that point. There are 3 hours of data collected from this test.

Table 10: Integrated emissions for 10_637E 2006 CAT C15 (rebuilt) tier 2 scraper

Dur.	Test Function	Fuel [2]	Power [3]	eLoad	eSpeed	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel)					Brake Specific Emissions (g/hp-h)					g/kWhr
Min	A-Work[4]	kg/hr	bhp	%	RPM	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]	bsFC
2.0	cold idle	10.45	42.8	30.7	856	33108	152.8	271	13.6	5.1	3168	14.6	26.0	1.30	0.49	773	3.57	6.33	0.32	0.119	327
6.3	Moving #1a	29.20	213.5	43.0	1660	92034	446.4	368	28.4	31.8	3152	15.3	12.6	0.97	1.09	431	2.09	1.72	0.13	0.149	183
6.1	Moving #1b	52.38	360.3	67.3	1840	165780	680.9	792	22.7	41.1	3165	13.0	15.1	0.43	0.78	460	1.89	2.20	0.06	0.114	195
2.6	hot idle	6.73	28.6	20.5	856	21352	85.7	163	9.3	1.8	3172	12.7	24.2	1.38	0.27	745	2.99	5.69	0.32	0.064	315
4.1	Moving #2a	44.52	325.4	61.6	1797	140884	616.7	511	30.4	46.7	3165	13.9	11.5	0.68	1.05	433	1.90	1.57	0.09	0.144	183
10.7	Moving #2b	45.61	333.4	61.6	1797	144298	576.6	615	31.5	46.1	3164	12.6	13.5	0.69	1.01	433	1.73	1.85	0.09	0.138	183
7.3	Moving #2c	46.48	348.7	65.6	1761	147221	653.0	648	34.8	55.3	3167	14.0	13.9	0.75	1.19	422	1.87	1.86	0.10	0.159	179
40.8	Overall	38.30	274.6	54.5	1631	121173	517.6	535	27.0	38.1	3164	13.5	14.0	0.71	1.00	441	1.88	1.95	0.10	0.139	187
	Idling Ave.	6.73	28.6	20.5	856	21352	85.7	163	9.3	1.8	3172	12.7	24.2	1.38	0.27	745	2.99	5.69	0.32	0.06	315
	Idling Stdev	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Idling COV																				
	Moving Ave.	43.64	316.2	59.8	1771	138043	594.7	587	29.6	44.2	3162	13.8	13.3	0.71	1.02	436	1.90	1.84	0.10	0.14	185
	Moving Stdev	8.63	59.0	9.7	68	27466	91.7	158	4.5	8.6	6	1.0	1.4	0.19	0.15	14	0.13	0.23	0.02	0.02	6
	Moving COV	20%	18.7%	16.2%	3.8%	19.9%	15.4%	27.0%	15.2%	19.4%	0.2%	7.5%	10.3%	27.3%	14.6%	3.3%	6.8%	12.6%	25.8%	11.8%	3.3%
	A-Work Ave.[7]	33.62	236.1	50.0	1509	106383	458.9	481	24.4	32.6	3165	13.7	16.7	0.89	0.84	528	2.29	3.03	0.16	0.13	224
	A-Work Stdev	18.53	145.2	18.7	450	58636	244.5	224	9.6	21.1	6	1.0	5.9	0.35	0.34	158	0.70	2.05	0.11	0.03	67
	A-Work COV	55%	61.5%	37.4%	29.8%	55.1%	53.3%	46.6%	39.6%	64.8%	0.2%	7.3%	35.2%	39.3%	40.9%	30.0%	30.7%	67.7%	69.2%	25.2%	29.9%

[1] Data filtered for ECM and EFM drop out

[2] Fuel calculated from carbon balance method using Sensors data

[3] Power calculated from offical published lug curve work sheet and ECM data using CAT ET tools

[4] Activity work for selected sections where the specific type of work is known

[5] Total PM using gravimetric span method and not the model alpha methods

[6] Average for the whole day independent of type of A-work

[7] Overall not included

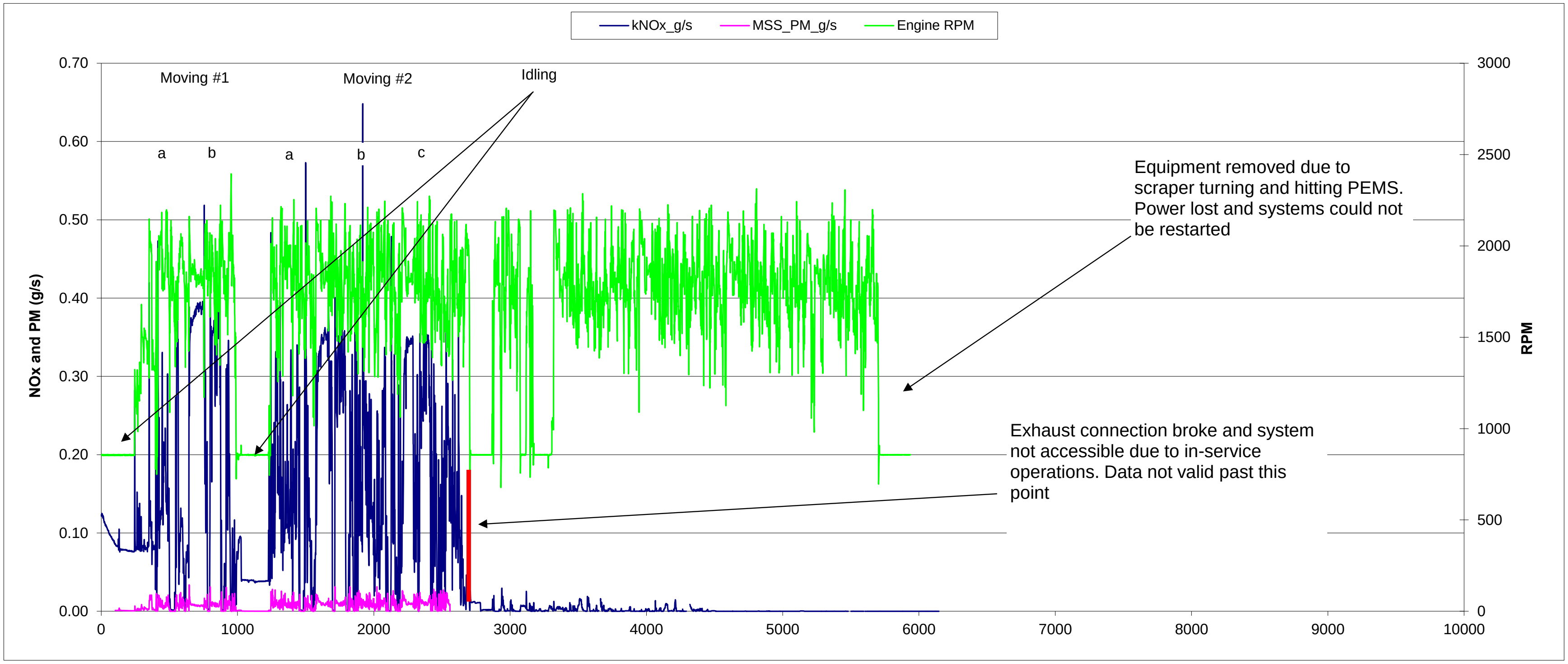


Figure 10: Modal emissions for 10_637E 2006 CAT C15 (rebuilt) tier 2 scraper

11_EC360B 2012.05.04

This 2006 Tier 3 Volvo EC360B excavator was owned and operated by Waste Management (WM). The test location was at the WM's El Sorbrante landfill site near Corona, CA. The excavator was removing trash cover dirt from a hill and loading trucks. The PEMS equipment was the new AVL M.O.V.E. 493 Gas PEMS, the AVL 483 MSS, and a new Semtech 5 inch flow tube. The excavator was very rough when travel and we had a lot of power issues in the AM hours. The power issue was resolved after lunch and about 5.5 hours of valid test data was collected.

Table 11: Integrated emissions for 11_E460B/c Volvo 2006 tier 3 excavator tested

Dur.	Test Function	Fuel [2]	Power [3]	eLoad	eSpeed	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel)					Brake Specific Emissions (g/hp-h)				
Min	A-Work[4]	kg/hr	bhp	%	RPM	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]
4.4	Digging #1a	28.3	154.2	58.8	1849	89017	131.5	411	31.5	23.2	3143	4.64	14.5	1.11	0.84	577	0.85	2.66	0.20	0.15
4.3	Idling #1	3.1	11.7	26.8	785	9875	3.7	91	3.2	1.2	3148	1.18	29.06	1.02	0.38	846	0.32	7.81	0.27	0.10
45.6	Digging #1b	30.2	167.6	63.9	1841	94942	133.8	457	34.8	36.7	3143	4.43	15.13	1.15	1.25	566	0.80	2.73	0.21	0.22
26.7	Digging #1c	32.5	169.4	64.6	1833	102015	162.0	491	38.5	50.4	3142	4.99	15.13	1.18	1.60	602	0.96	2.90	0.23	0.30
11.6	Digging #2a	30.0	157.0	60.0	1827	94111	174.0	437	32.0	47.2	3141	5.81	14.59	1.07	1.63	599	1.11	2.78	0.20	0.30
12.9	Digging #2b	31.9	166.0	63.1	1849	100166	151.6	460	35.4	49.2	3142	4.76	14.44	1.11	1.59	604	0.91	2.77	0.21	0.30
8.2	Digging #2c	30.8	159.0	60.6	1847	96835	151.8	446	36.1	47.4	3142	4.92	14.47	1.17	1.59	609	0.95	2.80	0.23	0.30
3.6	Idling #2	2.9	11.6	26.7	785	9224	2.1	88	3.1	0.0	3149	0.72	29.89	1.07	0.00	794	0.18	7.54	0.27	0.00
6.6	Idling #3	3.1	11.5	26.4	785	9690	2.6	90	3.2	1.0	3149	0.85	29.37	1.06	0.34	842	0.23	7.85	0.28	0.09
4.9	Digging #2d	29.8	153.3	58.5	1851	93658	160.4	439	34.8	54.9	3141	5.38	14.73	1.17	1.90	611	1.05	2.86	0.23	0.36
5.3	Digging #3a	30.6	158.6	60.4	1847	96039	155.7	457	32.1	51.2	3142	5.10	14.93	1.05	1.73	606	0.98	2.88	0.20	0.32
18.2	Digging #3b	29.1	152.5	58.8	1804	91280	140.5	435	33.7	48.2	3142	4.84	14.98	1.16	1.71	599	0.92	2.85	0.22	0.32
1.9	Idling #4	3.1	11.8	27.2	785	9667	3.1	92	3.5	1.9	3148	1.02	29.83	1.14	0.64	817	0.26	7.74	0.30	0.16
9.9	Digging #3c	30.5	159.4	60.7	1851	95733	139.0	470	34.8	47.7	3143	4.56	15.41	1.14	1.61	600	0.87	2.95	0.22	0.30
5.6	Moving #4	30.8	161.1	61.4	1850	96796	216.6	496	38.0	46.4	3138	7.02	16.09	1.23	1.56	601	1.34	3.08	0.24	0.29
1.7	Idling #4	3.0	11.9	27.3	785	9491	29.3	90	4.3	2.0	3134	9.66	29.56	1.43	0.70	800	2.47	7.55	0.37	0.17
330.5	Overall[6]	25.1	134.5	55.0	1650	78906	124.4	384	28.8	36.9	3142	4.95	15.3	1.15	1.52	587	0.93	2.86	0.21	0.27
	idling Ave.	3.05	11.7	26.9	785	9590	8.2	90	3.5	1.2	3145	2.7	29.5	1.14	0.41	820	0.69	7.70	0.30	0.10
	idling Stdev	0.08	0.1	0.4	0	245	11.8	2	0.5	0.8	7	3.9	0.3	0.17	0.28	24	0.99	0.15	0.04	0.07
	idling COV	2.5%	1.3%	1.4%	0.0%	2.6%	145%	1.8%	14.4%	67.1%	0.2%	145%	1.2%	14.8%	68.0%	2.9%	144%	1.9%	13%	66%
	digging Ave.	30.36	159.7	60.9	1840	95380	150.0	450	34.4	45.6	3142	4.9	14.8	1.13	1.55	597.33	0.94	2.82	0.22	0.29
	digging Stdev	1.22	6.0	2.2	15	3825	13.7	22	2.1	9.1	1	0.4	0.3	0.05	0.29	14	0.09	0.09	0.01	0.06
	digging COV	4.0%	3.8%	3.6%	0.8%	4.0%	9.1%	4.9%	6.2%	20.0%	0.0%	8.3%	2.3%	4.0%	19.0%	2.4%	9.7%	3.0%	4.7%	21%
	A-Work Ave.[7]	21.85	113.5	50.3	1511	68659	109.9	341	24.9	31.8	3143	4.4	19.5	1.14	1.19	667	0.89	4.36	0.24	0.23
	A-Work Stdev	13.13	71.1	16.4	506	41239	73.7	176	15.1	22.4	4	2.4	7.0	0.10	0.61	108	0.54	2.33	0.04	0.10
	A-Work COV	60%	62.6%	32.7%	33.5%	60.1%	67.1%	51.6%	60.4%	70.6%	0.1%	55.1%	35.9%	8.5%	50.9%	16.1%	61.3%	53.4%	18%	46%

[1] Data filtered for ECM and PEMS drop out

[2] ECM fuel rate not reported, fuel calculated from carbon balance method

[3] Power estimated from lug curve work sheet. Idle power is high, engine was at around 25% load, it's true data found in every idle point

[4] Activity work for selected sections where the specific type of work is known

[5] Total PM using gravimetric span method and not the model alpha methods

[6] Average for the whole day independent of type of A-work

[7] Overall not included

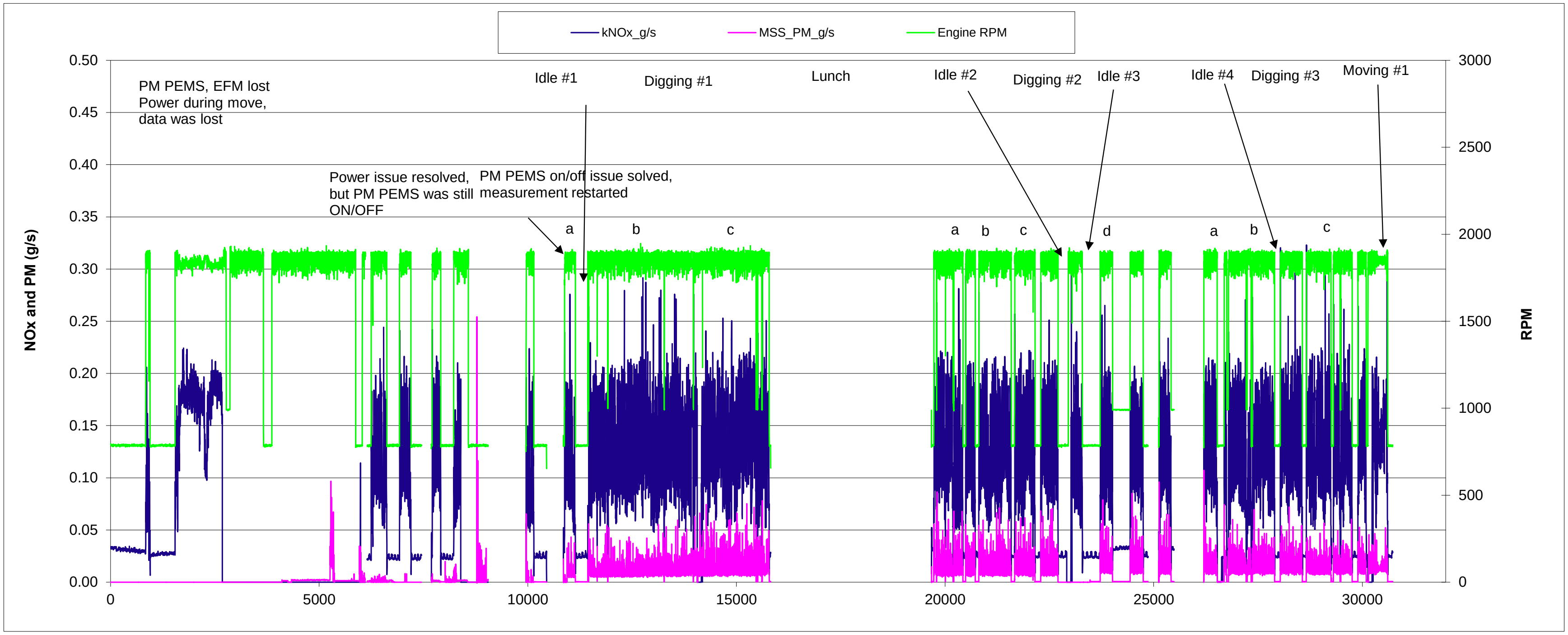


Figure 11: Modal emissions for 11_E460B/c Volvo 2006 tier 3 excavator

12_D8R 2012.05.14

This 2003 Tier 2 Caterpillar D8R II bulldozer was owned and operated by Waste Management (WM). The test location was at the WM's El Sorbrante landfill site near Corona, CA. The bulldozer was pushing trash from the dump site down to the pit area all day. The PEMS was the same as the pervious test at WM but was modified/resolved power issues. The ECM was collected by CAT ET and the last 3 hours of ECM data was not valid. There was 5.5 hours of valid data collected.

Table 12: Integrated emissions for 12_D8R CAT 2003 tier 2 bulldozer

Duration	Test Function	Power [2]	Torque	Fuel [3]	eLoad	eSpeed	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel)					Brake Specific Emissions (g/hp-h)				
Mins	A-Work[4]	bhp	ft-lb	kg/hr	%	rpm	CO2	CO	NOx	THC	mg PM [5]	CO2	CO	NOx	THC	mg PM [5]	CO2	CO	NOx	THC	mg PM [5]
2.2	Idiling #1	5.6	42.1	3.05	3.92	700	9600	6.2	154	6.0	1115	3153	2.036	50.53	1.973	366.15	1713	1.106	27.45	1.072	198.9
4.0	Idling #2	2.9	21.5	2.54	2.00	700	8005	5.3	125	5.6	1017	3152	2.078	49.28	2.21	400.57	2796	1.843	43.73	1.961	355.4
1.7	Idling #3	8.2	61.7	3.14	5.74	700	9886	6.8	163	5.6	1719	3153	2.181	52.01	1.771	548.16	1203	0.832	19.84	0.675	209.1
4.6	Idling #4	5.2	38.9	2.80	3.62	700	8824	5.6	143	5.0	1143	3153	1.986	50.93	1.802	408.4	1702	1.072	27.49	0.973	220.4
4.2	light push	135.0	385.1	19.93	46.8	1397	62752	132.9	496	16.1	16783	3149	6.672	24.87	0.806	842.21	465	0.985	3.67	0.119	124.3
4.2	light push	221.6	689.9	29.59	67.2	1623	93134	236.2	858	14.6	36283	3148	7.984	29.01	0.495	1226.4	420	1.066	3.87	0.066	163.7
4.2	light push	215.5	685.5	29.16	67.5	1627	91702	279.6	822	15.4	45816	3145	9.589	28.19	0.528	1571.4	426	1.297	3.81	0.071	212.6
4.2	light push	229.0	693.1	30.94	73.5	1713	97354	260.0	888	17.1	43145	3147	8.406	28.69	0.554	1394.7	425	1.136	3.88	0.075	188.4
3.3	light push	227.6	671.5	31.29	77.4	1771	98588	197.0	916	18.0	33202	3150	6.295	29.26	0.574	1061	433	0.866	4.02	0.079	145.9
3.4	light push	220.7	584.9	30.59	84.7	1962	96359	191.5	838	23.1	37588	3150	6.26	27.39	0.755	1228.7	437	0.868	3.80	0.105	170.3
3.4	light push	164.2	469.2	22.41	54.0	1584	70562	148.0	621	16.9	27493	3149	6.605	27.72	0.755	1227	430	0.901	3.78	0.103	167.4
4.2	heavy push	281.3	754.5	38.72	91.4	1961	122156	133.5	1055	22.2	38569	3155	3.448	27.25	0.573	996.08	434	0.475	3.75	0.079	137.1
4.2	heavy push	270.2	745.4	36.20	85.7	1905	114168	158.8	1051	19.5	33347	3153	4.387	29.02	0.54	921.07	423	0.588	3.89	0.072	123.4
4.2	heavy push	296.6	801.4	39.69	93.3	1948	125212	147.5	1188	20.1	30168	3155	3.716	29.92	0.506	760.04	422	0.497	4.00	0.068	101.7
4.2	heavy push	275.0	746.8	37.07	89.6	1925	116876	167.5	1072	21.0	34844	3153	4.519	28.91	0.568	940.02	425	0.609	3.90	0.077	126.7
2.7	heavy push	249.8	680.3	34.31	81.8	1807	108241	127.1	1019	19.0	24603	3154	3.704	29.69	0.553	717.01	433	0.509	4.08	0.076	98.5
4.2	heavy push	264.4	715.8	35.48	87.8	1938	111839	172.1	1023	21.8	31407	3152	4.85	28.83	0.613	885.29	423	0.651	3.87	0.082	118.8
20.7	heavy push	248.1	656.1	33.97	87.2	1989	107064	169.3	959	23.4	34279	3152	4.983	28.24	0.69	1009.2	432	0.682	3.87	0.094	138.2
338.7	Overall[7]	214.5	594.0	29.59	72.8	1744	93284	145.0	798	20.8	28428	3152	4.9	26.98	0.702	960.59	435	0.676	3.72	0.097	132.5
	Idling Average	5.5	41.0	2.9	3.8	700.1	9078.6	6.0	146	5.6	1248	3153	2.07	50.69	1.939	430.82	1853	1.213	29.63	1.170	246.0
	Idling stdev	2.2	16.5	0.3	1.5	0.2	844.99	0.7	16	0.4	318	0.631	0.083	1.127	0.202	80.353	672	0.437	10.06	0.553	73.5
	Idling COV	40.2%	40.2%	9.3%	40.2%	0.0%	9.3%	11.7%	11.2%	7.1%	25.5%	0.0%	4.0%	2.2%	10.4%	18.7%	36.3%	36.0%	34%	47%	29.9%
	Light Push Average	202.0	597.0	27.7	67.3	1668.2	87207	206.5	777	17.3	34330	3148	7.402	27.88	0.638	1221.6	434	1.017	3.83	0.088	167.5
	Light Push stdev	37.0	124.2	4.6	13.2	174.8	14414	55.1	157	2.8	9832	1.755	1.28	1.488	0.129	231.73	15	0.161	0.11	0.020	28.4
	Light Push COV	18.3%	20.8%	16.5%	19.6%	10.5%	16.5%	26.7%	20.2%	16.0%	28.6%	0.1%	17.3%	5.3%	20.1%	19.0%	3.4%	15.8%	3%	23%	16.9%
	Heavy Push Average	269.3	728.6	36.5	88.1	1924.7	115079	153.7	1052	21.0	32460	3154	4.23	28.84	0.577	889.81	427	0.573	3.91	0.078	120.6
	Heavy Push stdev	17.2	48.9	2.2	3.8	58.2	6810.6	18.0	70	1.6	4382	1.093	0.607	0.895	0.059	112.37	5	0.081	0.11	0.009	15.7
	Heavy Push COV	6.4%	6.7%	5.9%	4.3%	3.0%	5.9%	11.7%	6.6%	7.5%	13.5%	0.0%	14.4%	3.1%	10.3%	12.6%	1.3%	14.1%	3%	11%	13.0%
	A-Work Ave.[7]	184.5	524.6	25.6	61.3	1552.8	80685	141.4	744	16.1	26251	3151	4.983	33.32	0.904	916.85	747	0.888	9.59	0.325	166.7
	A-Work Stdev	107.9	290.8	13.7	34.4	498.3	43214	87.8	373	6.3	15521	2.841	2.384	9.841	0.598	354.31	687	0.350	12.08	0.533	62.1
	A-Work COV	58.5%	55.4%	53.5%	56.1%	32.1%	53.6%	62.1%	50.2%	38.8%	59.1%	0.1%	47.8%	29.5%	66.2%	38.6%	92.0%	39.4%	126%	164%	37.2%

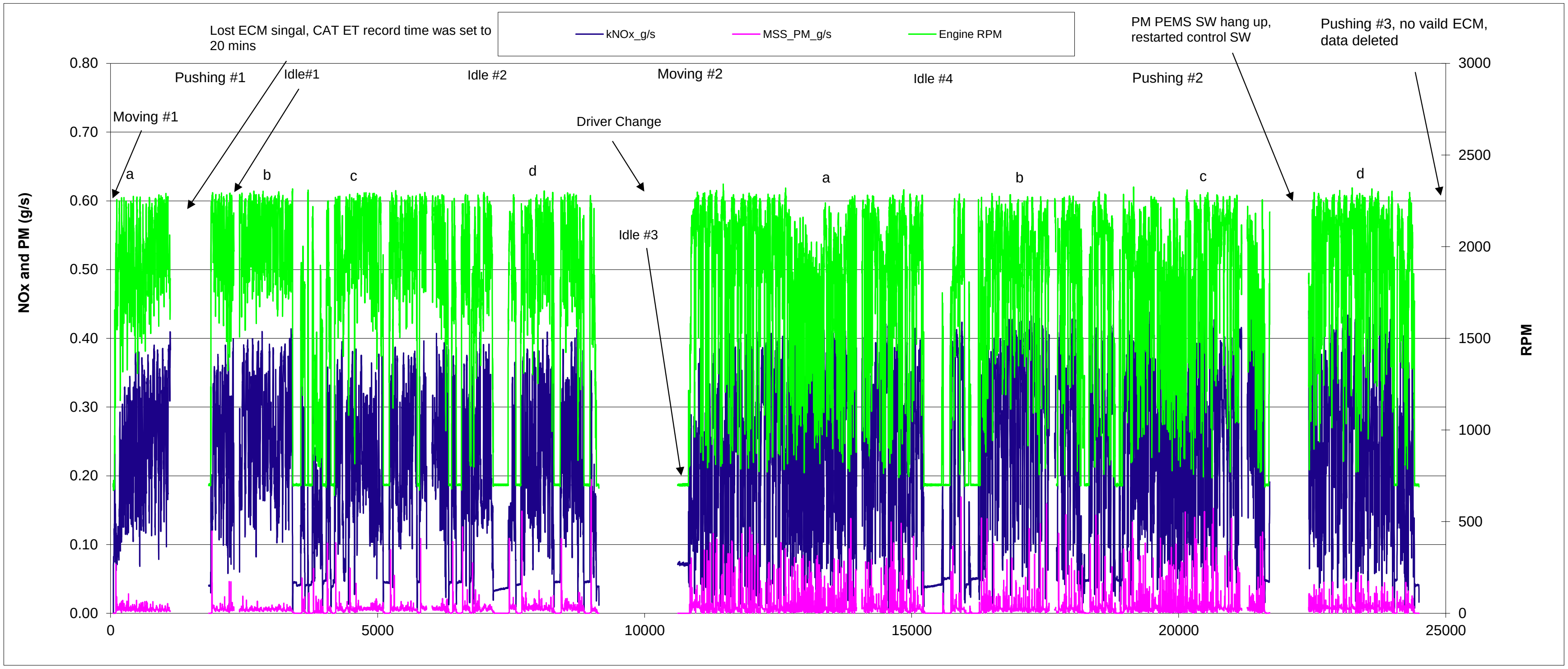


Figure 12: Modal emissions for 12_D8R CAT 2003 tier 2 bulldozer

13_120M: 2012.10.16

This 2008 Tier 3 Caterpillar 120M road grader was owned and operated by County of Riverside's Hemet yard. The test location was on Domenigoni Parkway near Winchester, CA. The grader was grading the medium section of the high way, kicking down weeds, flatting the dirt. The PEMS was the same AVL 493 and 483 systems with some slight mounting improvement. Overall, there was 4.7 hours of valid data collected. No J1939 was available; the ECM data was recorded by CAT ET.

Table 13: Integrated emissions for 13_120M_101G 2008 CAT tier 3 grader

Dur.	Test Function	Fuel [2]	Power [3]	eLoad	eSpeed	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel)					Brake Specific Emissions (g/hp-h)				
Min	A-Work[4]	kg/hr	bhp	%	RPM	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]
8.9	Cold Start Idle	2.9	14.5	24.9	800	9036	33.1	126	6.7	4.3	3137	11.48	43.6	2.32	1.48	625	2.29	8.69	0.46	0.29
4.6	Moving #1	14.2	77.6	50.4	1642	44392	197.4	212	26.6	35.2	3134	13.94	14.99	1.87	2.48	572	2.55	2.74	0.34	0.45
10.7	Grading #1a	10.4	51.6	33.5	1558	32714	130.9	191	14.8	30.6	3138	12.55	18.29	1.42	2.93	635	2.54	3.70	0.29	0.59
3.4	Idling #1	2.4	7.4	12.7	800	7639	23.6	134	4.6	0.4	3141	9.71	54.89	1.88	0.16	1039	3.21	18.15	0.62	0.05
14.4	Grading #1b	11.3	56.0	34.0	1886	35486	100.8	216	17.9	23.7	3143	8.93	19.17	1.59	2.10	633	1.80	3.86	0.32	0.42
17.6	Grading #1c	14.5	72.2	44.0	1771	45650	123.4	240	16.7	23.8	3145	8.50	16.52	1.15	1.64	632	1.71	3.32	0.23	0.33
3.2	Moving #2	17.1	94.5	60.1	1850	53695	222.6	283	16.0	34.6	3139	13.01	16.53	0.94	2.02	568	2.36	2.99	0.17	0.37
29.6	Idling #2	2.3	7.0	12.1	800	7190	25.5	127	4.3	0.9	3139	11.14	55.34	1.87	0.40	1026	3.64	18.10	0.61	0.13
6.5	Moving #3	10.9	66.1	43.3	1605	34136	152.1	257	14.8	17.9	3136	13.97	23.63	1.36	1.65	516	2.30	3.89	0.22	0.27
21.6	Grading #2a	12.7	62.0	37.9	2080	40101	92.3	252	19.7	20.9	3146	7.24	19.77	1.54	1.64	647	1.49	4.06	0.32	0.34
21.2	Grading #2b	12.7	67.4	41.3	2139	39995	94.7	270	19.9	21.2	3145	7.45	21.25	1.57	1.67	593	1.40	4.01	0.30	0.32
21.5	Grading #2c	9.0	37.5	24.1	1583	28267	119.4	211	14.1	18.3	3136	13.25	23.36	1.56	2.03	754	3.18	5.61	0.37	0.49
22.0	Grading #2d	10.0	43.7	26.7	2010	31422	132.5	211	18.0	18.4	3136	13.22	21.06	1.80	1.83	719	3.03	4.83	0.41	0.42
3.1	Moving #3	15.6	82.9	51.3	1821	48795	281.2	269	16.2	23.5	3130	18.04	17.27	1.04	1.51	588	3.39	3.25	0.20	0.28
3.5	Idling #4	2.3	7.0	12.0	800	7176	41.4	130	4.8	1.2	3127	18.05	56.68	2.08	0.54	1029	5.94	18.65	0.68	0.18
283.0	Overall[6]	10.6	51.8	34.1	1668	33222	108.0	220	15.3	18.9	3141	10.21	20.8	1.45	1.79	641	2.08	4.24	0.29	0.37
	Moving Ave.	14.44	80.27	51.3	1729	45254	213.3	255	18.4	27.8	3135	14.7	18.1	1.30	1.92	561	2.65	3.22	0.23	0.34
	Moving Stdev	2.65	11.78	6.9	124	8330	53.9	31	5.5	8.5	3	2.2	3.8	0.42	0.44	31	0.51	0.50	0.08	0.08
	Moving COV	18.4%	14.7%	13.4%	7.1%	18.4%	25.2%	12.0%	29.7%	30.6%	0.1%	15.2%	21.0%	32.3%	22.8%	5.6%	19.1%	15%	33%	25%
	Idling Ave.	2.34	7.11	12.3	800	7335	30.2	130	4.5	0.9	3136	13.0	55.6	1.94	0.37	1031	4.26	18.30	0.64	0.12
	Idling Stdev	0.08	0.21	0.4	0	263	9.8	3	0.2	0.4	7	4.5	0.9	0.12	0.19	6	1.47	0.31	0.04	0.06
	Idling COV	3.4%	3.0%	2.9%	0.0%	3.6%	32.4%	2.6%	5.5%	50.2%	0.2%	34.4%	1.7%	6.0%	52.0%	0.6%	34.4%	1.7%	6.2%	52%
	Grading Ave.	11.53	55.79	34.5	1861	36234	113.4	227	17.3	22.4	3141	10.2	19.9	1.52	1.98	659	2.16	4.20	0.32	0.42
	Grading Stdev	1.90	12.53	7.3	233	6019	17.1	28	2.3	4.2	5	2.7	2.2	0.20	0.46	56	0.74	0.77	0.06	0.10
	Grading COV	16.5%	22.5%	21.1%	12.5%	16.6%	15.1%	12.2%	13.1%	18.9%	0.1%	26.9%	11.2%	13.0%	23.3%	8.5%	34.3%	18%	19%	24%
	A-Work Ave.[7]	9.89	49.82	33.9	1543	31046	118.1	209	14.3	18.3	3138	12.0	28.2	1.60	1.61	705	2.72	7.06	0.37	0.33
	A-Work Stdev	5.10	29.32	15.0	495	16019	74.4	56	6.5	11.7	5	3.3	15.7	0.38	0.75	178	1.13	5.99	0.16	0.14
	A-Work COV	51.6%	58.9%	44.3%	32.0%	51.6%	63.0%	26.9%	45.5%	63.8%	0.2%	27.8%	55.8%	24.0%	46.7%	25.3%	41.5%	85%	43%	42%

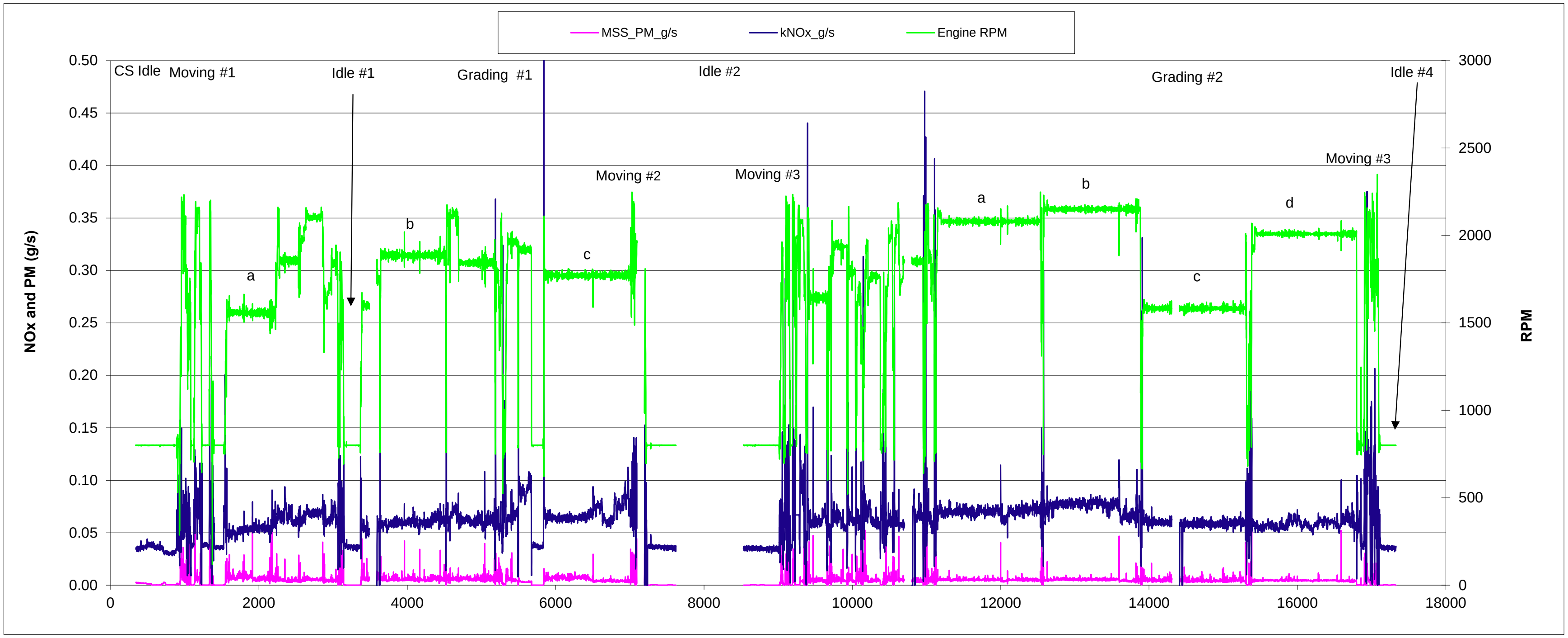


Figure 13: Modal emissions for 13_120M_101G 2008 CAT tier 3 grader

14_928Hz: 2012.10.17

This 2011 Tier 3 Caterpillar 928Hz wheel loader was owned and operated by County of Riverside's Hemet yard. The test location was at Riverside County's rock quarry off Lake St near Hemet, CA. The wheel loader was cleaning out a ditch area over grown by small trees. PEMS equipment was the same as the last test and there are just little over 4 hours of data collected. ECM data was recorded by CAT ET.

Table 14: Integrated emissions for 14_928Hz_72P CAT 2011 tier 3 wheel loader

Dur.	Test Function	Fuel [2]	Power [3]	eLoad	eSpeed	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel)					Brake Specific Emissions (g/hp-h)				
Min	A-Work[4]	kg/hr	bhp	%	RPM	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]
6.2	Cold Start Idle	3.2	17.8	27.3	830	10170	49.9	109	7.6	6.2	3131	15.37	33.65	2.33	1.90	571	2.80	6.14	0.42	0.35
3.0	Moving #1	14.4	86.5	50.9	1735	45389	111.5	180	24.3	25.2	3145	7.72	12.5	1.68	1.74	525	1.29	2.09	0.28	0.29
23.3	Loading #1a	7.3	36.8	29.9	1158	22912	94.3	201	11.0	12.4	3137	12.92	27.51	1.51	1.69	622	2.56	5.46	0.30	0.34
21.1	Loading #1b	6.7	34.6	27.2	1193	20882	89.9	186	10.7	11.3	3136	13.50	27.87	1.60	1.69	603	2.60	5.36	0.31	0.33
21.1	Loading #1c	6.9	34.4	26.4	1198	21571	95.2	185	10.8	11.5	3135	13.84	26.83	1.56	1.67	626	2.76	5.36	0.31	0.33
21.6	Loading #1d	6.9	34.9	27.4	1199	21780	92.9	188	10.8	10.8	3136	13.38	27.14	1.55	1.56	623	2.66	5.39	0.31	0.31
1.0	Idling #1	2.4	7.8	12.0	830	7418	27.0	129	5.7	0.8	3137	11.41	54.6	2.39	0.32	947	3.44	16.48	0.72	0.10
21.3	Loading #1e	7.3	36.5	27.6	1238	22810	105.0	193	4.9	10.8	3137	14.44	26.48	0.68	1.48	625	2.88	5.28	0.14	0.30
13.2	Idling #2	2.0	6.5	9.9	829	6341	27.3	105	2.6	1.1	3137	13.51	51.99	1.27	0.53	974	4.19	16.14	0.39	0.16
35.9	Loading #2a	5.8	37.6	27.9	1280	18275	102.3	200	12.1	13.5	3128	17.51	34.19	2.07	2.31	486	2.72	5.31	0.32	0.36
12.8	Loading #2b	5.9	37.7	28.1	1281	18380	104.2	203	11.7	14.0	3128	17.73	34.6	1.98	2.38	487	2.76	5.39	0.31	0.37
21.6	Loading #2c	5.6	36.5	26.9	1296	17489	108.7	195	11.2	14.4	3125	19.42	34.87	2.00	2.58	479	2.98	5.34	0.31	0.39
1.4	Moving #3	1.2	6.5	4.0	1405	3658	59.8	67	14.9	2.0	3045	49.77	55.95	12.44	1.63	567	9.27	10.42	2.32	0.30
3.3	Idling #4	1.6	7.7	11.9	830	5070	26.7	126	5.6	4.5	3125	16.45	77.64	3.44	2.8	655	3.45	16.27	0.72	0.59
244.6	Overall[6]	5.8	31.9	26.0	1159	18284	85.1	182	9.6	10.3	3134	14.59	31.26	1.64	1.8	573	2.67	5.71	0.30	0.32
	Moving Ave.	7.82	46.5	27.5	1570	24523	85.63	123.8	19.62	13.57	3095	28.75	34.22	7.06	1.69	545.85	5.28	6.25	1.30	0.30
	Moving Stdev	9.36	56.6	33.1	234	29508	36.54	80.05	6.62	16.42	70.6	29.74	30.72	7.61	0.08	30.00	5.64	5.89	1.44	0.01
	Moving COV	120%	122%	121%	15%	120%	42.7%	64.7%	33.7%	121%	2.3%	103%	89.8%	108%	4.7%	5.5%	107%	94%	111%	3.1%
	Idling Ave.	2.00	7.4	11.3	830	6276	27.00	120.1	4.60	2.13	3133	13.79	61.41	2.37	1.22	858.46	3.70	16.30	0.61	0.28
	Idling Stdev	0.37	0.7	1.1	0.6	1175	0.31	13.05	1.77	2.10	6.55	2.53	14.12	1.09	1.38	176.69	0.43	0.17	0.19	0.27
	Idling COV	18.6%	10%	10%	0.1%	18.7%	1.1%	10.9%	38.4%	99%	0.2%	18.4%	23.0%	46.0%	113%	20.6%	11.7%	1.0%	31%	94%
	Loading Ave.	6.55	36.2	27.7	1230	20512	99.08	193.8	10.39	12.33	3133	15.34	29.94	1.62	1.92	568.96	2.74	5.36	0.29	0.34
	Loading Stdev	0.68	1.3	1.1	51	2158	6.80	7.18	2.26	1.47	4.89	2.49	3.85	0.45	0.43	70.90	0.14	0.06	0.06	0.03
	Loading COV	10.4%	4%	4%	4%	10.5%	6.9%	3.7%	21.7%	11.9%	0.2%	16.2%	12.9%	27.5%	22.4%	12.5%	5.1%	1.0%	21%	10%
	A-Work Ave.[7]	5.52	30.1	24.1	1165	17296	78.20	162.0	10.27	9.88	3127	16.93	37.56	2.61	1.74	627.82	3.31	7.89	0.51	0.32
	A-Work Stdev	3.42	21.0	11.6	261	10772	32.72	44.87	5.30	6.58	24.4	9.89	16.77	2.90	0.69	152.55	1.83	4.85	0.54	0.11
	A-Work COV	62.0%	70%	48%	22%	62.3%	41.8%	27.7%	51.6%	66.6%	0.8%	58.4%	44.6%	111%	39.8%	24.3%	55.2%	62%	106%	34%

[1] Data filtered for ECM and PEMS drop outt

[2] ECM fuel rate not reported, fuel calculated from carbon balance method

[3] Power estimated from lug curve work sheet

[4] Activity work for selected sections where the specific type of work is known

[5] Total PM using gravimetric span method and not the model alpha methods

[6] Average for the whole day independent of type of A-work

[7] Overall not included

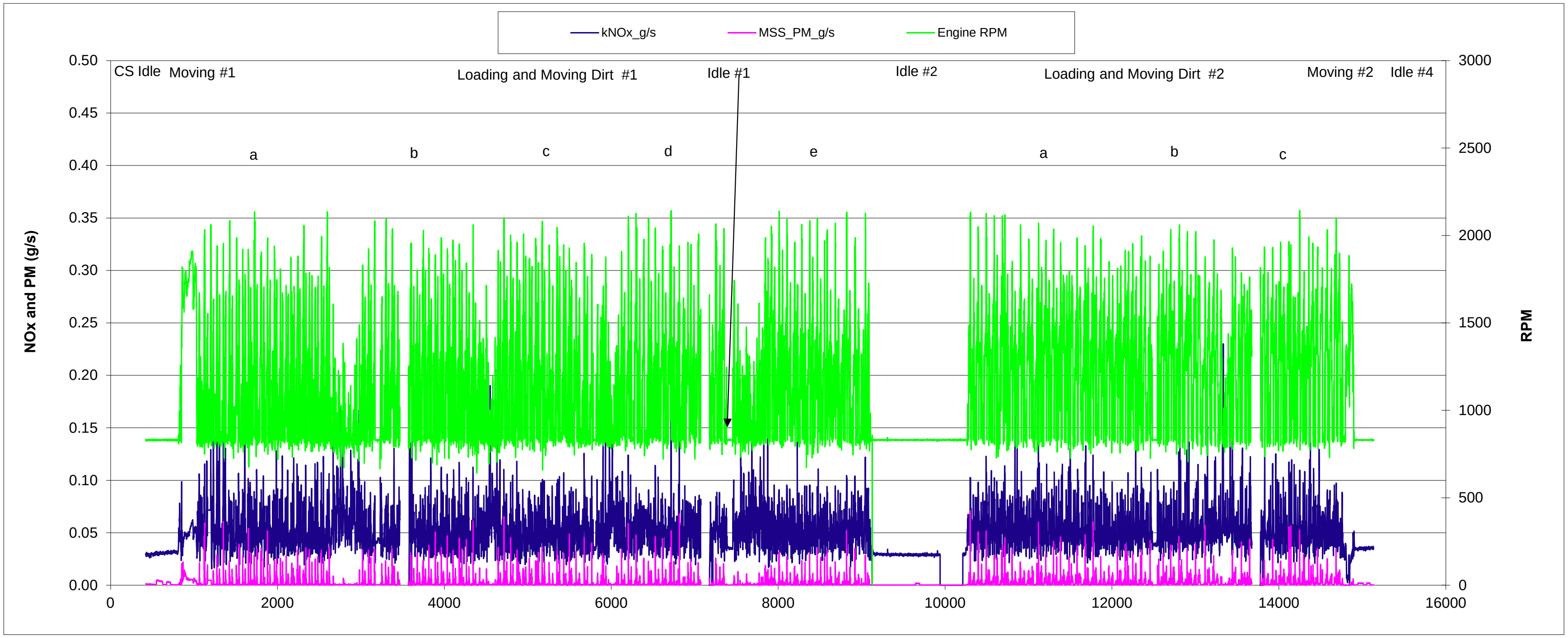


Figure 14: Modal emissions f for 14_928Hz_72P CAT 2011 tier 3 wheel loader

15_120M: 2012.10.18

This 2010 Tier 3 Caterpillar 120M road grader was owned and operated by County of Riverside's Perris yard. The test location near Homeland, CA. The grader was grading the dirt road section of Briggs Rd. The work most involves scarpering off the top layer, smoothing out surface, and laydown new dirt. PEMS equipment was the same as the last test and there are 4.6 hours of data collected. ECM data was recorded by CAT ET.

Table 15: Integrated emissions for 15_120M_103G 2010 CAT tier 3 grader

Dur.	Test Function	Fuel [2]	Power [3]	eLoad	eSpeed	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel)					Brake Specific Emissions (g/hp-h)				
Min	A-Work[4]	kg/hr	bhp	%	RPM	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]
7.1	Cold Start Idle	2.8	13.7	23.6	800	8842	34.8	115	6.0	0.6	3127	12.29	40.61	2.11	0.20	646	2.54	8.39	0.44	0.04
24.1	Moving #1	16.8	96.8	61.3	1712	52705	163.4	227	16.3	22.5	3135	9.72	13.51	0.97	1.34	544	1.69	2.35	0.17	0.23
4.6	Idling #1	2.1	6.9	12.0	800	6421	23.4	97	5.3	0.2	3127	11.41	47.45	2.56	0.10	925	3.37	14.03	0.76	0.03
16.5	Grading #1a	9.7	56.0	38.0	1531	30412	122.9	160	13.2	23.1	3129	12.65	16.45	1.36	2.38	543	2.19	2.85	0.24	0.41
4.1	Idling #2	2.0	6.8	11.7	800	6209	21.1	96	5.3	0.2	3128	10.64	48.56	2.66	0.10	919	3.12	14.26	0.78	0.03
35.4	Grading #1b	7.3	37.8	27.7	1414	22846	111.6	142	12.6	21.0	3124	15.26	19.38	1.73	2.88	605	2.95	3.75	0.33	0.56
6.6	Idling #3	2.0	6.9	11.9	800	6361	24.1	98	5.9	0.2	3126	11.85	47.95	2.89	0.11	924	3.50	14.17	0.86	0.03
22.9	Grading #1c	8.9	47.2	31.6	1568	27751	116.4	157	14.1	28.1	3128	13.12	17.69	1.59	3.17	588	2.47	3.32	0.30	0.60
30.9	Grading #1d	6.4	31.2	23.2	1357	19931	91.9	138	11.8	21.6	3125	14.41	21.56	1.85	3.40	640	2.95	4.41	0.38	0.69
2.6	Idling #4	2.3	7.8	13.4	800	7303	25.8	108	6.2	0.4	3127	11.05	46.32	2.65	0.17	940	3.32	13.92	0.80	0.05
36.6	Grading #2a	7.6	38.2	26.1	1533	23690	108.0	149	13.0	23.6	3126	14.24	19.67	1.71	3.12	620	2.82	3.90	0.34	0.62
1.3	Idling #5	2.2	7.0	12.1	800	6824	24.6	104	6.1	0.3	3127	11.25	47.8	2.81	0.14	971	3.49	14.84	0.87	0.04
23.9	Grading #2d	9.0	46.7	30.3	1644	28116	117.0	157	14.3	27.8	3128	13.01	17.51	1.59	3.10	602	2.50	3.37	0.31	0.60
1.3	Idling #6	2.2	7.3	12.6	800	6755	24.7	103	5.6	0.3	3127	11.41	47.68	2.61	0.15	923	3.37	14.07	0.77	0.04
273.1	Overall[6]	7.4	38.6	28.2	1353	23177	96.2	146	11.6	18.4	3128	12.98	19.65	1.57	2.49	601	2.49	3.78	0.30	0.48
	Idling Ave.	2.1	7.1	12.3	800	6645	23.9	101	5.7	0.3	3127	11.27	47.63	2.70	0.13	933	3.36	14.21	0.81	0.04
	Idling Stdev	0.1	0.4	0.6	0.1	399	1.6	5	0.4	0.1	0.844	0.41	0.74	0.13	0.03	20	0.14	0.33	0.05	0.01
	Idling COV	6.0%	5.2%	5.2%	0.01%	6.0%	6.6%	4.7%	7.1%	28.1%	0.0%	3.6%	1.6%	4.7%	21.9%	2.1%	4.1%	2.3%	5.9%	23%
	Grading Ave.	8.1	42.9	29.5	1508	25458	111.3	150	13.2	24.2	3126	13.78	18.71	1.64	3.01	599	2.65	3.60	0.32	0.58
	Grading Stdev	1.3	8.8	5.1	104.8	3934	10.8	9	0.9	3.1	2.034	1.01	1.849	0.17	0.35	33	0.31	0.54	0.05	0.09
	Grading COV	15.4%	20.6%	17.4%	7.0%	15.5%	9.7%	6.1%	7.0%	12.6%	0.1%	7.3%	9.9%	10.2%	11.7%	5.5%	11.6%	15%	15%	16%
	A-Work Ave.[7]	5.8	29.3	24.0	1169	18155	72.1	132	9.7	12.1	3127	12.31	32.3	2.08	1.46	742	2.88	8.40	0.52	0.28
	A-Work Stdev	4.4	26.7	13.9	391.3	13794	50.7	37	4.2	12.4	2.601	1.57	15.09	0.61	1.45	175	0.54	5.40	0.26	0.28
	A-Work COV	75.9%	91.0%	58.2%	33.5%	76.0%	70.3%	27.8%	43.4%	102%	0.1%	12.8%	46.7%	29.6%	99.4%	23.6%	18.9%	64%	50%	97%

[1] Data filtered for ECM and PEMS drop outt

[2] ECM fuel rate not reported, fuel calculated from carbon balance method

[3] Power estimated from lug curve work sheet

[4] Activity work for selected sections where the specific type of work is known

[5] Total PM using gravimetric span method and not the model alpha methods

[6] Average for the whole day independent of type of A-work

[7] Overall not included

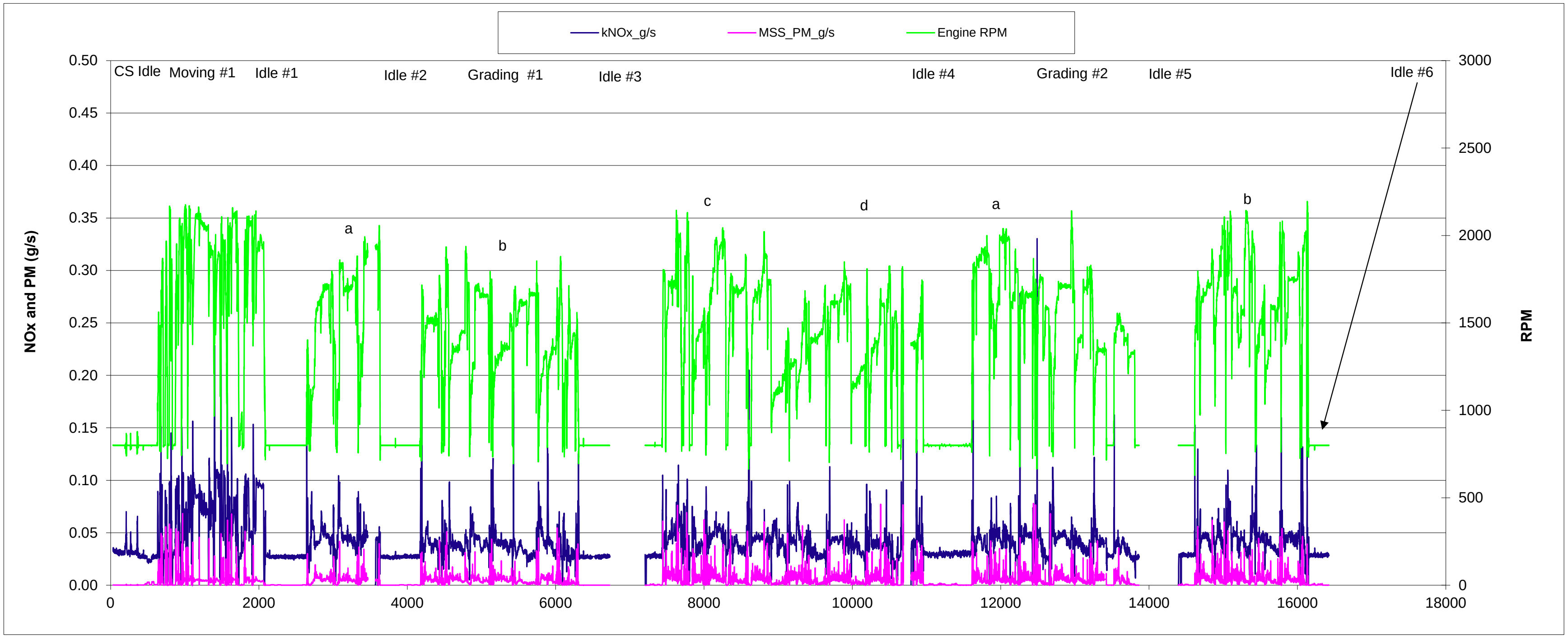


Figure 15: Modal emissions 15_120M_103G 2010 CAT tier 3 grader

16_120M: 2012.10.22

This 2008 Tier 3 Caterpillar 120M road grader was owned and operated by County of Riverside's main yard. The test location was near Mead Valley, CA. The work most involves scarpering off the top layer, smoothing out surface, and laydown new dirt. PEMS equipment was the same as the last test and there was 3.9 hours of data collected. ECM data was recorded by CAT ET.

Table 16: Integrated emissions for 16_120M_97G 2008 CAT tier 3 grader

Dur.	Test Function	Fuel [2]	Power [3]	eLoad	eSpeed	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel)					Brake Specific Emissions (g/hp-h)				
Min	A-Work[4]	kg/hr	bhp	%	RPM	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]
26.4	Cold Start Idle	2.4	11.2	19.3	800	7550	39.6	101	5.0	1.1	3121	16.37	41.66	2.06	0.48	673	3.53	8.98	0.44	0.10
26.2	Moving #1	12.8	72.4	47.5	1672	40087	225.9	196	15.3	30.5	3122	17.60	15.29	1.19	2.38	554	3.12	2.71	0.21	0.42
2.3	Idling #1	1.4	7.3	12.6	801	4509	21.5	68	3.0	0.2	3123	14.88	47.12	2.10	0.13	616	2.93	9.29	0.41	0.02
10.8	Grading #1a	11.7	64.0	41.1	1774	36651	137.7	177	15.3	28.2	3131	11.76	15.11	1.31	2.42	573	2.15	2.77	0.24	0.44
18.1	Grading #1b	11.2	62.3	39.4	1861	35142	162.6	178	14.4	31.2	3127	14.47	15.85	1.28	2.79	564	2.61	2.86	0.23	0.50
21.8	Grading #1c	8.1	45.0	30.3	1572	25160	145.2	142	11.9	26.5	3120	18.01	17.6	1.48	3.30	560	3.23	3.16	0.27	0.59
8.5	Idling #2	1.9	7.0	12.0	800	5875	32.3	89	4.6	0.1	3118	17.14	47.34	2.43	0.06	845	4.65	12.83	0.66	0.02
10.3	Grading #2a	11.7	63.0	38.9	1885	36560	160.0	171	15.6	33.3	3128	13.68	14.67	1.33	2.86	580	2.54	2.72	0.25	0.53
2.2	Idling #3	2.1	7.5	12.8	801	6695	34.9	104	4.4	0.2	3121	16.25	48.28	2.05	0.11	897	4.67	13.88	0.59	0.03
26.1	Grading #2b	9.9	54.0	34.1	1995	31019	133.3	192	14.6	26.4	3128	13.44	19.39	1.48	2.67	574	2.47	3.56	0.27	0.49
24.9	Grading #2c	9.3	49.3	30.8	1852	29069	144.7	173	14.0	26.6	3124	15.55	18.54	1.51	2.87	589	2.93	3.50	0.28	0.54
11.5	Grading #2d	6.7	33.1	23.5	1539	20753	130.7	152	11.2	17.9	3117	19.63	22.86	1.68	2.70	627	3.95	4.60	0.34	0.54
235.0	Overall[6]	8.4	45.0	32.2	1525	26144	136.8	162	11.8	22.1	3123	16.35	19.34	1.41	2.65	581	3.04	3.59	0.26	0.49
	Idling Ave.	1.8	7.2	12.5	800	5693	29.5	87	4.0	0.2	3121	16.09	47.58	2.19	0.10	786	4.08	12.00	0.55	0.02
	Idling Stdev	0.4	0.3	0.4	0.3	1104	7.1	18	0.8	0.1	2.303	1.14	0.617	0.21	0.03	150	1.00	2.41	0.13	0.01
	Idling COV	19.4%	3.6%	3.5%	0.04%	19.4%	24.0%	20.6%	21.2%	36.3%	0.1%	7.1%	1.3%	9.4%	34.5%	19.1%	24.4%	20%	23%	33%
	Grading Ave.	9.8	53.0	34.0	1782	30622	144.9	169	13.9	27.2	3125	15.22	17.72	1.44	2.80	581	2.84	3.31	0.27	0.52
	Grading Stdev	1.9	11.4	6.3	168.5	6081	12.5	17	1.7	4.9	4.694	2.75	2.874	0.14	0.27	22	0.60	0.66	0.04	0.05
	Grading COV	19.7%	21.6%	18.5%	9.5%	19.9%	8.6%	10.0%	12.0%	17.9%	0.2%	18.1%	16.2%	9.9%	9.5%	3.9%	21.0%	20%	13%	9.0%
	A-Work Ave.[7]	7.4	39.7	28.5	1446	23256	114.0	145	10.8	18.5	3123	15.73	26.98	1.66	1.90	638	3.23	5.90	0.35	0.35
	A-Work Stdev	4.4	25.3	12.3	493.7	13683	65.5	44	5.0	13.9	4.079	2.22	14.39	0.40	1.28	115	0.82	4.18	0.15	0.23
	A-Work COV	58.8%	63.8%	43.1%	34.1%	58.8%	57.4%	30.2%	46.5%	74.9%	0.1%	14.1%	53.3%	24.3%	67.6%	18.0%	25.5%	71%	42%	66%

[1] Data filtered for ECM and PEMS drop outt

[2] ECM fuel rate not reported, fuel calculated from carbon balance method

[3] Power estimated from lug curve work sheet

[4] Activity work for selected sections where the specific type of work is known

[5] Total PM using gravimetric span method and not the model alpha methods

[6] Average for the whole day independent of type of A-work

[7] Overall not included

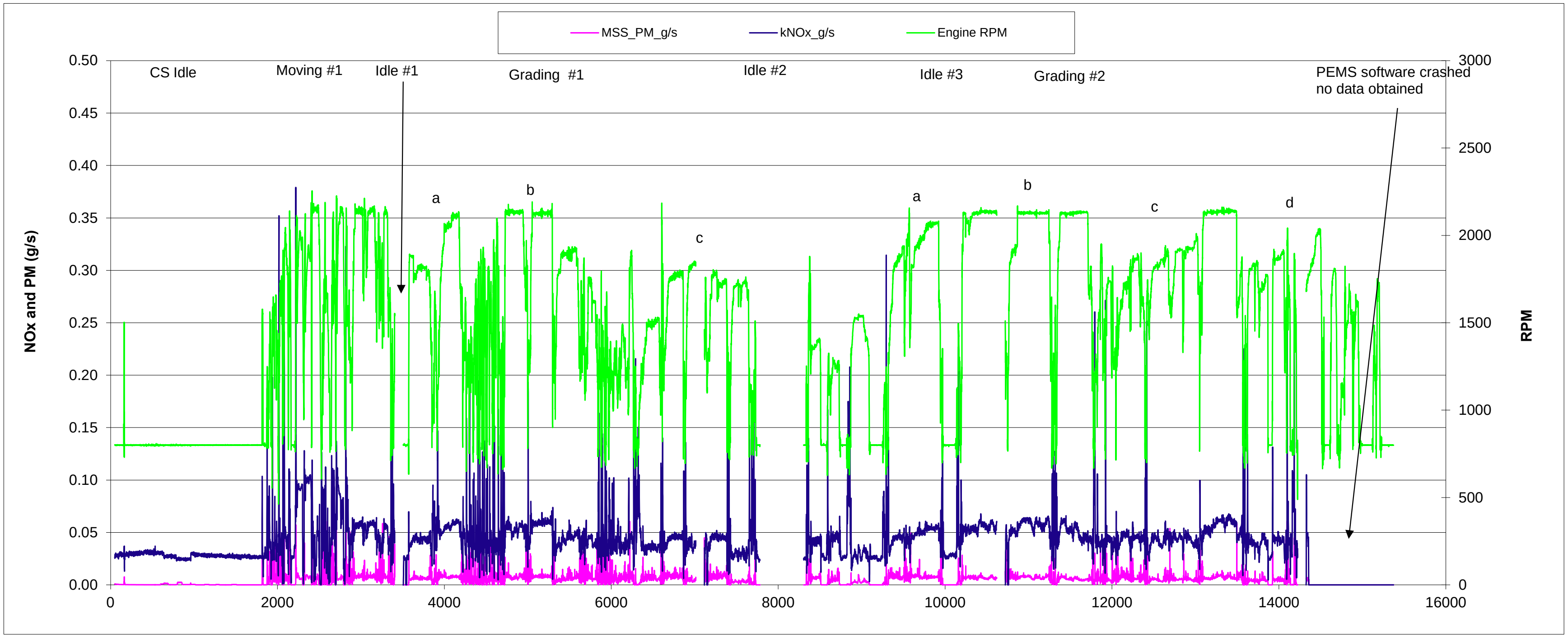


Figure 16: Modal emissions for 16_120M_97G 2008 CAT tier 3 grader

17_120M_DPF: 2012.10.23

This 2010 Tier 3 Caterpillar 120M road grader was owned and operated by County of Riverside's Perris yard. This unit was equipped with an aftermarket Huss DPF. The test location was near Mystic Lake near Perris, CA. The grader was grading the dirt road section of Davis Road. . PEMS equipment was the same as the last test and there are 4.3 hours of data collected. ECM data was recorded by CAT ET.

Table 17: Integrated emissions for 17_120M_106G_DPF 2008 CAT tier 3 grader

Dur.	Test Function	Fuel [1]	Power [2]	eLoad	eSpeed	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel)					Brake Specific Emissions (g/hp-hr)				
Min		kg/hr	bhp	%	RPM	CO2	CO	NOx	THC	PM [3]	CO2	CO	NOx	THC	PM [3]	CO2	CO	NOx	THC	PM [3]
1.1	Idling #1	2.0	5.4	9.1	800	6280	31.3	99	1.8	0.01	3126	15.59	49.14	0.89	0.01	1156	5.77	18.17	0.33	0.002
26.4	Grading #1a	23.1	144.0	86.3	1978	72551	129.7	276	12.3	1.3	3143	5.62	11.94	0.53	0.05	504	0.90	1.91	0.09	0.01
33.1	Grading #1b	14.6	82.6	50.4	1842	45646	159.5	201	11.6	1.7	3134	10.95	13.79	0.80	0.12	553	1.93	2.43	0.14	0.02
1.9	Idling #2	2.2	6.3	10.5	799	6748	26.7	106	3.1	0.02	3129	12.37	49.34	1.42	0.01	1077	4.26	16.99	0.49	0.00
30.2	Grading #1c	12.4	71.4	43.1	2037	38790	145.4	208	11.8	1.4	3132	11.74	16.77	0.95	0.11	544	2.04	2.91	0.16	0.02
21.9	Grading #1d	8.4	42.9	25.6	1916	26423	102.5	158	12.2	0.8	3130	12.14	18.72	1.45	0.10	616	2.39	3.68	0.29	0.02
0.7	Idling #3	2.4	7.3	12.3	800	7416	29.6	109	4.2	0.03	3128	12.50	46	1.78	0.01	1012	4.05	14.89	0.58	0.00
2.2	Idling #4	2.5	7.2	12.1	801	7667	32.7	113	4.4	0.05	3127	13.32	46.23	1.81	0.02	1061	4.52	15.68	0.61	0.01
23.6	Grading #2a	12.3	70.0	43.6	1883	38605	139.9	203	13.4	5.2	3132	11.35	16.45	1.08	0.42	552	2.00	2.90	0.19	0.07
17.0	Grading #2b	8.2	42.1	29.3	1608	25577	135.6	189	11.0	4.2	3123	16.56	23.08	1.35	0.52	607	3.22	4.49	0.26	0.10
257.2	Overall[6]	12.1	68.4	42.8	1774	37982	130.9	198	11.1	2.0	3133	10.80	16.31	0.92	0.16	555	1.91	2.89	0.16	0.03
	Idling Ave.	2.25	6.56	11.01	800	7028	30.1	107	3.4	0.03	3127	13.45	47.68	1.48	0.01	1076.6	4.65	16.43	0.50	0.00
	Idling Stdev	0.20	0.89	1.49	0.6	631	2.6	6	1.2	0.02	1.4	1.49	1.81	0.43	0.01	59.61	0.77	1.45	0.13	0.00
	Idling COV	9.0%	13.6%	13.6%	0.07%	9.0%	8.6%	5.8%	36.1%	60.4%	0.05%	11.1%	3.8%	29.0%	52.9%	5.5%	16.6%	8.8%	25%	51%
	Grading Ave.	13.17	75.49	46.38	1877	41265	135.4	206	12.0	2.4	3132	11.39	16.79	1.03	0.22	562.47	2.08	3.05	0.19	0.04
	Grading Stdev	5.45	37.34	21.66	149.0	17191	19.0	39	0.8	1.8	6.4	3.49	3.90	0.34	0.20	42.09	0.75	0.91	0.08	0.04
	Grading COV	41.4%	49.5%	46.7%	7.9%	41.7%	14.1%	18.8%	6.5%	74.2%	0.2%	30.6%	23.2%	33.4%	89.2%	7.5%	36.1%	30%	40%	92%
	A-Work Ave.[7]	8.80	47.92	32.23	1446	27570	93.3	166	8.6	1.5	3130	12.22	29.15	1.21	0.14	768.12	3.11	8.41	0.31	0.03
	A-Work Stdev	6.95	45.19	24.39	567.2	21838	56.3	59	4.6	1.8	5.4	2.94	16.24	0.42	0.18	269.55	1.51	6.99	0.19	0.03
	A-Work COV	79.0%	94.3%	75.7%	39.2%	79.2%	60.3%	35.3%	53.2%	124%	0.2%	24.1%	55.7%	35.2%	132%	35.1%	48.5%	83%	59%	129%

[1] Data filtered for ECM and PEMS drop outt

[2] ECM fuel rate not reported, fuel calculated from carbon balance method

[3] Power estimated from lug curve work sheet

[4] Activity work for selected sections where the specific type of work is known

[5] Total PM using gravimetric span method and not the model alpha methods

[6] Average for the whole day independent of type of A-work

[7] Overall not included

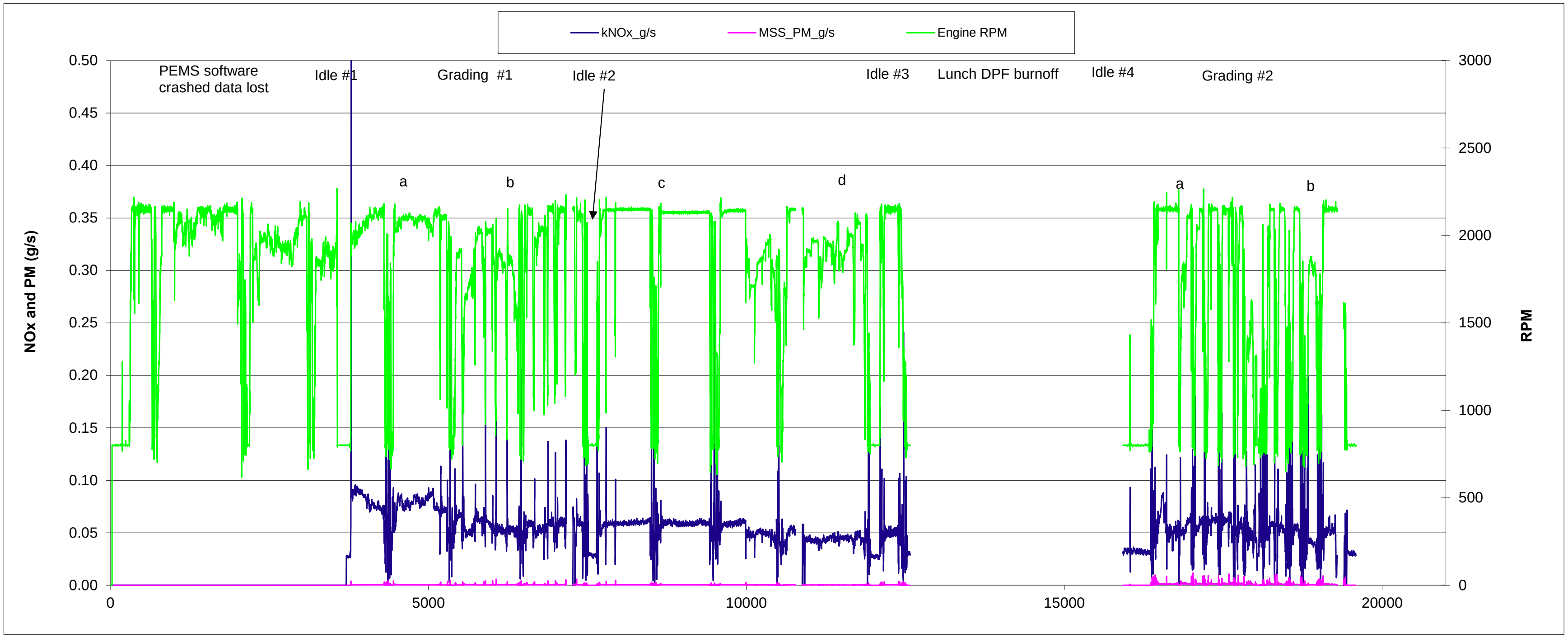


Figure 17: Modal emissions for 17_120M_106G_DPF 2008 CAT tier 3 grader

18_928Hz: 2012.10.29

This 2011 Tier 3 Caterpillar 928Hz wheel loader was owned and operated by County of Riverside's Blythe yard. The testing location was in Riverside County's Blythe Rock Quarry off Highway 78. The wheel loader was digging up dirt/earth and put into a large pile. PEMS equipment was the same as the last test and there was 3.8 hours of data collected. ECM data was recorded by CAT ET.

Table 18: Integrated emissions for 18_928Hz_70P 2011 CAT tier 3 wheel loader

Dur.	Test Function	Fuel [2]	Power [3]	eLoad	eSpeed	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel)					Brake Specific Emissions (g/hp-h)				
Min	A-Work[4]	kg/hr	bhp	%	RPM	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]
1.3	Idling #1	2.2	8.4	12.9	830	6988	27.1	100	4.4	0.6	3128	12.15	44.7	1.98	0.28	833	3.23	11.90	0.53	0.08
1.1	Moving #1	13.7	75.5	45.1	1814	42963	142.3	176	21.7	21.7	3132	10.37	12.8	1.58	1.59	569	1.88	2.33	0.29	0.29
15.7	Digging #1a	17.8	104.0	63.4	1755	55803	123.5	289	16.3	14.8	3140	6.95	16.24	0.92	0.83	537	1.19	2.78	0.16	0.14
18.4	Digging #1b	17.8	101.9	63.1	1736	55903	139.7	303	14.3	15.9	3138	7.85	17.02	0.81	0.89	549	1.37	2.97	0.14	0.16
26.6	Digging #1c	16.7	93.7	57.9	1705	52367	142.1	284	13.9	16.5	3137	8.52	17.03	0.84	0.99	559	1.52	3.03	0.15	0.18
3.9	Idling #2	2.2	7.0	10.7	830	7015	20.9	109	4.3	1.5	3133	9.32	48.89	1.92	0.67	1008	3.00	15.74	0.62	0.22
30.9	Digging #2a	16.9	95.9	59.5	1713	52979	130.1	289	14.5	16.7	3139	7.71	17.1	0.86	0.99	552	1.36	3.01	0.15	0.17
10.6	Digging #2b	19.5	109.0	66.7	1807	61198	142.7	326	14.5	17.0	3139	7.32	16.7	0.75	0.88	561	1.31	2.99	0.13	0.16
36.7	Digging #2c	17.2	97.6	60.5	1708	54015	145.5	304	13.4	18.0	3138	8.45	17.66	0.78	1.05	554	1.49	3.12	0.14	0.18
34.8	Digging #2d	16.8	93.4	58.4	1685	52824	133.7	303	13.2	16.9	3138	7.94	18	0.78	1.01	566	1.43	3.24	0.14	0.18
0.6	Moving #2	5.8	27.8	23.7	1118	18062	56.0	193	8.3	5.3	3133	9.71	33.49	1.44	0.93	649	2.01	6.94	0.30	0.19
5.1	Idling #3	1.8	4.4	6.7	830	5570	18.3	92	4.4	1.0	3129	10.31	51.94	2.49	0.56	1268	4.18	21.04	1.01	0.23
224.8	Overall[6]	16.0	89.9	56.1	1650	50162	130.0	282	13.4	15.8	3138	8.13	17.64	0.84	0.99	558	1.45	3.14	0.15	0.18
	Moving Ave.	9.74	51.67	34.4	1466	30512	99.11	184.3	15.02	13.53	3133	10.04	23.14	1.51	1.26	609.00	1.95	4.63	0.29	0.24
	Moving Stdev	5.62	33.71	15.2	492	17608	61.03	12.30	9.51	11.59	1.04	0.47	14.62	0.10	0.47	56.53	0.09	3.26	0.01	0.07
	Moving COV	57.7%	65.2%	44.1%	33.6%	57.7%	61.6%	6.7%	63.3%	85.6%	0.0%	4.7%	63.2%	6.9%	37.1%	9.3%	4.6%	70%	2.4%	28%
	Idling Ave.	2.08	6.58	10.1	830	6524	22.12	100.6	4.38	1.04	3130	10.59	48.51	2.13	0.50	1036	3.47	16.23	0.72	0.17
	Idling Stdev	0.26	2.03	3.1	0	826	4.53	8.55	0.08	0.44	2	1.44	3.64	0.31	0.20	218.93	0.62	4.59	0.26	0.08
	Idling COV	12.6%	30.8%	30.8%	0.0%	12.7%	20.5%	8.5%	1.7%	42.1%	0.1%	13.6%	7.5%	14.8%	39.7%	21.1%	17.9%	28%	36%	49%
	Digging Ave.	17.53	99.35	61.3	1730	55013	136.8	299.6	14.31	16.54	3138	7.82	17.11	0.82	0.95	553.86	1.38	3.02	0.14	0.17
	Digging Stdev	0.98	5.82	3.2	41	3071	7.94	14.08	1.02	1.01	1	0.57	0.58	0.06	0.08	9.48	0.11	0.14	0.01	0.02
	Digging COV	5.6%	5.9%	5.2%	2.4%	5.6%	5.8%	4.7%	7.1%	6.1%	0.0%	7.2%	3.4%	7.0%	8.5%	1.7%	8.2%	4.7%	5.7%	9.5%
	A-Work Ave.[7]	12.37	68.21	44.0	1461	38807	101.8	230.6	11.95	12.16	3135	8.88	25.96	1.26	0.89	683.67	2.00	6.59	0.31	0.18
	A-Work Stdev	7.10	42.73	23.4	421	22301	53.73	90.36	5.45	7.69	4.12	1.53	14.56	0.60	0.31	233.91	0.96	6.24	0.27	0.05
	A-Work COV	57.4%	62.6%	53.2%	28.8%	57.5%	52.8%	39.2%	45.6%	63.2%	0.00	17.2%	56.1%	47.7%	35.2%	34.2%	47.8%	95%	88%	28%

[1] Data filtered for ECM and PEMS drop outt

[2] ECM fuel rate not reported, fuel calculated from carbon balance method

[3] Power estimated from lug curve work sheet

[4] Activity work for selected sections where the specific type of work is known

[5] Total PM using gravimetric span method and not the model alpha methods

[6] Average for the whole day independent of type of A-work

[7] Overall not included

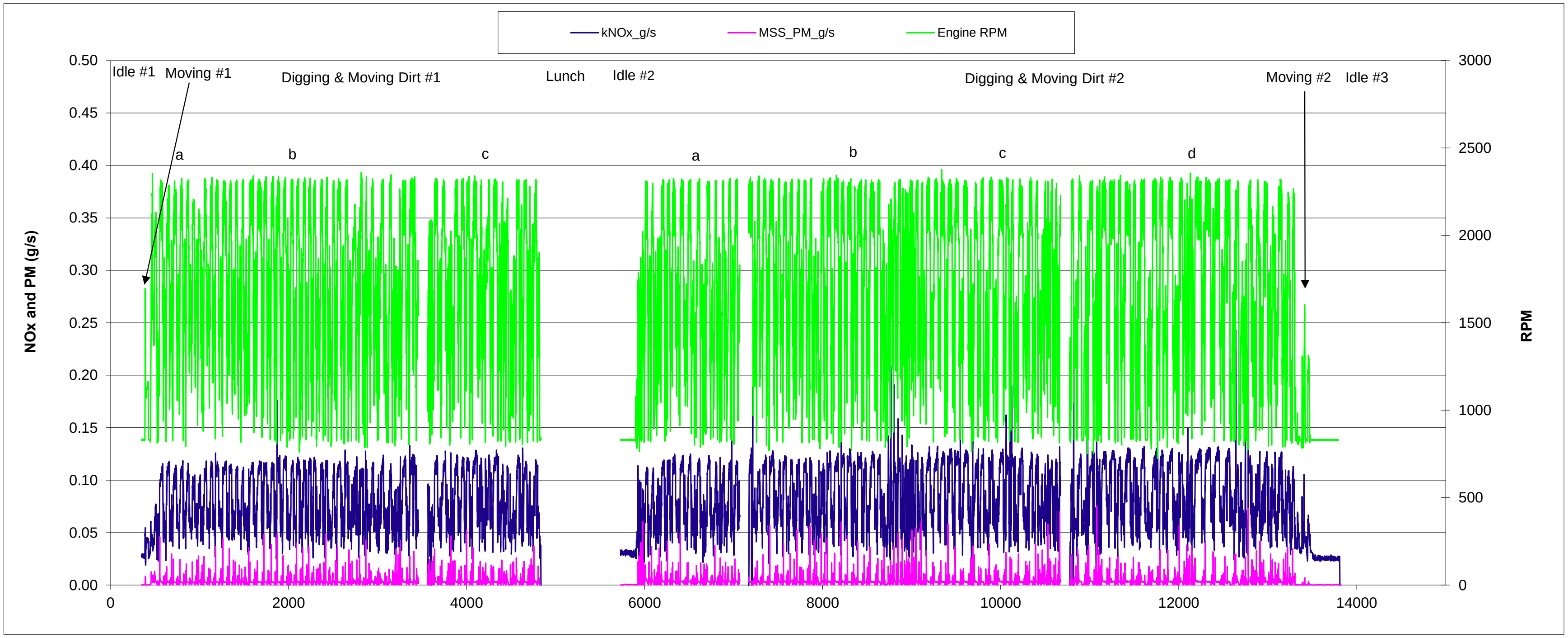


Figure 18: Modal emissions for 18_928Hz_70P 2011 CAT tier 3 wheel loader

19_613G: 2012.10.30

This 2010 Tier 3 Caterpillar 613G scrapper was owned and operated by County of Riverside's Thermal yard. The test location was at the Riverside County Rock Quarry at Thermal, CA. The scrapper was scrapping dirt off the sides of the gravel pit and move into the dumping location about half mile away. PEMS equipment was the same as the last test and there was 3.6 hours of data collected. ECM data was recorded by CAT ET.

Table 19: Integrated emissions for 19_613G_10W 2010 CAT tier 3 scraper

Dur.	Test Function	Fuel [2]	Power [3]	eLoad	eSpeed	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel)					Brake Specific Emissions (g/hp-h)				
Min	A-Work[4]	kg/hr	bhp	%	RPM	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]
6.0	Cold Start Idle	3.0	15.0	29.3	700	9472	25.6	118	3.3	1.3	3136	8.46	39.21	1.09	0.42	633	1.71	7.91	0.22	0.09
14.6	Moving #1	29.2	150.3	79.3	1969	91566	271.9	374	9.1	23.7	3138	9.32	12.81	0.31	0.81	609	1.81	2.49	0.06	0.16
27.2	Idiling #1	2.3	9.0	17.6	700	7071	13.6	105	1.8	0.5	3141	6.03	46.65	0.81	0.24	785	1.51	11.66	0.20	0.06
4.2	Moving #2	30.0	154.7	82.8	2009	94282	150.7	413	10.1	18.3	3144	5.03	13.77	0.34	0.61	609	0.97	2.67	0.07	0.12
17.7	Scraping #1a	27.5	134.8	73.3	2171	86618	113.3	388	7.3	18.9	3146	4.12	14.1	0.27	0.69	643	0.84	2.88	0.05	0.14
2.4	Idling #2	2.3	7.8	15.3	700	7122	12.5	115	2.3	0.7	3142	5.52	50.76	1.03	0.33	909	1.60	14.68	0.30	0.09
21.7	Scraping #1b	28.9	145.3	78.4	2138	90782	224.6	413	6.3	19.7	3140	7.77	14.3	0.22	0.68	625	1.55	2.85	0.04	0.14
34.0	Scraping #1c	30.2	155.8	83.1	2110	95030	186.9	451	5.3	20.9	3143	6.18	14.9	0.17	0.69	610	1.20	2.89	0.03	0.13
24.3	Idling #3	2.2	7.8	15.3	700	6875	11.9	110	1.4	0.3	3143	5.42	50.29	0.66	0.16	879	1.52	14.07	0.18	0.04
23.7	Scraping #2a	28.0	148.4	79.7	2137	87864	216.0	411	6.4	22.7	3140	7.72	14.7	0.23	0.81	592	1.46	2.77	0.04	0.15
20.6	Scraping #2b	29.3	145.0	78.2	2151	92005	172.0	437	5.5	21.4	3143	5.88	14.94	0.19	0.73	634	1.19	3.01	0.04	0.15
2.9	Moving #3	10.1	45.3	30.6	1343	31662	181.5	236	5.1	11.8	3124	17.91	23.31	0.50	1.17	699	4.01	5.22	0.11	0.26
3.6	Idling #4	2.3	7.7	15.1	700	7171	12.8	118	2.3	1.4	3141	5.59	51.55	1.02	0.62	929	1.65	15.24	0.30	0.18
217.8	Overall[6]	19.9	100.7	58.4	1638	62630	137.4	315	5.0	14.3	3142	6.89	15.79	0.25	0.72	622	1.36	3.13	0.05	0.14
	Scraping Ave.	28.8	145.9	78.6	2141	90460	182.6	420	6.2	20.7	3143	6.33	14.59	0.22	0.72	620.74	1.25	2.88	0.04	0.14
	Scraping Stdev	1.1	7.5	3.5	22	3349	44.2	24	0.8	1.5	2.34	1.51	0.37	0.04	0.05	20.11	0.28	0.09	0.01	0.01
	Scraping COV	3.7%	5.2%	4.5%	1.0%	4%	24.2%	5.8%	13.1%	7.1%	0.1%	23.9%	2.6%	17%	8%	3%	22%	3%	18%	6%
	Idling Ave.	2.2	8.1	15.8	700	7060	12.7	112	2.0	0.8	3142	5.64	49.81	0.88	0.34	875.44	1.57	13.91	0.25	0.10
	Idling Stdev	0.0	0.6	1.2	0.1	130	0.7	6	0.4	0.5	0.72	0.27	2.17	0.18	0.20	63.38	0.07	1.57	0.06	0.06
	Idling COV	1.9%	7.5%	7.5%	0.01%	2%	5.6%	5.0%	22.0%	61.1%	0.02%	4.8%	4%	20%	60%	7%	4%	11%	25%	65%
	Moving Ave.	23.1	116.8	64.2	1774	72503	201.4	341	8.1	17.9	3135	10.75	16.63	0.38	0.86	639.20	2.26	3.46	0.08	0.18
	Moving Stdev	11.2	62.0	29.2	374	35396	63.0	93	2.7	6.0	10.60	6.56	5.80	0.10	0.28	51.97	1.57	1.53	0.03	0.07
	Moving COV	48.6%	53.1%	45.5%	21.1%	49%	31.3%	27.2%	32.8%	33.3%	0.3%	61.0%	34.9%	27%	32%	8%	69%	44%	36%	41%
	A-Work Ave.[7]	17.3	86.7	52.2	1502	54425	122.6	284	5.1	12.4	3140	7.30	27.79	0.53	0.61	704.30	1.62	6.80	0.13	0.13
	A-Work Stdev	13.3	69.5	30.9	693	41851	95.8	149	2.8	9.9	5.64	3.51	16.83	0.35	0.27	125.48	0.77	5.21	0.10	0.06
	A-Work COV	76.9%	80.2%	59.3%	46.1%	77%	78.2%	52.6%	54.4%	79.8%	0.2%	48.1%	60.5%	67%	44%	18%	48%	77%	79%	42%

[1] Data filtered for ECM and EFM drop out

[2] ECM fuel rate reported but looks strangely high, fuel calculated from carbon balance method

[3] Power estimated from lug curve work sheet

[4] Activity work for selected sections where the specific type of work is known

[5] Total PM using gravimetric span method and not the model alpha methods

[6] Average for the whole day independent of type of A-work

[7] Overall not included

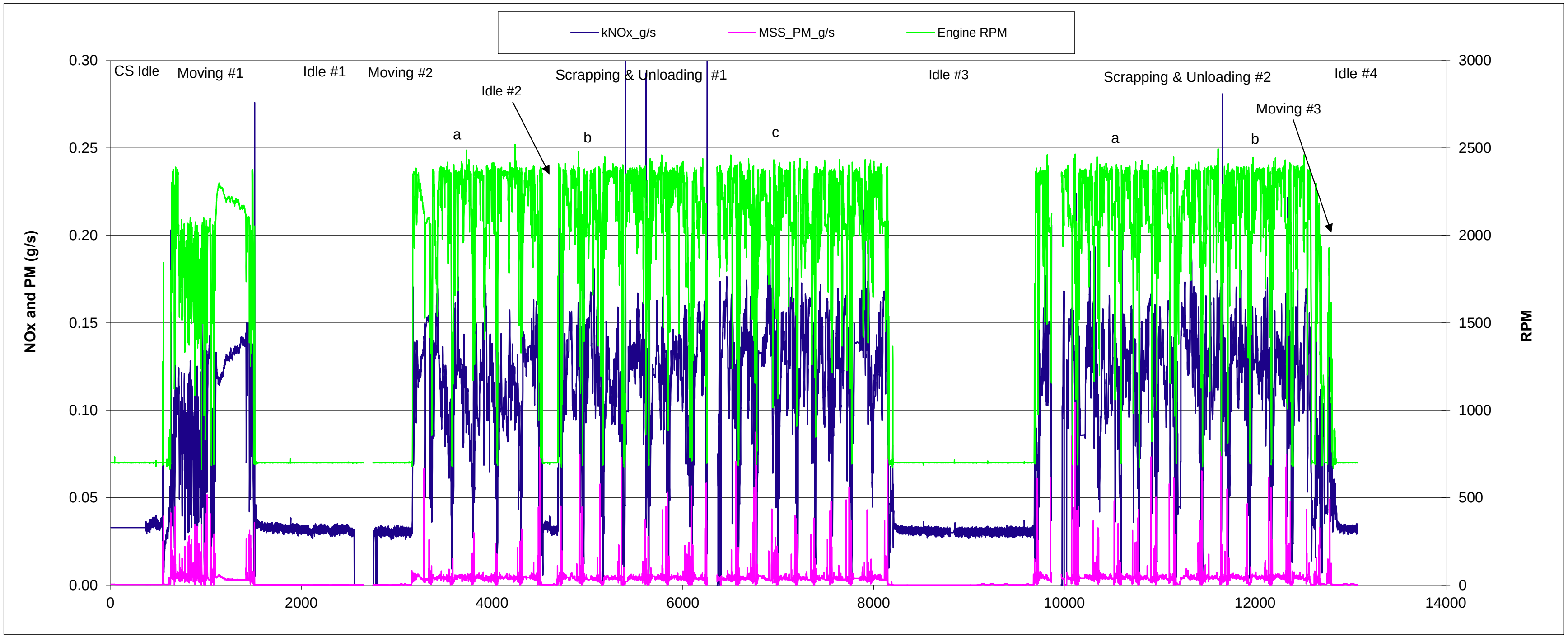


Figure 19: Modal emissions for 19_613G_10W 2010 CAT tier 3 scraper

20_928Hz: 2012.10.31

This 2011 Tier 3 Caterpillar 928Hz wheel loader was owned and operated by County of Riverside's Sky Valley yard. The test location was on Ave 38 near Thousand Palms, CA. The wheel loader was cleaning off the shoulder on Ave 38. The sand from the sand dunes near Ave 38 drifts to the road and eventually covers the road if no cleaning is done. The working generally involves cleaning the shoulder with the bucket and dumps the sand off the road when bucket is full. PEMS equipment was the same as the last test and there was 3.7 hours of data collected. ECM data was recorded by CAT ET.

Table 20: Integrated emissions for 20_928Hz_71P 2011 CAT tier 3 wheel loader

Dur.	Test Function	Fuel [2]	Power [3]	eLoad	eSpeed	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel)					Brake Specific Emissions (g/hp-h)				
Min	A-Work[4]	kg/hr	bhp	%	RPM	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]	CO_2	CO	NO_x	THC	PM [5]
3.5	Cold Start Idle	3.8	21.5	32.6	831	12032	53.1	105	5.6	4.5	3127	13.80	27.31	1.46	1.18	561	2.47	4.90	0.26	0.21
3.1	Moving #1	18.4	106.9	63.2	1858	57636	149.7	204	28.8	38.6	3136	8.14	11.12	1.57	2.10	539	1.40	1.91	0.27	0.36
23.4	Pushing #1a	13.3	68.1	42.3	1831	41695	102.8	192	16.9	25.1	3137	7.73	14.42	1.28	1.89	612	1.51	2.81	0.25	0.37
2.7	Idiling #1	1.8	4.3	6.5	830	5766	12.9	99	4.1	0.66	3135	7.01	54.04	2.21	0.36	1351	3.02	23.29	0.95	0.15
46.3	Pushing #1b	12.4	61.5	38.1	1780	38895	99.0	195	15.4	20.0	3137	7.98	15.75	1.24	1.62	633	1.61	3.18	0.25	0.33
36.2	Pushing #1c	13.8	68.5	42.1	1814	43273	107.7	209	15.6	20.0	3137	7.81	15.13	1.13	1.46	631	1.57	3.05	0.23	0.29
15.5	Idling #2	2.3	6.3	9.6	830	7195	20.0	118	4.3	0.14	3134	8.71	51.35	1.86	0.06	1135	3.15	18.59	0.67	0.02
19.1	Pushing #2a	13.9	68.5	43.3	1919	43674	107.2	205	17.5	24.2	3137	7.70	14.74	1.26	1.75	638	1.56	3.00	0.26	0.35
30.4	Pushing #2b	12.8	65.7	40.4	1665	40275	124.9	214	13.4	21.2	3135	9.72	16.66	1.04	1.66	613	1.90	3.26	0.20	0.32
29.4	Pushing #2c	10.0	47.8	31.6	1507	31348	109.0	197	12.6	18.3	3132	10.90	19.64	1.25	1.84	656	2.28	4.11	0.26	0.38
2.2	Moving #2	12.8	57.0	36.1	1929	40055	114.8	195	17.0	29.6	3135	8.98	15.27	1.33	2.32	703	2.01	3.43	0.30	0.52
3.4	Idling #3	2.3	6.2	9.4	830	7160	19.8	121	5.0	1.89	3133	8.67	52.83	2.18	0.83	1154	3.19	19.47	0.80	0.30
223.1	Overall[6]	11.3	56.1	36.0	1625	35573	97.7	191	13.9	18.7	3136	8.61	16.8	1.22	1.66	634	1.74	3.39	0.25	0.33
	Pushing Ave.	12.7	63.3	39.6	1753	39860	108.4	202	15.2	21.5	3136	8.64	16.06	1.20	1.70	630	1.74	3.23	0.24	0.34
	Pushing Stdev	1.4	8.1	4.3	146	4542	8.9	9	1.9	2.6	2.1	1.35	1.93	0.09	0.16	16	0.30	0.46	0.02	0.03
	Pushing COV	11%	12.8%	10.9%	8.3%	11.4%	8.2%	4.3%	12.7%	12.3%	0.1%	15.6%	12.0%	7.7%	9.3%	2.6%	17.2%	14%	9%	10%
	Idling Ave.	2.1	5.6	8.5	830	6707	17.6	113	4.4	0.89	3134	8.13	52.74	2.08	0.42	1213	3.12	20.45	0.81	0.16
	Idling Stdev	0.3	1.2	1.8	0	815	4.0	12	0.5	0.90	1.3	0.97	1.35	0.19	0.39	120	0.09	2.50	0.14	0.14
	Idling COV	12%	20.7%	20.7%	0.0%	12.2%	23.0%	10.3%	11.0%	100%	0.0%	11.9%	2.6%	9.3%	93.1%	9.9%	2.9%	12%	17%	88%
	Moving Ave.	15.6	81.9	49.6	1893	48846	132.2	200	22.9	34.1	3135	8.56	13.20	1.45	2.21	621	1.71	2.67	0.28	0.44
	Moving Stdev	4.0	35.3	19.1	50	12432	24.7	7	8.4	6.4	0.4	0.59	2.93	0.17	0.15	116	0.43	1.07	0.02	0.11
	Moving COV	25%	43.1%	38.5%	2.7%	25.5%	18.7%	3.3%	36.5%	18.6%	0.01%	6.9%	22.2%	11.6%	7.0%	18.7%	25.4%	40%	7.2%	25%
	A-Work Ave.[7]	9.8	48.5	32.9	1469	30750	85.1	171	13.0	17.0	3135	8.93	25.69	1.48	1.42	769	2.14	7.58	0.39	0.30
	A-Work Stdev	5.7	32.2	16.7	485	17829	46.2	45	7.3	12.5	3	1.85	16.78	0.39	0.69	276	0.67	7.86	0.26	0.13
	A-Work COV	58%	66.3%	50.8%	33.0%	58.0%	54.3%	26.5%	56.3%	73.3%	0.09%	20.7%	65%	26%	49%	35.9%	31.5%	104%	66%	42%

[1] Data filtered for ECM and EFM drop out
[2] ECM fuel rate reported but looks strangely high, fuel calculated from carbon balance method
[3] Power estimated from lug curve work sheet
[4] Activity work for selected sections where the specific type of work is known
[5] Total PM using gravimetric span method and not the model alpha methods
[6] Average for the whole day independent of type of A-work
[7] Overall not included

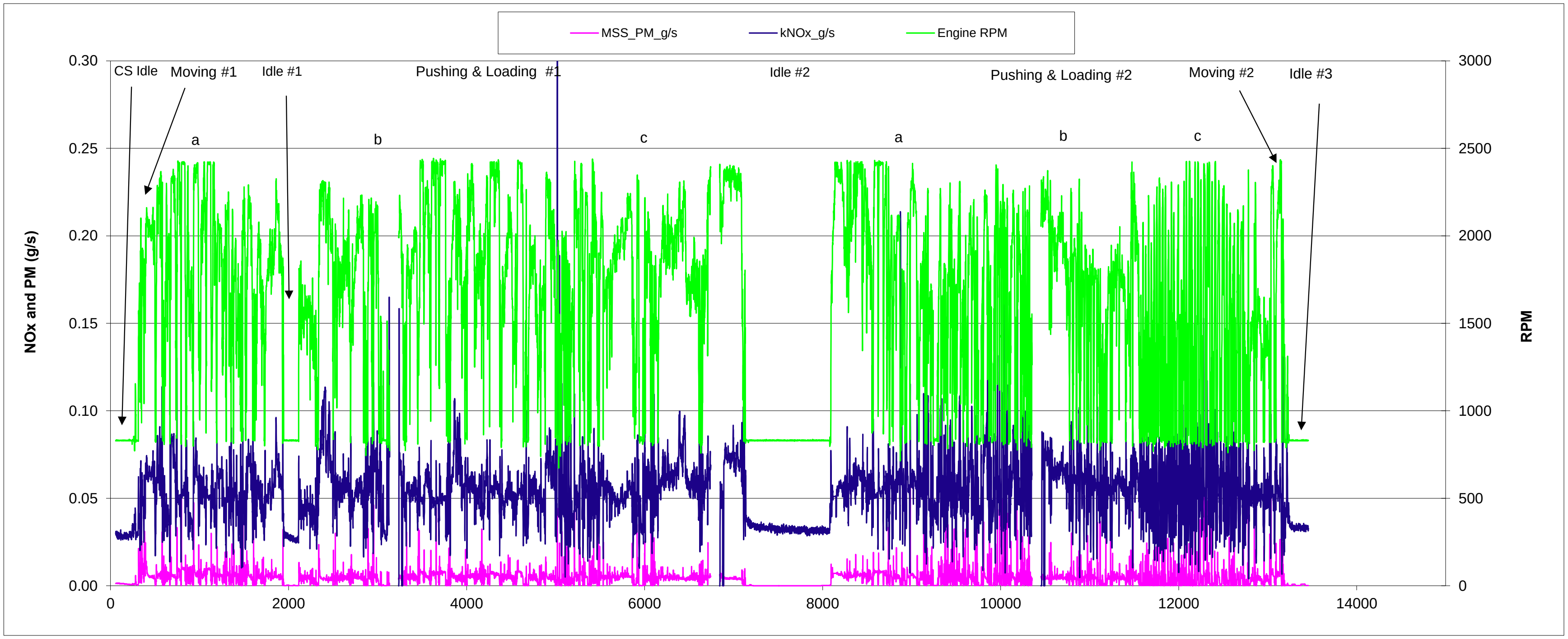


Figure 20: Modal emissions for 20_928Hz_71P 2011 CAT tier 3 wheel loader

21_D6T_JM: 2012.11.13

This 2012 Tier 4i Caterpillar D6T bulldozer was a rental unit owned by Johnson Machinery in Riverside, CA. The test site was at WM's El Sorbrante landfill site near Corona, CA. The dozer was pushing rock piles for different designated distances in the bottom of the new cell. PEMS equipment was the same the same as the last test but the PM PEMS received some major improvements. There was 3.6 hours of valid data collected.

Table 21: Integrated emissions for 21_D6T_JM 2012 CAT tier 4i bulldozer

Duration	Test Function	Fuel [4]	Power [1]	Torque	Fuel [3]	eLoad	eSpeed	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel) [4]					Brake Specific Emissions (g/hp-hr)				
Mins		kg/hr	bhp	ft-lb	kg/hr	%	RPM	CO2	CO	NOx	THC	mg PM [3]	CO2	CO	NOx	THC	ng PM [3]	CO2	CO	NOx	THC	mg PM [2]
18.1	high idle	12.6	66.8	194.4	14.1	31.8	1240	44579	-4.9	140	1.9	19.1	3162	-0.35	9.90	0.14	1.36	667	-0.07	2.09	0.029	0.29
6.0	low idle	3.1	5.5	36.1	3.6	8.9	800	11215	4.2	114	9.1	5.1	3152	1.19	32.0	2.56	1.44	2038	0.77	20.69	1.655	0.93
3.3	low idle	3.4	6.3	41.4	4.0	10.2	800	12504	-4.0	105	3.3	8.6	3161	-1.01	26.7	0.83	2.17	1982	-0.63	16.72	0.517	1.36
5	ave	3.2	5.9	38.8	3.8	9.6	800	11859	0.1	110	6.2	6.9	3157	0.09	29.3	1.69	1.80	2010	0.07	18.70	1.086	1.15
1.9	stdev	0.2	0.6	3.7	0.3	0.9	0.1	911	5.8	6	4.1	2.4	6.296	1.55	3.77	1.23	0.51	40	0.99	2.81	0.804	0.30
41.9%	COV	7.6%	9.7%	9.7%	7.5%	9.6%	0.0%	7.7%	4337%	5.4%	66.8%	35.6%	0.2%	1656%	12.8%	72.5%	28.5%	2.0%	1403%	15.0%	74.1%	26.4%
2.1	low idle	2.8	4.6	30.4	3.4	7.5	800	10603	-2.6	93	1.0	10.1	3162	-0.78	27.7	0.30	3.00	2291	-0.57	20.07	0.219	2.17
2.6	low idle	2.8	4.6	30.4	3.4	7.5	800	10661	-3.5	96	0.8	9	3163	-1.03	28.6	0.23	2.72	2305	-0.75	20.82	0.166	1.98
12.4	low idle	2.8	4.6	30.4	3.3	7.5	800	10436	-4.3	101	0.9	6.8	3163	-1.30	30.7	0.26	2.07	2255	-0.93	21.89	0.186	1.48
7.5	low idle	2.9	4.9	32.2	3.4	8.0	800	10872	-4.2	102	0.8	8.4	3163	-1.23	29.6	0.23	2.44	2213	-0.86	20.69	0.164	1.71
6	ave	3	4.7	30.8	3.4	7.6	800	10643	-3.7	98	0.9	8.6	3163	-1.09	29.1	0.26	2.56	2266	-0.78	20.87	0.184	1.84
4.9	stdev	0.1	0.1	0.9	0.1	0.2	0.0	180	0.8	4	0.1	1.4	0.436	0.23	1.29	0.03	0.40	41	0.16	0.75	0.026	0.31
79.4%	COV	2.0%	3.0%	3.0%	1.7%	3.0%	0.0%	1.7%	-21%	4.3%	12.7%	15.9%	0.0%	-21.2%	4.4%	13.3%	15.5%	1.8%	-20.1%	3.6%	14.0%	16.6%
5.0	medium push	16.1	81.8	252.0	17.9	34.8	1661	56750	-8.3	134	5.5	39.6	3162	-0.46	7.45	0.31	2.21	694	-0.10	1.63	0.067	0.48
6.8	medium push	16.6	85.1	254.1	18.6	35.8	1711	58847	-6.8	132	4.8	36.0	3162	-0.36	7.08	0.26	1.93	691	-0.08	1.55	0.056	0.42
9.4	medium push	20.8	108.7	295.7	23.7	46.9	1918	74871	-10.2	148	4.5	45.1	3162	-0.43	6.27	0.19	1.90	689	-0.09	1.37	0.041	0.41
24.8	medium push	19.8	101.1	271.5	22.5	43.8	1944	71014	-11.6	144	3.9	36.2	3162	-0.52	6.40	0.17	1.61	702	-0.11	1.42	0.038	0.36
11.5	ave	18.3	94.2	268.3	20.7	40.3	1808	65370	-9.2	139	4.7	39.2	3162	-0.44	6.80	0.23	1.91	694	-0.10	1.49	0.051	0.42
9.0	stdev	2.3	12.9	20.2	2.8	6.0	143.2	8926	2.1	8	0.7	4.2	0.25	0.06	0.56	0.06	0.24	6	0.01	0.12	0.014	0.05
78.6%	COV	12.7%	13.6%	7.5%	13.6%	14.8%	7.9%	13.7%	-23%	5.7%	14.7%	10.8%	0.0%	-14.2%	8.2%	26.9%	12.7%	0.8%	-14.9%	8.2%	26.8%	12.3%
36.6	heavy push	26.7	154.9	416.9	30.0	67.0	1937	94760	-9.1	178	3.4	47.2	3162	-0.31	5.95	0.11	1.57	612	-0.06	1.15	0.022	0.30
7.7	heavy push	24.3	137.6	392.5	26.7	58.2	1815	84298	-8.8	159	2.4	34.9	3162	-0.33	5.97	0.09	1.31	612	-0.06	1.16	0.017	0.25
32.4	heavy push	27.0	156.1	419.1	30.3	67.5	1958	95886	-10.9	182	2.7	41.5	3162	-0.36	6.00	0.09	1.37	614	-0.07	1.16	0.017	0.27
8.2	heavy push	25.0	145.8	405.8	27.8	62.3	1825	87926	-4.4	186	3.4	34.7	3162	-0.16	6.70	0.12	1.25	603	-0.03	1.28	0.023	0.24
21	ave	25.7	148.6	408.6	28.7	63.7	1883	90717	-8.3	176	3.0	39.6	3162	-0.29	6.16	0.10	1.38	610	-0.06	1.19	0.020	0.27
15.4	stdev	1.3	8.7	12.2	1.8	4.4	74.3	5539	2.8	12	0.5	6.0	0.19	0.09	0.37	0.02	0.14	5	0.02	0.06	0.003	0.03
72.8%	COV	5.1%	5.8%	3.0%	6.1%	6.9%	3.9%	6.1%	-34%	6.8%	17.6%	15.1%	0.0%	-31.3%	5.9%	16.6%	10.3%	0.8%	-31.9%	5.1%	16.0%	10.7%
213.9	Overall Ave	16.9	90.7	254.9	19.1	40.6	1553	60278	-6.8	145	3.4	30.0	3162	-0.36	7.62	0.18	1.57	665	-0.08	1.60	0.037	0.33

[1] Power estimated from published lug curve and % laod, see delailed work sheet

[2] Total PM using gravimetric span method and not the model alpha methods. Units of mg/hr or mg/kgfuel or mg/hp-h.

[3] Carbon balance fuel rate calculation using gaseous PEMS

[4] ECM reported fuel rate

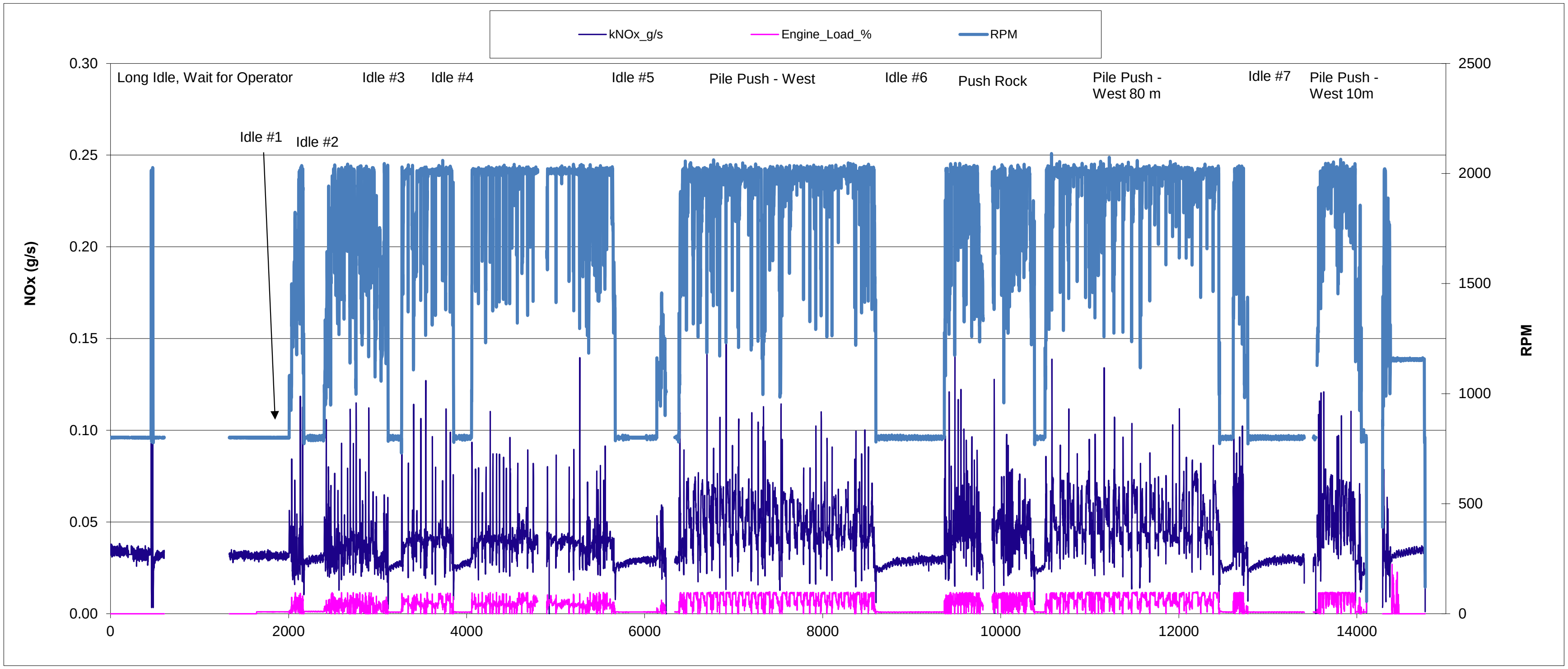


Figure 21: Modal emissions for 21_D6T_JM 2012 CAT tier 4i bulldozer

22_D7E_WM: 2012.12.04

Table 22: Integrated emissions for 22_D7E_WM 2011 CAT tier 4i bulldozer

Duration	Test Function	Fuel [1]	Torque	Power [2]	Fuel [4]	eLoad	eSpeed	Vel GPS	Dist	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel) [4]					Brake Specific Emissions (g/hp-hr)				
Mins		kg/hr	ft-lb	bhp	kg/hr	%	RPM	km/h	m	CO2	CO	NOx	THC	mg PM [3]	CO2	CO	NOx	THC	mg PM [3]	CO2	CO	NOx	THC	mg PM [3]
9.6	cs low idle	3.8	78.7	12.0	3.9	15.1	800	0.0	0.8	12209	55.9	163	7.4	8.9	3133	14.36	41.9	1.90	2.29	1018	4.66	13.61	0.616	0.74
10.6	cs low idle	2.9	53.8	8.2	3.1	10.3	800	0.0	3.0	9747	48.8	121	9.6	8.0	3128	15.66	38.7	3.09	2.55	1189	5.95	14.73	1.173	0.97
10.1	ave	3.3	66.3	10.1	3.5	12.7	800	0.0	1.9	10978	52.4	142	8.5	8.4	3131	15.01	40.3	2.49	2.42	1103	5.31	14.17	0.895	0.86
0.7	stdev	0.6	17.6	2.7	0.6	3.4	0	0.0	1.5	1741	5.1	30	1.6	0.7	4.089	0.92	2.2	0.84	0.19	121	0.91	0.79	0.394	0.16
6.5%	COV	17.6%	26.6%	26.6%	15.7%	26.6%	0.0%	73.9%	78.6%	15.9%	9.7%	21.2%	18.5%	8.0%	0.1%	6.1%	5.5%	33.8%	7.8%	11.0%	17.2%	5.6%	44.0%	18.8%
1.0	low idle	2.4	37.1	5.6	2.5	7.1	800	0.1	2.2	8038	-3.3	81	3.8	6.1	3159	-1.30	31.7	1.49	2.40	1423	-0.58	14.26	0.669	1.08
1.0	low idle	2.6	42.3	6.4	2.8	8.1	800	0.0	0.0	8867	-3.1	87	1.5	5.2	3162	-1.12	30.9	0.53	1.84	1376	-0.49	13.44	0.229	0.80
0.5	low idle	2.8	49.8	7.6	3.0	9.6	799	0.0	0.0	9405	-4.8	93	1.7	5.4	3163	-1.61	31.3	0.58	1.82	1241	-0.63	12.28	0.228	0.71
0.5	low idle	3.0	55.1	8.4	3.1	10.5	801	0.0	0.1	9800	28.4	96	4.3	6.0	3143	9.12	30.9	1.39	1.93	1167	3.39	11.46	0.516	0.72
0.8	ave	2.7	46.1	7.0	2.9	8.8	800	0.0	0.6	9027	4.3	89	2.8	5.7	3157	1.27	31.2	0.99	2.00	1302	0.42	12.86	0.410	0.83
0.3	stdev	0.2	8.0	1.2	0.2	1.5	1	0.1	1.1	763	16.1	7	1.4	0.5	9.163	5.24	0.38	0.51	0.28	119	1.98	1.24	0.220	0.17
37.7%	COV	9.0%	17.3%	17.3%	8.6%	17.2%	0.1%	174.2%	185.9%	8.4%	374.1%	7.8%	50.9%	8.2%	0.3%	410.8%	1.2%	51.6%	13.8%	9.1%	469.9%	9.6%	53.5%	21.1%
0.5	high idle 1	8.0	102.7	30.6	8.3	9.9	1581	1.2	10.2	26193	-4.3	150	11.5	20.9	3158	-0.52	18.1	1.38	2.52	855	-0.14	4.91	0.375	0.68
0.5	high idle 1	7.9	90.0	27.6	9.1	8.8	1591	1.5	13.3	28703	-1.1	142	7.5	19.7	3160	-0.12	15.6	0.83	2.17	1042	-0.04	5.14	0.273	0.72
0.5	high idle 1	7.2	77.5	22.9	7.4	7.5	1551	0.4	3.1	23362	-2.4	152	10.6	21.7	3158	-0.33	20.5	1.43	2.94	1020	-0.107	6.64	0.461	0.95
0.5	ave	7.7	90.1	27.0	8.3	8.7	1574	1.0	8.9	26086	-2.6	148	9.9	20.8	3159	-0.32	18.1	1.21	2.54	972	-0.10	5.56	0.370	0.78
0.0	stdev	0.4	12.6	3.9	0.8	1.2	21	0.6	5.2	2672	1.6	6	2.1	1.0	0.805	0.20	2.5	0.33	0.38	102	0.05	0.94	0.094	0.15
0.0%	COV	5.7%	14.0%	14.4%	10.2%	14.2%	1.3%	58.9%	58.9%	10.2%	-60.8%	3.8%	21.0%	4.8%	0.0%	-60.9%	13.7%	27.6%	15.1%	10.5%	-52.9%	16.9%	25.5%	18.6%
2.7	high idle 2	3.4	51.9	9.9	6.9	6.0	1000	0.0	0.4	21552	135.7	108	1.2	9.2	3130	19.72	15.6	0.17	1.34	2182	13.74	10.89	0.117	0.94
4.1	high idle 2	3.4	51.2	9.8	6.9	5.9	1000	0.0	0.4	21710	73.6	107	0.8	67.1	3145	10.67	15.5	0.12	9.72	2225	7.55	10.96	0.087	6.88
2.3	high idle 2	3.4	52.1	9.9	6.9	6.0	1000	0.1	3.0	21627	23.7	108	0.7	17.2	3156	3.46	15.7	0.10	2.51	2182	2.395	10.87	0.072	1.74
3.0	ave	3.4	51.7	9.8	6.9	6.0	1000	0.0	1.3	21630	77.7	107	0.9	31.2	3144	11.28	15.6	0.13	4.52	2196	7.89	10.91	0.092	3.18
0.9	stdev	0.0	0.4	0.1	0.0	0.0	0	0.0	1.5	79	56.1	0	0.2	31.4	12.9	8.14	0.12	0.03	4.54	25	5.68	0.04	0.023	3.22
29.7%	COV	0.6%	0.8%	0.8%	0.4%	0.8%	0.0%	129.8%	116.4%	0.4%	72.2%	0.4%	24.6%	100.5%	0.4%	72.2%	0.8%	24.4%	100.3%	1.1%	72.0%	0.4%	24.5%	101.3%
1.7	Moving #1	15.1	198.9	67.6	15.4	20.8	1798	2.8	80.7	48206	138.2	154	40.2	17.9	3140	9.00	10.0	2.62	1.17	713	2.05	2.28	0.596	0.27
1.7	Moving #1	13.4	158.6	54.4	13.6	16.7	1802	4.0	110.2	42846	6.8	120	28.7	14.9	3155	0.50	8.8	2.12	1.09	788	0.13	2.20	0.528	0.27
3.4	Moving #1	16.5	214.1	73.3	16.0	22.5	1800	4.5	251.4	50381	5.1	110	24.5	13.3	3157	0.32	6.9	1.53	0.84	687	0.07	1.50	0.334	0.18
1.4	Moving #1	10.7	168.7	49.5	10.3	18.0	1534	1.6	35.1	32387	-0.6	130	14.2	11.1	3158	-0.06	12.6	1.38	1.08	654	-0.01	2.62	0.287	0.22
2.0	ave	13.9	185.0	61.2	13.8	19.5	1733	3.2	119.3	43455	37.4	128	26.9	14.3	3152	2.44	9.6	1.91	1.05	711	0.56	2.15	0.436	0.24
0.9	stdev	2.5	25.8	11.1	2.6	2.6	133	1.3	93.3	8030	67.3	19	10.8	2.9	8.461	4.38	2.4	0.57	0.14	57	0.99	0.47	0.149	0.04
44.8%	COV	18.0%	14.0%	18.2%	18.6%	13.5%	7.7%	40.5%	78.2%	18.5%	180.1%	14.7%	40.1%	20.0%	0.3%	179.5%	25.1%	29.7%	13.8%	8.0%	178.5%	21.9%	34.2%	17.8%
5.1	heavy push	37.5	704.7	219.8	35.9	68.9	1668	7.3	621.8	113384	14.8	325	9.4	36.3	3161	0.41	9.1	0.26	1.01	516	0.07	1.48	0.043	0.17
4.2	heavy push	37.3	716.1	222.7	36.4	69.9	1662	6.5	451.2	115050	11.6	347	6.3	32.3	3161	0.32	9.5	0.17	0.89	517	0.05	1.56	0.028	0.15
4.9	heavy push	36.9	675.7	216.2	35.1	67.8	1688	7.3	601.3	110962	9.9	357	6.2	34.4	3161	0.28	10.2	0.18	0.98	513	0.05	1.65	0.029	0.16
3.4	heavy push	36.9	706.2	220.0	35.7	69.0	1676	7.1	398.5	112815	9.3	365	6.0	34.6	3161	0.26	10.2	0.17	0.97	513	0.04	1.66	0.027	0.16
4.4	ave	37.1	700.6	219.7	35.8	68.9	1673	7.1	518.2	113053	11.4	348	7.0	34.4	3161	0.32	9.7	0.20	0.96	515	0.05	1.59	0.032	0.16
0.8	stdev	0.3	17.4	2.7	0.5	0.8	11	0.4	110.2	1686	2.5	17	1.6	1.6	0.242	0.07	0.56	0.04	0.05	2	0.01	0.09	0.007	0.01
18.3%	COV	0.9%	2.5%	1.2%	1.5%	1.2%	0.7%	5.7%	21.3%	1.5%	21.8%	5.0%	23.0%	4.8%	0.0%	21.2%	5.7%	22.7%	5.5%	0.4%	21.5%	5.4%	22.9%	5.4%
3.4	medium push	28.7	510.7	160.9	31.8	50.5	1655	5.8	325.2	100120	170.6	214	2.8	66.4	3153	5.37	6.7	0.09	2.09	622	1.06	1.33	0.017	0.41
3.4	medium push	26.9	470.8	149.6	25.6	46.9	1692	5.5	308.5	80861	8.7	205	11.3	27.3	3160	0.34	8.0	0.44	1.07	540	0.06	1.37	0.076	0.18
3.2	medium push	27.6	490.6	154.9	26.8	48.5	1689	5.7	307.1	84771	9.6	234	11.1	29.8	3160	0.36	8.7	0.41	1.11	547	0.06	1.51	0.072	0.19
8.4	medium push	24.2	399.4	127.5	22.9	40.0	1708	5.2	721.3	72414	4.5	200	10.5	25.3	3160	0.20	8.7	0.46	1.10	568	0.036	1.57	0.083	0.20
4.6	ave	26.9	467.8	148.2	26.8	46.5	1686	5.6	415.5	84542	48.3	213	9.0	37.2	3158	1.57	8.0	0.35	1.34	569	0.30	1.44	0.062	0.25
2.5	stdev	1.9	48.5	14.6	3.7	4.6	22	0.3	204.0	11595	81.5	15	4.1	19.5	3.438	2.54	0.93	0.18	0.50	37	0.50	0.11	0.030	0.11
55.3%	COV	7.2%	10.4%	9.8%	13.8%	9.8%	1.3%	5.1%	49.1%	13.7%	168.7%	7.2%	45.9%	52.6%	0.1%	162.1%	11.6%	50.1%	37.1%	6.5%	166.0%	7.8%	48.4%	45.0%
172.6	Overall	19.7	249.0	106.7	19.9	35.3	1466	3.7	10583.8	62902	45.4	201	9.7	38.0	3157	2.28	10.11	0.49	1.91	590	0.426	1.89	0.091	0.36

[1] ECM reported fuel rate

[2] Power estimated from published lug curve and % laod, see delailed work sheet

[3] Total PM using gravimetric span method and not the model alpha methods. Units of mg/hr or mg/kgfuel or mg/hp-h.

[4] Carbon balance fuel rate calculation using gaseous PEMS

This 2011 Tier 4i Caterpillar D7E bulldozer was owned and operated by Waste Management (WM). The testing location was in WM's old cell at the El Sorbrante landfill site near Corona, CA. The dozer was pushing trash from the dump site down to the cell. The PEMS equipment was the same as the last test with some major mounting improvements. DPF regeneration occurred towards the end of the test but no PM increase was observed. There was 2.9 hours of data collected.

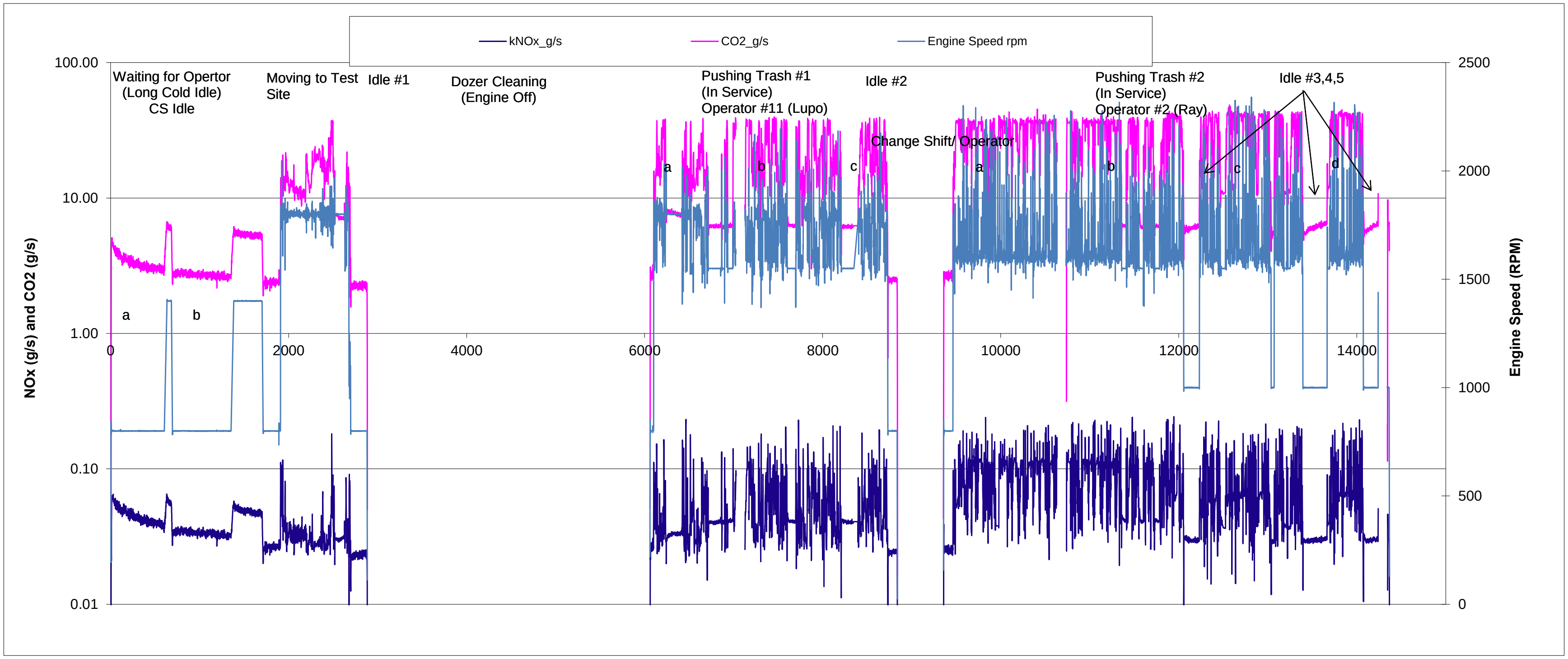


Figure 22: Modal emissions for 22_D7E_WM 2011 CAT tier 4i bulldozer

23_D8T_JM: 2012.12.06

Table 23: Integrated emissions for 23_D8T_JM 2012 CAT tier 4i bulldozer

Duration	Test Function	Fuel [1]	Power [2]	Torque	Fuel [4]	eLoad	eSpeed	Vel GPS	Dist[6]	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel) [4]					Brake Specific Emissions (g/hp-hr)				
Mins		kg/hr	bhp	ft-lb	kg/hr	%	RPM	km/h	m	CO_2	CO	NOx	THC	mg PM [3]	CO_2	CO	NOx	THC	mg PM [3]	CO_2	CO	NOx	THC	mg PM [3]
3.4	heavy push	42.2	249.5	638.2	45.5	84.9	2075	3.6	199.4	143760	-28.4	341	3.3	24.5	3163	-0.62	7.503	0.07	0.54	576	-0.11	1.37	0.013	0.10
3.4	heavy push	45.4	273.9	749.4	47.7	86.2	1933	6.9	386.7	150980	-21.7	385	1.8	56.0	3163	-0.46	8.062	0.04	1.17	551	-0.08	1.41	0.007	0.20
3.4	heavy push	40.2	236.6	606.6	42.8	81.2	2080	3.6	203.1	135258	-28.3	328	3.1	24.1	3163	-0.66	7.66	0.07	0.56	572	-0.12	1.38	0.013	0.10
3.4	heavy push	38.1	236.4	688.4	40.2	72.6	1821	6.0	337.1	127049	-22.6	317	2.4	65.1	3163	-0.56	7.886	0.06	1.62	537	-0.10	1.34	0.010	0.28
3.4	heavy push	42.7	264.6	738.7	44.5	83.9	1912	5.5	308.4	140688	-22.5	364	1.5	59.2	3163	-0.51	8.188	0.03	1.33	532	-0.09	1.38	0.006	0.22
3.4	heavy push	39.0	221.7	566.7	41.5	76.4	2092	3.5	196.7	131339	-29.0	312	2.9	25.7	3163	-0.70	7.523	0.07	0.62	592	-0.13	1.41	0.013	0.12
3.4	ave	41.3	247.1	664.7	43.7	80.8	1986	4.9	271.9	138179	-25.4	341	2.5	42.4	3163	-0.58	7.804	0.06	0.97	560	-0.10	1.38	0.010	0.17
0.0	stdev	2.7	19.5	73.3	2.8	5.3	112.8	1.5	83.0	8724	3.5	28	0.7	19.6	0.099	0.09	0.287	0.02	0.46	24	0.02	0.03	0.003	0.07
0.0	COV	6.5%	7.9%	11.0%	6.3%	6.6%	5.7%	30.5%	30.5%	6.3%	-13.6%	8.3%	28.8%	46.1%	0.0%	-16.0%	3.7%	30.3%	47.5%	4.2%	-19.6%	1.9%	33.1%	44.0%
3.4	medium push	39.0	214.9	564.1	42.7	71.2	2036	3.6	201.2	134912	-28.9	330	2.9	22.8	3163	-0.68	7.741	0.07	0.53	628	-0.13	1.54	0.014	0.11
3.4	medium push	28.8	158.2	455.3	30.3	53.1	1826	5.6	311.9	95826	-23.9	258	5.4	33.6	3163	-0.79	8.499	0.18	1.11	606	-0.15	1.63	0.034	0.21
3.4	medium push	37.5	203.3	530.1	40.1	68.0	2063	3.8	209.6	126837	-30.6	302	3.2	24.5	3163	-0.76	7.54	0.08	0.61	624	-0.15	1.49	0.016	0.12
3.4	medium push	38.7	213.7	565.2	41.5	69.8	2019	3.8	214.6	131295	-28.3	313	2.5	22.6	3163	-0.68	7.543	0.06	0.55	614	-0.13	1.47	0.012	0.11
3.4	medium push	36.8	217.6	619.0	38.4	68.4	1829	5.7	317.1	121513	-23.0	330	4.4	80.3	3163	-0.60	8.589	0.11	2.09	558	-0.11	1.52	0.020	0.37
3.4	medium push	36.4	219.6	601.8	38.5	72.2	1922	6.1	340.4	121882	-24.3	331	1.4	42.2	3163	-0.63	8.584	0.04	1.10	555	-0.11	1.51	0.007	0.19
3.4	ave	36.2	204.6	555.9	38.6	67.1	1949	4.8	265.8	122044	-26.5	311	3.3	37.7	3163	-0.69	8.083	0.09	1.00	598	-0.13	1.52	0.017	0.18
0.0	stdev	3.8	23.4	58.4	4.4	7.0	105.6	1.1	63.7	13870	3.2	29	1.4	22.2	0.14	0.07	0.526	0.05	0.60	33	0.02	0.06	0.010	0.10
0.0%	COV	10.4%	11.4%	10.5%	11.4%	10.5%	5.4%	24.0%	24.0%	11.4%	-11.9%	9.2%	42.5%	59.0%	0.0%	-10.7%	6.5%	56.2%	59.8%	5.5%	-14.7%	3.7%	56.4%	54.9%
3.4	cold low idle	3.2	3.2	24.2	4.0	8.2	700	0.0	1	12602	6.2	144	8.3	4.4	3153	1.56	36.12	2.07	1.10	3908	1.93	44.77	2.562	1.37
3.4	cold low idle	3.2	3.3	25.1	4.0	8.1	700	0.0	2	12542	10.8	144	8.7	3.9	3151	2.72	36.23	2.17	0.98	3757	3.24	43.21	2.593	1.16
3.4	cold low idle	3.2	3.3	24.4	4.0	8.0	700	0.1	5	12453	15.9	143	9.7	4.2	3148	4.02	36.16	2.46	1.07	3829	4.89	43.99	2.994	1.30
2.9	cold low idle	5.6	11.4	60.0	13.9	5.7	1000	0.0	0	44001	-14.2	173	14.7	4.5	3160	-1.02	12.41	1.06	0.32	3850	-1.25	15.12	1.290	0.39
3.2	ave	3.8	5.3	33.4	6.5	7.5	775	0.0	2.1	20400	4.7	151	10.4	4.3	3153	1.82	30.23	1.94	0.87	3836	2.21	36.77	2.360	1.06
0.2	stdev	1.2	4.1	17.7	5.0	1.2	150.0	0.0	2.2	15734	13.2	14	3.0	0.3	5.26	2.15	11.88	0.61	0.37	62	2.60	14.45	0.740	0.45
7.5%	COV	32.3%	76.8%	53.1%	76.9%	15.9%	19.4%	101.9%	101.9%	77.1%	282.5%	9.6%	28.9%	6.2%	0.2%	117.9%	39.3%	31.5%	42.4%	1.6%	117.9%	39.3%	31.3%	42.7%
0.4	high idle	5.0	8.0	42.0	5.4	4.0	1001	0.2	1	16975	-9.6	47	1.9	7.4	3164	-1.79	8.77	0.36	1.38	2120	-1.20	5.88	0.239	0.93
0.4	high idle	4.7	7.0	36.6	5.9	3.4	1027	0.3	2	18541	-10.2	75	1.2	5.5	3164	-1.74	12.82	0.20	0.94	2636	-1.45	10.68	0.166	0.78
0.5	high idle	4.9	7.3	38.3	4.9	3.6	1001	0.2	2	15634	-8.2	70	1.5	17.1	3164	-1.67	14.16	0.30	3.46	2140	-1.13	9.58	0.202	2.34
2.0	high idle	5.8	11.9	62.6	10.6	6.0	1000	0.1	2	33496	-12.6	154	2.6	16.1	3163	-1.19	14.57	0.24	1.52	2810	-1.06	12.94	0.215	1.35
0.8	ave	5.1	8.6	44.9	6.7	4.3	1007	0.2	1.8	21162	-10.2	87	1.8	11.5	3164	-1.60	12.58	0.27	1.83	2426	-1.21	9.77	0.206	1.35
0.8	stdev	0.5	2.3	12.0	2.6	1.2	13.2	0.1	0.3	8308	1.8	47	0.6	5.9	0.407	0.27	2.647	0.07	1.12	350	0.17	2.95	0.030	0.71
96.4%	COV	9.5%	26.5%	26.8%	39.3%	27.2%	1.3%	45.9%	16.7%	39.3%	-18.1%	54.0%	34.1%	51.4%	0.0%	-17.2%	21.0%	24.8%	61.4%	14.4%	-14.0%	30.2%	14.8%	52.2%
2.2	low idle	3.0	2.8	20.8	3.5	7.0	700	0.0	0	11180	-7.1	99	0.8	7.6	3164	-2.02	28	0.22	2.14	4026	-2.57	35.63	0.279	2.73
1.0	low idle	3.3	3.2	22.8	3.7	7.7	719	0.1	1	11687	-6.0	86	0.7	9.8	3164	-1.61	23.16	0.18	2.66	3676	-1.87	26.90	0.204	3.09
1.7	low idle	3.3	3.5	25.9	3.6	8.9	700	0.1	1	11254	-6.8	99	1.2	13.7	3164	-1.92	27.82	0.35	3.86	3255	-1.98	28.62	0.357	3.97
3.4	low idle	3.5	4.2	31.4	3.6	10.6	700	0.0	1	11526	-6.3	106	0.3	19.6	3164	-1.73	29.14	0.09	5.39	2752	-1.50	25.34	0.074	4.69
2.1	ave	3.3	3.4	25.3	3.6	8.5	705	0.0	1.0	11412	-6.6	97	0.7	12.7	3164	-1.82	27.03	0.21	3.51	3427	-1.98	29.12	0.229	3.62
1.0	stdev	0.2	0.6	4.6	0.1	1.6	9.7	0.0	0.7	236	0.5	9	0.4	5.3	0.295	0.18	2.645	0.11	1.44	549	0.44	4.54	0.120	0.89
47.8%	COV	6.8%	17.5%	18.3%	2.1%	18.2%	1.4%	80.3%	68.9%	2.1%	-8.1%	8.8%	51.4%	41.7%	0.0%	-10.1%	9.8%	52.5%	41.1%	16.0%	-22.4%	15.6%	52.6%	24.5%
325.7	Overall	20.9	104.0	279.8	23.4	39.4	1548	2.6	14303	74074	-15.6	222	6.0	731.5	3162	-0.67	9.492	0.26	31.23	712	-0.15	2.14	0.058	7.03

[1] ECM reported fuel rate

[2] Power estimated from published lug curve and % laod, see delailed work sheet

[3] Total PM using gravimetric span method and not the model alpha methods. Units of mg/hr or mg/kgfuel or mg/hp-h.

[4] Carbon balance fuel rate calculation using gaseous PEMS

[5] The load is a count of full buckets (3 yards 3in minus rock) added to the dumpster

[6] Distance in meters = {((km/hr)*1000)/3600 sec/hr]*Duration (sec). Only applicable to test function bin 0.5 and bin 2 because others involve forward and backward travel.

This 2012 Tier 4i Caterpillar D8T bulldozer was a rental unit owned by Johnson Machinery in Riverside, CA. The test site was at WM's El Sorbrante landfill site near Corona, CA. The dozer was pushing rock piles for different designated distances in the bottom of the new cell. Later in the day the dozer was doing travel and pull test over predetermined distances for the AQIP project. DPF regeneration occurred during the test. There was 5.5 hours of data collected.

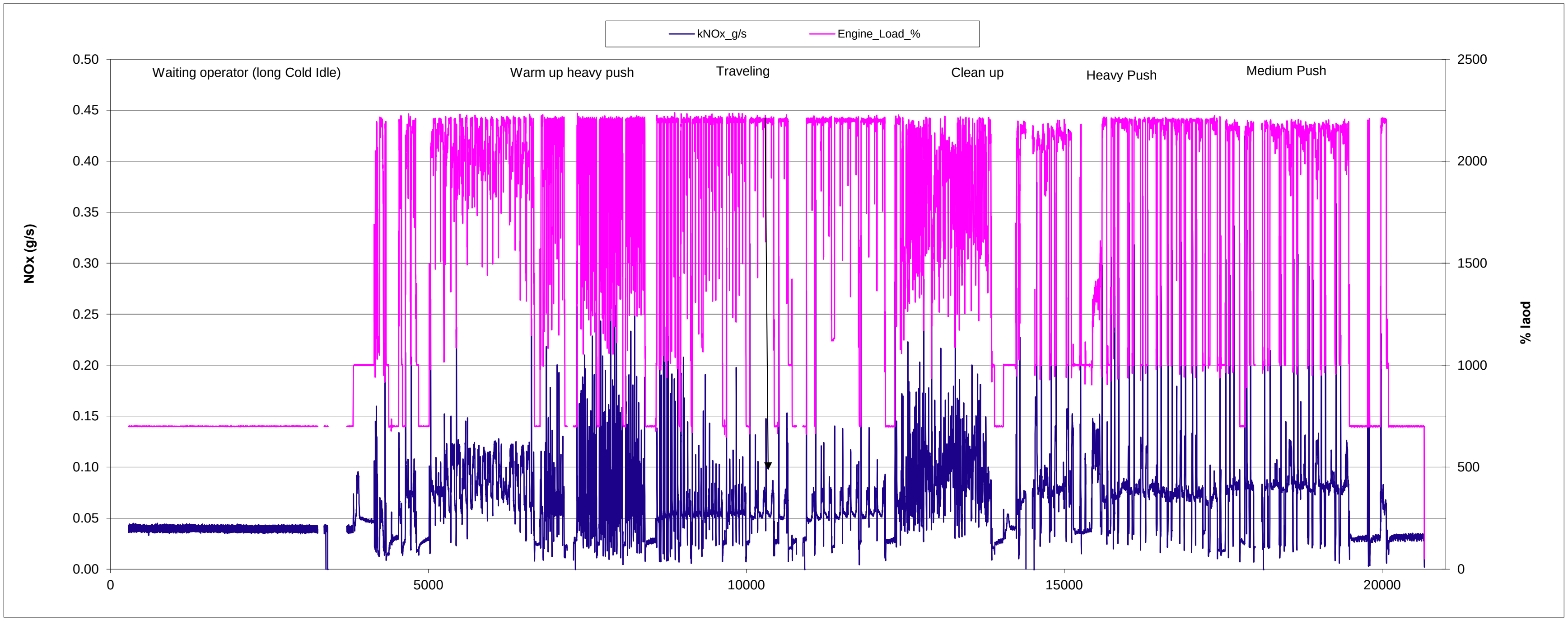


Figure 23: Modal emissions for 23_D8T_JM 2012 CAT tier 4i bulldozer

24_D6T_OC: 2012.12.11

This 2012 Tier 4i Caterpillar D6T bulldozer was a rental unit owned by Johnson Machinery in Riverside, CA. The test site was at Orange County Water District's levee on the Santa Ana River near Anaheim, CA. The dozer is operated by Orange County's operator. The worked started with cleaning the slope of the levee, and then excavate dirt out of 50'x50' area for the AQIP project for various depths. The PEMS equipment was the same as the last tests, and there was 4.4 hours of valid data collected.

Table 24: Integrated emissions for 24_D6T_OC 2012 CAT tier 4i bulldozer

Duration	Test Function	Fuel [6]	Power [2]	Torque	Fuel [4]	eLoad	eSpeed	Vel GPS	Dist	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel) [4]					Brake Specific Emissions (g/hp-hr)				
Mins		kg/hr	bhp	ft-lb	kg/hr	%	RPM	km/h	m	CO2	CO	NOx	THC	mg PM [3]	CO2	CO	NOx	THC	mg PM [3]	CO2	CO	NOx	THC	mg PM [3]
5.5	bld slope	26.5	153.9	429.1	27.1	65.5	1887	3.8	346.8	85616	-17.6	160	2.8	25.9	3163	-0.65	5.894	0.10	0.96	556	-0.11	1.04	0.018	0.17
5.9	bld slope	25.4	145.0	406.9	25.8	61.8	1881	3.8	374.2	81574	-18.7	155	2.7	26.3	3163	-0.72	6.016	0.10	1.02	563	-0.13	1.07	0.019	0.18
5.0	bld slope	25.9	146.6	406.0	26.0	62.7	1906	3.8	314.6	82117	-20.4	152	2.8	26.8	3163	-0.78	5.867	0.11	1.03	560	-0.14	1.04	0.019	0.18
5.5	bld slope	25.6	146.2	407.4	25.8	62.2	1904	3.9	359.4	81619	-17.1	156	2.7	31.8	3163	-0.66	6.047	0.10	1.23	558	-0.12	1.07	0.018	0.22
5.5	ave	25.8	147.9	412.4	26.2	63.0	1895	3.8	348.7	82731	-18.4	156	2.7	27.7	3163	-0.70	5.956	0.10	1.06	559	-0.12	1.05	0.019	0.19
0.4	stdev	0.5	4.0	11.2	0.6	1.7	12.9	0.1	25.4	1939	1.5	3	0.1	2.7	0.092	0.06	0.089	0.00	0.12	3	0.01	0.02	0.000	0.02
6.7%	COV	1.9%	2.7%	2.7%	2.3%	2.7%	0.7%	1.8%	7.3%	2.3%	-7.9%	1.9%	2.2%	9.9%	0.0%	-8.9%	1.5%	2.1%	11.2%	0.5%	-9.2%	1.7%	2.3%	11.2%
8.1	heavy push	26.0	149.9	422.5	25.5	64.0	1838	3.6	484.1	80574	-15.7	159	2.4	33.8	3163	-0.62	6.234	0.10	1.33	537	-0.10	1.06	0.016	0.23
9.1	heavy push	27.2	157.7	440.8	27.0	67.2	1865	3.5	528.6	85422	-19.3	155	3.0	35.1	3163	-0.72	5.741	0.11	1.30	542	-0.12	0.98	0.019	0.22
10.1	heavy push	27.3	156.3	428.6	26.8	67.0	1912	3.7	615.4	84757	-21.9	154	2.4	34.1	3163	-0.82	5.739	0.09	1.27	542	-0.14	0.98	0.015	0.22
8.0	heavy push	28.4	165.6	459.0	27.7	70.7	1890	3.3	447.2	87647	-15.9	159	2.0	34.2	3163	-0.57	5.741	0.07	1.23	529	-0.10	0.96	0.012	0.21
8.8	ave	27.2	157.4	437.7	26.7	67.2	1876	3.5	518.8	84600	-18.2	157	2.5	34.3	3163	-0.68	5.864	0.09	1.28	538	-0.12	1.00	0.016	0.22
1.0	stdev	1.0	6.4	16.1	0.9	2.7	32.0	0.1	72.5	2955	3.0	3	0.4	0.6	0.159	0.11	0.247	0.02	0.04	6	0.02	0.04	0.003	0.01
10.9%	COV	3.6%	4.1%	3.7%	3.5%	4.1%	1.7%	3.8%	14.0%	3.5%	-16.4%	1.7%	15.6%	1.7%	0.0%	-16.0%	4.2%	16.4%	3.1%	1.1%	-17.0%	4.3%	17.2%	3.8%
9.1	medium push	24.7	137.8	364.0	24.6	60.0	1985	4.0	600.8	77745	-21.9	133	10.7	32.3	3162	-0.89	5.408	0.43	1.31	564	-0.16	0.97	0.077	0.23
7.0	medium push	25.2	140.8	372.5	25.0	61.2	1984	3.8	445.8	79030	-22.5	135	3.4	33.8	3163	-0.90	5.416	0.14	1.35	561	-0.16	0.96	0.024	0.24
7.1	medium push	24.7	139.1	368.3	24.7	60.5	1976	4.1	481.9	78008	-23.1	135	3.1	32.1	3163	-0.94	5.468	0.12	1.30	561	-0.17	0.97	0.022	0.23
7.3	medium push	25.4	142.5	378.1	25.3	61.9	1982	4.1	500.5	80067	-19.1	140	3.1	33.1	3163	-0.75	5.527	0.12	1.31	562	-0.13	0.98	0.022	0.23
7.6	ave	25.0	140.0	370.7	24.9	60.9	1982	4.0	507.3	78713	-21.7	136	5.1	32.8	3163	-0.87	5.455	0.20	1.32	562	-0.15	0.97	0.036	0.23
1.0	stdev	0.4	2.1	6.0	0.3	0.8	4.2	0.1	66.3	1059	1.8	3	3.7	0.8	0.476	0.08	0.055	0.15	0.02	2	0.01	0.01	0.027	0.00
13.3%	COV	1.4%	1.5%	1.6%	1.3%	1.4%	0.2%	3.2%	13.1%	1.3%	-8.2%	2.2%	74.1%	2.4%	0.0%	-9.2%	1.0%	75.2%	1.8%	0.3%	-9.2%	0.9%	75.6%	1.7%
4.2	low idle	2.9	5.0	32.7	3.1	8.1	800	0.0	1.7	9835	18.0	106	4.4	3.5	3148	5.77	34.0	1.42	1.12	1973	3.62	21.3	0.888	0.70
4.2	low idle	2.8	4.7	30.8	3.1	7.6	800	0.0	0.0	9800	-7.9	99	1.6	6.5	3164	-2.54	32.1	0.50	2.08	2090	-1.68	21.2	0.331	1.38
8.4	low idle	2.8	4.6	30.5	2.9	7.5	800	0.1	11.8	9216	-7.5	93	1.9	5.4	3164	-2.57	32.1	0.67	1.86	1983	-1.61	20.1	0.419	1.17
8.4	low idle	2.8	4.7	30.9	3.0	7.6	800	0.0	1.8	9341	3.6	95	6.9	5.2	3153	1.20	32.0	2.33	1.77	1988	0.76	20.2	1.472	1.11
6.3	ave	2.8	4.8	31.2	3.0	7.7	800	0.0	3.8	9548	1.6	98	3.7	5.2	3157	0.47	32.55	1.23	1.71	2008	0.27	20.7	0.777	1.09
2.4	stdev	0.1	0.2	1.0	0.1	0.3	0.2	0.0	5.4	316	12.2	6	2.5	1.2	8.024	3.96	1	0.84	0.41	55	2.50	0.66	0.524	0.28
38.3%	COV	1.9%	3.3%	3.3%	3.4%	3.3%	0.0%	122.8%	140.2%	3.3%	783.4%	5.9%	67.0%	23.8%	0.3%	851.1%	3.1%	68.0%	24.2%	2.7%	923.1%	3.2%	67.3%	25.9%
3.4	moving	18.2	88.9	242.3	18.6	38.8	1922	3.9	215.9	58780	-20.5	112	3.1	27.8	3163	-1.11	6.034	0.16	1.50	661	-0.23	1.26	0.034	0.31
3.4	moving	22.1	121.5	336.2	24.0	52.7	1895	5.2	290.1	75813	-14.5	149	3.0	36.0	3163	-0.61	6.222	0.13	1.50	624	-0.12	1.23	0.025	0.30
3.4	moving	20.0	99.8	260.9	20.0	43.6	2010	6.7	375.3	63355	-22.9	117	3.3	29.2	3163	-1.14	5.818	0.16	1.46	635	-0.23	1.17	0.033	0.29
3.4	moving	21.7	113.3	306.4	21.8	48.9	1962	6.3	352.9	68861	-20.8	126	3.4	32.5	3163	-0.95	5.803	0.16	1.49	608	-0.18	1.11	0.030	0.29
3.4	ave	20.5	105.9	286.4	21.1	46.0	1947	5.5	308.5	66702	-19.7	126	3.2	31.4	3163	-0.95	5.969	0.15	1.49	632	-0.19	1.19	0.031	0.30
0.0	stdev	1.8	14.4	42.7	2.3	6.0	50.2	1.3	71.6	7340	3.6	17	0.2	3.7	0.327	0.24	0.199	0.02	0.02	22	0.05	0.06	0.004	0.01
0.0%	COV	8.6%	13.6%	14.9%	11.0%	13.1%	2.6%	23.2%	23.2%	11.0%	-18.2%	13.1%	6.2%	11.7%	0.0%	-25.7%	3.3%	12.2%	1.3%	3.5%	-27.4%	5.4%	13.9%	3.7%
265	Overall	14.2	74.5	217.4	14.2	34.5	1370	2.1	9232.2	45044	-10.5	121	3.3	19.6	3162	-0.74	8.479	0.23	1.37	605	-0.14	1.62	0.044	0.26

[2] Power estimated from published lug curve and % laod, see delailed work sheet

[3] Total PM using gravimetric span method and not the model alpha methods. Units of mg/hr or mg/kgfuel or mg/hp-h.

[4] Carbon balance fuel rate calculation using gaseous PEMS

[5] The load is a count of full buckets (3 yards 3in minus rock) added to the dumpster

[6] ECM reported fuel rate

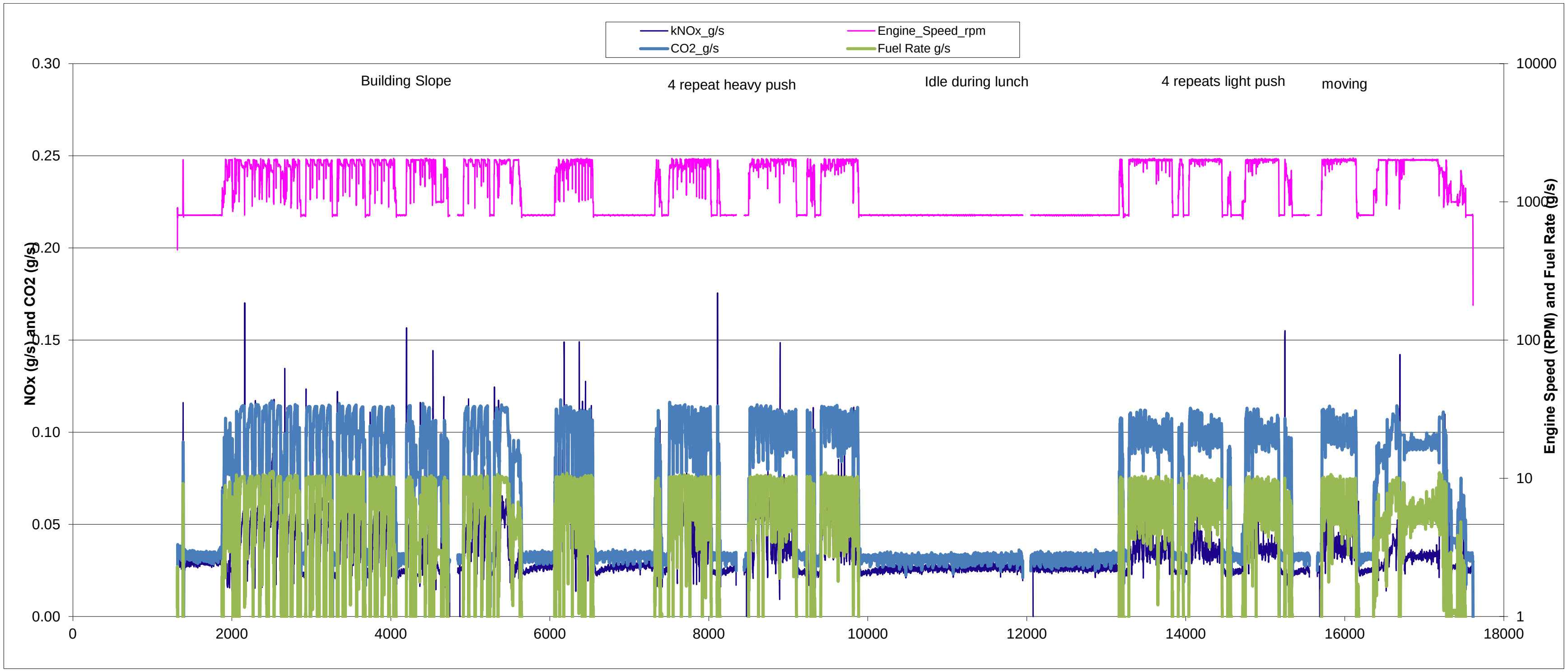


Figure 24: Modal emissions for 24_D6T_OC 2012 CAT tier 4i bulldozer

25_D7E_OC: 2012.12.12

This 2011 Tier 4i Caterpillar D7E bulldozer was owned by Orange County Water District. The test site was at Orange County Water District's levee on the Santa Ana River near Anaheim, CA. The dozer is operated by Orange County's operator. The worked started with cleaning the slope of the levee, and then excavate dirt out of 50'x50' area for the AQIP project for various depths. The PEMS equipment was the same as the last tests. One hour of PEMS data was lost due to compute issue, and there was 2.5 hours of valid data collected.

Table 25: Integrated emissions for 25_D7E_OC 2011 CAT tier 4i bulldozer

Duration	Test Function	Fuel [6]	Power [2]	Torque	Fuel [4]	eLoad	eSpeed	Vel GPS	Dist	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel) [4]					Brake Specific Emissions (g/hp-hr)				
Mins		kg/hr	bhp	ft-lb	kg/hr	%	RPM	km/h	m	CO2	CO	NOx	THC	mg PM [3]	CO2	CO	NOx	THC	mg PM [3]	CO2	CO	NOx	THC	mg PM [3]
4.8	bld slope	24.2	136.1	429.0	21.9	42.7	1738	4.3	341.8	69332	-6.0	163	3.8	0.2	3162	-0.27	7.45	0.17	0.01	509	-0.04	1.20	0.028	0.00
4.4	bld slope	25.3	142.9	449.7	22.9	44.7	1762	4.3	311.2	72257	-6.5	165	3.1	2.2	3162	-0.29	7.213	0.14	0.09	506	-0.05	1.15	0.022	0.02
4.3	bld slope	25.9	145.7	462.1	23.1	45.6	1757	4.3	307.5	73020	-6.9	172	3.4	2.0	3162	-0.30	7.427	0.15	0.09	501	-0.05	1.18	0.024	0.01
4.2	bld slope	25.8	148.1	469.8	23.3	46.4	1757	4.3	297.7	73722	-6.7	178	2.8	2.3	3162	-0.29	7.643	0.12	0.10	498	-0.05	1.20	0.019	0.02
4.4	ave	25.3	143.2	452.6	22.8	44.8	1754	4.3	314.5	72083	-6.5	169	3.3	1.7	3162	-0.29	7.433	0.14	0.07	503	-0.05	1.18	0.023	0.01
0.3	stdev	0.8	5.2	17.8	0.6	1.6	10.4	0.0	19.0	1929	0.4	7	0.4	1.0	0.077	0.01	0.176	0.02	0.04	5	0.00	0.02	0.004	0.01
6.3%	COV	3.2%	3.6%	3.9%	2.7%	3.6%	0.6%	0.5%	6.0%	2.7%	-5.9%	4.0%	12.6%	59.7%	0.0%	-3.6%	2.4%	15.0%	59.3%	1.0%	-3.0%	2.0%	15.8%	59.2%
5.2	heavy push	27.8	156.4	496.7	25.4	49.1	1652	3.8	330.5	80161	-7.9	226	4.2	3.7	3162	-0.31	8.918	0.17	0.15	512	-0.05	1.45	0.027	0.02
6.2	heavy push	26.3	144.0	453.2	23.6	45.2	1663	4.0	419.2	74574	-11.6	212	2.4	8.0	3162	-0.49	9.005	0.10	0.34	518	-0.08	1.47	0.017	0.06
6.3	heavy push	27.3	152.5	482.3	24.5	47.9	1661	3.6	379.9	77472	-10.0	214	2.3	13.6	3162	-0.41	8.731	0.09	0.56	508	-0.07	1.40	0.015	0.09
5.7	heavy push	28.1	159.0	503.6	25.6	49.9	1652	3.6	346.4	81004	-9.8	229	1.9	15.2	3162	-0.38	8.935	0.08	0.59	509	-0.06	1.44	0.012	0.10
5.9	ave	27.4	153.0	484.0	24.8	48.0	1657	3.8	369.0	78303	-9.8	220	2.7	10.1	3162	-0.40	8.897	0.11	0.41	512	-0.06	1.44	0.018	0.07
0.5	stdev	0.7	6.6	22.3	0.9	2.1	5.7	0.2	39.3	2907	1.5	8	1.0	5.3	0.212	0.07	0.117	0.04	0.21	4	0.01	0.03	0.006	0.03
8.6%	COV	2.7%	4.3%	4.6%	3.7%	4.3%	0.3%	5.2%	10.6%	3.7%	-15.1%	3.8%	37.3%	52.2%	0.0%	-18.4%	1.3%	35.8%	51.0%	0.9%	-18.9%	2.1%	36.0%	50.5%
5.3	medium push	22.9	122.2	387.0	19.2	39.0	1654	4.1	363.2	60814	-11.1	172	2.2	14.5	3163	-0.58	8.94	0.11	0.76	498	-0.09	1.41	0.018	0.12
0.7	high idle	6.9	21.5	72.7	5.6	7.0	1550	0.0	0.4	17685	-13.7	144	4.4	6.1	3163	-2.45	25.8	0.79	1.10	824	-0.64	6.7	0.206	0.29
0.2	high idle	6.8	21.0	71.2	5.6	6.9	1550	0.0	0.0	17871	-10.8	142	2.6	5.5	3164	-1.91	25.1	0.46	0.97	850	-0.51	6.8	0.122	0.26
0.5	ave	6.9	21.2	72.0	5.6	6.9	1550	0.0	0.2	17778	-12.2	143	3.5	5.8	3163	-2.18	25.49	0.62	1.03	837	-0.57	6.7	0.164	0.27
0.3	stdev	0.1	0.3	1.0	0.0	0.1	0.4	0.0	0.3	131	2.0	2	1.3	0.5	0.145	0.38	0.504	0.24	0.09	18	0.09	0.01	0.059	0.02
69.4%	COV	1.2%	1.4%	1.4%	0.7%	1.5%	0.0%	141.4%	141.4%	0.7%	-16.8%	1.2%	37.3%	8.2%	0.0%	-17.5%	2.0%	38.0%	8.9%	2.2%	-15.4%	0.2%	36.0%	6.8%
1.5	low idle	2.8	7.6	50.0	2.3	9.6	800	0.2	6.0	7255	-4.3	87	0.9	2.2	3164	-1.88	37.8	0.40	0.96	952	-0.57	11.4	0.119	0.29
1.6	low idle	2.4	5.5	36.4	2.0	7.0	800	0.0	0.4	6294	-4.2	81	0.6	3.5	3164	-2.09	40.7	0.30	1.77	1136	-0.75	14.6	0.108	0.64
2.0	low idle	2.3	5.3	35.0	1.9	6.7	800	0.0	0.0	6149	-4.4	81	0.5	4.3	3165	-2.27	41.7	0.27	2.19	1155	-0.83	15.2	0.099	0.80
2.0	low idle	2.5	6.3	41.6	2.1	8.0	800	0.0	0.4	6639	-5.1	83	1.0	3.9	3164	-2.43	39.7	0.47	1.86	1049	-0.81	13.2	0.157	0.61
3.3	low idle	2.6	6.3	41.7	2.2	8.0	800	0.0	0.6	6955	-5.1	84	0.5	8.4	3165	-2.32	38.3	0.21	3.81	1095	-0.80	13.2	0.071	1.32
5.0	low idle	2.5	6.3	41.6	2.2	8.0	800	0.0	0.4	6904	-5.4	86	0.4	7.3	3165	-2.49	39.4	0.19	3.36	1090	-0.86	13.6	0.066	1.16
1.7	low idle	2.5	6.2	40.5	2.6	7.8	800	0.0	0.0	8339	-6.3	84	1.3	5.7	3164	-2.41	32.0	0.48	2.16	1353	-1.03	13.7	0.205	0.92
2.4	ave	2.5	6.2	40.9	2.2	7.9	800	0.0	1.1	6933	-5.0	84	0.7	5.0	3165	-2.27	38.5	0.33	2.30	1119	-0.81	13.5	0.118	0.82
1.3	stdev	0.2	0.7	4.8	0.2	0.9	0.1	0.1	2.2	729	0.8	2	0.3	2.2	0.53	0.22	3.188	0.12	0.98	123	0.14	1.22	0.049	0.35
53.1%	COV	6.4%	11.8%	11.8%	10.5%	11.9%	0.0%	217.4%	193.9%	10.5%	-15.4%	2.6%	43.4%	43.7%	0.0%	-9.6%	8.3%	36.1%	42.4%	11.0%	-17.1%	9.0%	41.5%	42.6%
11.4	moving	22.2	111.4	326.3	19.1	34.2	1793	5.3	1006.5	60356	-3.5	178	8.2	73.3	3161	-0.18	9.3	0.43	3.84	542	-0.03	1.6	0.074	0.66
12.6	moving	18.4	87.6	259.1	16.1	27.0	1777	4.3	896.0	50964	-11.4	107	3.3	1.7	3162	-0.71	6.7	0.21	0.11	582	-0.13	1.2	0.038	0.02
16.2	moving	15.3	67.0	196.2	14.4	20.6	1796	5.5	1475.1	45672	-15.2	110	4.6	8.2	3163	-1.05	7.6	0.32	0.57	681	-0.23	1.6	0.069	0.12
10.2	ave	18.6	88.7	260.5	16.6	27.3	1789	5.0	1125.9	52331	-10.0	132	5.4	27.7	3162	-0.65	7.872	0.32	1.50	602	-0.13	1.5	0.060	0.27
6.7	stdev	3.4	22.2	65.1	2.4	6.8	10.3	0.7	307.5	7437	6.0	40	2.6	39.6	0.944	0.44	1.35	0.11	2.04	72	0.10	0.23	0.020	0.34
66.2%	COV	18.4%	25.0%	25.0%	14.2%	25.0%	0.6%	13.0%	27.3%	14.2%	-59.7%	30.3%	47.3%	142.7%	0.0%	-67.8%	17.2%	35.3%	135.3%	11.9%	-75.6%	15.5%	32.4%	128.6%
135.9	Overall Ave	16.2	82.2	260.8	14.4	27.6	1466	3.1	6952.8	45632	-7.1	140	3.1	14.5	3162	-0.49	9.717	0.21	1.01	555	-0.09	1.70	0.038	0.18

[2] Power estimated from published lug curve and % laod, see delailed work sheet

[3] Total PM using gravimetric span method and not the model alpha methods. Units of mg/hr or mg/kgfuel or mg/hp-h.

[4] Carbon balance fuel rate calculation using gaseous PEMS

[6] ECM reported fuel rate

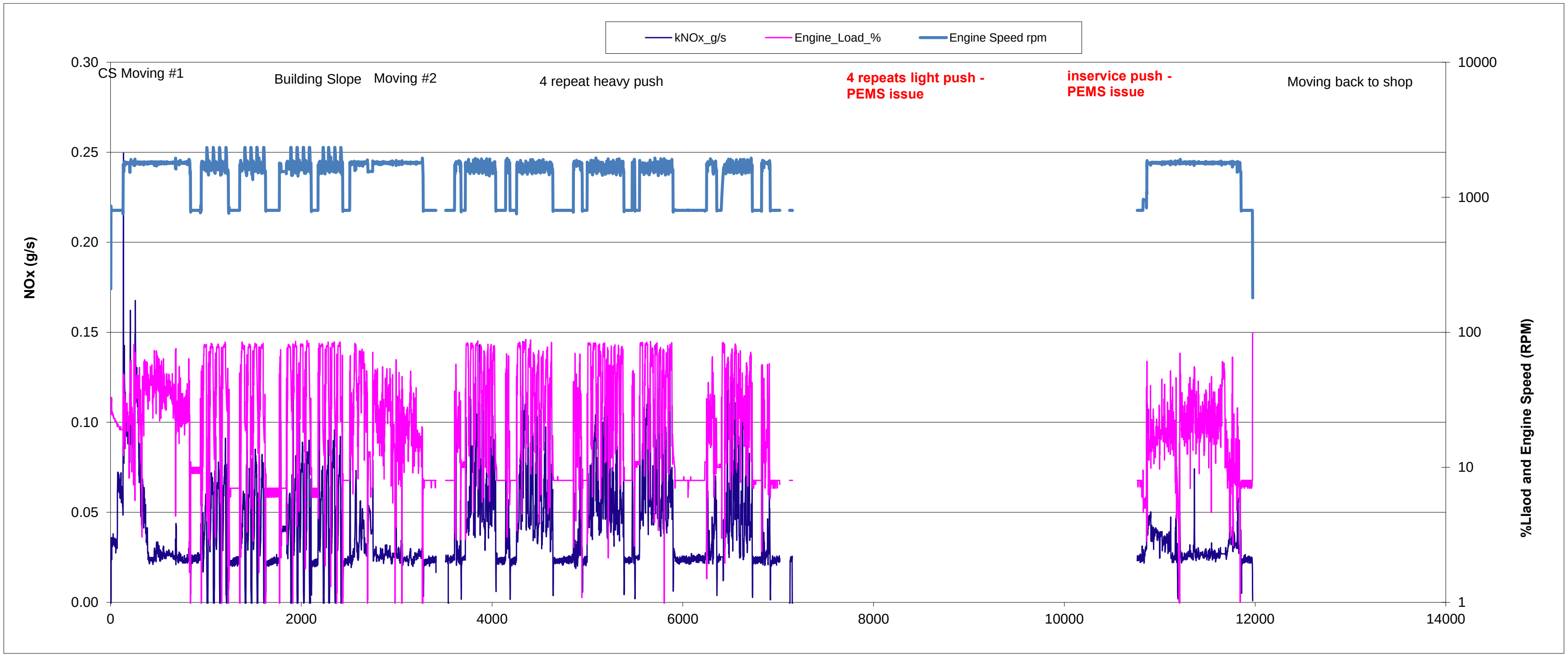


Figure 25: Modal emissions for 25_D7E_OC 2011 CAT tier 4i bulldozer

26_PC200: 2012.03.01 Table 26: Integrated emissions for 26_PC200 2007 Komatsu tier 3 excavator

Duration	Test Function	Fuel [6]	Power [2]	Torque	Fuel [4]	eLoad	eSpeed	Vel GPS	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel) [4]					Brake Specific Emissions (g/hp-hr)				
Mins		kg/hr	bhp	ft-lb	kg/hr	%	RPM	km/h	CO2	CO	NOx	THC	mg PM [3]	CO2	CO	NOx	THC	mg PM [3]	CO2	CO	NOx	THC	mg PM [3]
15.3	Travel #1	17.5	82.5	210.5	16.7	60.1	2058	2.8	52747	84.0	196	18.6	13052	3151	5.02	11.72	1.11	779.63	640	1.02	2.38	0.226	158.30
13.8	Travel #2	18.5	85.8	218.9	17.6	62.7	2058	3.0	55437	91.8	218	16.9	16060	3151	5.22	12.39	0.96	912.79	646	1.07	2.54	0.197	187.16
12.9	Travel #3	18.8	88.2	225.2	18.0	64.5	2057	3.1	56663	93.0	228	16.8	15558	3151	5.17	12.66	0.94	865.15	642	1.05	2.58	0.191	176.30
14.0	ave	18.3	85.5	218.2	17.4	62.5	2058	2.9	54949	89.6	214	17.4	14890	3151	5.13	12.26	1.00	852.52	643	1.05	2.50	0.204	173.92
1.2	stdev	0.7	2.9	7.4	0.6	2.2	0.5	0.2	2003	4.9	16	1.0	1611	0.16	0.11	0.482	0.10	67.47	3	0.03	0.11	0.019	14.58
8.8%	COV	3.7%	3.4%	3.4%	3.6%	3.5%	0.0%	6.0%	3.6%	5.5%	7.5%	5.9%	10.8%	0.0%	2.0%	3.9%	9.6%	7.9%	0.5%	2.5%	4.2%	9.3%	8.4%
8.8	Trench 45 #1	17.1	96.2	256.3	16.6	63.7	1978	0.1	52180	75.5	216	16.5	10767	3152	4.56	13.07	0.99	650.36	543	0.79	2.25	0.171	111.95
8.0	Trench 45 #2	17.7	99.1	264.1	17.1	65.5	1978	0.0	53827	72.3	234	15.4	11455	3153	4.24	13.7	0.90	670.91	543	0.73	2.36	0.155	115.56
8.4	Trench 45 #3	18.3	102.4	273.4	17.8	67.8	1973	0.1	56084	69.0	256	14.3	10987	3153	3.88	14.41	0.80	617.73	548	0.67	2.50	0.140	107.32
8.0	Trench 45 #4	19.8	124.5	347.1	19.7	82.1	1899	0.4	62223	112.4	365	9.5	9767	3152	5.69	18.49	0.48	494.69	500	0.90	2.93	0.076	78.46
8.3	ave	18.22	105.54	285.21	17.79	69.78	1956.93	0.16	56079	82.3	268	13.91	10744	3152	4.59	14.92	0.80	608.42	533	0.77	2.51	0.14	103.32
0.4	stdev	1.2	12.9	41.8	1.4	8.4	38.8	0.2	4398.1	20.2	66.8	3.1	712	0.8	0.8	2.4	0.2	78.9	22.4	0.1	0.3	0.0	16.9
4.6%	COV	6.5%	12.2%	14.7%	7.9%	12.0%	2.0%	100.4%	8%	24.6%	24.9%	22.0%	6.6%	0.0%	17.1%	16.4%	28.0%	13.0%	4.2%	12.7%	11.9%	30.6%	16.4%
8.9	Trench 90 #1	17.1	96.7	258.1	16.6	64.0	1974	0.6	52237	75.0	221	15.8	10513	3152	4.52	13.32	0.95	634.35	540	0.78	2.28	0.163	108.74
8.9	Trench 90 #2	17.6	98.8	263.8	17.2	65.4	1976	0.8	54351	69.7	240	14.9	11201	3153	4.05	13.94	0.86	649.78	550	0.71	2.43	0.151	113.38
8.5	Trench 90 #3	18.2	102.9	275.8	17.8	68.0	1968	0.5	56114	68.0	258	14.0	10450	3154	3.82	14.52	0.79	587.26	545	0.66	2.51	0.136	101.52
7.7	Trench 90 #4	18.8	112.3	305.2	18.2	73.5	1938	0.7	57463	100.4	303	10.9	9798	3151	5.50	16.61	0.60	537.36	512	0.89	2.70	0.097	87.28
8.5	ave	17.9	102.7	275.7	17.5	67.7	1964.1	0.7	55041	78.3	255.6	13.9	10491	3152	4.5	14.6	0.8	602.2	537	0.8	2.5	0.1	102.7
0.6	stdev	0.7	6.9	21.0	0.7	4.2	17.6	0.1	2262.2	15.0	35.1	2.1	574	0.9	0.7	1.4	0.2	50.7	17.1	0.1	0.2	0.0	11.4
6.8%	COV	4.1%	6.7%	7.6%	4.1%	6.2%	0.9%	18.5%	4.1%	19.2%	13.7%	15.5%	5.5%	0.0%	16.7%	9.8%	19.0%	8.4%	3.2%	13.4%	7.0%	21.1%	11.1%
8.1	Trench 180 #1	17.5	99.2	265.7	16.9	65.6	1966	1.2	53367	73.6	231	15.4	10579	3152	4.35	13.62	0.91	624.90	538	0.74	2.32	0.155	106.68
8.4	Trench 180 #2	18.0	102.0	273.8	17.5	67.1	1962	0.9	55338	66.8	252	14.4	10902	3153	3.80	14.36	0.82	621.24	543	0.65	2.47	0.141	106.92
8.8	Trench 180 #3	18.4	106.2	286.0	18.0	69.8	1955	1.2	56654	65.2	269	13.4	10151	3154	3.63	15	0.75	565.12	534	0.61	2.54	0.126	95.61
11.0	Trench 180 #4	18.1	106.1	286.6	17.4	69.6	1951	1.1	54891	129.8	276	12.8	10216	3148	7.45	15.82	0.73	585.89	517	1.22	2.60	0.121	96.26
9.1	ave	18.0	103.4	278.0	17.5	68.0	1958.6	1.1	55062	83.8	256.9	14.0	10462	3152	4.8	14.7	0.8	599.3	533	0.8	2.5	0.1	101.4
1.3	stdev	0.4	3.4	10.1	0.4	2.0	7.0	0.1	1356	30.9	20.3	1.1	348	2.7	1.8	0.9	0.1	28.8	11.1	0.3	0.1	0.0	6.3
14.5%	COV	2.1%	3.3%	3.6%	2.4%	3.0%	0.4%	13.3%	2.5%	36.8%	7.9%	8.1%	3.3%	0.1%	37.1%	6.4%	10.1%	4.8%	2.1%	34.8%	4.7%	11.5%	6.2%
2.4	Dress #1	17.3	94.9	255.3	17.0	63.5	1964	0.7	53532	77.3	237	15.2	10144	3152	4.55	13.93	0.90	597.32	564	0.81	2.49	0.160	106.95
2.5	Dress #2	16.9	95.3	257.0	16.7	63.3	1961	0.9	52762	72.4	240	14.4	10037	3152	4.32	14.32	0.86	599.71	554	0.76	2.52	0.151	105.34
3.6	Dress #3	18.3	105.7	286.3	17.9	69.9	1946	1.0	56472	66.5	280	12.8	10199	3154	3.72	15.64	0.72	569.61	534	0.63	2.65	0.121	96.53
5.4	Dress #4	18.8	107.1	289.9	17.9	71.3	1951	0.9	56252	152.6	290	12.3	10649	3146	8.53	16.23	0.69	595.65	525	1.42	2.71	0.115	99.44
3.5	ave	17.8	100.7	272.1	17.4	67.0	1956	0.9	54754	92.2	262	13.7	10257	3151	5.28	15.03	0.79	590.57	544	0.91	2.59	0.137	102.06
1.4	stdev	0.9	6.6	18.5	0.6	4.2	8.4	0.1	1885	40.5	27	1.3	270	3.3	2.20	1.086	0.10	14.07	18	0.35	0.10	0.022	4.90
40.5%	COV	4.9%	6.5%	6.8%	3.5%	6.3%	0.4%	12.0%	3.4%	43.9%	10.5%	9.8%	2.6%	0.1%	41.6%	7.2%	13.0%	2.4%	3.3%	39.0%	4.0%	16.1%	4.8%
4.1	Backfill #1	17.3	96.0	256.2	16.7	63.7	1975	0.7	52730	75.0	224	15.6	10170	3152	4.48	13.41	0.93	607.92	549	0.78	2.34	0.162	105.94
3.8	Backfill #2	17.5	98.6	264.1	17.1	65.0	1970	0.8	53904	69.6	241	14.7	10528	3153	4.07	14.09	0.86	615.76	547	0.71	2.44	0.150	106.75
4.2	Backfill #3	18.5	104.9	281.6	18.2	69.3	1966	1.0	57534	65.8	279	12.9	10363	3154	3.61	15.29	0.71	568.14	549	0.63	2.66	0.123	98.82
4.0	ave	17.8	99.8	267.3	17.4	66.0	1970	0.8	54723	70.1	248	14.4	10354	3153	4.05	14.26	0.83	597.27	548	0.70	2.48	0.145	103.83
0.2	stdev	0.6	4.6	13.0	0.8	3.0	4.5	0.2	2505	4.6	28	1.4	179	1.0	0.44	0.954	0.11	25.54	1	0.08	0.16	0.020	4.36
4.4%	COV	3.6%	4.6%	4.9%	4.5%	4.5%	0.2%	19.5%	4.6%	6.6%	11.3%	9.4%	1.7%	0.0%	10.8%	6.7%	13.7%	4.3%	0.3%	10.9%	6.6%	13.7%	4.2%
3.8	Idle	2.5	15.0	75.7	2.2	17.7	1038	0.0	6950	14.9	54	6.4	1262	3142	6.76	24.44	2.87	570.64	464	1.00	3.61	0.425	84.35
1.8	Idle	2.5	14.5	73.5	2.1	17.2	1038	0.0	6644	12.1	53	6.0	1044	3144	5.72	25.17	2.85	494.18	457	0.83	3.66	0.414	71.90
2.0	Idle	2.4	14.1	71.4	2.1	16.7	1039	0.0	6470	12.7	52	5.6	1088	3144	6.17	25.13	2.72	528.47	458	0.90	3.66	0.397	77.02
1.1	Idle	2.5	14.4	73.1	2.1	17.1	1038	0.0	6693	11.7	56	5.5	1103	3145	5.49	26.31	2.58	518.43	463	0.81	3.88	0.380	76.39
1.8	Idle	2.4	14.3	72.5	2.1	16.9	1039	0.0	6576	12.2	54	5.3	1131	3145	5.86	25.96	2.53	541.10	459	0.85	3.79	0.369	78.93
2.1	Idle	2.3	14.1	71.1	2.0	16.6	1039	0.0	6242	42.9	53	4.9	1121	3121	21.47	26.44	2.45	560.56	444	3.05	3.76	0.349	79.73
2.8	Idle	2.4	14.1	71.2	2.1	16.6	1039	0.1	6522	12.9	54	5.2	989	3144	6.23	25.8	2.51	476.55	463	0.92	3.80	0.369	70.18
1.1	Idle	2.3	14.1	71.2	2.1	16.6	1039	0.1	6611	11.6	54	5.5	1155	3145	5.53	25.88	2.62	549.49	469	0.83	3.86	0.391	81.97
2.1	ave	2.4	14.3	72.5	2.1	16.9	1039	0.0	6589	16.4	54	5.5	1112	3141	7.90	25.64	2.64	529.93	460	1.15	3.75	0.387	77.56
0.9	stdev	0.1	0.3	1.6	0.1	0.4	0.5	0.0	201	10.8	1	0.5	81	8.4	5.50	0.675	0.16	32.43	8	0.77	0.10	0.025	4.79
43.7%	COV	2.8%	2.2%	2.2%	2.9%	2.2%	0.0%	139.6%	3.1%	65.8%	2.3%	8.3%	7.2%	0.3%	69.6%	2.6%	5.9%	6.1%	1.6%	67.2%	2.6%	6.5%	6.2%
403.7	Overall	12.6	69.0	195.9	12.0	49.2	1663	0.8	37772	69.3	183	11.7	7535	3149.85	5.78	15.28	0.98	628.34	547	1.00	2.65	0.170	109.19

[2] Power estimated from published lug curve and % laod, see delailed work sheet

[3] Total PM using gravimetric span method and not the model alpha methods. Units of mg/hr or mg/kgfuel or mg/hp-h.

[4] Carbon balance fuel rate calculation using gaseous PEMS

[6] ECM reported fuel rate

This 2007 Tier 3 Komatsu PC200 excavator was a rental unit owned by Road Machinery in Sacramento, CA. The test site was at Diamond D Engineering's headquarter in Woodland, CA. The operator was from Diamond D Engineering. The excavator was performed the test cycle for the AQIP project which involves traveling, trenching 45, 90, 180 degrees, dressing work, and backfilling trenches. The PEMS equipment was the same as the last tests, and there was 6.7 hours of valid data collected.

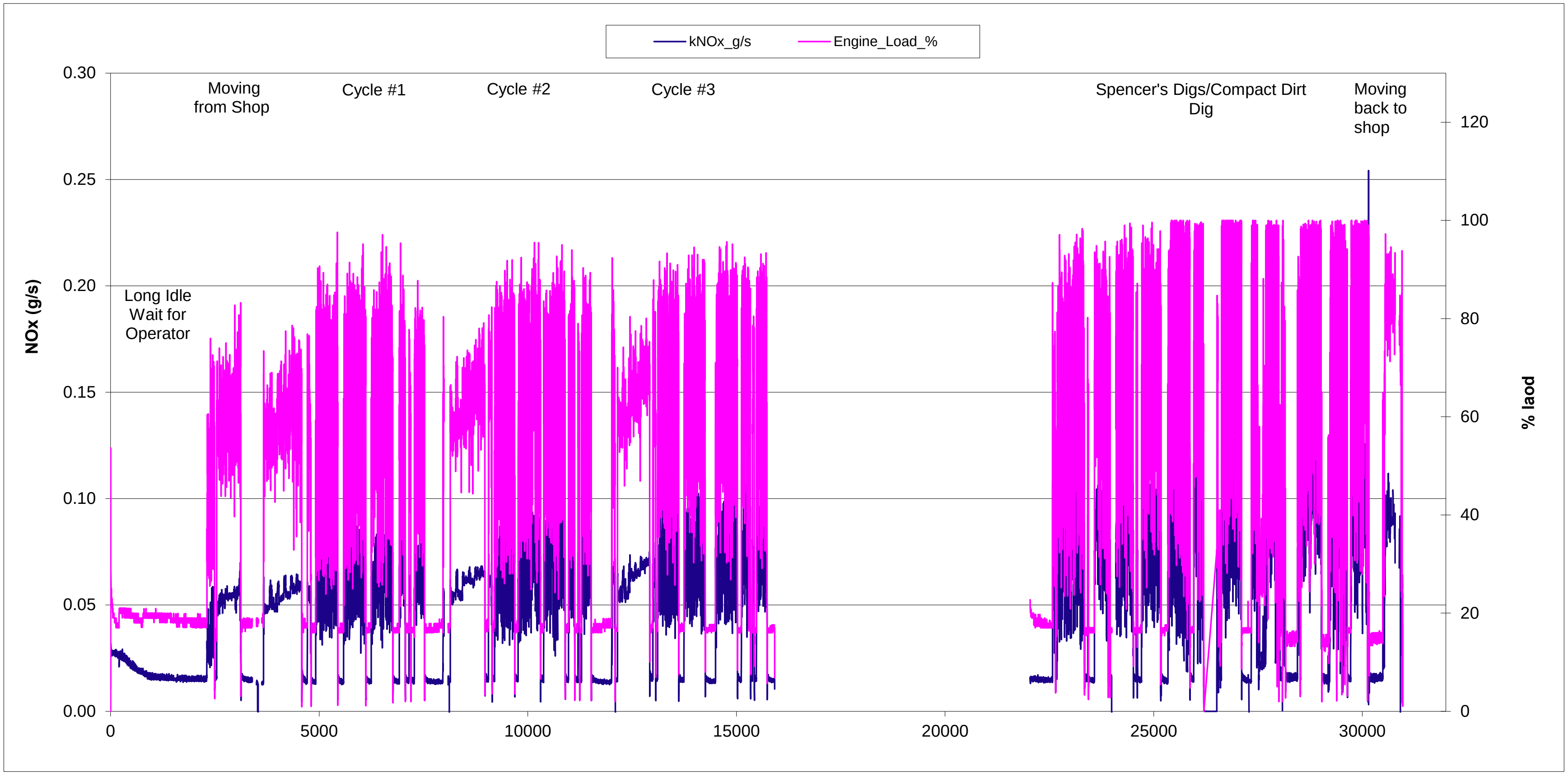


Figure 26: Modal emissions for 26_PC200 2007 Komatsu tier 3 excavator

27_HB215: 2013.02.28 Table 27: Integrated emissions for 27_HB215 2011 Komatsu tier 3 excavator

Duration	Test Function	Fuel [6]	Power [2]	Torque	Fuel [4]	eLoad	eSpeed	Vel GPS	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel) [4]					Brake Specific Emissions (g/hp-hr)				
Mins		kg/hr	bhp	ft-lb	kg/hr	%	RPM	km/h	CO2	CO	NOx	THC	mg PM [3]	CO2	CO	NOx	THC	mg PM [3]	CO2	CO	NOx	THC	mg PM [3]
10.5	Travel #1	19.1	110.6	290.3	20.2	78.7	1997	3.7	63546	89.0	258	10.4	18832.0	3153	4.42	12.81	0.52	934.53	575	0.81	2.33	0.094	170.34
10.5	Travel #2	18.9	109.4	287.1	19.8	77.7	1997	3.8	62320	84.3	260	9.2	17436.9	3154	4.27	13.17	0.46	882.43	570	0.77	2.38	0.084	159.44
10.3	Travel #3	18.8	108.4	284.5	19.7	77.1	1998	3.8	61984	82.4	266	8.7	16551.9	3154	4.19	13.54	0.44	842.24	572	0.76	2.46	0.080	152.75
10.4	ave	18.9	109.4	287.3	19.9	77.8	1997.4	3.8	62617	85.3	261.5	9.4	17607.0	3154	4.3	13.2	0.5	886.4	572.2	0.8	2.4	0.1	160.8
0.1	stdev	0.2	1.1	2.9	0.3	0.8	0.1	0.1	822.1	3.4	4.2	0.9	1149.5	0.3	0.1	0.4	0.0	46.3	2.5	0.0	0.1	0.0	8.9
1.3%	COV	1.0%	1.0%	1.0%	1.3%	1.0%	0.0%	1.9%	1.3%	4.0%	1.6%	9.5%	6.5%	0.0%	2.7%	2.8%	8.2%	5.2%	0.4%	3.0%	2.6%	8.5%	5.5%
8.0	Trench 45 #1	14.9	99.1	298.9	15.3	69.0	1711	0.1	48210	85.7	271	4.4	15473.9	3152	5.60	17.69	0.29	1011.79	487	0.87	2.73	0.045	156.22
8.0	Trench 45 #2	15.3	100.7	305.1	15.7	70.0	1708	0.2	49414	91.5	288	4.0	15070.2	3152	5.84	18.39	0.26	961.29	491	0.91	2.86	0.040	149.68
10.1	Trench 45 #3	15.2	99.3	297.9	15.7	68.9	1724	0.1	49431	89.7	290	4.0	14752.0	3152	5.72	18.51	0.26	940.72	498	0.90	2.92	0.040	148.55
8.7	ave	15.15	99.68	300.64	15.55	69.29	1714.10	0.12	49018	88.98	283	4.16	15098.70	3152	5.72	18.20	0.27	971.27	491.77	0.89	2.84	0.04	151.49
1.2	stdev	0.2	0.9	3.9	0.2	0.6	8.5	0.1	700.6	3.0	10.9	0.2	361.8	0.1	0.1	0.4	0.0	36.6	5.6	0.0	0.1	0.0	4.1
14.0%	COV	1.2%	0.9%	1.3%	1.4%	0.9%	0.5%	45.6%	1.4%	3.3%	3.8%	5.6%	2.4%	0.0%	2.0%	2.4%	7.1%	3.8%	1.1%	2.7%	3.5%	6.1%	2.7%
9.1	Trench 90 #1	14.5	93.3	283.9	14.7	65.3	1701	0.6	46396	86.7	266	4.2	15792.6	3152	5.89	18.06	0.29	1072.83	497	0.93	2.85	0.045	169.26
7.8	Trench 90 #2	14.8	96.4	293.3	15.0	67.3	1706	0.8	47258	88.9	280	3.8	14988.1	3152	5.93	18.7	0.26	999.62	490	0.92	2.91	0.040	155.55
8.5	Trench 90 #3	14.8	96.1	294.0	14.9	67.6	1692	0.6	47077	88.6	282	3.7	14274.8	3152	5.93	18.9	0.25	955.73	490	0.92	2.94	0.038	148.54
8.4	ave	14.7	95.3	290.4	14.9	66.7	1699	0.7	46911	88.1	276	3.9	15018.5	3152	5.92	18.55	0.26	1009.39	493	0.92	2.90	0.041	157.78
0.6	stdev	0.2	1.7	5.6	0.1	1.3	7.0	0.1	454.5	1.2	9.0	0.3	759.3	0.0	0.0	0.4	0.0	59.2	4.1	0.0	0.0	0.0	10.5
7.4%	COV	1.2%	1.8%	1.9%	1.0%	1.9%	0.4%	16.7%	1.0%	1.4%	3.2%	7.1%	5.1%	0.0%	0.4%	2.4%	8.0%	5.9%	0.8%	0.4%	1.5%	8.9%	6.7%
8.4	Trench 180 #1	15.2	97.6	296.9	15.5	68.3	1705	1.2	48811	93.9	279	4.2	15359.2	3152	6.06	18.04	0.27	991.70	500	0.96	2.86	0.043	157.33
8.5	Trench 180 #2	14.8	95.6	295.5	15.1	67.6	1671	1.2	47505	94.7	283	3.7	14165.6	3151	6.28	18.79	0.24	939.70	497	0.99	2.96	0.039	148.21
8.3	Trench 180 #3	15.4	98.4	301.9	15.5	69.3	1693	1.0	48764	95.6	291	3.7	14585.7	3152	6.18	18.81	0.24	942.64	495	0.97	2.96	0.038	148.16
8.4	ave	15.1	97.2	298.1	15.3	68.4	1690	1.1	48360	94.7	285	3.9	14703.5	3151	6.17	18.55	0.25	958.02	497	0.97	2.93	0.040	151.23
0.1	stdev	0.3	1.5	3.4	0.2	0.9	17.0	0.1	741	0.9	6	0.3	605.4	0.13	0.11	0.442	0.02	29.21	2	0.01	0.06	0.003	5.28
1.6%	COV	2.1%	1.5%	1.1%	1.5%	1.3%	1.0%	9.1%	1.5%	0.9%	2.1%	8.1%	4.1%	0.0%	1.8%	2.4%	7.3%	3.0%	0.5%	1.5%	2.0%	7.8%	3.5%
2.4	Dress #1	12.5	81.2	253.7	12.3	57.7	1648	0.8	38591	85.2	227	4.0	15278.8	3150	6.96	18.5	0.32	1247.15	476	1.05	2.79	0.049	188.28
3.5	Dress #2	12.6	82.8	260.8	12.7	59.4	1635	1.1	40110	92.0	246	3.8	13453.5	3150	7.23	19.28	0.30	1056.45	484	1.11	2.96	0.046	162.40
2.6	Dress #3	14.4	93.8	291.7	14.2	66.7	1657	0.8	44636	99.8	264	3.9	15637.4	3150	7.04	18.66	0.27	1103.58	476	1.06	2.82	0.041	166.67
2.8	ave	13.2	85.9	268.7	13.1	61.3	1647	0.9	41112	92.4	246	3.9	14789.9	3150	7.08	18.81	0.30	1135.73	478	1.08	2.86	0.045	172.45
0.6	stdev	1.1	6.9	20.2	1.0	4.8	11.2	0.2	3144	7.3	19	0.1	1171.2	0.209	0.14	0.412	0.03	99.33	5	0.03	0.09	0.004	13.87
20.6%	COV	8.1%	8.0%	7.5%	7.6%	7.8%	0.7%	19.9%	7.6%	7.9%	7.7%	2.0%	7.9%	0.0%	2.0%	2.2%	8.5%	8.7%	1.0%	3.0%	3.2%	8.5%	8.0%
5.0	Backfill #1	14.1	92.0	278.4	14.6	64.0	1713	1.0	46052	88.0	257	4.4	16293.3	3152	6.02	17.58	0.30	1115.03	501	0.96	2.79	0.048	177.09
4.3	Backfill #2	14.4	94.0	286.1	14.6	65.4	1702	0.5	45869	93.3	270	4.0	15703.1	3151	6.41	18.52	0.28	1078.75	488	0.99	2.87	0.043	167.07
4.2	Backfill #3	15.3	99.1	302.0	15.5	69.3	1701	0.5	48793	94.5	286	4.0	15489.3	3152	6.10	18.47	0.26	1000.47	492	0.95	2.88	0.041	156.24
4.5	ave	14.6	95.0	288.8	14.9	66.2	1705	0.7	46905	91.9	271	4.2	15828.6	3151	6.18	18.19	0.28	1064.75	494	0.97	2.85	0.044	166.80
0.4	stdev	0.7	3.7	12.0	0.5	2.7	6.6	0.3	1638	3.5	15	0.2	416.4	0.306	0.20	0.53	0.02	58.55	6	0.02	0.05	0.004	10.43
9.4%	COV	4.5%	3.9%	4.2%	3.5%	4.1%	0.4%	43.1%	3.5%	3.8%	5.4%	5.7%	2.6%	0.0%	3.3%	2.9%	8.0%	5.5%	1.3%	2.3%	1.7%	9.0%	6.3%
2.4	Idle	0.7	5.1	37.8	1.2	11.7	702	0.0	3702	4.8	55	1.3	168.2	3152	4.11	46.56	1.10	143.26	733	0.95	10.82	0.257	33.30
2.9	Idle	0.7	5.3	39.8	1.2	12.3	702	0.1	3725	4.0	56	1.2	148.3	3154	3.40	47.05	0.98	125.58	699	0.75	10.43	0.218	27.85
2.8	Idle	0.7	5.5	41.3	1.2	12.8	702	0.0	3770	4.6	56	1.2	162.9	3153	3.88	46.7	1.03	136.20	683	0.84	10.12	0.223	29.51
2.6	Idle	0.7	5.4	40.6	1.2	12.5	702	0.0	3740	4.3	55	1.2	148.7	3153	3.65	46.7	1.01	125.38	689	0.80	10.20	0.221	27.40
4.0	Idle	0.7	5.5	40.9	1.2	12.6	702	0.0	3725	4.5	55	1.2	19.1	3153	3.79	46.28	1.02	16.14	681	0.82	10.00	0.221	3.49
3.6	Idle	0.7	5.3	39.9	1.2	12.3	702	0.0	3745	4.3	56	1.2	151.7	3153	3.59	47.33	0.99	127.76	702	0.80	10.54	0.221	28.44
3.0	ave	0.7	5.4	40.1	1.2	12.4	702	0.0	3735	4.4	55	1.2	133.2	3153	3.74	46.77	1.02	112.39	698	0.83	10.35	0.227	25.00
0.6	stdev	0.0	0.2	1.2	0.0	0.4	0.0	0.0	23	0.3	1	0.0	56.5	0.512	0.24	0.37	0.04	47.67	19	0.07	0.31	0.015	10.75
19.9%	COV	3.0%	3.1%	3.1%	0.6%	3.1%	0.0%	126.7%	0.6%	6.4%	1.1%	3.9%	42.4%	0.0%	6.5%	0.8%	4.2%	42.4%	2.7%	8.2%	2.9%	6.5%	43.0%
282.3	Overall Ave	9.1	55.6	173.0	9.3	43.9	1347	0.9	30087	52.9	175	4.0	8653.1	3235	5.69	18.85	0.43	930.49	541	0.95	3.15	0.073	155.59

[2] Power estimated from published lug curve and % laod, see delailed work sheet

[3] Total PM using gravimetric span method and not the model alpha methods. Units of mg/hr or mg/kgfuel or mg/hp-h.

[4] Carbon balance fuel rate calculation using gaseous PEMS

[6] ECM reported fuel rate

This 2011 Tier 3 Komatsu HB215 excavator was a rental unit owned by Road Machinery in Redding, CA. The test site was at Diamond D Engineering's headquarter in Woodland, CA. The excavator was performed the test cycle for the AQIP project which involves traveling, trenching 45, 90, 180 degrees, dressing work, and backfilling trenches. The PEMS equipment was the same as the last tests, and there was 4.7 hours of valid data collected.

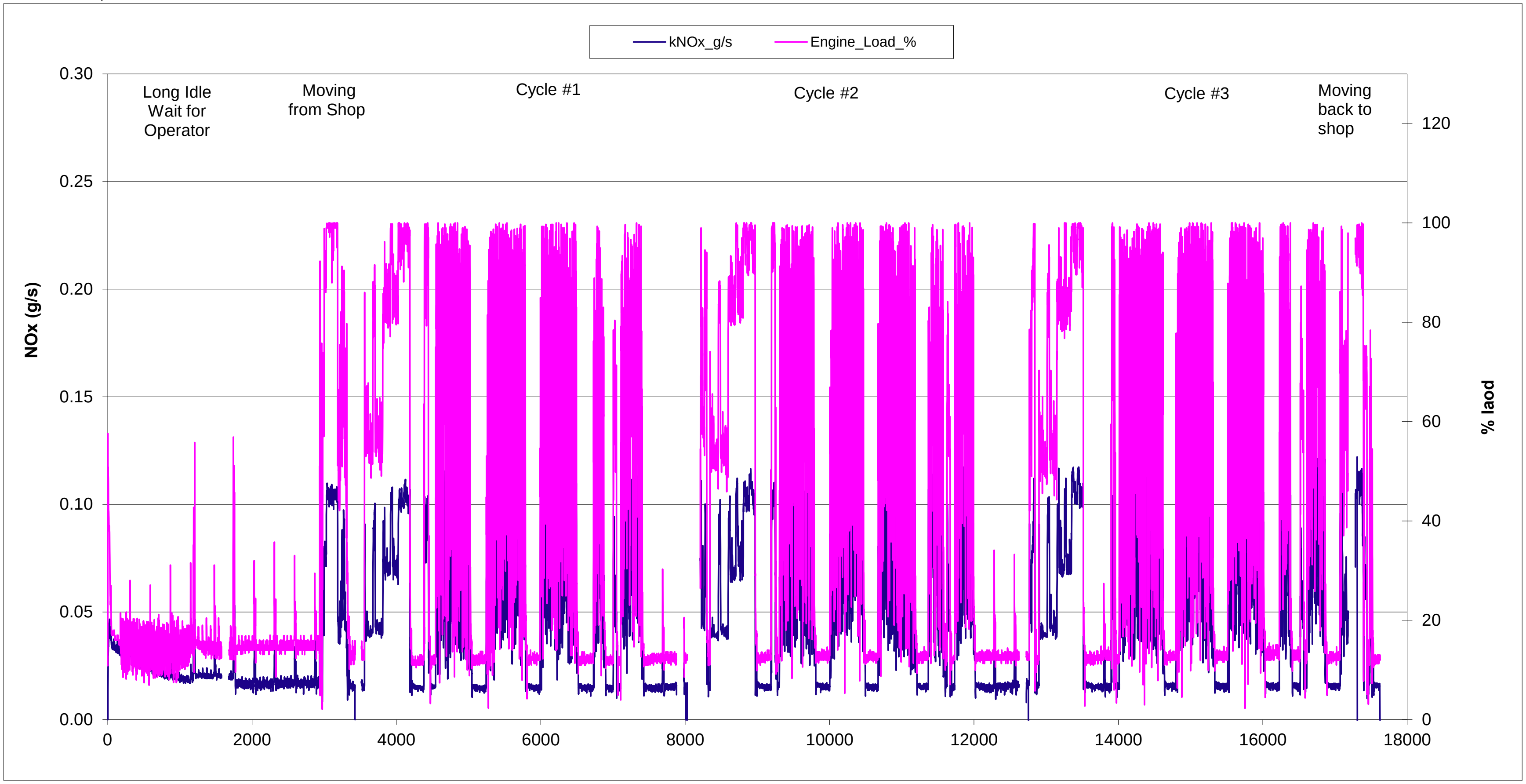


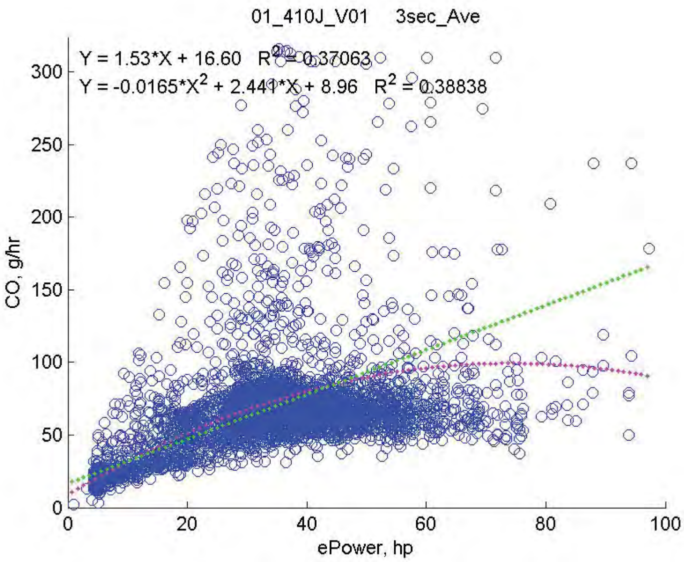
Figure 27: Modal emissions for 27_HB215 2011 Komatsu tier 3 excavator

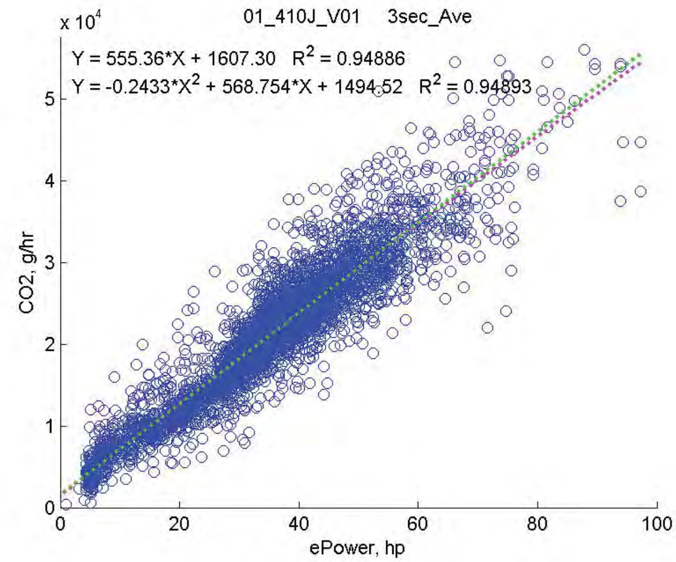
Appendix B. Detailed Modal Emissions vs Power Figures by Unit

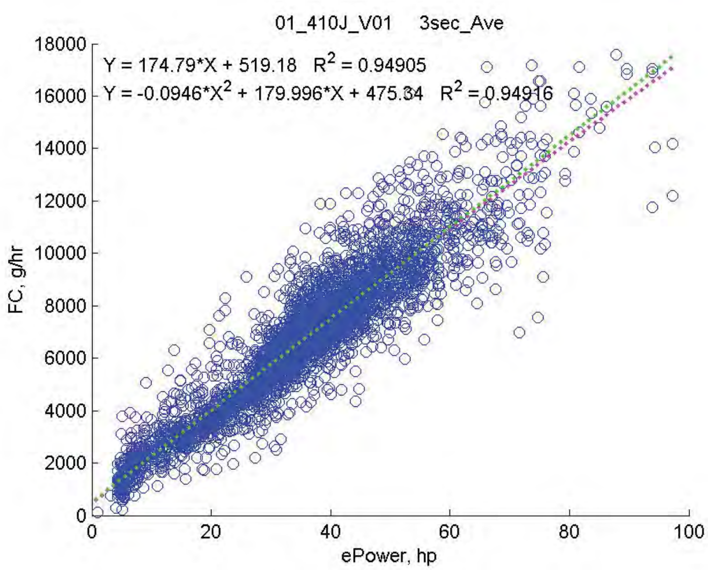
Time alignment between power and emissions is difficult due to the response time of the engine compared to the response time of the instruments. The engine response is on the order of 100 ms where the emissions response time is around 1-2 seconds. One solution is to implement a running average or a filter on the real time data to improve the relationship between power and emissions. Too little filtering and the data are very noisy. Too much filtering and you lose the relationship between power and emissions. This Appendix shows the detailed correlation figures for each pollutant for each vehicle.

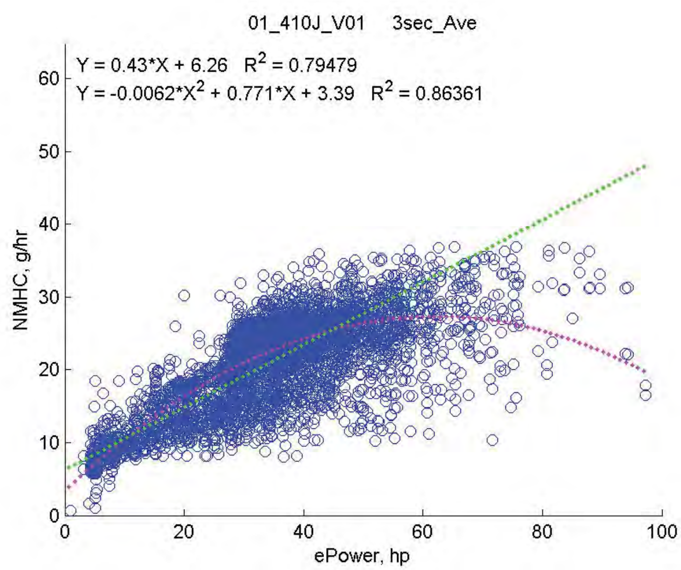
A moving average of three seconds was implemented in MATLAB using the function called "MEDFILT1". MEDFILT1 is a one dimensional median filter function in MATLAB (see MATLAB user manual). The filter uses the median calculation between the points not an average. The three second median filter was used (n=3) for all the real-time gaseous, PM and ECM measurements presented in the Appendix 9.0 figures.

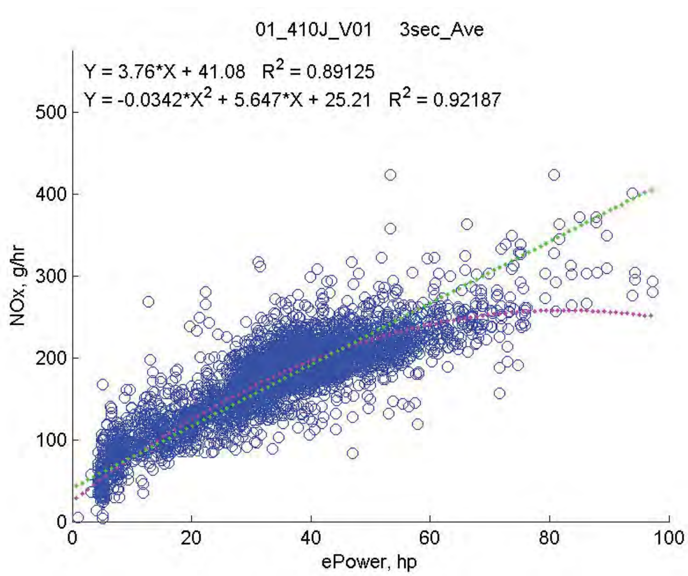
The least squared regression best fit coefficients in each figure were analyzed using MATLAB's "polyfit" command. The Polyfit command finds the coefficients of a polynomial P(X) of degree N that fits the data Y best in a least-squares sense. P is a row vector of length N+1 containing the polynomial coefficients in descending powers, P(1)*X^N + P(2)*X^(N-1) +...+ P(N)*X + P(N+1) (MATLAB user manual). For this analysis the order of the coefficients used were N = 1 and N = 2, representing a linear and polynomial fit, respectively. In addition to the regression equation for a linear and polynomial fit, the goodness of fit is also shown on each figure with the R^2 term. A more detailed analysis is provided in the report comparing the correlations between units and by activity mode.

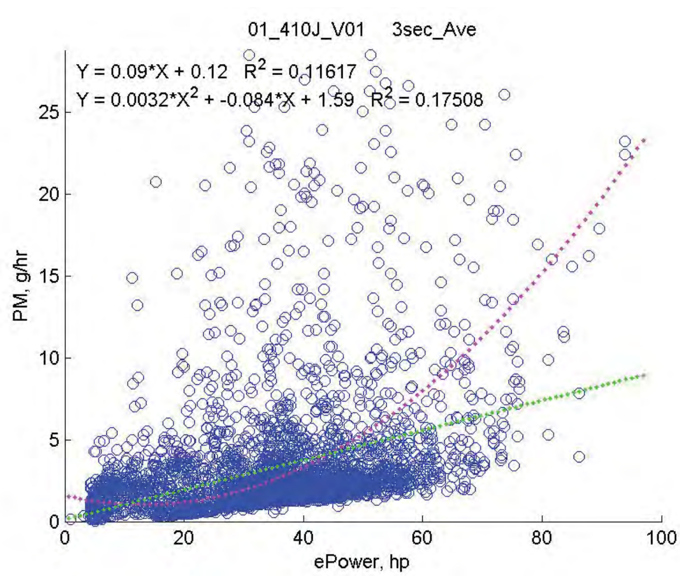

01_410J_V01 3sec_Ave
Y = 1.53*X + 16.60 R^2 = 0.37063
Y = -0.0165*X^2 + 2.441*X + 8.96 R^2 = 0.38838
CO, g/hr
ePower, hp

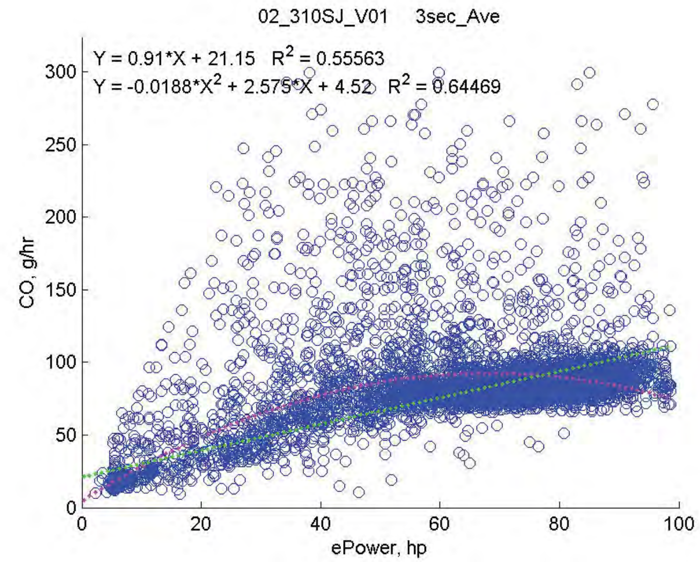

01_410J_V01 3sec_Ave
x 10^4
Y = 555.36*X + 1607.30 R^2 = 0.94886
Y = -0.2433*X^2 + 568.754*X + 1494.52 R^2 = 0.94893
CO2, g/hr
ePower, hp

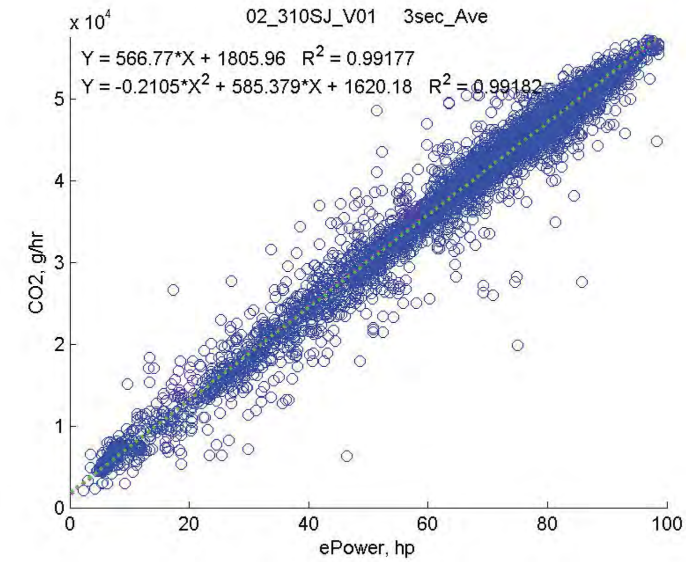

01_410J_V01 3sec_Ave
Y = 174.79*X + 519.18 R^2 = 0.94905
Y = -0.0946*X^2 + 179.996*X + 475.34 R^2 = 0.94916
FC, g/hr
ePower, hp

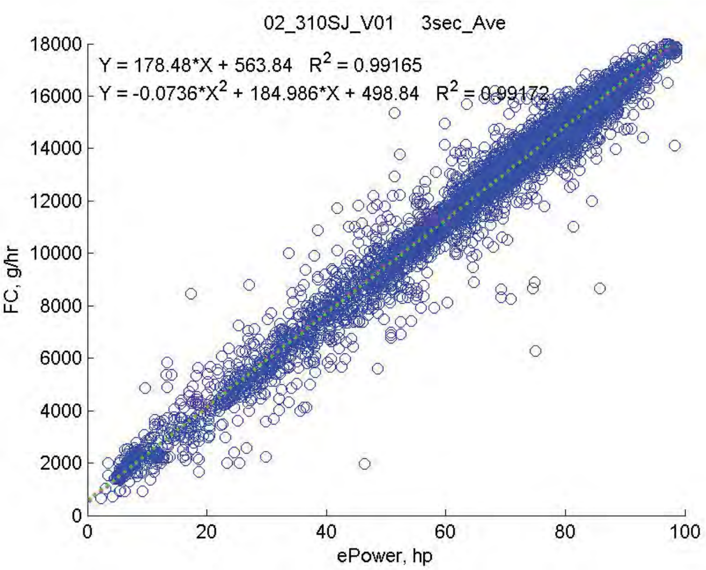

01_410J_V01 3sec_Ave
Y = 0.43*X + 6.26 R^2 = 0.79479
Y = -0.0062*X^2 + 0.771*X + 3.39 R^2 = 0.86361
NMHC, g/hr
ePower, hp

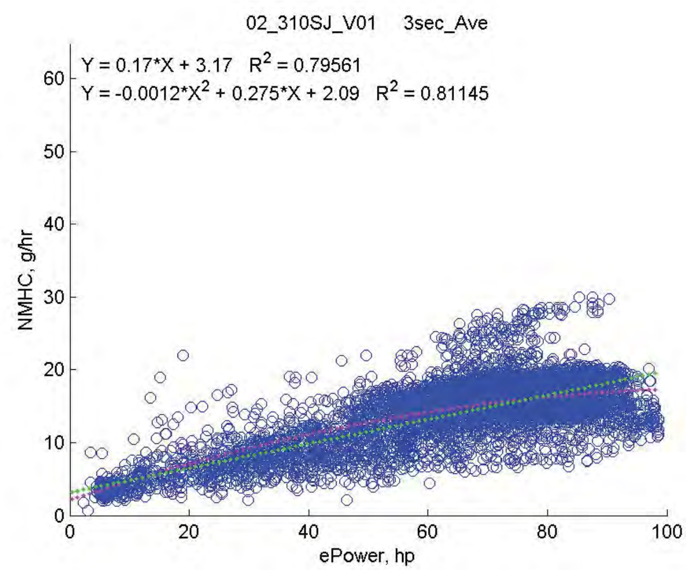

01_410J_V01 3sec_Ave
Y = 3.76*X + 41.08 R^2 = 0.89125
Y = -0.0342*X^2 + 5.647*X + 25.21 R^2 = 0.92187
NOx, g/hr
ePower, hp

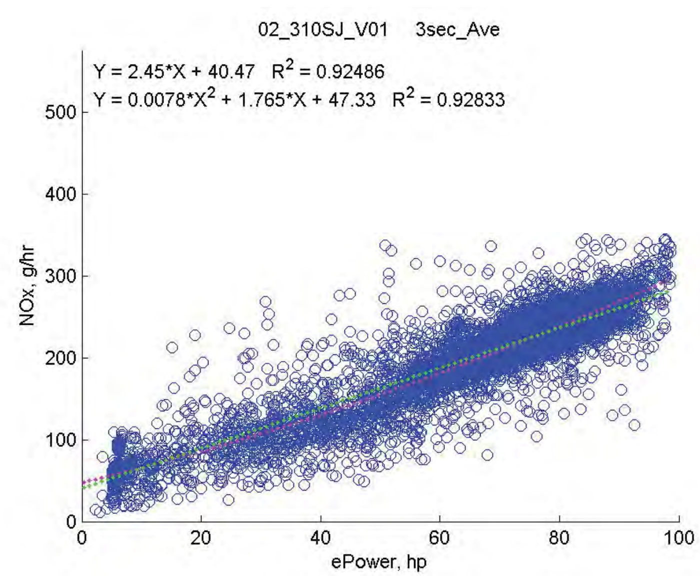

01_410J_V01 3sec_Ave
Y = 0.09*X + 0.12 R^2 = 0.11617
Y = 0.0032*X^2 + -0.084*X + 1.59 R^2 = 0.17508
PM, g/hr
ePower, hp

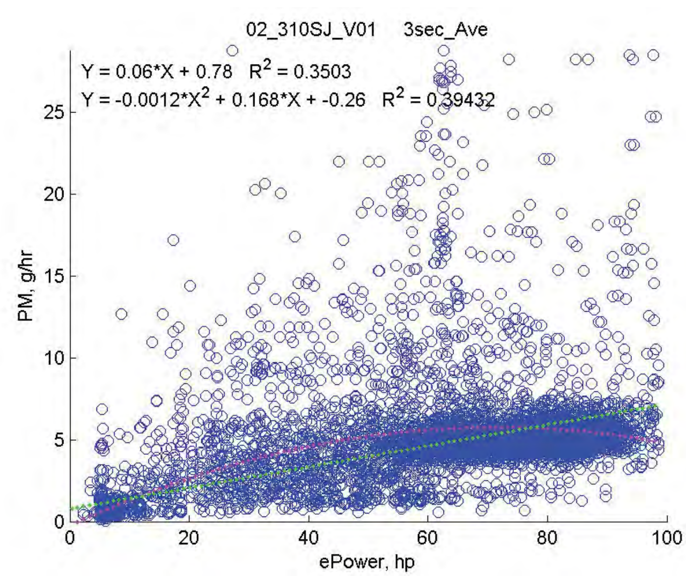

02_310SJ_V01 3sec_Ave
Y = 0.91*X + 21.15 R^2 = 0.55563
Y = -0.0188*X^2 + 2.575*X + 4.52 R^2 = 0.64469
CO, g/hr
ePower, hp

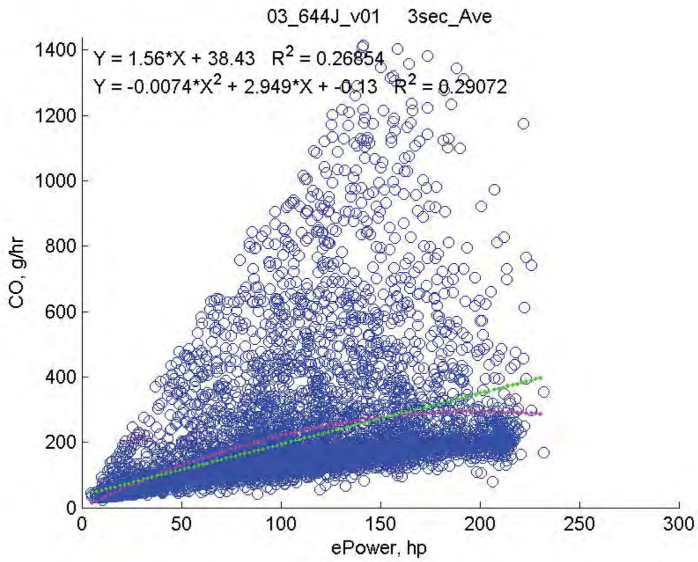

02_310SJ_V01 3sec_Ave
x 10^4
Y = 566.77*X + 1805.96 R^2 = 0.99177
Y = -0.2105*X^2 + 585.379*X + 1620.18 R^2 = 0.99182
CO2, g/hr
ePower, hp

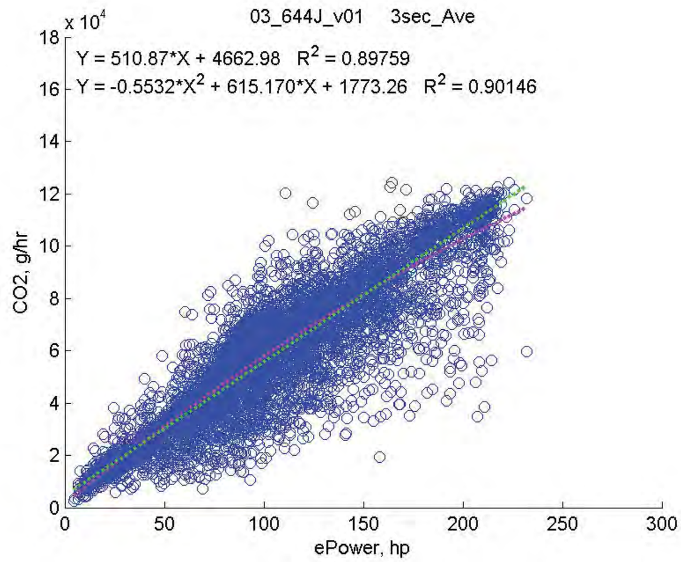

02_310SJ_V01 3sec_Ave
Y = 178.48*X + 563.84 R^2 = 0.99165
Y = -0.0736*X^2 + 184.986*X + 498.84 R^2 = 0.99172
FC, g/hr
ePower, hp

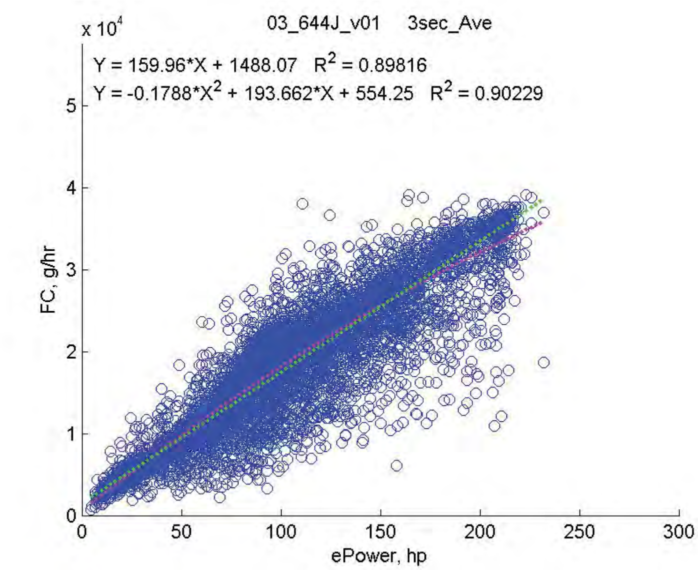

02_310SJ_V01 3sec_Ave
Y = 0.17*X + 3.17 R^2 = 0.79561
Y = -0.0012*X^2 + 0.275*X + 2.09 R^2 = 0.81145
NMHC, g/hr
ePower, hp

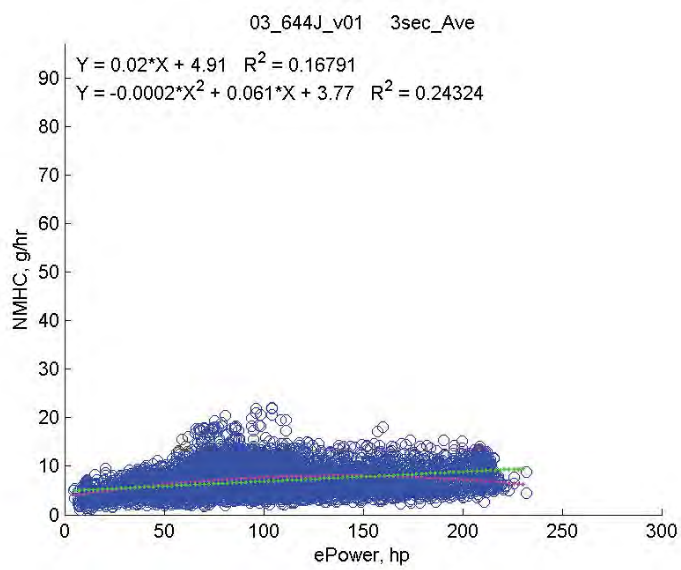

02_310SJ_V01 3sec_Ave
Y = 2.45*X + 40.47 R^2 = 0.92486
Y = 0.0078*X^2 + 1.765*X + 47.33 R^2 = 0.92833
NOx, g/hr
ePower, hp

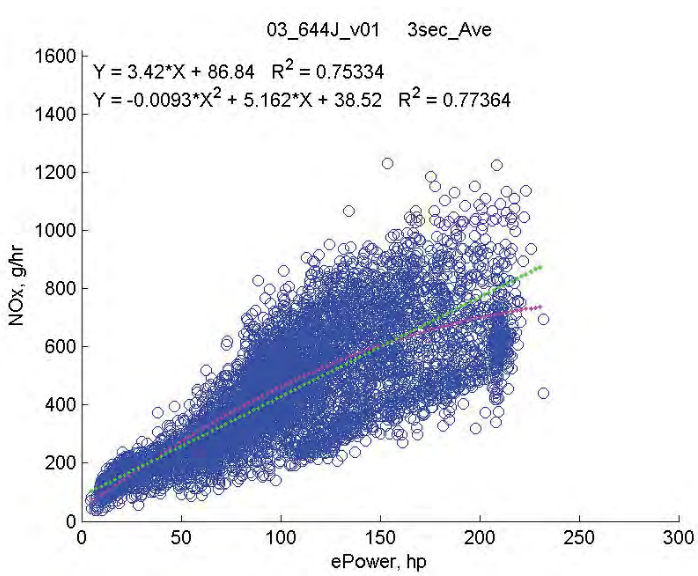

02_310SJ_V01 3sec_Ave
Y = 0.06*X + 0.78 R^2 = 0.3503
Y = -0.0012*X^2 + 0.168*X + -0.26 R^2 = 0.39432
PM, g/hr
ePower, hp

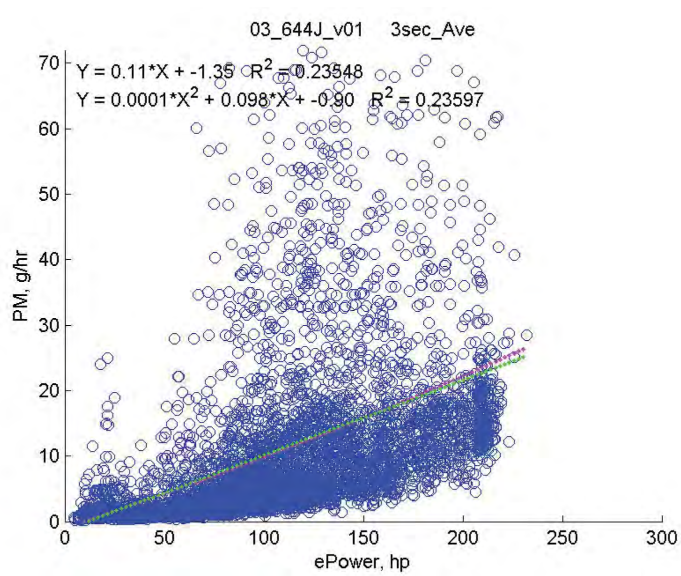

03_644J_v01 3sec_Ave
Y = 1.56*X + 38.43 R^2 = 0.26854
Y = -0.0074*X^2 + 2.949*X + -0.13 R^2 = 0.29072
CO, g/hr
ePower, hp

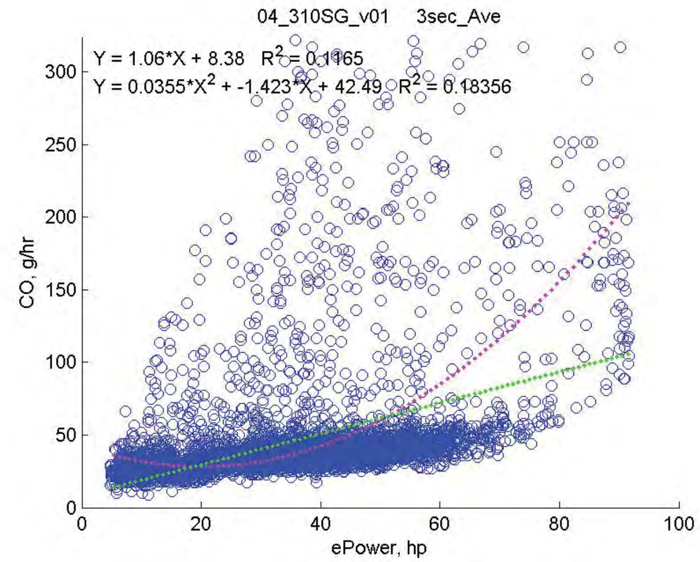

03_644J_v01 3sec_Ave
x 10^4
Y = 510.87*X + 4662.98 R^2 = 0.89759
Y = -0.5532*X^2 + 615.170*X + 1773.26 R^2 = 0.90146
CO2, g/hr
ePower, hp

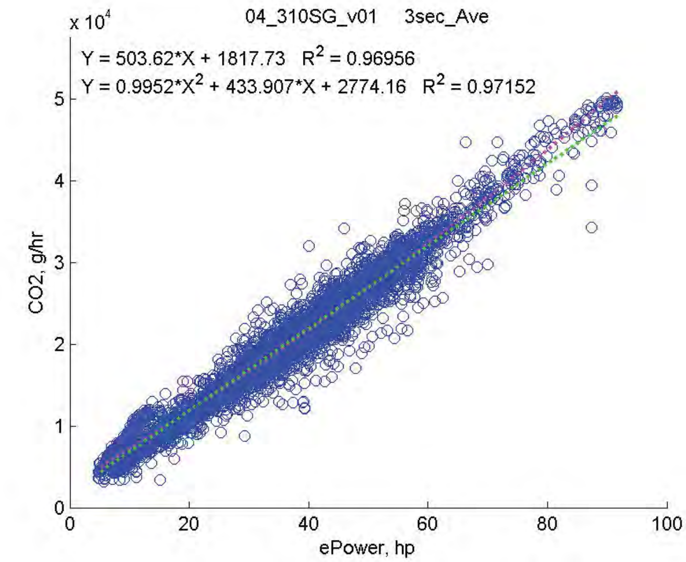

03_644J_v01 3sec_Ave
x 10^4
Y = 159.96*X + 1488.07 R^2 = 0.89816
Y = -0.1788*X^2 + 193.662*X + 554.25 R^2 = 0.90229
FC, g/hr
ePower, hp

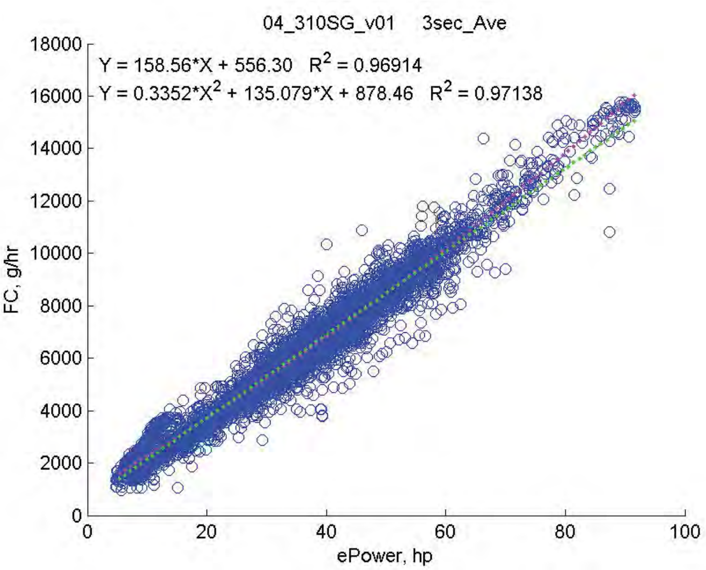

03_644J_v01 3sec_Ave
Y = 0.02*X + 4.91 R^2 = 0.16791
Y = -0.0002*X^2 + 0.061*X + 3.77 R^2 = 0.24324
NMHC, g/hr
ePower, hp

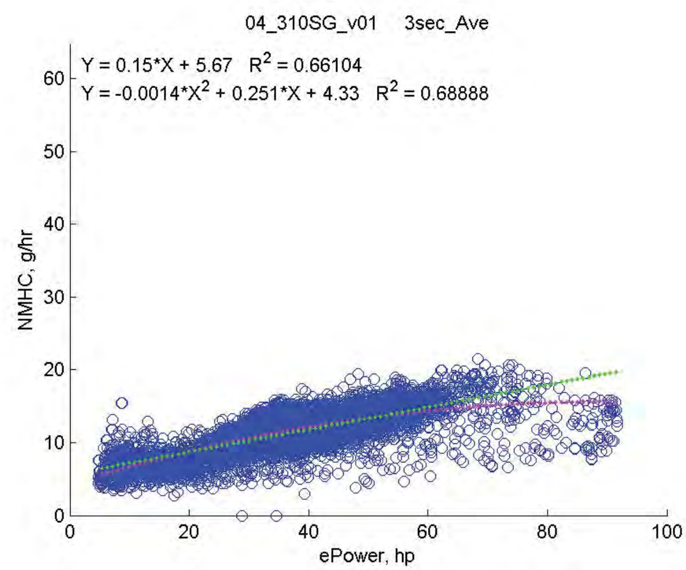

03_644J_v01 3sec_Ave
Y = 3.42*X + 86.84 R^2 = 0.75334
Y = -0.0093*X^2 + 5.162*X + 38.52 R^2 = 0.77364
NOx, g/hr
ePower, hp

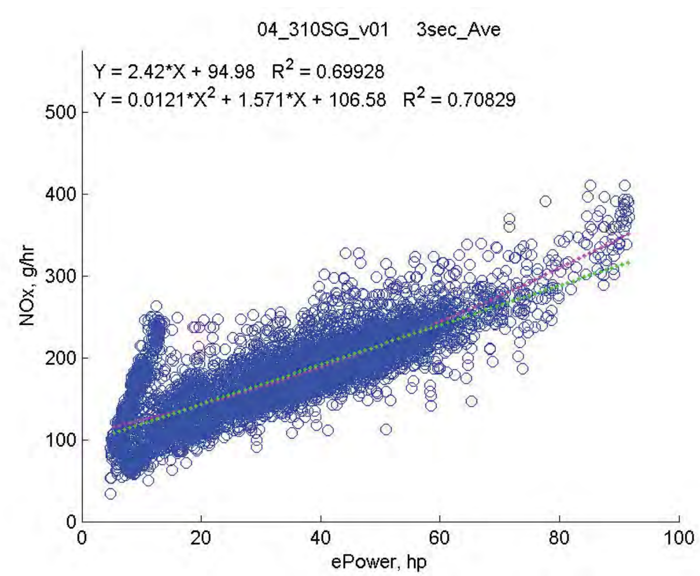

03_644J_v01 3sec_Ave
Y = 0.11*X + -1.35 R^2 = 0.23548
Y = 0.0001*X^2 + 0.098*X + -0.90 R^2 = 0.23597
PM, g/hr
ePower, hp

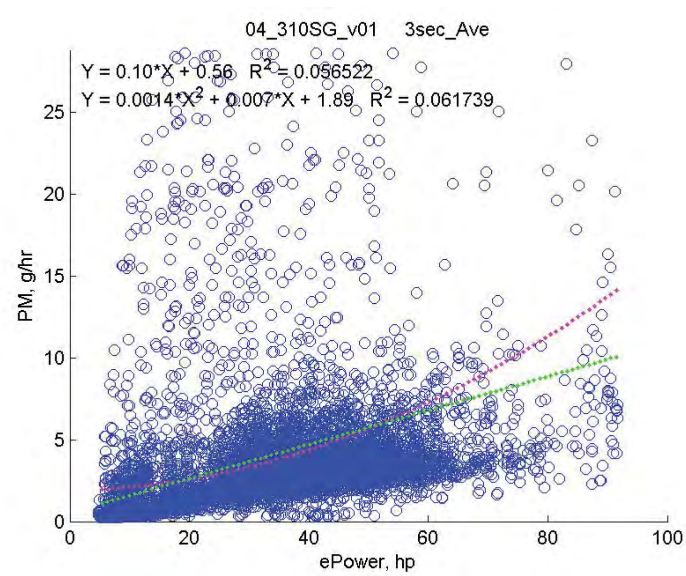

04_310SG_v01 3sec_Ave
Y = 1.06*X + 8.38 R2 = 0.1165
Y = 0.0355*X2 + -1.423*X + 42.49 R2 = 0.18356
CO, g/hr
ePower, hp

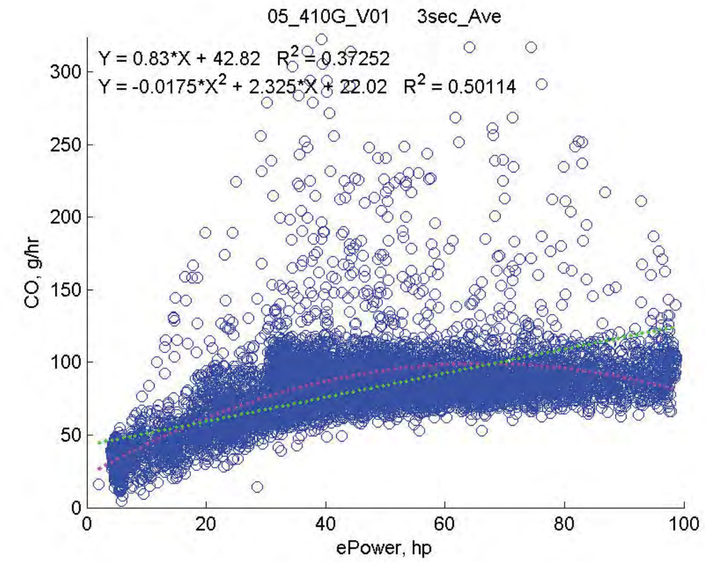

04_310SG_v01 3sec_Ave
x 10^4
Y = 503.62*X + 1817.73 R2 = 0.96956
Y = 0.9952*X2 + 433.907*X + 2774.16 R2 = 0.97152
CO2, g/hr
ePower, hp

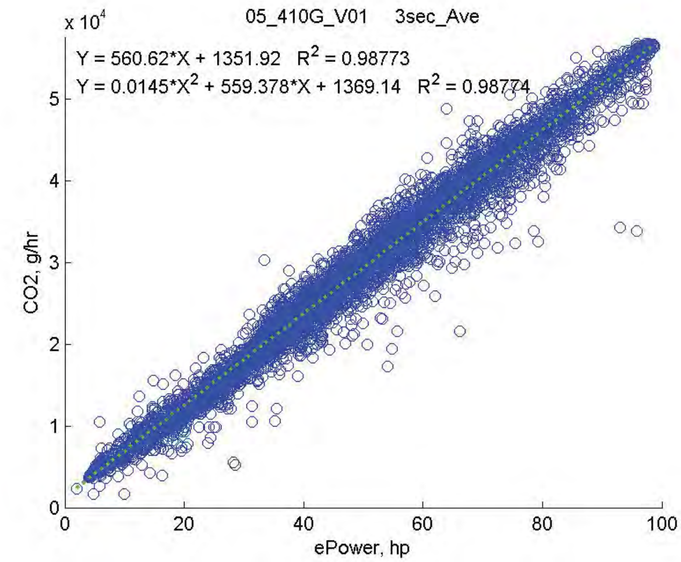

04_310SG_v01 3sec_Ave
Y = 158.56*X + 556.30 R2 = 0.96914
Y = 0.3352*X2 + 135.079*X + 878.46 R2 = 0.97138
FC, g/hr
ePower, hp

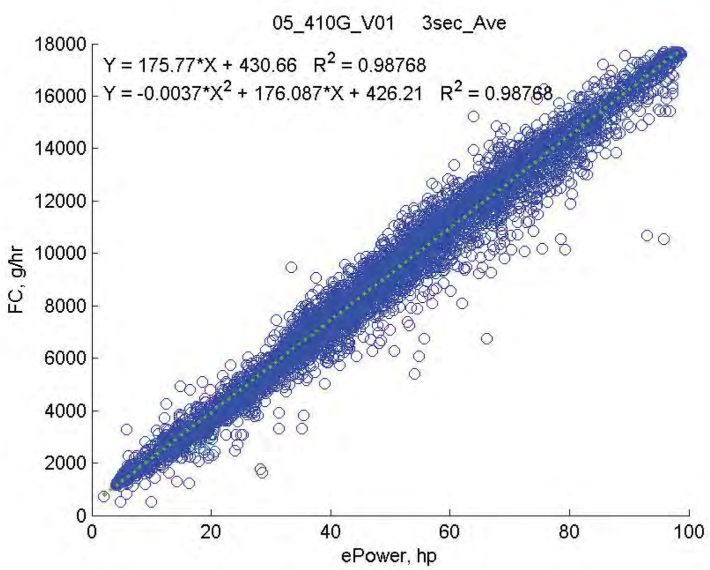

04_310SG_v01 3sec_Ave
Y = 0.15*X + 5.67 R2 = 0.66104
Y = -0.0014*X2 + 0.251*X + 4.33 R2 = 0.68888
NMHC, g/hr
ePower, hp

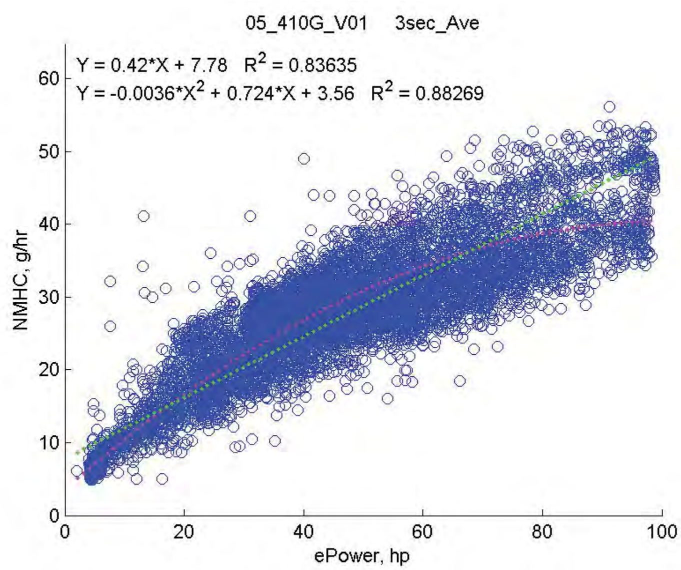

04_310SG_v01 3sec_Ave
Y = 2.42*X + 94.98 R2 = 0.69928
Y = 0.0121*X2 + 1.571*X + 106.58 R2 = 0.70829
NOx, g/hr
ePower, hp

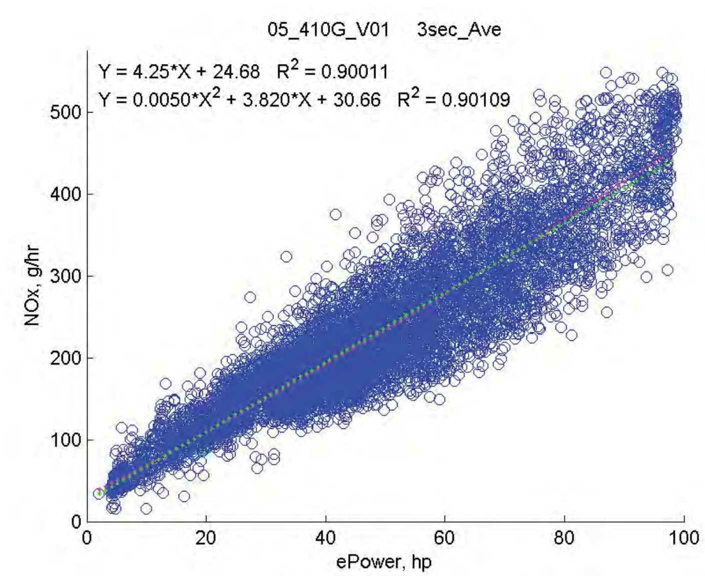

04_310SG_v01 3sec_Ave
Y = 0.10*X + 0.56 R2 = 0.056522
Y = 0.0014*X2 + 0.007*X + 1.89 R2 = 0.061739
PM, g/hr
ePower, hp

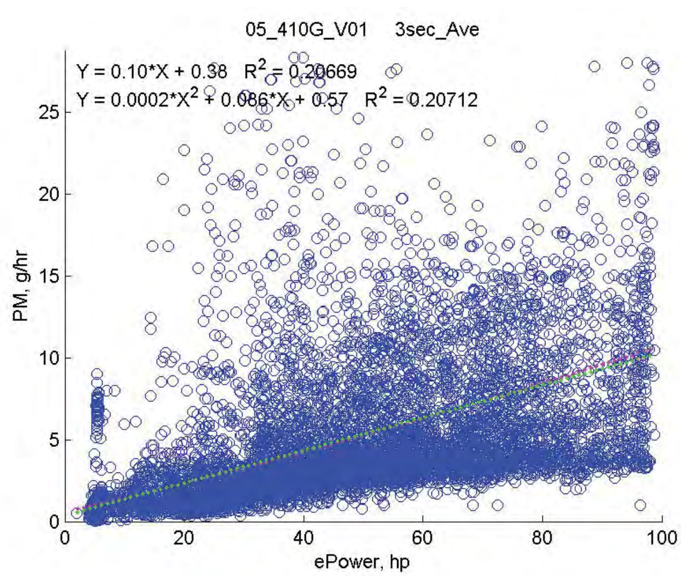

05_410G_V01 3sec_Ave
Y = 0.83*X + 42.82 R2 = 0.37252
Y = -0.0175*X2 + 2.325*X + 22.02 R2 = 0.50114
CO, g/hr
ePower, hp

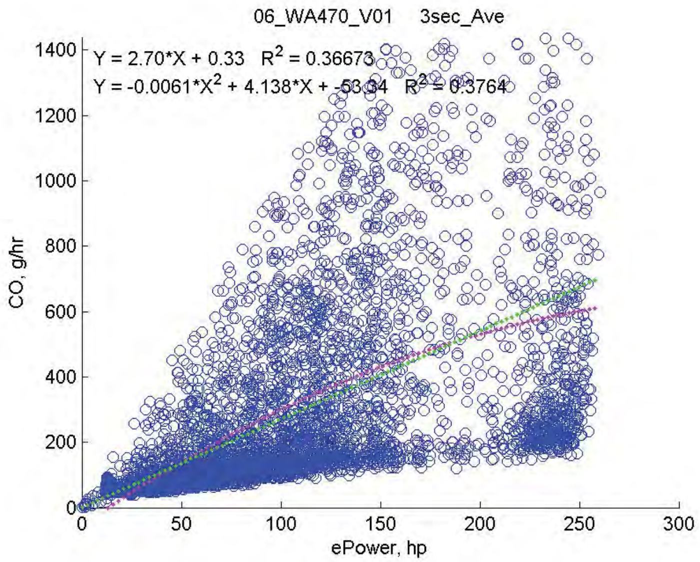

05_410G_V01 3sec_Ave
x 10^4
Y = 560.62*X + 1351.92 R2 = 0.98773
Y = 0.0145*X2 + 559.378*X + 1369.14 R2 = 0.98774
CO2, g/hr
ePower, hp

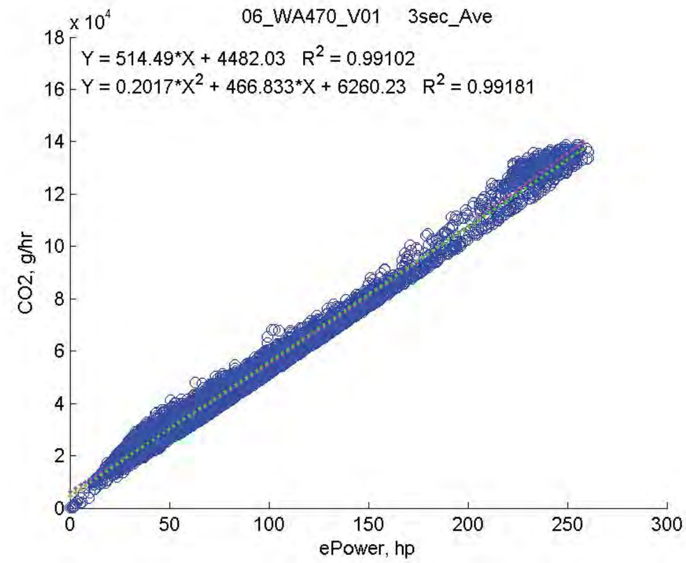

05_410G_V01 3sec_Ave
Y = 175.77*X + 430.66 R2 = 0.98768
Y = -0.0037*X2 + 176.087*X + 426.21 R2 = 0.98768
FC, g/hr
ePower, hp

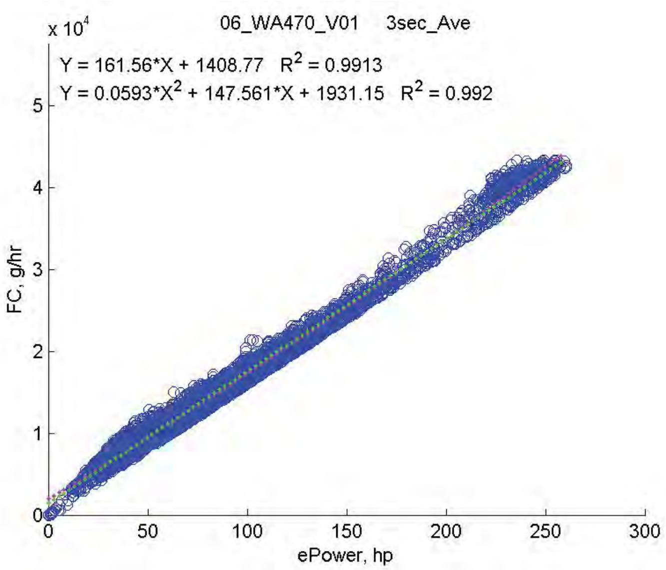

05_410G_V01 3sec_Ave
Y = 0.42*X + 7.78 R2 = 0.83635
Y = -0.0036*X2 + 0.724*X + 3.56 R2 = 0.88269
NMHC, g/hr
ePower, hp

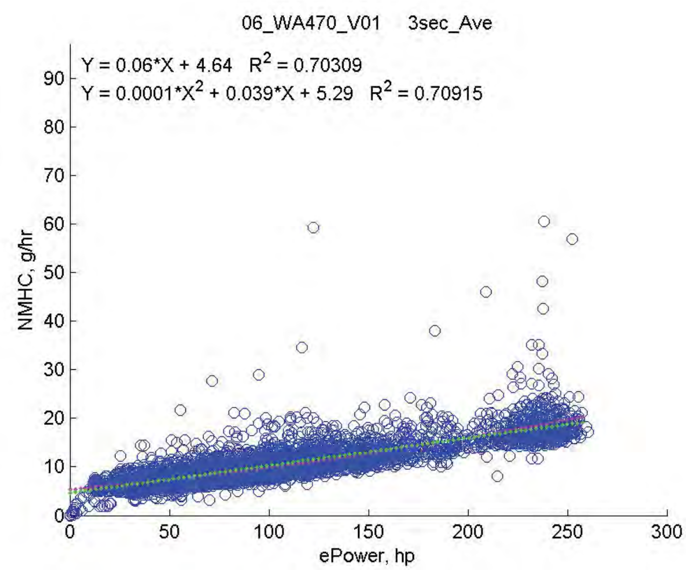

05_410G_V01 3sec_Ave
Y = 4.25*X + 24.68 R2 = 0.90011
Y = 0.0050*X2 + 3.820*X + 30.66 R2 = 0.90109
NOx, g/hr
ePower, hp

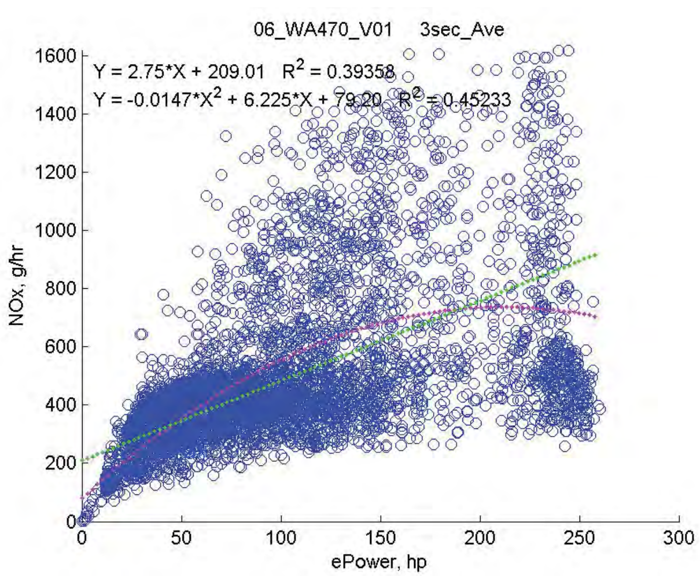

05_410G_V01 3sec_Ave
Y = 0.10*X + 0.38 R2 = 0.20669
Y = 0.0002*X2 + 0.086*X + 0.57 R2 = 0.20712
PM, g/hr
ePower, hp

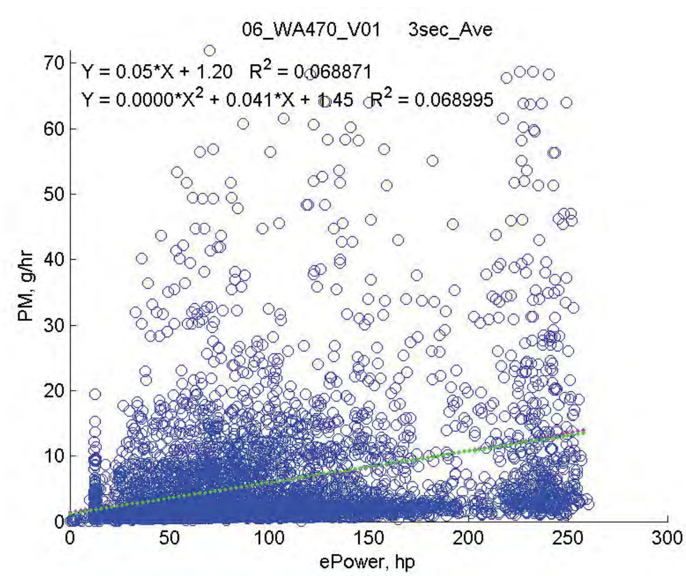

06_WA470_V01 3sec_Ave
Y = 2.70*X + 0.33 R2 = 0.36673
Y = -0.0061*X2 + 4.138*X + -53.34 R2 = 0.3764
CO, g/hr
ePower, hp

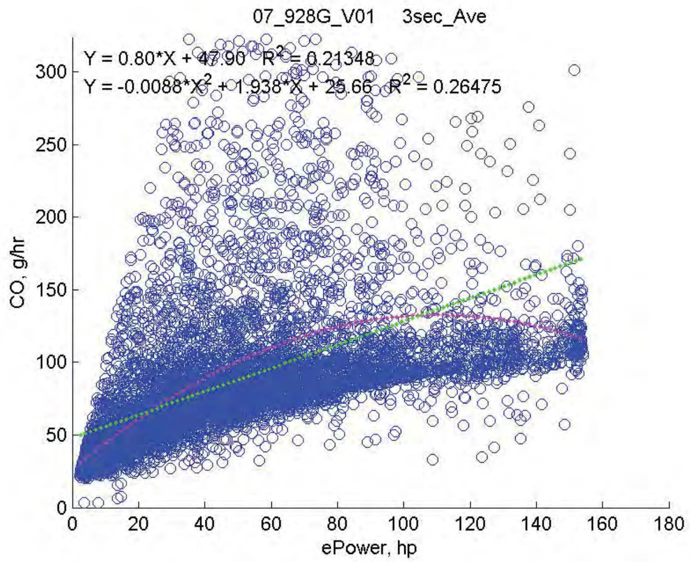

06_WA470_V01 3sec_Ave
x 10^4
Y = 514.49*X + 4482.03 R2 = 0.99102
Y = 0.2017*X2 + 466.833*X + 6260.23 R2 = 0.99181
CO2, g/hr
ePower, hp

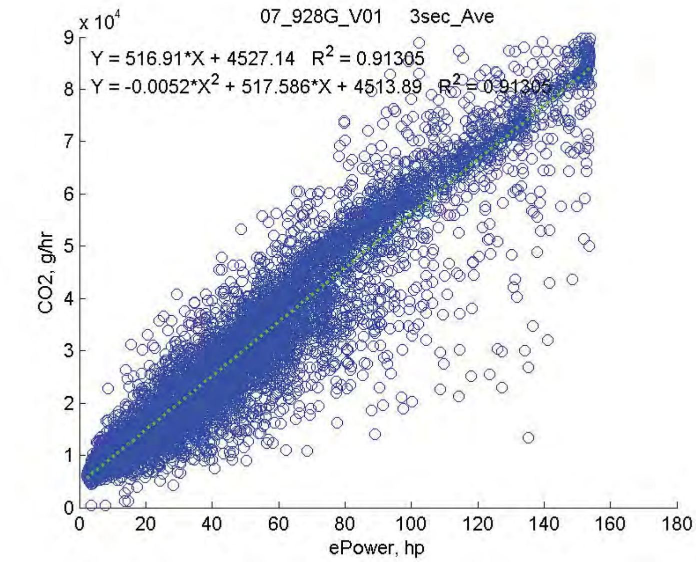

06_WA470_V01 3sec_Ave
x 10^4
Y = 161.56*X + 1408.77 R2 = 0.9913
Y = 0.0593*X2 + 147.561*X + 1931.15 R2 = 0.992
FC, g/hr
ePower, hp

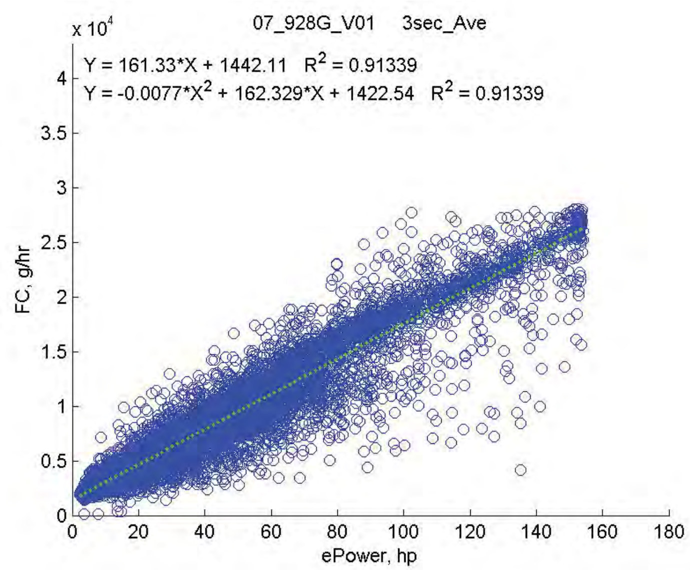

06_WA470_V01 3sec_Ave
Y = 0.06*X + 4.64 R2 = 0.70309
Y = 0.0001*X2 + 0.039*X + 5.29 R2 = 0.70915
NMHC, g/hr
ePower, hp

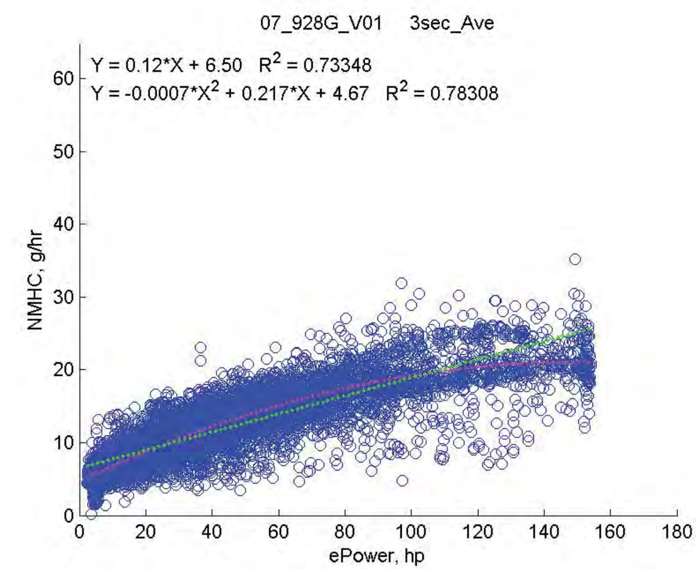

06_WA470_V01 3sec_Ave
Y = 2.75*X + 209.01 R2 = 0.39358
Y = -0.0147*X2 + 6.225*X + 79.20 R2 = 0.45233
NOx, g/hr
ePower, hp

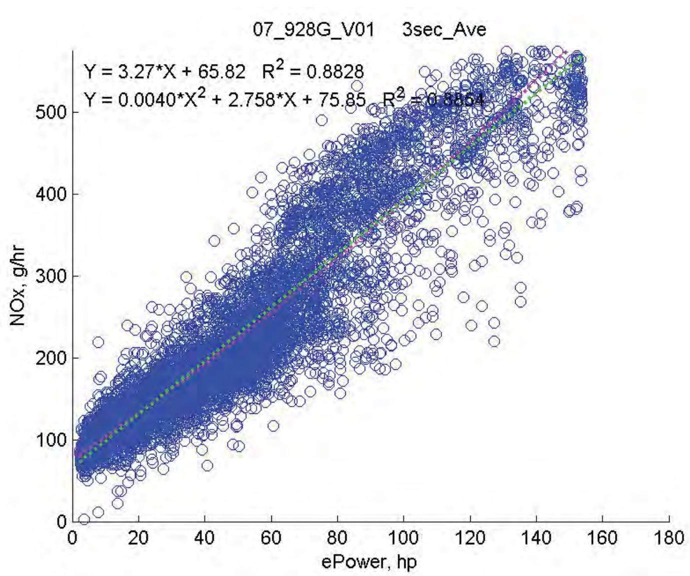

06_WA470_V01 3sec_Ave
Y = 0.05*X + 1.20 R2 = 0.068871
Y = 0.0000*X2 + 0.041*X + 1.45 R2 = 0.068995
PM, g/hr
ePower, hp

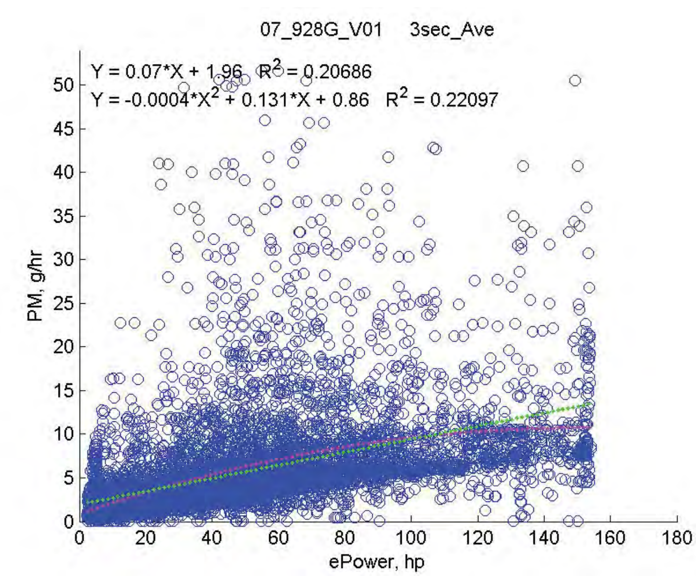

07_928G_V01 3sec_Ave
Y = 0.80*X + 47.90 R2 = 0.21348
Y = -0.0088*X2 + 1.938*X + 25.66 R2 = 0.26475
CO, g/hr
ePower, hp

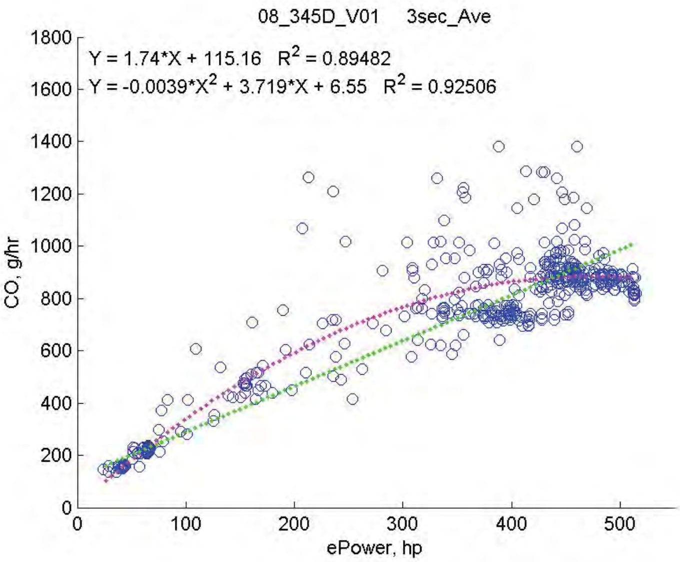

07_928G_V01 3sec_Ave
x 10^4
Y = 516.91*X + 4527.14 R2 = 0.91305
Y = -0.0052*X2 + 517.586*X + 4513.89 R2 = 0.91305
CO2, g/hr
ePower, hp

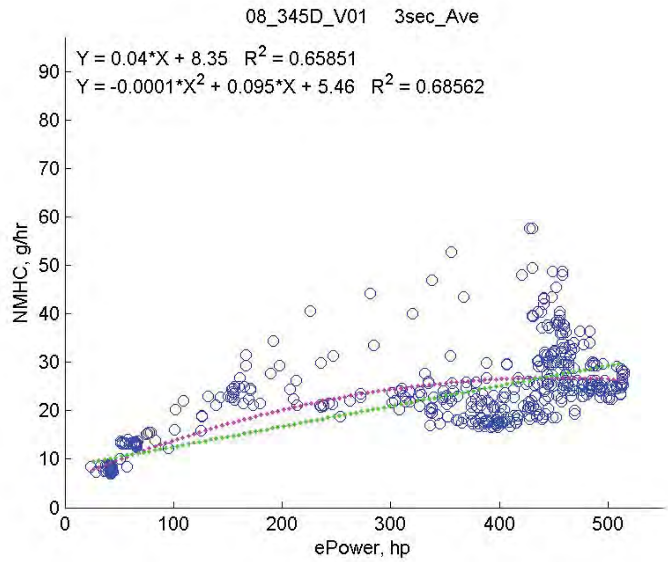

07_928G_V01 3sec_Ave
x 10^4
Y = 161.33*X + 1442.11 R2 = 0.91339
Y = -0.0077*X2 + 162.329*X + 1422.54 R2 = 0.91339
FC, g/hr
ePower, hp

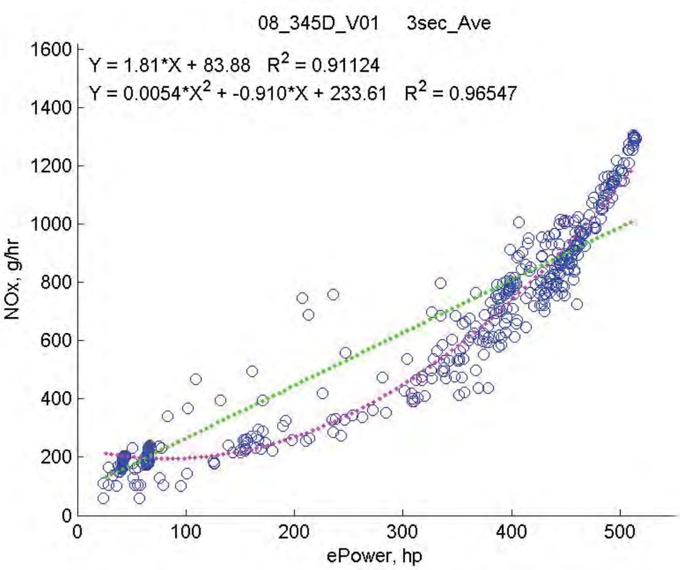

07_928G_V01 3sec_Ave
Y = 0.12*X + 6.50 R2 = 0.73348
Y = -0.0007*X2 + 0.217*X + 4.67 R2 = 0.78308
NMHC, g/hr
ePower, hp

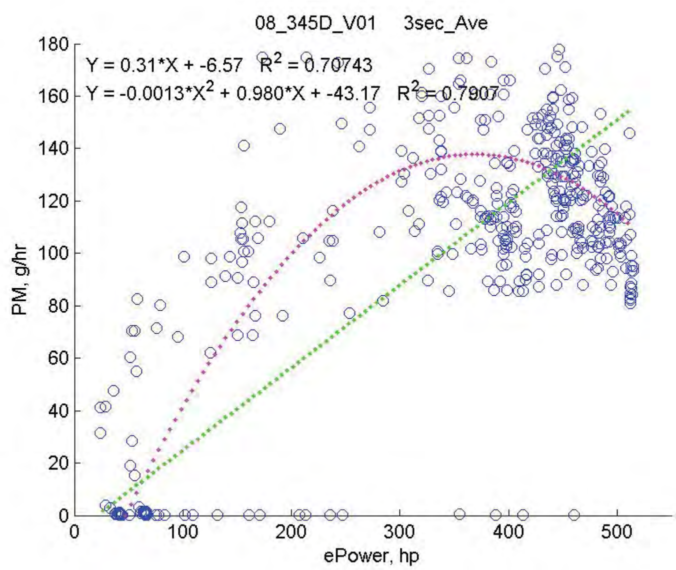

07_928G_V01 3sec_Ave
Y = 3.27*X + 65.82 R2 = 0.8828
Y = 0.0040*X2 + 2.758*X + 75.85 R2 = 0.8864
NOx, g/hr
ePower, hp

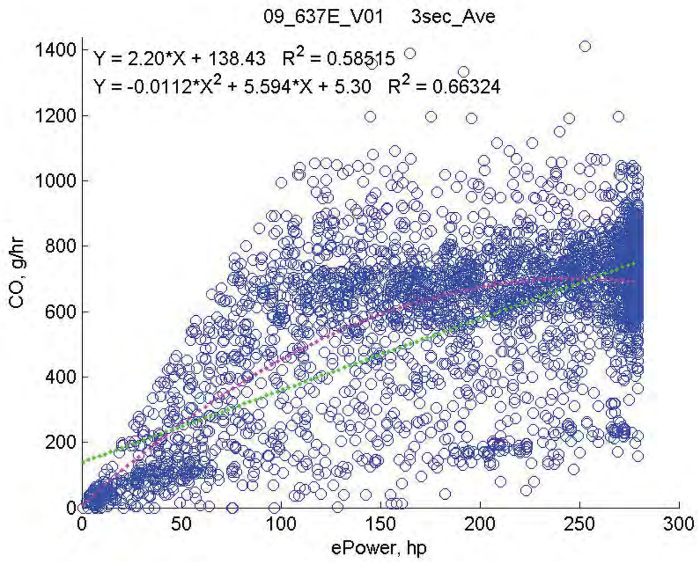

07_928G_V01 3sec_Ave
Y = 0.07*X + 1.96 R2 = 0.20686
Y = -0.0004*X2 + 0.131*X + 0.86 R2 = 0.22097
PM, g/hr
ePower, hp

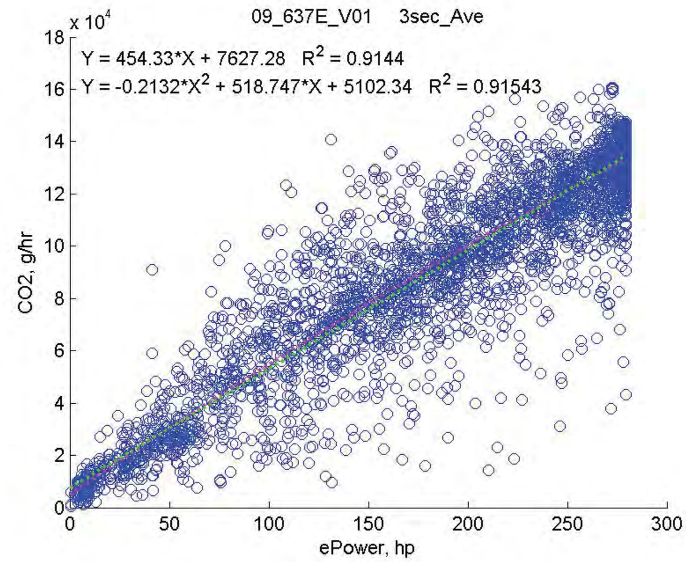

08_345D_V01 3sec_Ave
Y = 1.74*X + 115.16 R2 = 0.89482
Y = -0.0039*X2 + 3.719*X + 6.55 R2 = 0.92506
CO, g/hr
ePower, hp

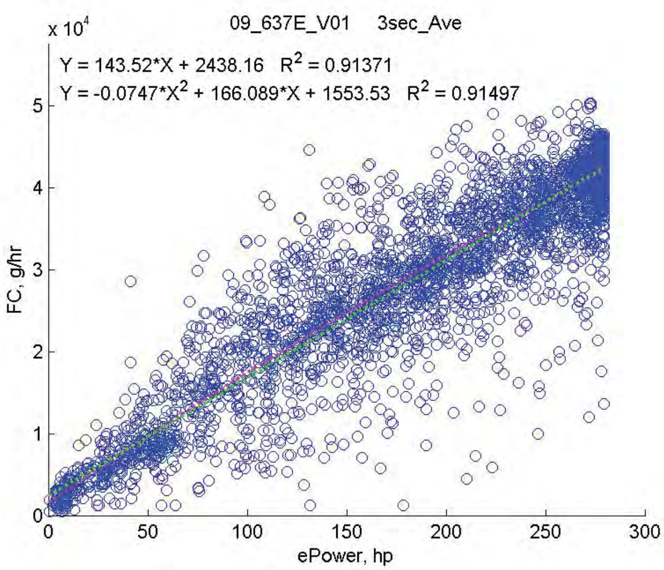

08_345D_V01 3sec_Ave
Y = 0.04*X + 8.35 R2 = 0.65851
Y = -0.0001*X2 + 0.095*X + 5.46 R2 = 0.68562
NMHC, g/hr
ePower, hp

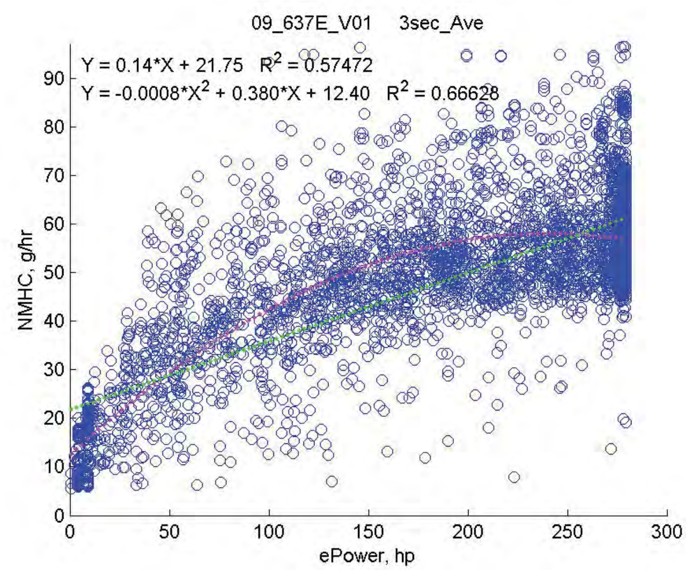

08_345D_V01 3sec_Ave
Y = 1.81*X + 83.88 R2 = 0.91124
Y = 0.0054*X2 + -0.910*X + 233.61 R2 = 0.96547
NOx, g/hr
ePower, hp

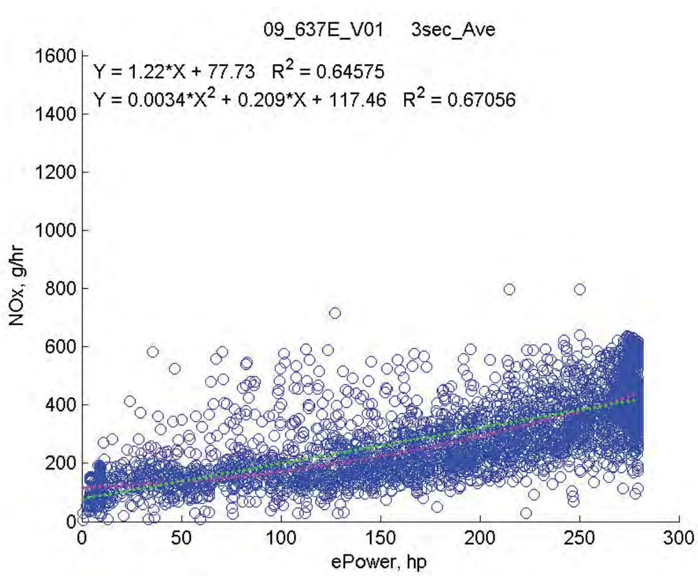

08_345D_V01 3sec_Ave
Y = 0.31*X + -6.57 R2 = 0.70743
Y = -0.0013*X2 + 0.980*X + -43.17 R2 = 0.7907
PM, g/hr
ePower, hp

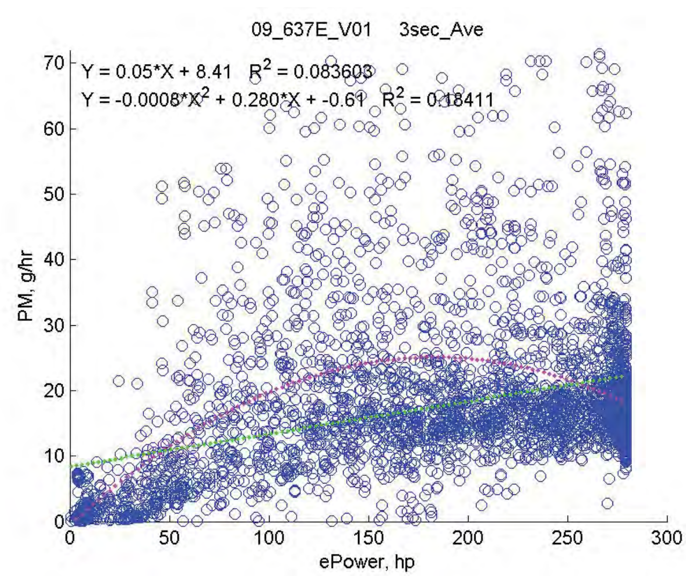

09_637E_V01 3sec_Ave
Y = 2.20*X + 138.43 R^2 = 0.58515
Y = -0.0112*X^2 + 5.594*X + 5.30 R^2 = 0.66324
CO, g/hr
ePower, hp

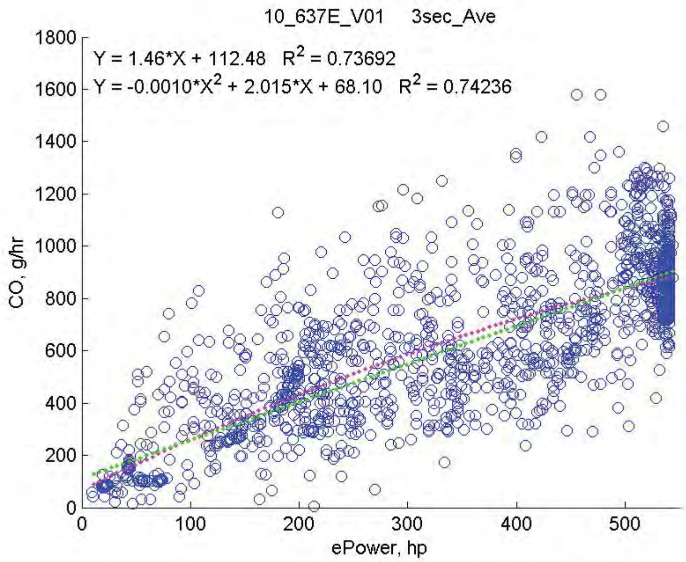

09_637E_V01 3sec_Ave
x 10^4
Y = 454.33*X + 7627.28 R^2 = 0.9144
Y = -0.2132*X^2 + 518.747*X + 5102.34 R^2 = 0.91543
CO2, g/hr
ePower, hp

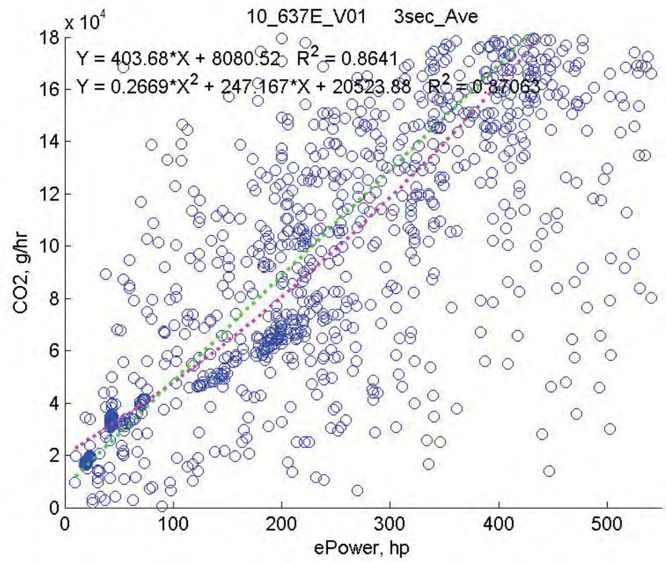

09_637E_V01 3sec_Ave
x 10^4
Y = 143.52*X + 2438.16 R^2 = 0.91371
Y = -0.0747*X^2 + 166.089*X + 1553.53 R^2 = 0.91497
FC, g/hr
ePower, hp

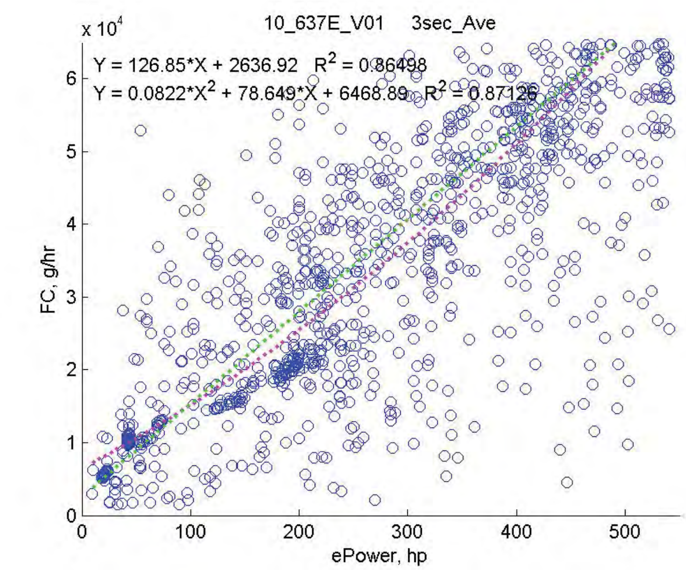

09_637E_V01 3sec_Ave
Y = 0.14*X + 21.75 R^2 = 0.57472
Y = -0.0008*X^2 + 0.380*X + 12.40 R^2 = 0.66628
NMHC, g/hr
ePower, hp

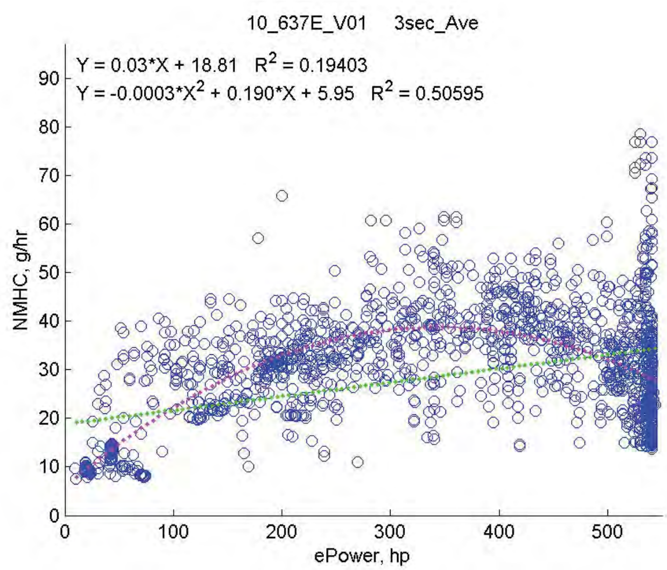

09_637E_V01 3sec_Ave
Y = 1.22*X + 77.73 R^2 = 0.64575
Y = 0.0034*X^2 + 0.209*X + 117.46 R^2 = 0.67056
NOx, g/hr
ePower, hp

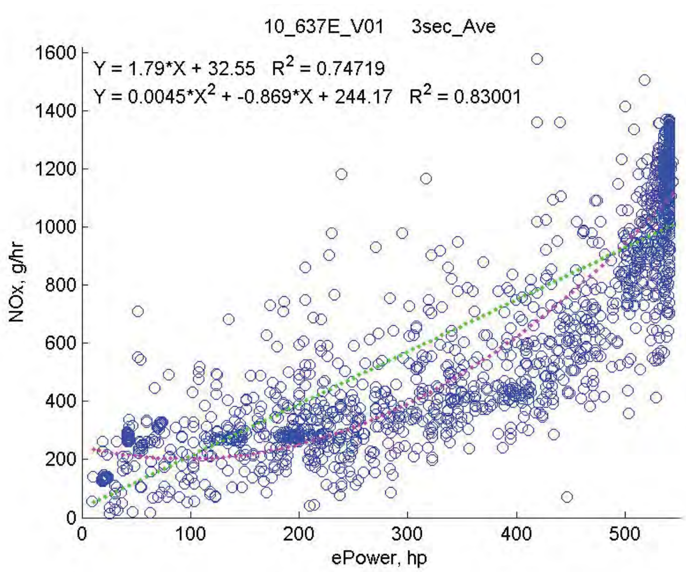

09_637E_V01 3sec_Ave
Y = 0.05*X + 8.41 R^2 = 0.083603
Y = -0.0008*X^2 + 0.280*X + -0.61 R^2 = 0.18411
PM, g/hr
ePower, hp

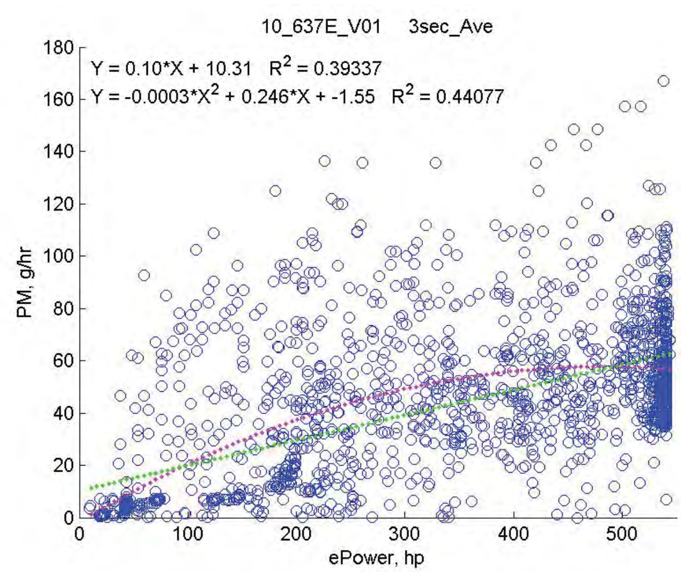

10_637E_V01 3sec_Ave
Y = 1.46*X + 112.48 R2 = 0.73692
Y = -0.0010*X2 + 2.015*X + 68.10 R2 = 0.74236
CO, g/hr
ePower, hp

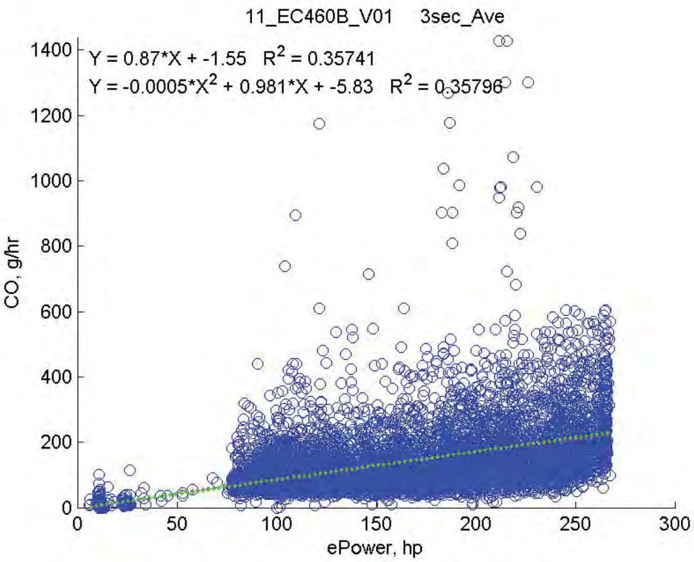

10_637E_V01 3sec_Ave
x 10^4
Y = 403.68*X + 8080.52 R2 = 0.8641
Y = 0.2669*X2 + 247.167*X + 20523.88 R2 = 0.87063
CO2, g/hr
ePower, hp

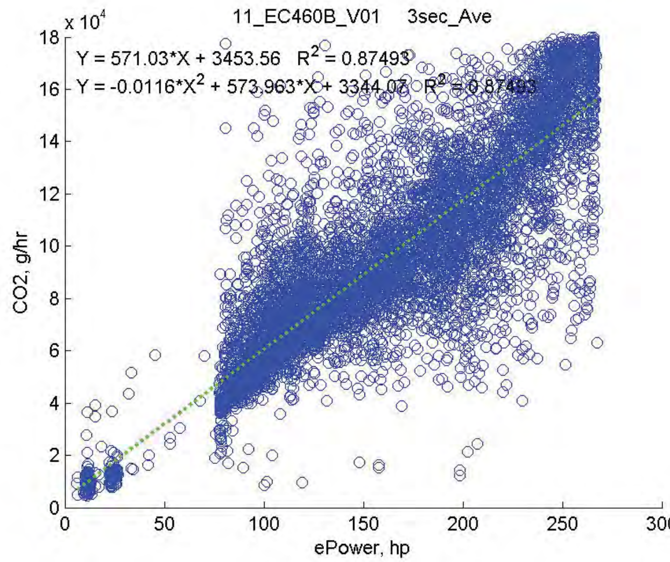

10_637E_V01 3sec_Ave
x 10^4
Y = 126.85*X + 2636.92 R2 = 0.86498
Y = 0.0822*X2 + 78.649*X + 6468.89 R2 = 0.87126
FC, g/hr
ePower, hp

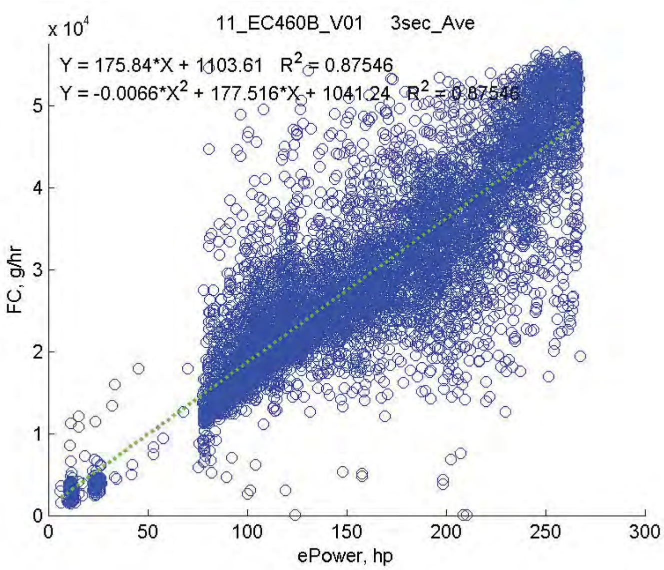

10_637E_V01 3sec_Ave
Y = 0.03*X + 18.81 R2 = 0.19403
Y = -0.0003*X2 + 0.190*X + 5.95 R2 = 0.50595
NMHC, g/hr
ePower, hp

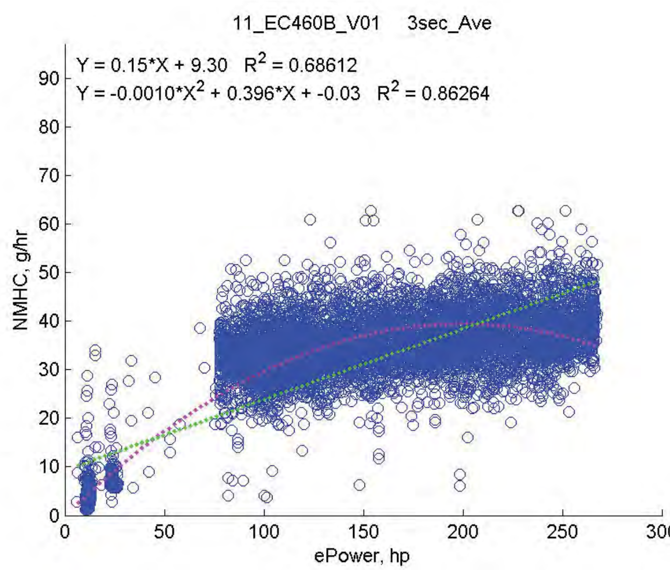

10_637E_V01 3sec_Ave
Y = 1.79*X + 32.55 R2 = 0.74719
Y = 0.0045*X2 + -0.869*X + 244.17 R2 = 0.83001
NOx, g/hr
ePower, hp

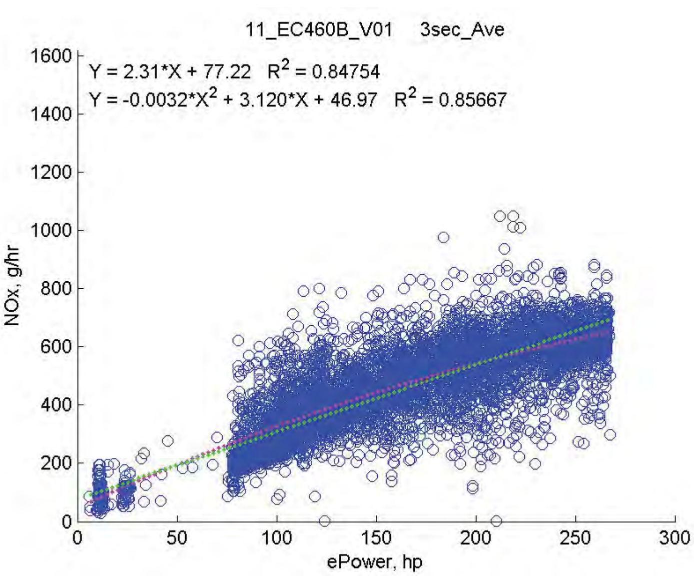

10_637E_V01 3sec_Ave
Y = 0.10*X + 10.31 R2 = 0.39337
Y = -0.0003*X2 + 0.246*X + -1.55 R2 = 0.44077
PM, g/hr
ePower, hp

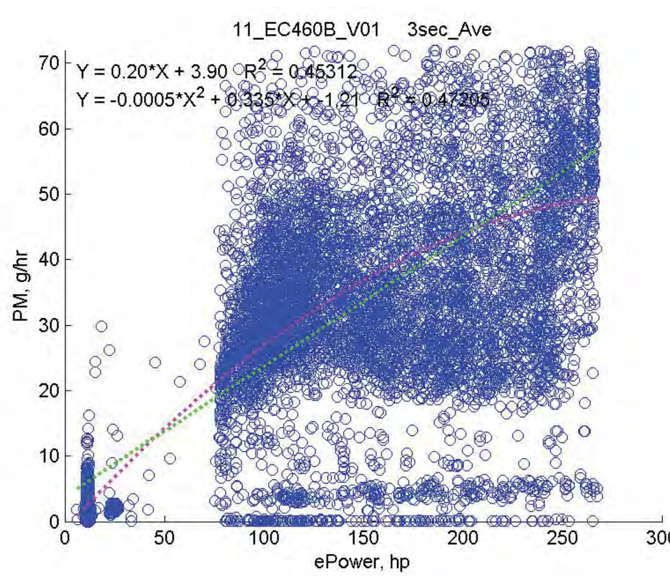

11_EC460B_V01 3sec_Ave
Y = 0.87*X + -1.55 R^2 = 0.35741
Y = -0.0005*X^2 + 0.981*X + -5.83 R^2 = 0.35796
CO, g/hr
ePower, hp

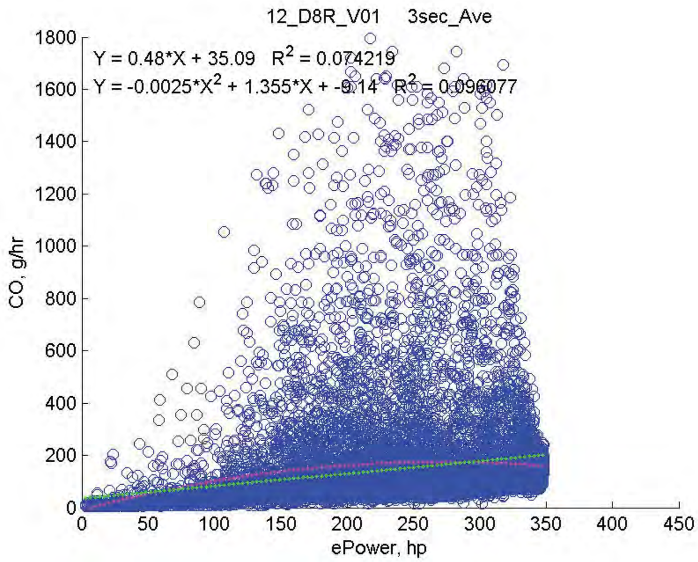

11_EC460B_V01 3sec_Ave
x 10^4
Y = 571.03*X + 3453.56 R^2 = 0.87493
Y = -0.0116*X^2 + 573.963*X + 3344.07 R^2 = 0.87493
CO2, g/hr
ePower, hp

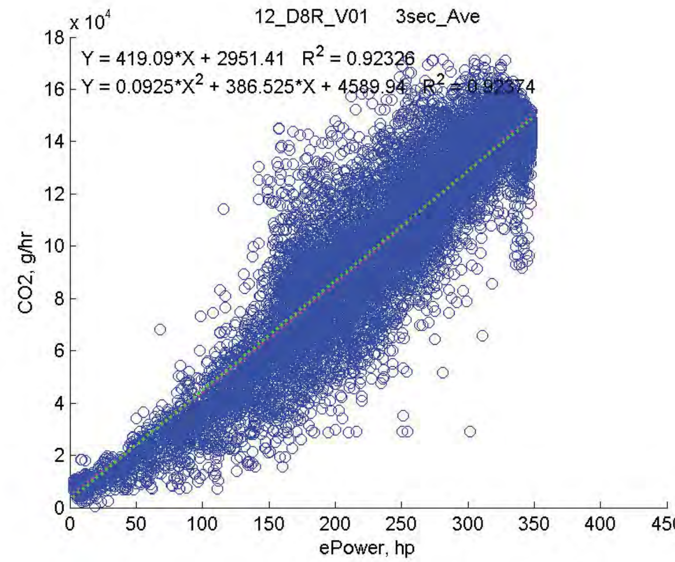

11_EC460B_V01 3sec_Ave
x 10^4
Y = 175.84*X + 1103.61 R^2 = 0.87546
Y = -0.0066*X^2 + 177.516*X + 1041.24 R^2 = 0.87546
FC, g/hr
ePower, hp

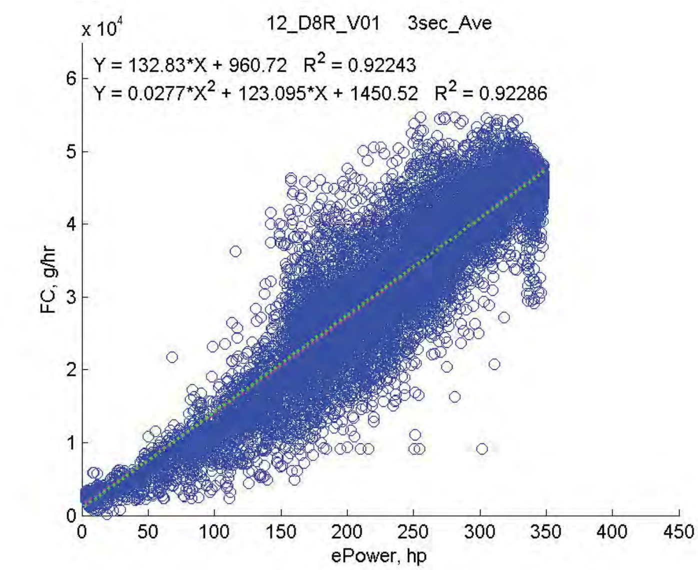

11_EC460B_V01 3sec_Ave
Y = 0.15*X + 9.30 R^2 = 0.68612
Y = -0.0010*X^2 + 0.396*X + -0.03 R^2 = 0.86264
NMHC, g/hr
ePower, hp

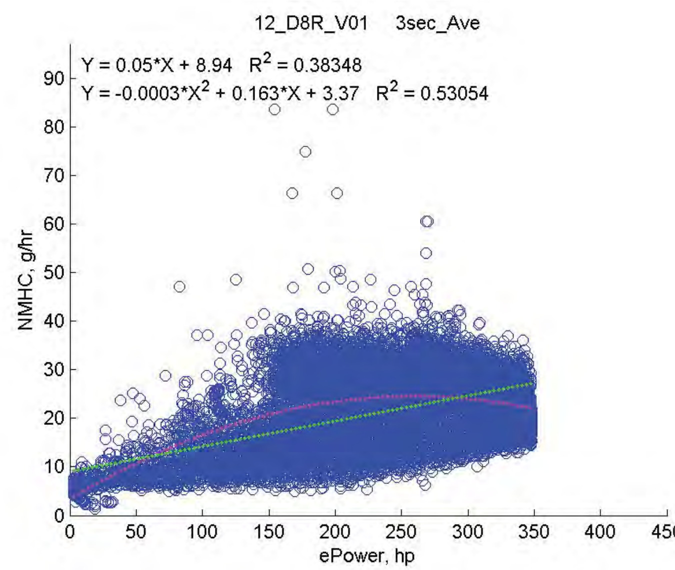

11_EC460B_V01 3sec_Ave
Y = 2.31*X + 77.22 R^2 = 0.84754
Y = -0.0032*X^2 + 3.120*X + 46.97 R^2 = 0.85667
NOx, g/hr
ePower, hp

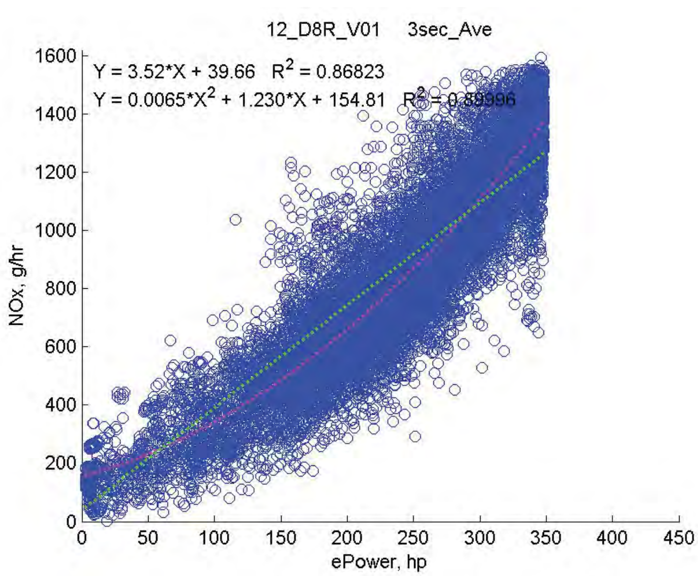

11_EC460B_V01 3sec_Ave
Y = 0.20*X + 3.90 R^2 = 0.45312
Y = -0.0005*X^2 + 0.335*X + -1.21 R^2 = 0.47205
PM, g/hr
ePower, hp

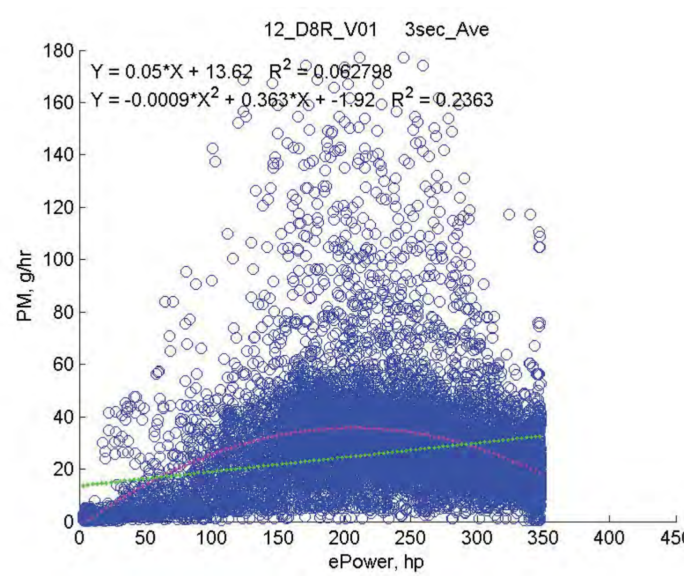

12_D8R_V01 3sec_Ave
Y = 0.48*X + 35.09 R2 = 0.074219
Y = -0.0025*X2 + 1.355*X + -9.14 R2 = 0.096077
CO, g/hr
ePower, hp

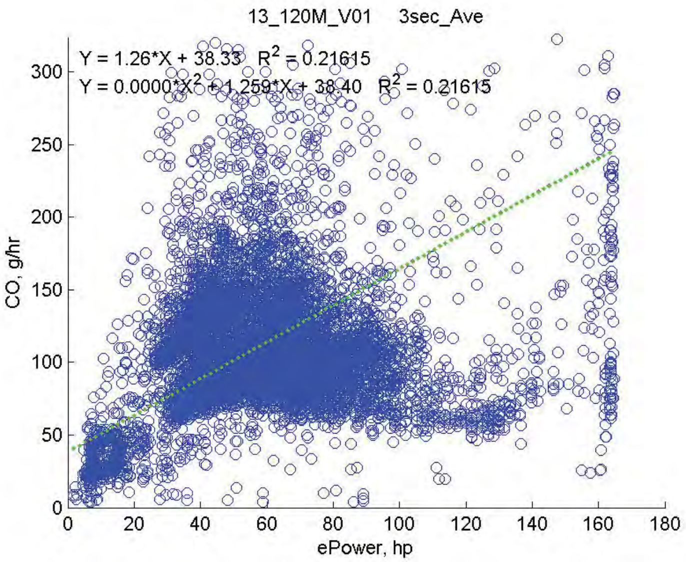

12_D8R_V01 3sec_Ave
x 10^4
Y = 419.09*X + 2951.41 R2 = 0.92326
Y = 0.0925*X2 + 386.525*X + 4589.94 R2 = 0.92374
CO2, g/hr
ePower, hp

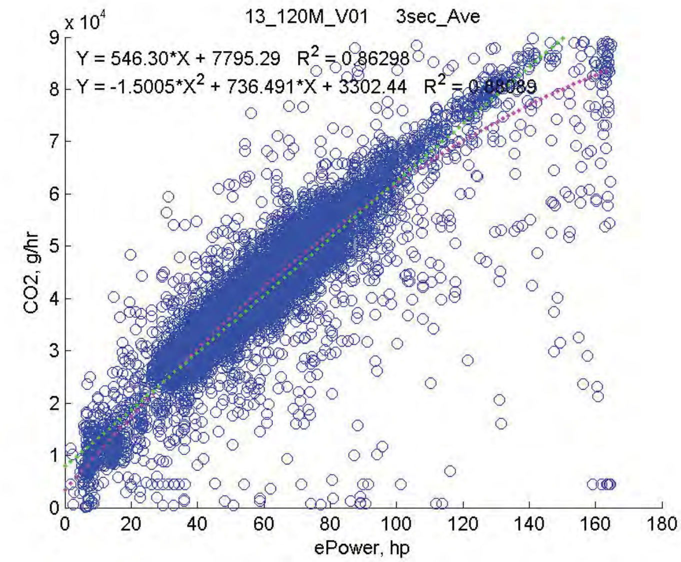

12_D8R_V01 3sec_Ave
x 10^4
Y = 132.83*X + 960.72 R2 = 0.92243
Y = 0.0277*X2 + 123.095*X + 1450.52 R2 = 0.92286
FC, g/hr
ePower, hp

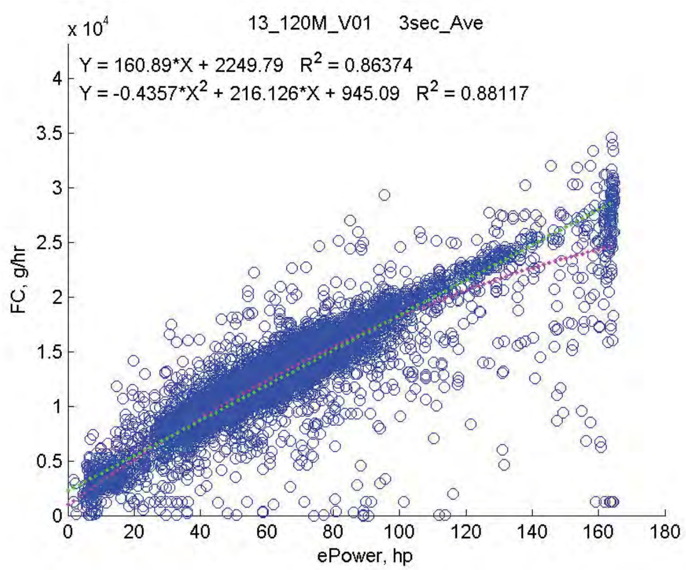

12_D8R_V01 3sec_Ave
Y = 0.05*X + 8.94 R2 = 0.38348
Y = -0.0003*X2 + 0.163*X + 3.37 R2 = 0.53054
NMHC, g/hr
ePower, hp

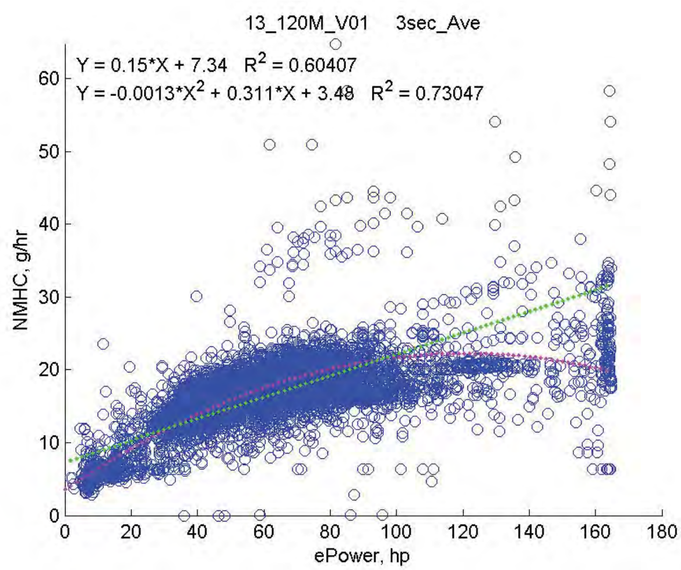

12_D8R_V01 3sec_Ave
Y = 3.52*X + 39.66 R2 = 0.86823
Y = 0.0065*X2 + 1.230*X + 154.81 R2 = 0.89996
NOx, g/hr
ePower, hp

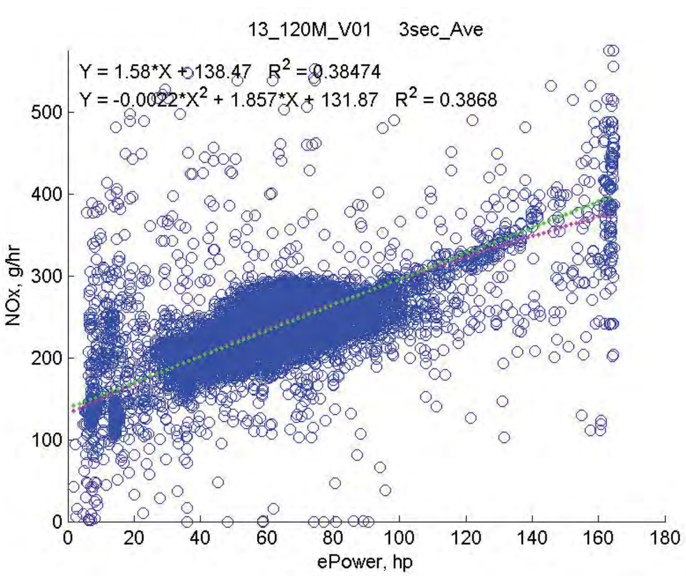

12_D8R_V01 3sec_Ave
Y = 0.05*X + 13.62 R2 = 0.062798
Y = -0.0009*X2 + 0.363*X + -1.92 R2 = 0.2363
PM, g/hr
ePower, hp

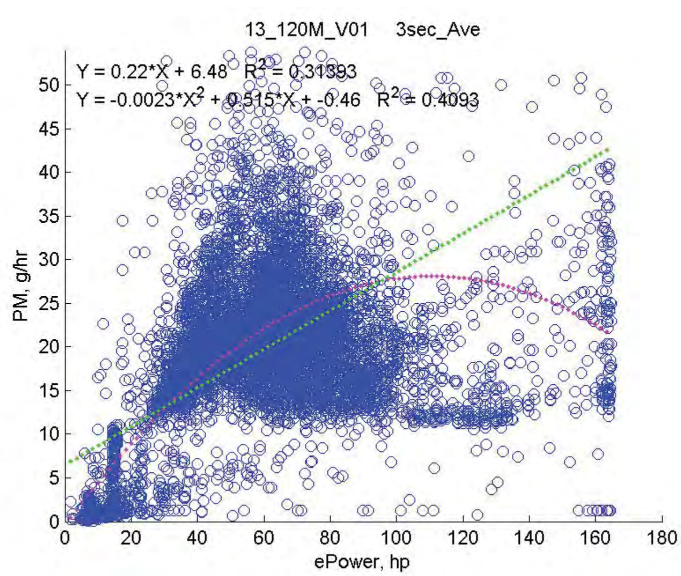

13_120M_V01 3sec_Ave
Y = 1.26*X + 38.33 R2 = 0.21615
Y = 0.0000*X2 + 1.259*X + 38.40 R2 = 0.21615
CO, g/hr
ePower, hp

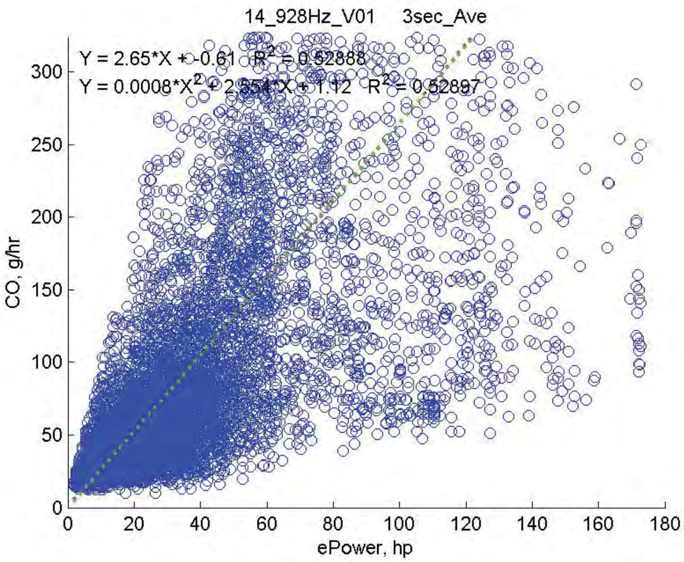

13_120M_V01 3sec_Ave
x 10^4
Y = 546.30*X + 7795.29 R2 = 0.86298
Y = -1.5005*X2 + 736.491*X + 3302.44 R2 = 0.88089
CO2, g/hr
ePower, hp

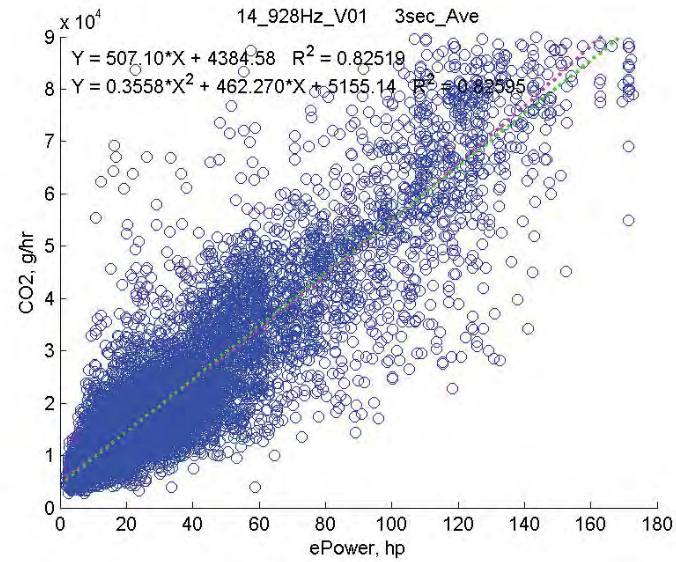

13_120M_V01 3sec_Ave
x 10^4
Y = 160.89*X + 2249.79 R2 = 0.86374
Y = -0.4357*X2 + 216.126*X + 945.09 R2 = 0.88117
FC, g/hr
ePower, hp

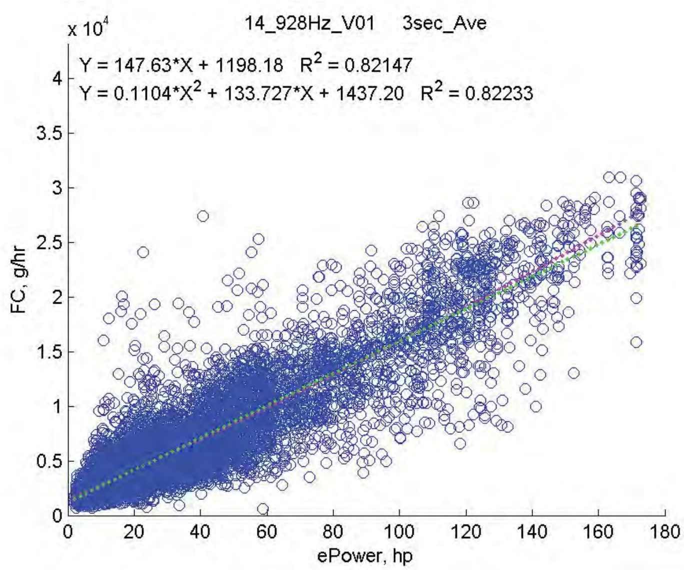

13_120M_V01 3sec_Ave
Y = 0.15*X + 7.34 R2 = 0.60407
Y = -0.0013*X2 + 0.311*X + 3.48 R2 = 0.73047
NMHC, g/hr
ePower, hp

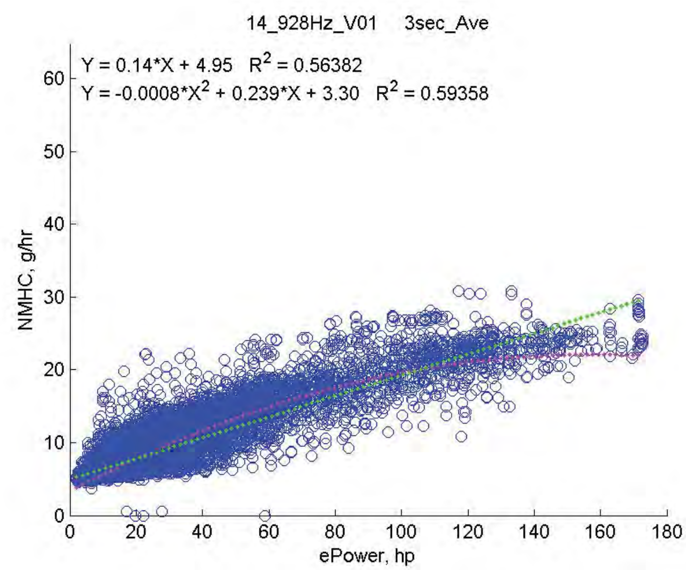

13_120M_V01 3sec_Ave
Y = 1.58*X + 138.47 R2 = 0.38474
Y = -0.0022*X2 + 1.857*X + 131.87 R2 = 0.3868
NOx, g/hr
ePower, hp

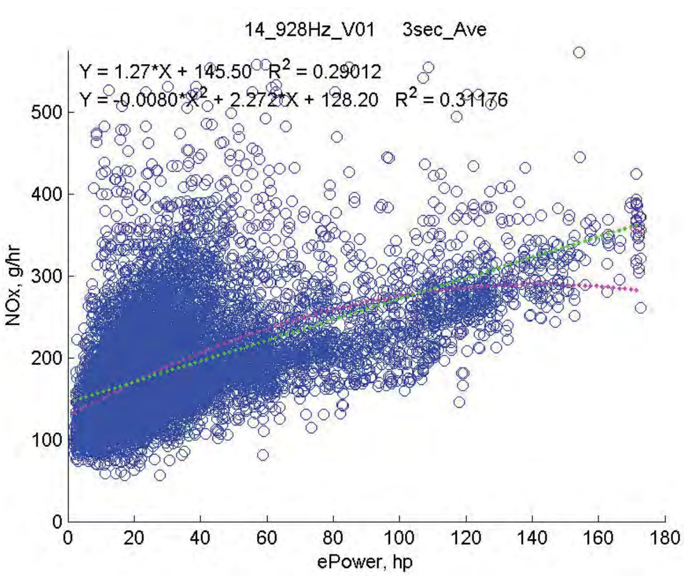

13_120M_V01 3sec_Ave
Y = 0.22*X + 6.48 R2 = 0.31393
Y = -0.0023*X2 + 0.515*X + -0.46 R2 = 0.4093
PM, g/hr
ePower, hp

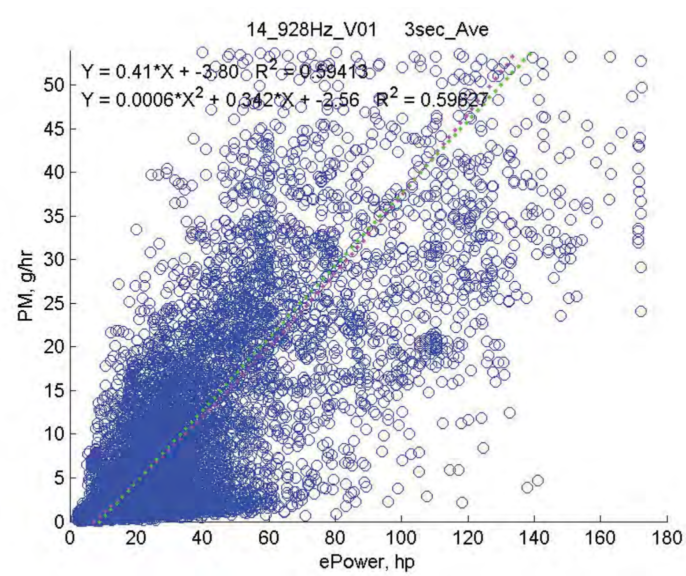

14_928Hz_V01 3sec_Ave
Y = 2.65*X + -0.61 R^2 = 0.52888
Y = 0.0008*X^2 + 2.554*X + 1.12 R^2 = 0.52897
CO, g/hr
ePower, hp

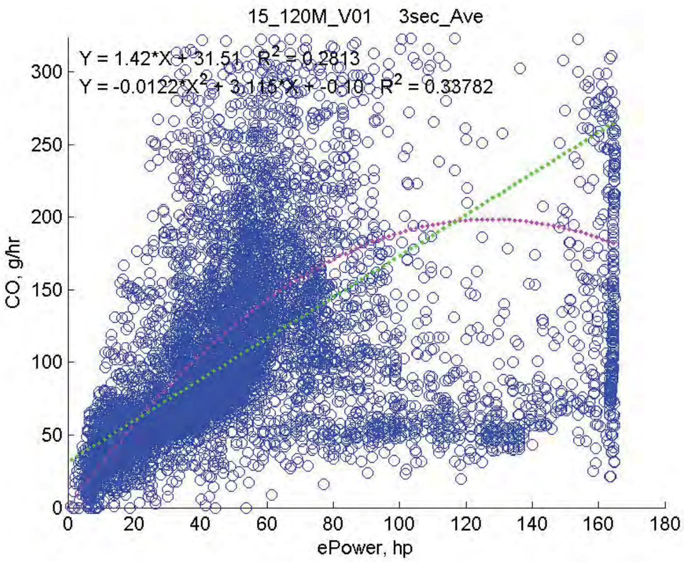

14_928Hz_V01 3sec_Ave
x 10^4
Y = 507.10*X + 4384.58 R^2 = 0.82519
Y = 0.3558*X^2 + 462.270*X + 5155.14 R^2 = 0.82595
CO2, g/hr
ePower, hp

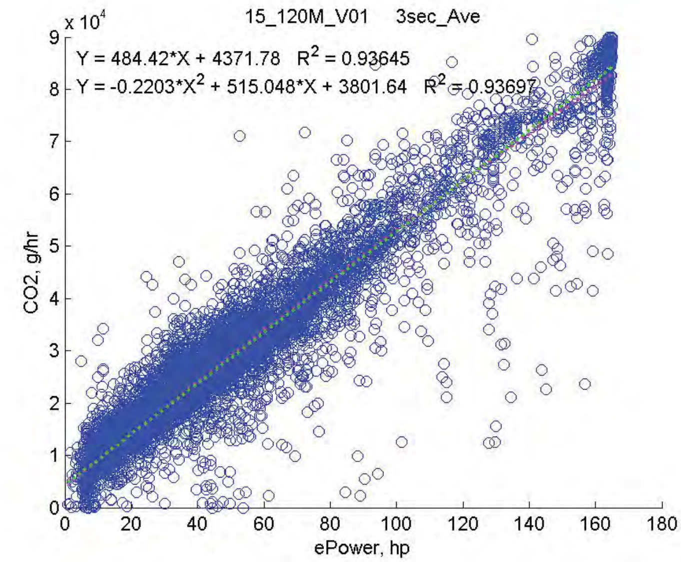

14_928Hz_V01 3sec_Ave
x 10^4
Y = 147.63*X + 1198.18 R^2 = 0.82147
Y = 0.1104*X^2 + 133.727*X + 1437.20 R^2 = 0.82233
FC, g/hr
ePower, hp

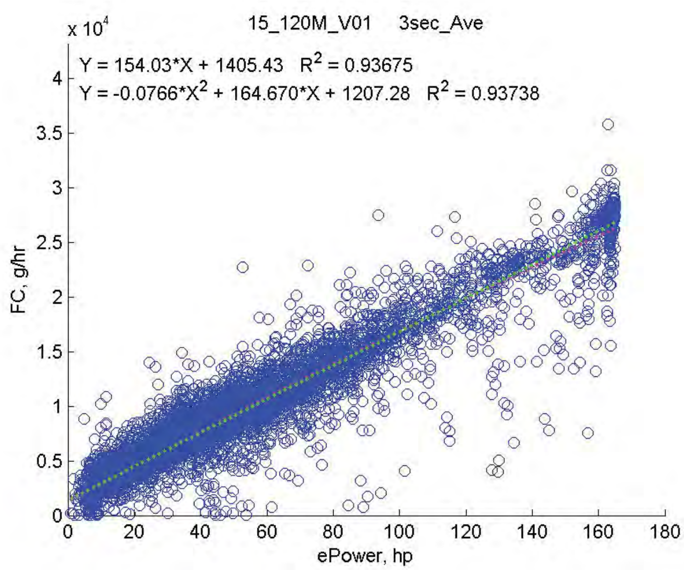

14_928Hz_V01 3sec_Ave
Y = 0.14*X + 4.95 R^2 = 0.56382
Y = -0.0008*X^2 + 0.239*X + 3.30 R^2 = 0.59358
NMHC, g/hr
ePower, hp

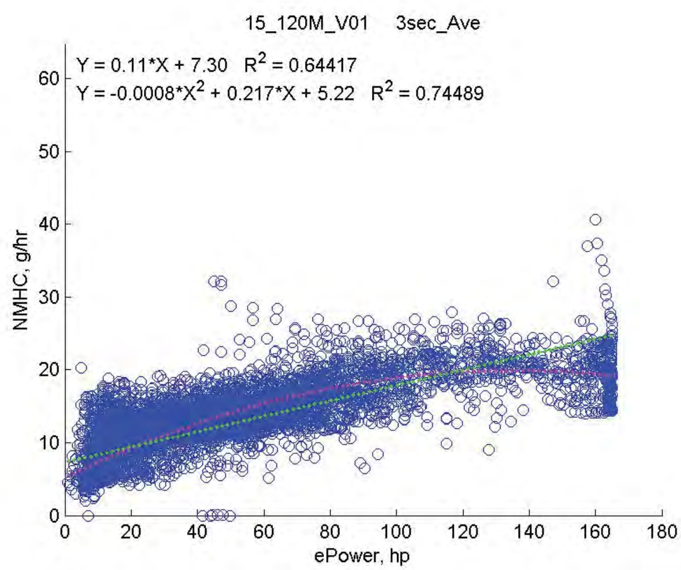

14_928Hz_V01 3sec_Ave
Y = 1.27*X + 145.50 R^2 = 0.29012
Y = -0.0080*X^2 + 2.272*X + 128.20 R^2 = 0.31176
NOx, g/hr
ePower, hp

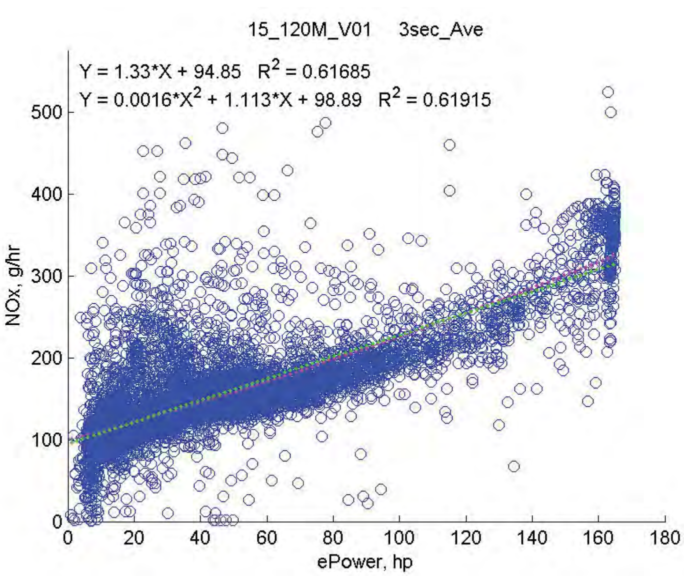

14_928Hz_V01 3sec_Ave
Y = 0.41*X + -3.80 R^2 = 0.59413
Y = 0.0006*X^2 + 0.342*X + -2.56 R^2 = 0.59627
PM, g/hr
ePower, hp

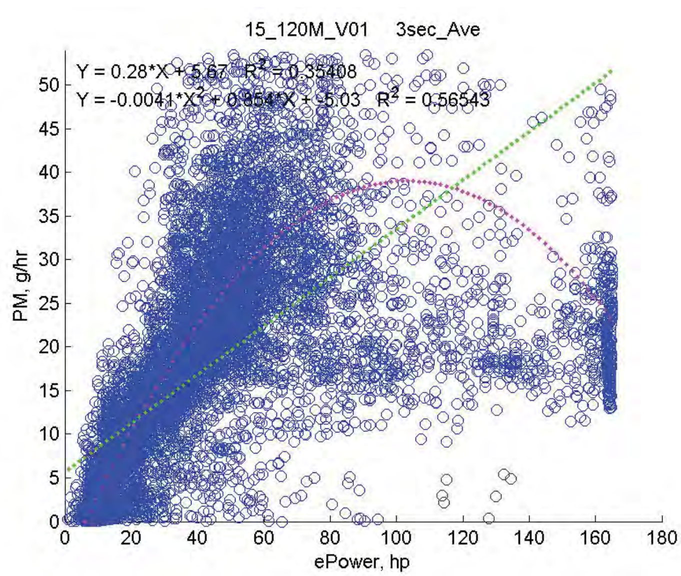

15_120M_V01 3sec_Ave
Y = 1.42*X + 31.51 R^2 = 0.2813
Y = -0.0122*X^2 + 3.115*X + -0.10 R^2 = 0.33782
CO, g/hr
ePower, hp

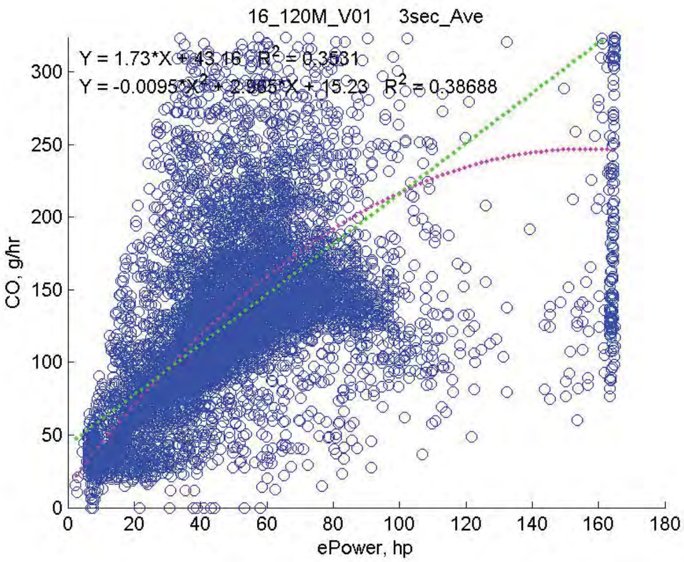

15_120M_V01 3sec_Ave
x 10^4
Y = 484.42*X + 4371.78 R^2 = 0.93645
Y = -0.2203*X^2 + 515.048*X + 3801.64 R^2 = 0.93697
CO2, g/hr
ePower, hp

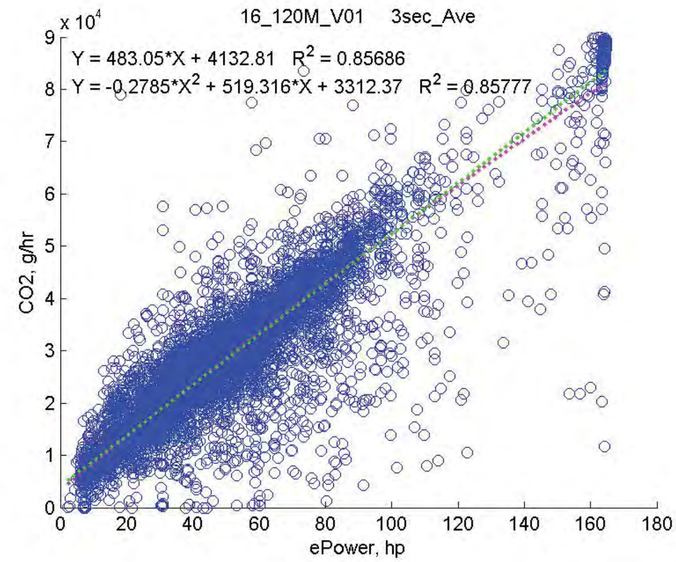

15_120M_V01 3sec_Ave
x 10^4
Y = 154.03*X + 1405.43 R^2 = 0.93675
Y = -0.0766*X^2 + 164.670*X + 1207.28 R^2 = 0.93738
FC, g/hr
ePower, hp

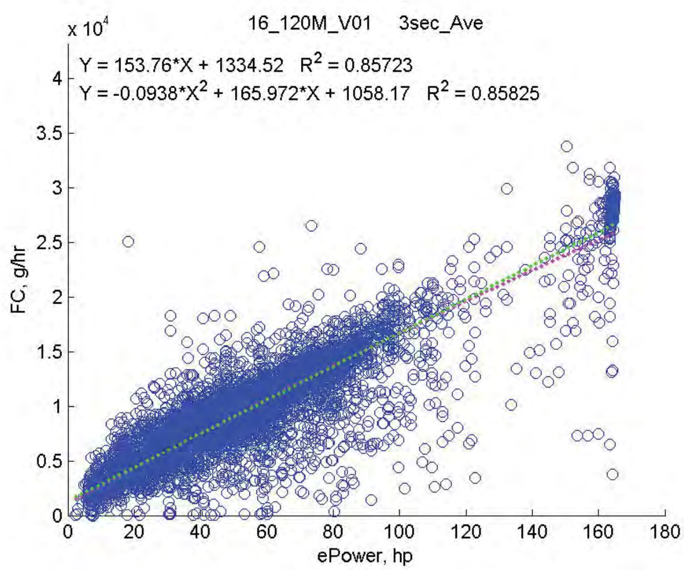

15_120M_V01 3sec_Ave
Y = 0.11*X + 7.30 R^2 = 0.64417
Y = -0.0008*X^2 + 0.217*X + 5.22 R^2 = 0.74489
NMHC, g/hr
ePower, hp

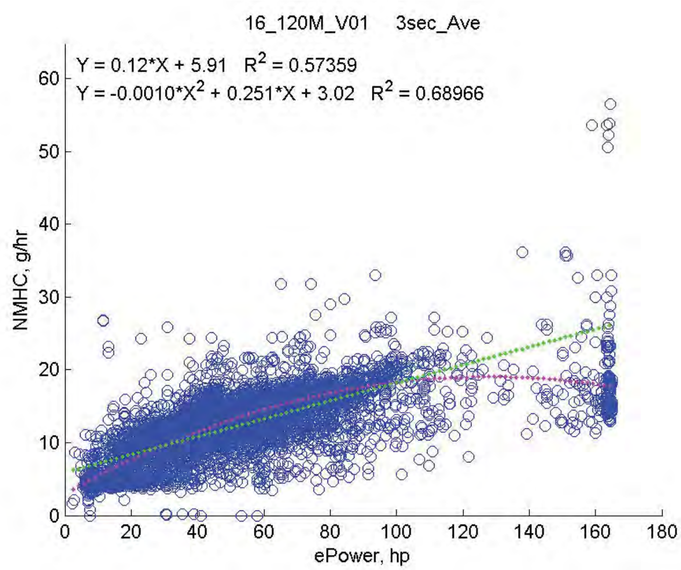

15_120M_V01 3sec_Ave
Y = 1.33*X + 94.85 R^2 = 0.61685
Y = 0.0016*X^2 + 1.113*X + 98.89 R^2 = 0.61915
NOx, g/hr
ePower, hp

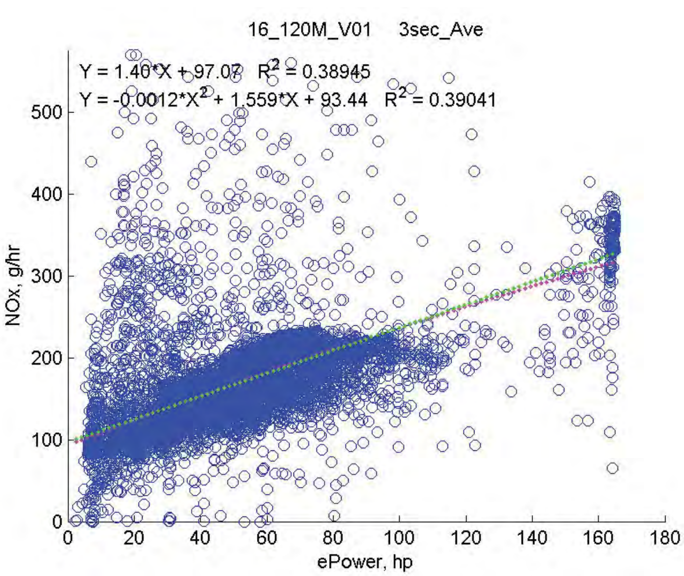

15_120M_V01 3sec_Ave
Y = 0.28*X + 5.67 R^2 = 0.35408
Y = -0.0041*X^2 + 0.854*X + -5.03 R^2 = 0.56543
PM, g/hr
ePower, hp

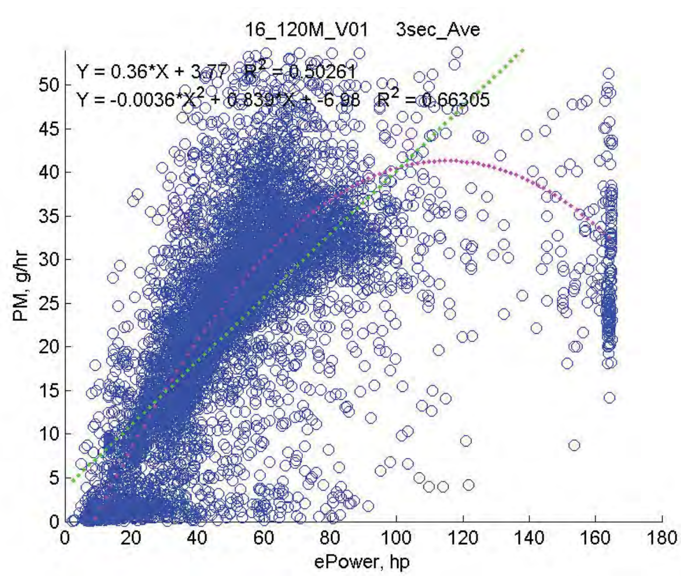

16_120M_V01 3sec_Ave
Y = 1.73*X + 43.16 R^2 = 0.3531
Y = -0.0095*X^2 + 2.985*X + 15.23 R^2 = 0.38688
CO, g/hr
ePower, hp

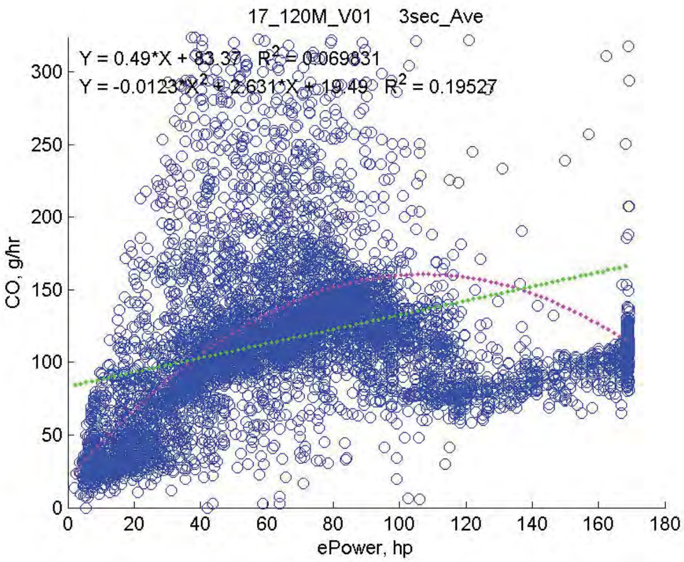

16_120M_V01 3sec_Ave
x 10^4
Y = 483.05*X + 4132.81 R^2 = 0.85686
Y = -0.2785*X^2 + 519.316*X + 3312.37 R^2 = 0.85777
CO2, g/hr
ePower, hp

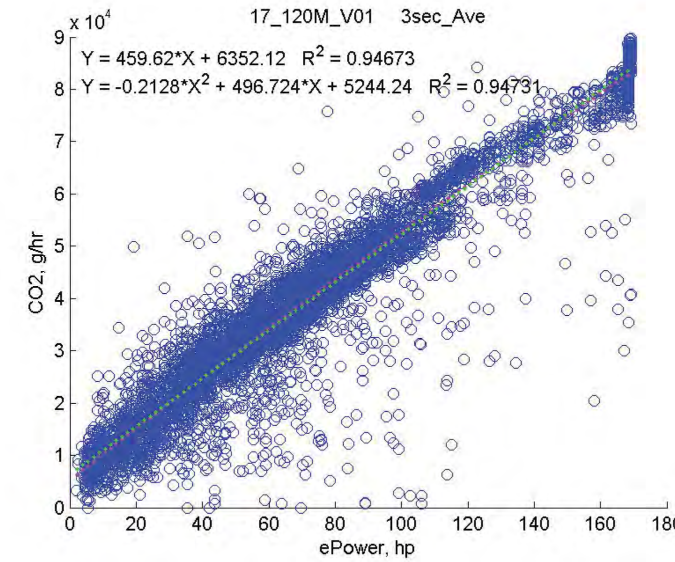

16_120M_V01 3sec_Ave
x 10^4
Y = 153.76*X + 1334.52 R^2 = 0.85723
Y = -0.0938*X^2 + 165.972*X + 1058.17 R^2 = 0.85825
FC, g/hr
ePower, hp

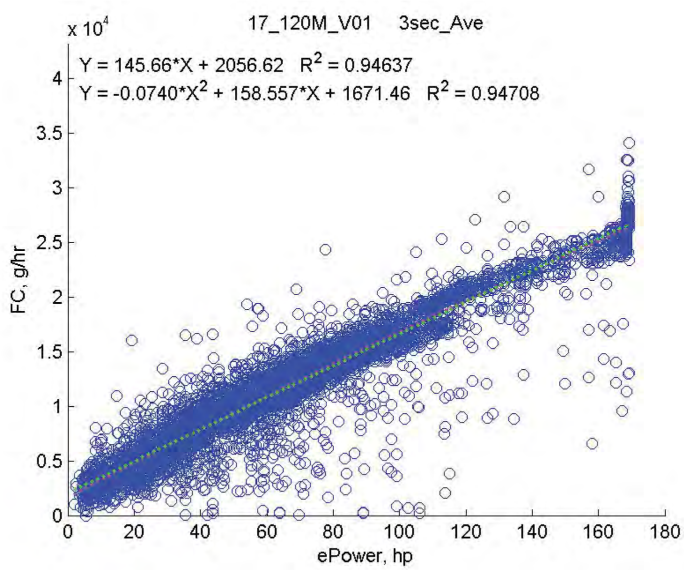

16_120M_V01 3sec_Ave
Y = 0.12*X + 5.91 R^2 = 0.57359
Y = -0.0010*X^2 + 0.251*X + 3.02 R^2 = 0.68966
NMHC, g/hr
ePower, hp

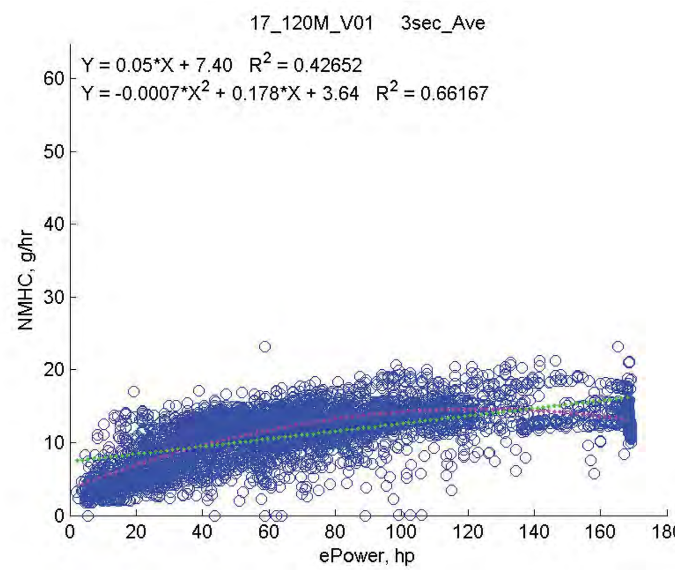

16_120M_V01 3sec_Ave
Y = 1.40*X + 97.07 R^2 = 0.38945
Y = -0.0012*X^2 + 1.559*X + 93.44 R^2 = 0.39041
NOx, g/hr
ePower, hp

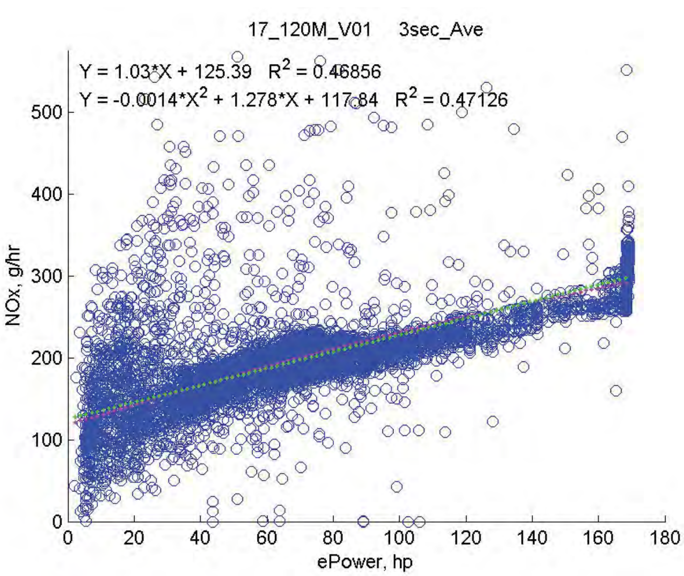

16_120M_V01 3sec_Ave
Y = 0.36*X + 3.77 R^2 = 0.50261
Y = -0.0036*X^2 + 0.839*X + -6.98 R^2 = 0.66305
PM, g/hr
ePower, hp

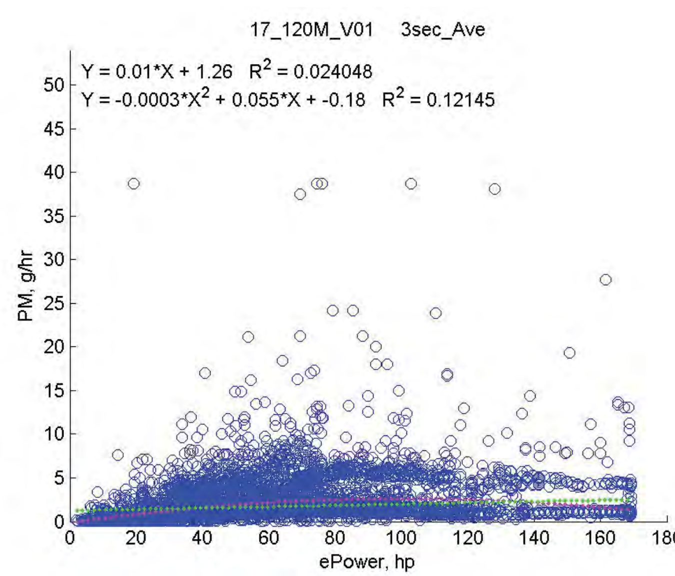

17_120M_V01 3sec_Ave
Y = 0.49*X + 83.37 R2 = 0.069831
Y = -0.0123*X2 + 2.631*X + 19.49 R2 = 0.19527
CO, g/hr
ePower, hp

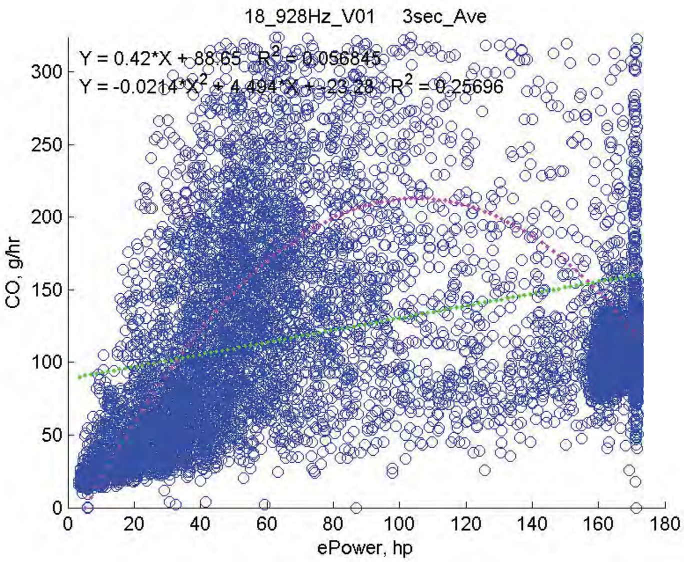

17_120M_V01 3sec_Ave
x 10^4
Y = 459.62*X + 6352.12 R2 = 0.94673
Y = -0.2128*X2 + 496.724*X + 5244.24 R2 = 0.94731
CO2, g/hr
ePower, hp

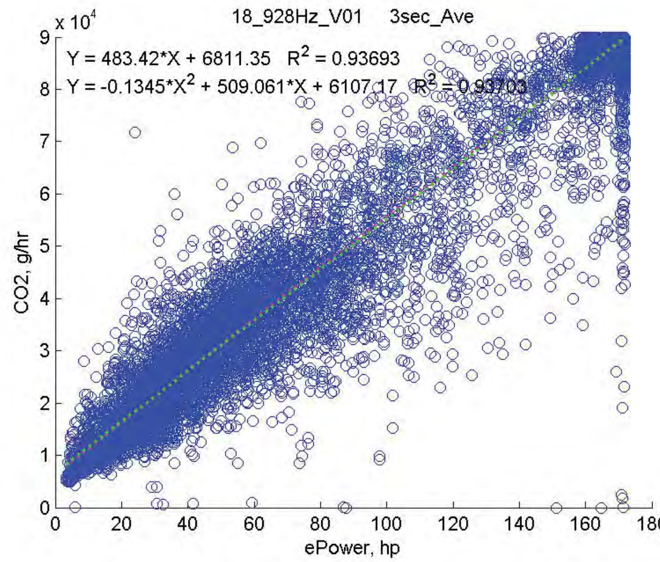

17_120M_V01 3sec_Ave
x 10^4
Y = 145.66*X + 2056.62 R2 = 0.94637
Y = -0.0740*X2 + 158.557*X + 1671.46 R2 = 0.94708
FC, g/hr
ePower, hp

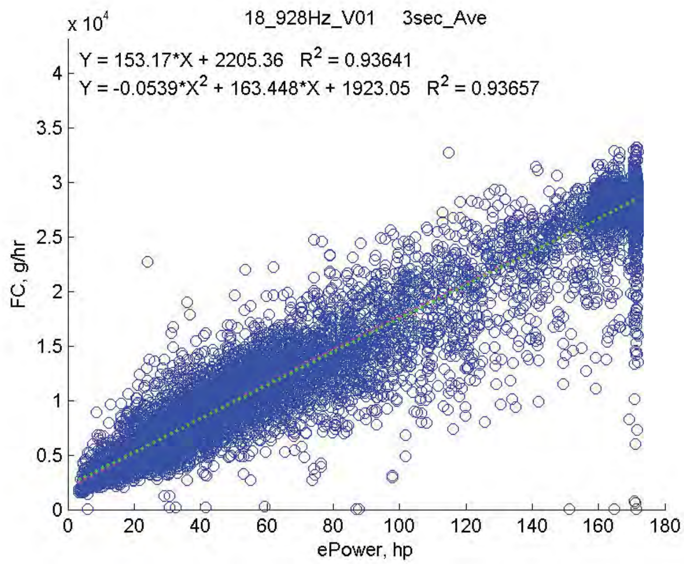

17_120M_V01 3sec_Ave
Y = 0.05*X + 7.40 R2 = 0.42652
Y = -0.0007*X2 + 0.178*X + 3.64 R2 = 0.66167
NMHC, g/hr
ePower, hp

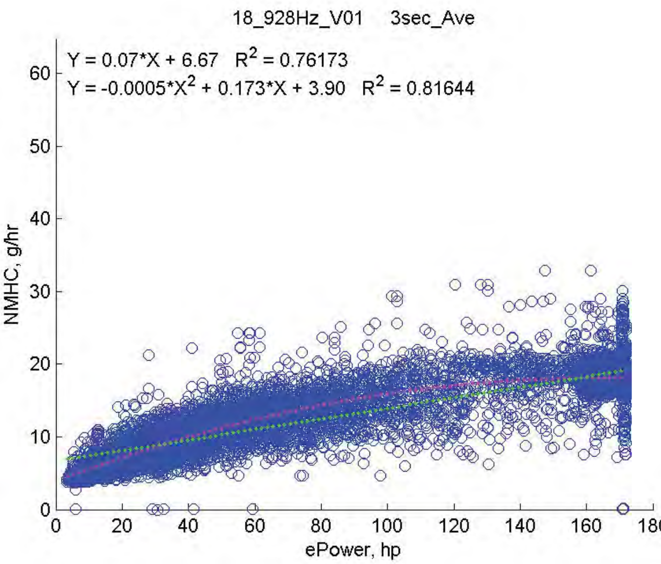

17_120M_V01 3sec_Ave
Y = 1.03*X + 125.39 R2 = 0.46856
Y = -0.0014*X2 + 1.278*X + 117.84 R2 = 0.47126
NOx, g/hr
ePower, hp

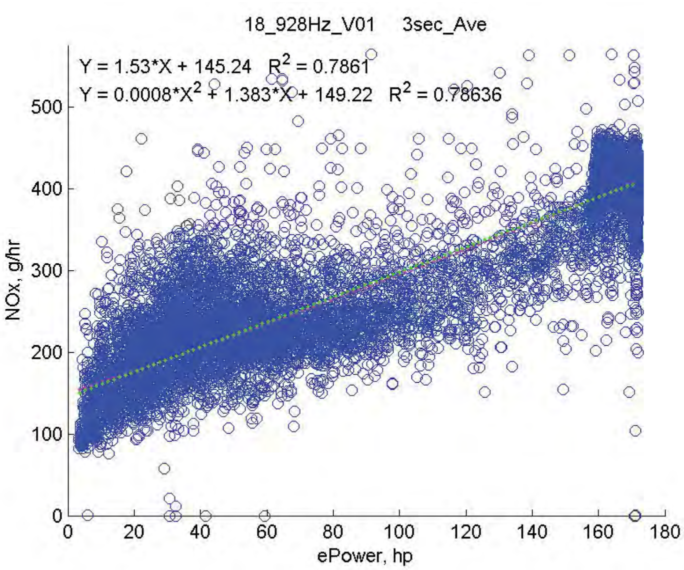

17_120M_V01 3sec_Ave
Y = 0.01*X + 1.26 R2 = 0.024048
Y = -0.0003*X2 + 0.055*X + -0.18 R2 = 0.12145
PM, g/hr
ePower, hp

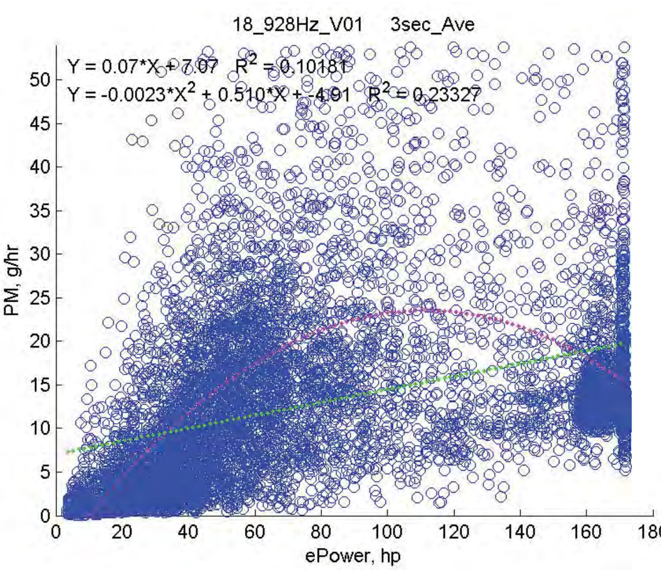

18_928Hz_V01 3sec_Ave
Y = 0.42*X + 88.65 R^2 = 0.056845
Y = -0.0214*X^2 + 4.494*X + -23.28 R^2 = 0.25696
CO, g/hr
ePower, hp

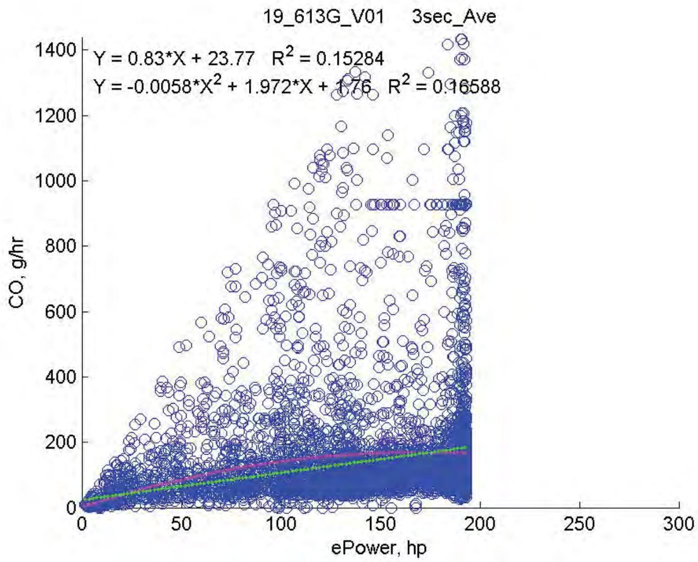

18_928Hz_V01 3sec_Ave
x 10^4
Y = 483.42*X + 6811.35 R^2 = 0.93693
Y = -0.1345*X^2 + 509.061*X + 6107.17 R^2 = 0.93703
CO2, g/hr
ePower, hp

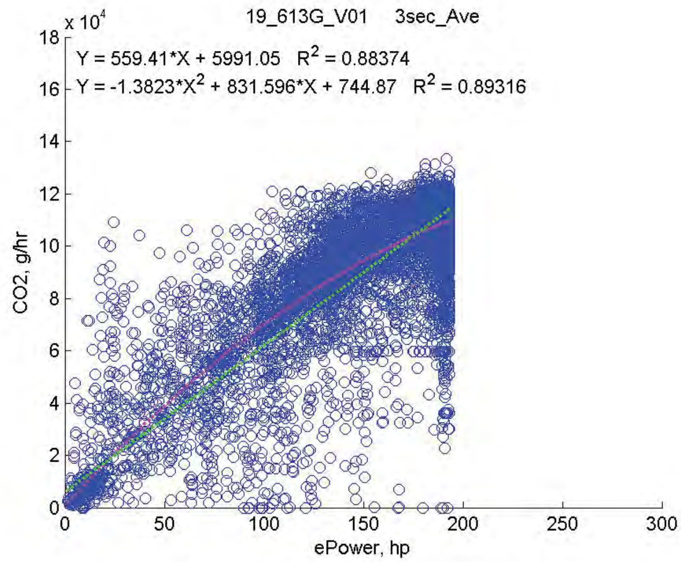

18_928Hz_V01 3sec_Ave
x 10^4
Y = 153.17*X + 2205.36 R^2 = 0.93641
Y = -0.0539*X^2 + 163.448*X + 1923.05 R^2 = 0.93657
FC, g/hr
ePower, hp

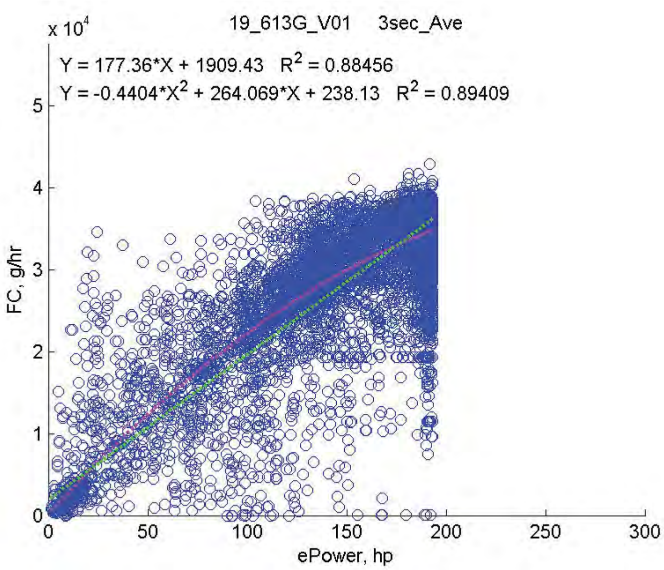

18_928Hz_V01 3sec_Ave
Y = 0.07*X + 6.67 R^2 = 0.76173
Y = -0.0005*X^2 + 0.173*X + 3.90 R^2 = 0.81644
NMHC, g/hr
ePower, hp

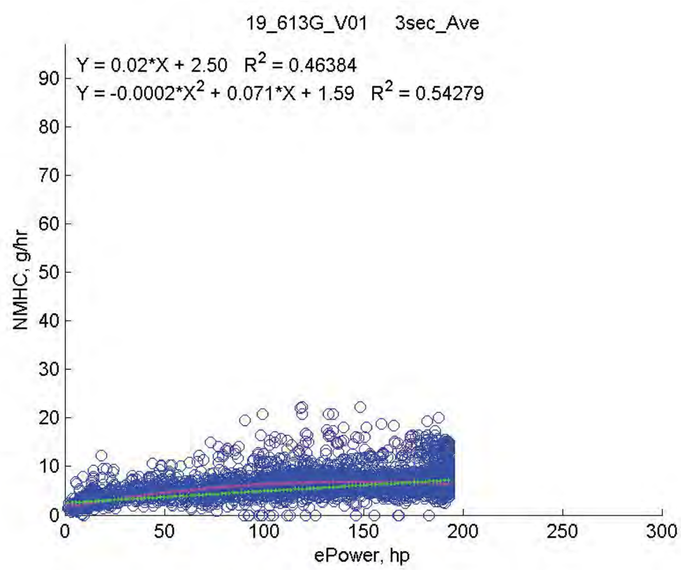

18_928Hz_V01 3sec_Ave
Y = 1.53*X + 145.24 R^2 = 0.7861
Y = 0.0008*X^2 + 1.383*X + 149.22 R^2 = 0.78636
NOx, g/hr
ePower, hp

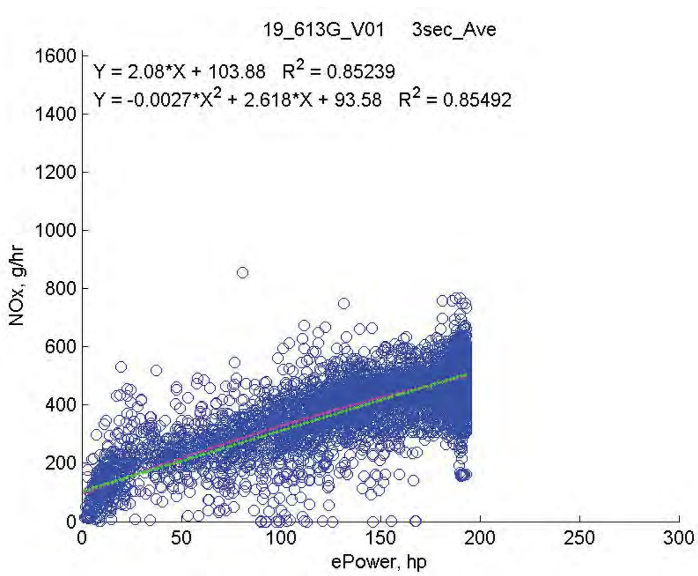

18_928Hz_V01 3sec_Ave
Y = 0.07*X + 7.07 R^2 = 0.10181
Y = -0.0023*X^2 + 0.510*X + -4.91 R^2 = 0.23327
PM, g/hr
ePower, hp

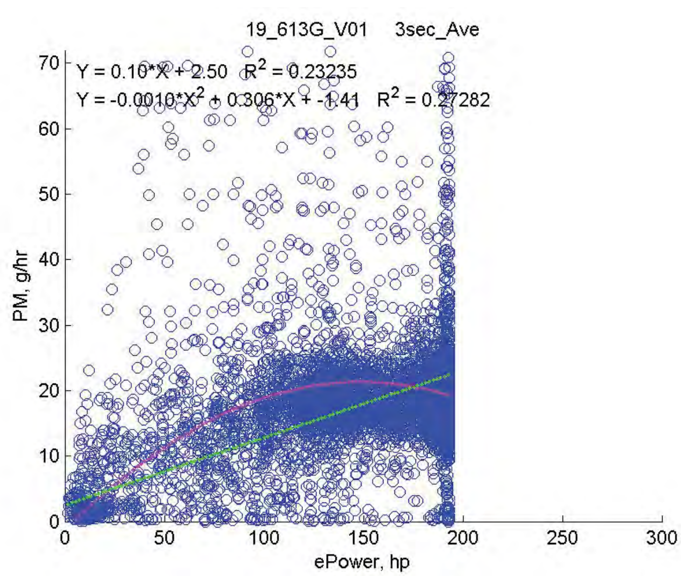

19_613G_V01 3sec_Ave
Y = 0.83*X + 23.77 R2 = 0.15284
Y = -0.0058*X2 + 1.972*X + 1.76 R2 = 0.16588
CO, g/hr
ePower, hp

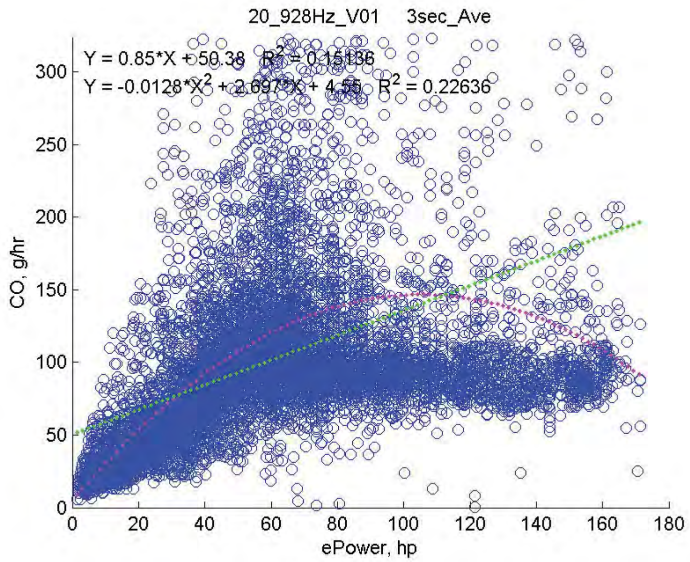

19_613G_V01 3sec_Ave
x 10^4
Y = 559.41*X + 5991.05 R2 = 0.88374
Y = -1.3823*X2 + 831.596*X + 744.87 R2 = 0.89316
CO2, g/hr
ePower, hp

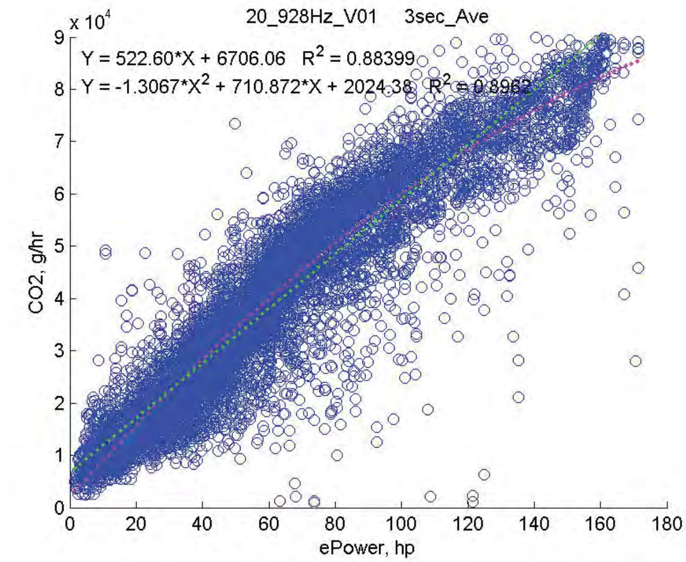

19_613G_V01 3sec_Ave
x 10^4
Y = 177.36*X + 1909.43 R2 = 0.88456
Y = -0.4404*X2 + 264.069*X + 238.13 R2 = 0.89409
FC, g/hr
ePower, hp

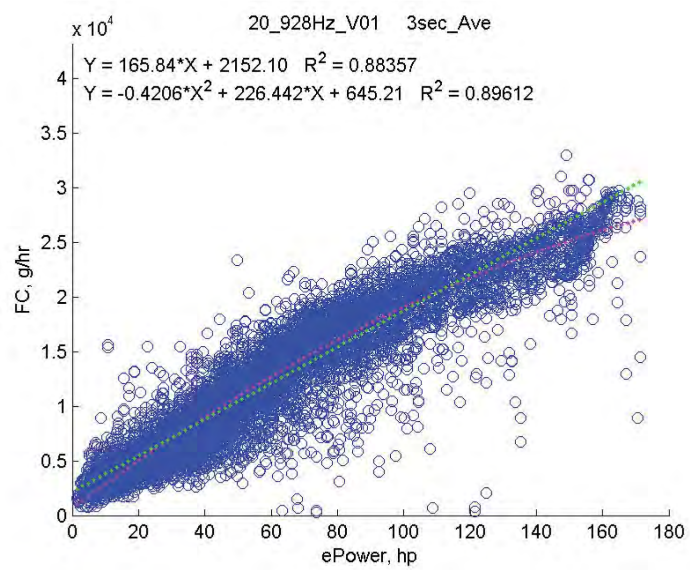

19_613G_V01 3sec_Ave
Y = 0.02*X + 2.50 R2 = 0.46384
Y = -0.0002*X2 + 0.071*X + 1.59 R2 = 0.54279
NMHC, g/hr
ePower, hp

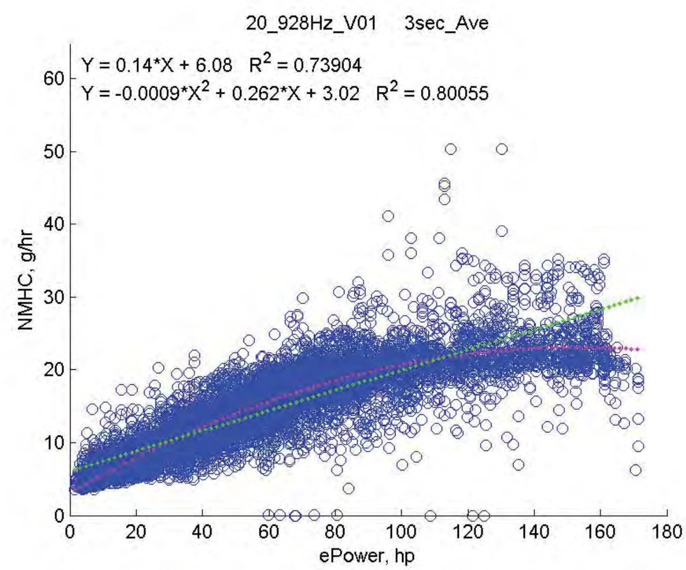

19_613G_V01 3sec_Ave
Y = 2.08*X + 103.88 R2 = 0.85239
Y = -0.0027*X2 + 2.618*X + 93.58 R2 = 0.85492
NOx, g/hr
ePower, hp

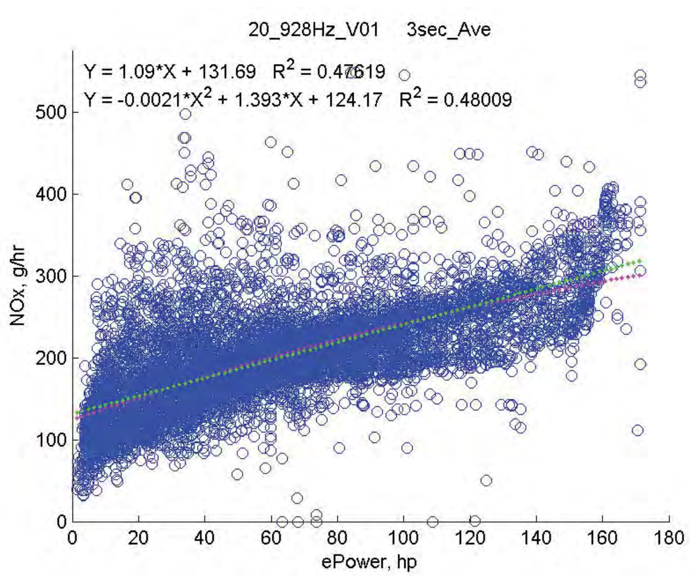

19_613G_V01 3sec_Ave
Y = 0.10*X + 2.50 R2 = 0.23235
Y = -0.0010*X2 + 0.306*X + -1.41 R2 = 0.27282
PM, g/hr
ePower, hp

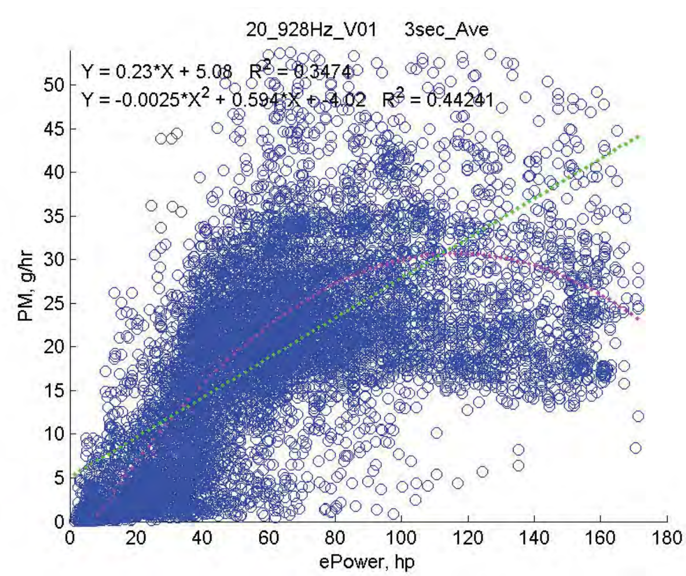

20_928Hz_V01 3sec_Ave
Y = 0.85*X + 50.38 R2 = 0.15136
Y = -0.0128*X2 + 2.697*X + 4.55 R2 = 0.22636
CO, g/hr
ePower, hp

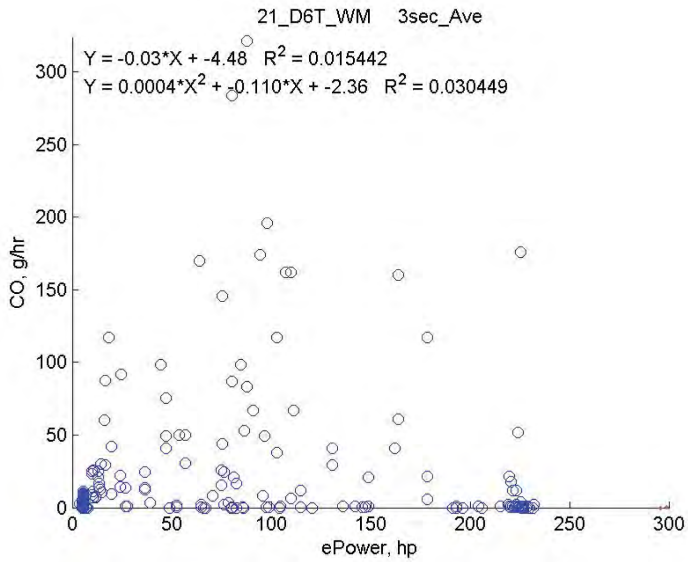

20_928Hz_V01 3sec_Ave
x 10^4
Y = 522.60*X + 6706.06 R2 = 0.88399
Y = -1.3067*X2 + 710.872*X + 2024.38 R2 = 0.8962
CO2, g/hr
ePower, hp

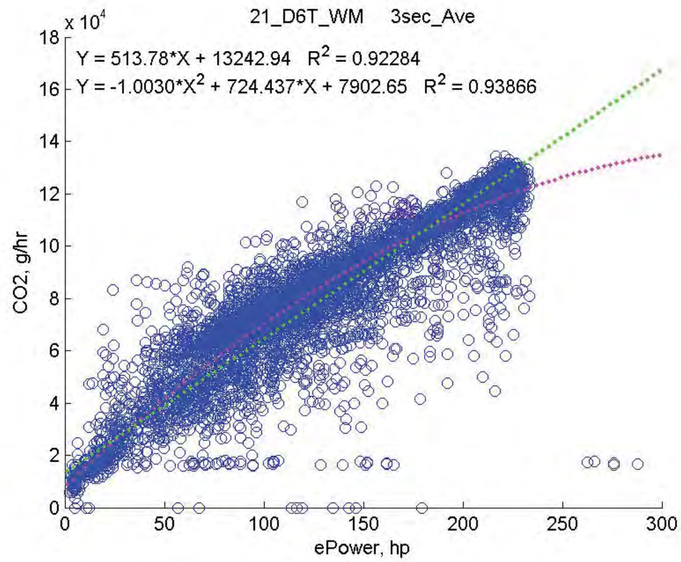

20_928Hz_V01 3sec_Ave
x 10^4
Y = 165.84*X + 2152.10 R2 = 0.88357
Y = -0.4206*X2 + 226.442*X + 645.21 R2 = 0.89612
FC, g/hr
ePower, hp

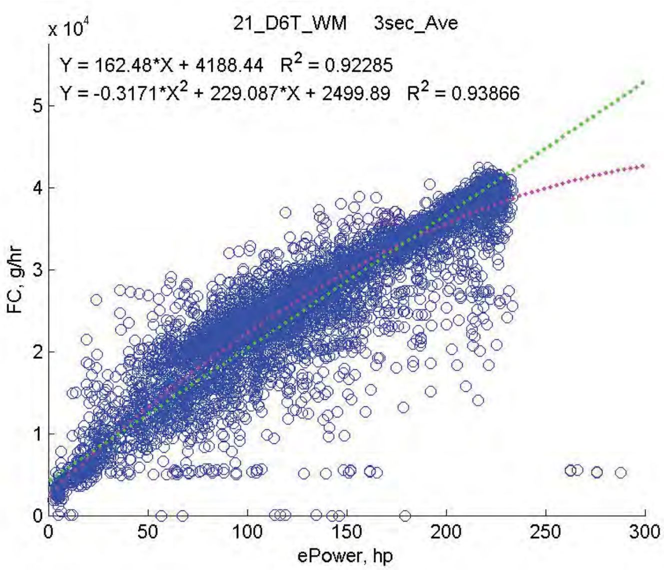

20_928Hz_V01 3sec_Ave
Y = 0.14*X + 6.08 R2 = 0.73904
Y = -0.0009*X2 + 0.262*X + 3.02 R2 = 0.80055
NMHC, g/hr
ePower, hp

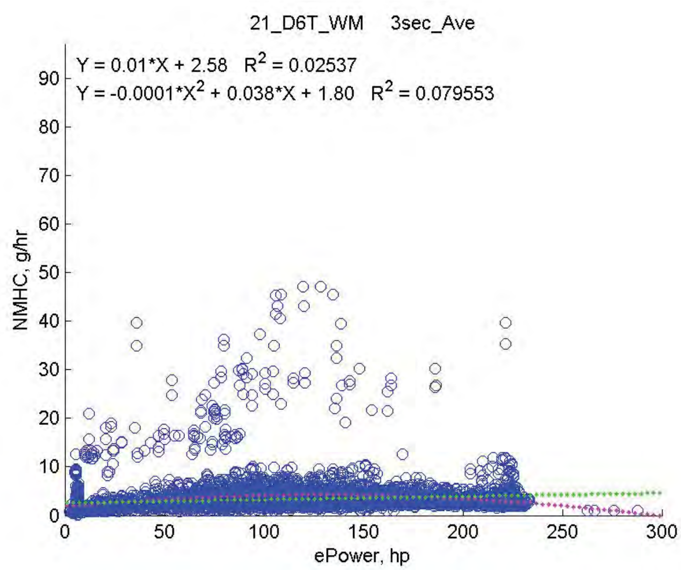

20_928Hz_V01 3sec_Ave
Y = 1.09*X + 131.69 R2 = 0.47619
Y = -0.0021*X2 + 1.393*X + 124.17 R2 = 0.48009
NOx, g/hr
ePower, hp

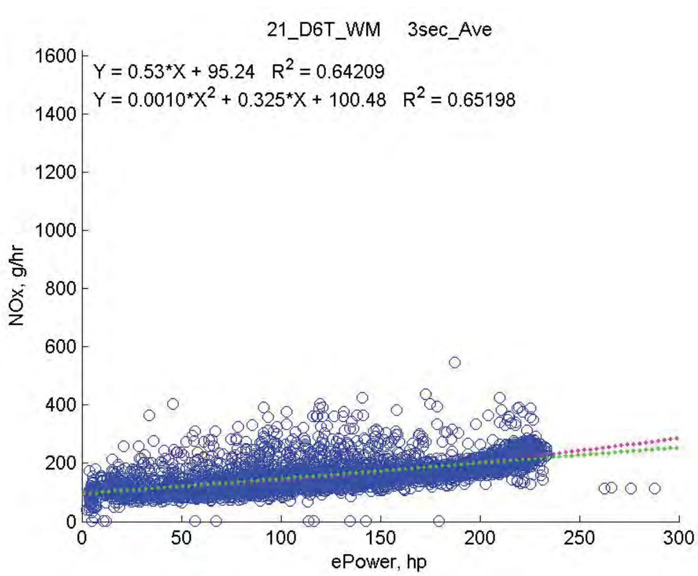

20_928Hz_V01 3sec_Ave
Y = 0.23*X + 5.08 R2 = 0.3474
Y = -0.0025*X2 + 0.594*X + -4.02 R2 = 0.44241
PM, g/hr
ePower, hp

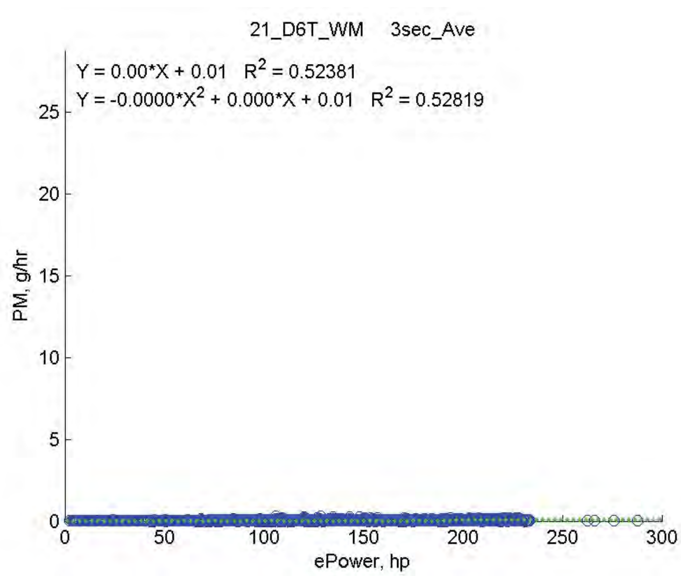

21_D6T_WM 3sec_Ave
Y = -0.03*X + -4.48 R2 = 0.015442
Y = 0.0004*X2 + -0.110*X + -2.36 R2 = 0.030449
CO, g/hr
ePower, hp

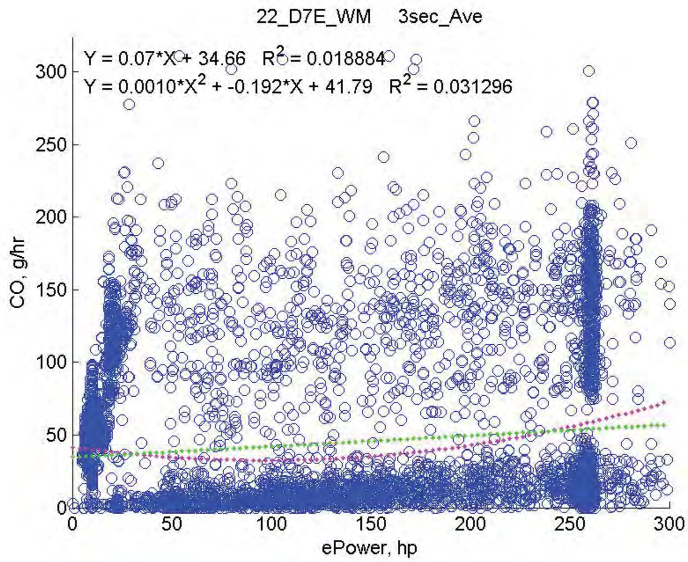

21_D6T_WM 3sec_Ave
x 10^4
Y = 513.78*X + 13242.94 R2 = 0.92284
Y = -1.0030*X2 + 724.437*X + 7902.65 R2 = 0.93866
CO2, g/hr
ePower, hp

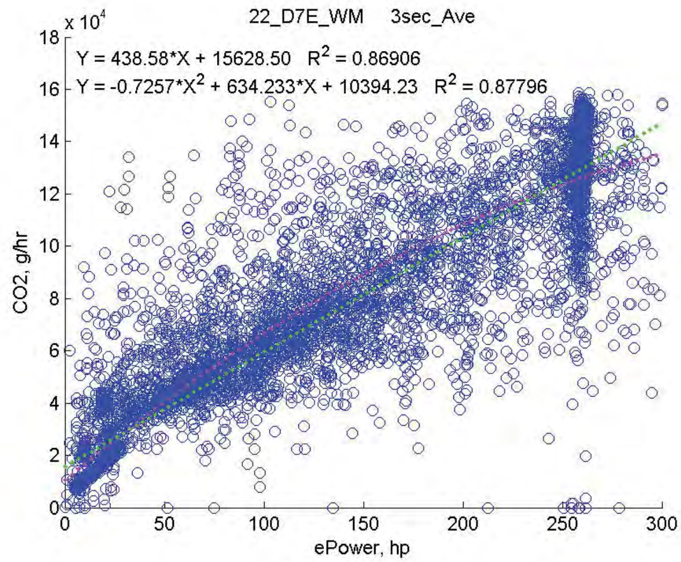

21_D6T_WM 3sec_Ave
x 10^4
Y = 162.48*X + 4188.44 R2 = 0.92285
Y = -0.3171*X2 + 229.087*X + 2499.89 R2 = 0.93866
FC, g/hr
ePower, hp

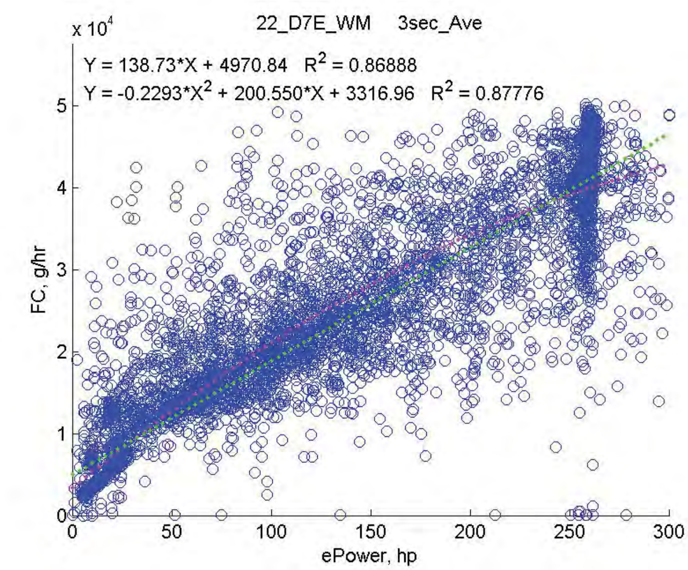

21_D6T_WM 3sec_Ave
Y = 0.01*X + 2.58 R2 = 0.02537
Y = -0.0001*X2 + 0.038*X + 1.80 R2 = 0.079553
NMHC, g/hr
ePower, hp

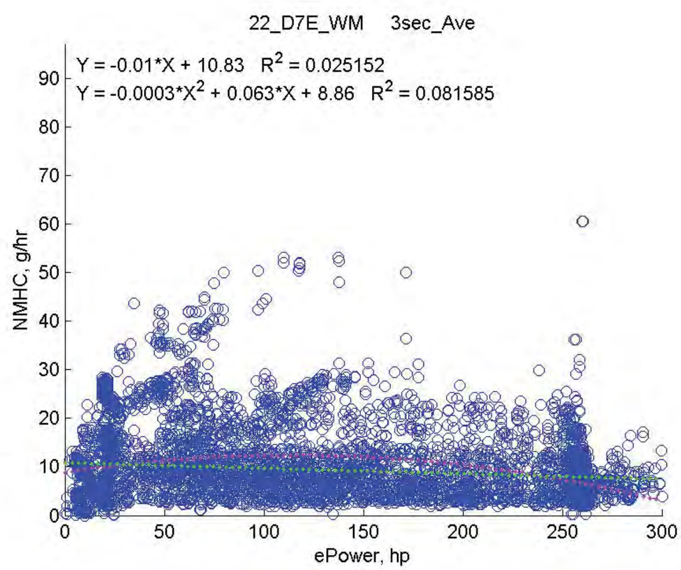

21_D6T_WM 3sec_Ave
Y = 0.53*X + 95.24 R2 = 0.64209
Y = 0.0010*X2 + 0.325*X + 100.48 R2 = 0.65198
NOx, g/hr
ePower, hp

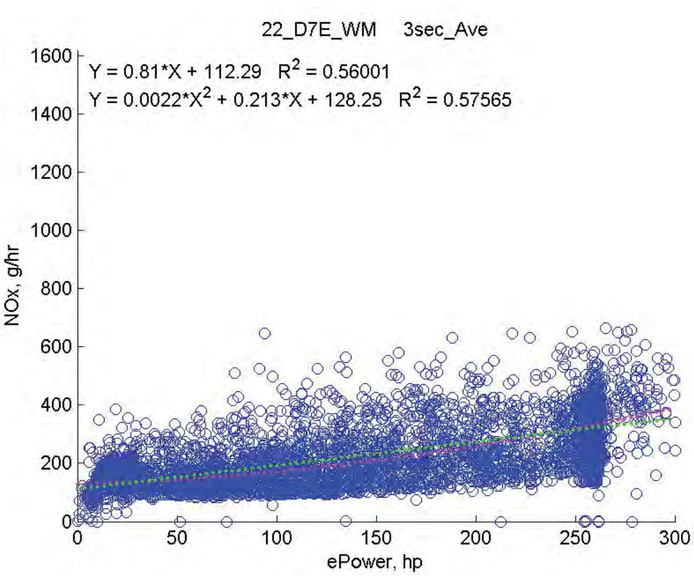

21_D6T_WM 3sec_Ave
Y = 0.00*X + 0.01 R2 = 0.52381
Y = -0.0000*X2 + 0.000*X + 0.01 R2 = 0.52819
PM, g/hr
ePower, hp

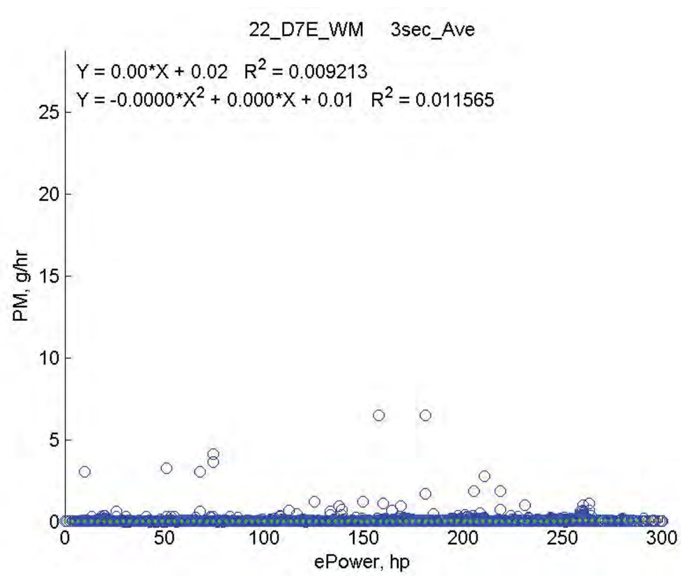

22_D7E_WM 3sec_Ave
Y = 0.07*X + 34.66 R2 = 0.018884
Y = 0.0010*X2 + -0.192*X + 41.79 R2 = 0.031296
CO, g/hr
ePower, hp

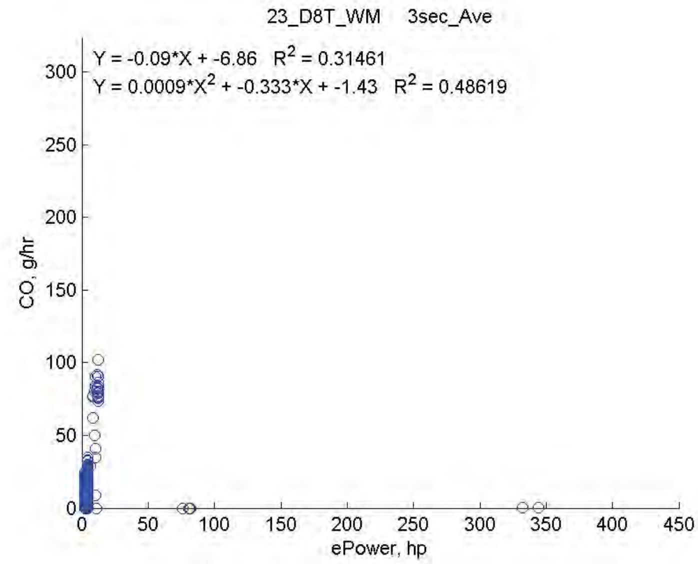

22_D7E_WM 3sec_Ave
x 10^4
Y = 438.58*X + 15628.50 R2 = 0.86906
Y = -0.7257*X2 + 634.233*X + 10394.23 R2 = 0.87796
CO2, g/hr
ePower, hp

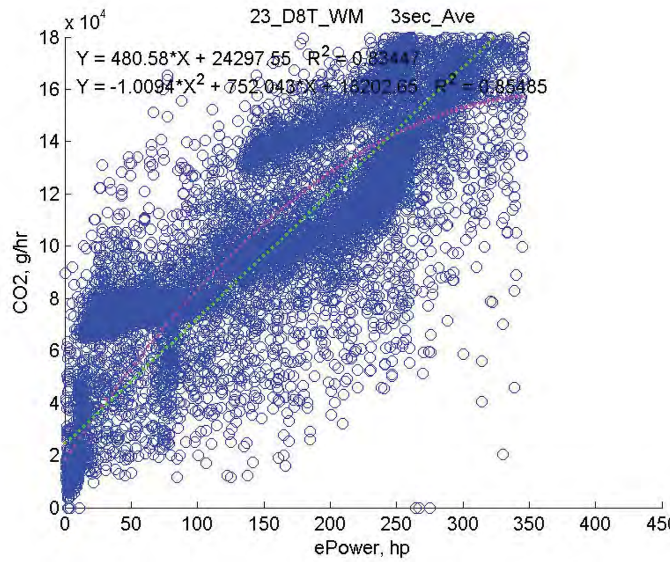

22_D7E_WM 3sec_Ave
x 10^4
Y = 138.73*X + 4970.84 R2 = 0.86888
Y = -0.2293*X2 + 200.550*X + 3316.96 R2 = 0.87776
FC, g/hr
ePower, hp

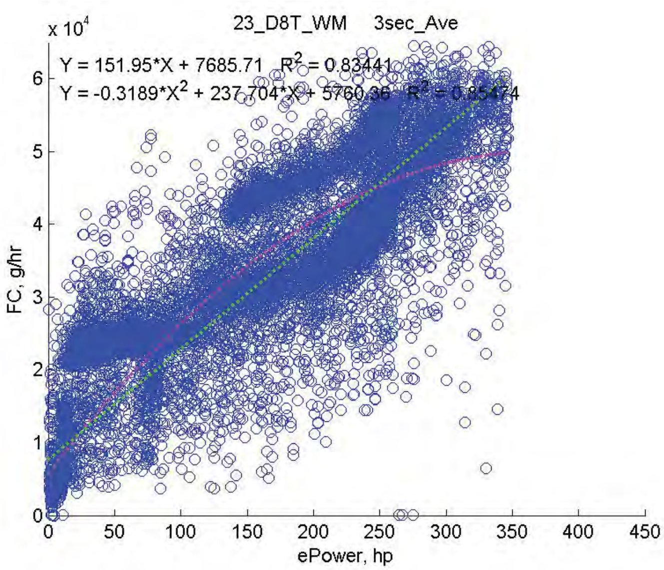

22_D7E_WM 3sec_Ave
Y = -0.01*X + 10.83 R2 = 0.025152
Y = -0.0003*X2 + 0.063*X + 8.86 R2 = 0.081585
NMHC, g/hr
ePower, hp

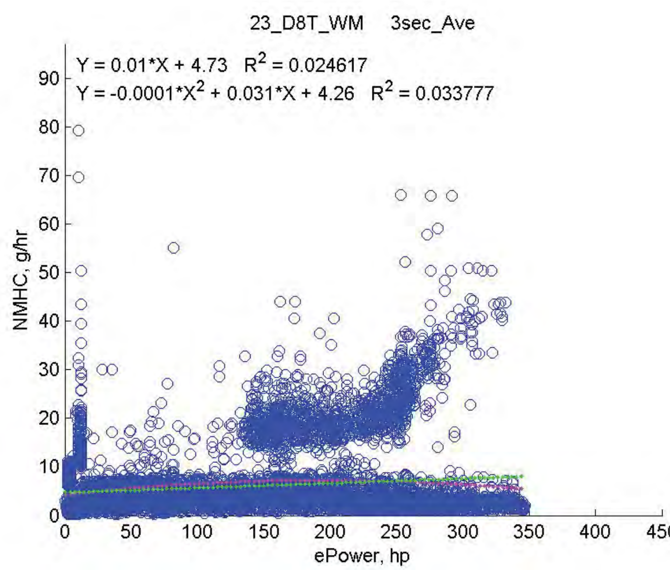

22_D7E_WM 3sec_Ave
Y = 0.81*X + 112.29 R2 = 0.56001
Y = 0.0022*X2 + 0.213*X + 128.25 R2 = 0.57565
NOx, g/hr
ePower, hp

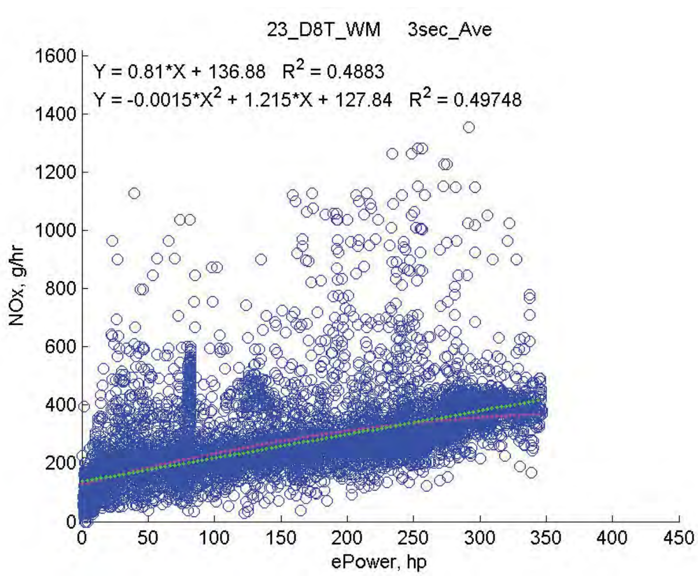

22_D7E_WM 3sec_Ave
Y = 0.00*X + 0.02 R2 = 0.009213
Y = -0.0000*X2 + 0.000*X + 0.01 R2 = 0.011565
PM, g/hr
ePower, hp

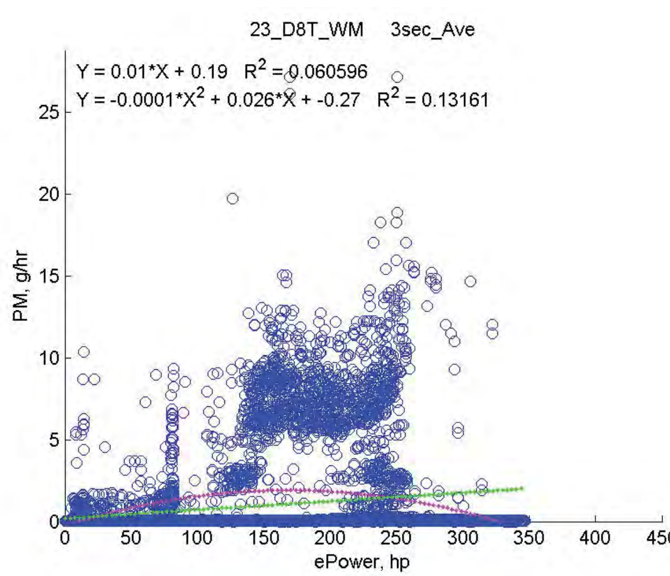

23_D8T_WM 3sec_Ave
Y = -0.09*X + -6.86 R2 = 0.31461
Y = 0.0009*X2 + -0.333*X + -1.43 R2 = 0.48619
CO, g/hr
ePower, hp

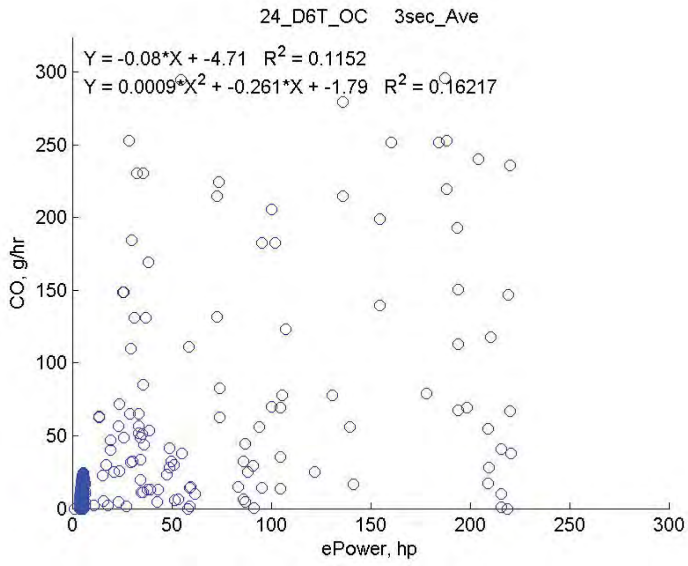

23_D8T_WM 3sec_Ave
x 10^4
Y = 480.58*X + 24297.55 R2 = 0.83447
Y = -1.0094*X2 + 752.043*X + 18202.65 R2 = 0.85485
CO2, g/hr
ePower, hp

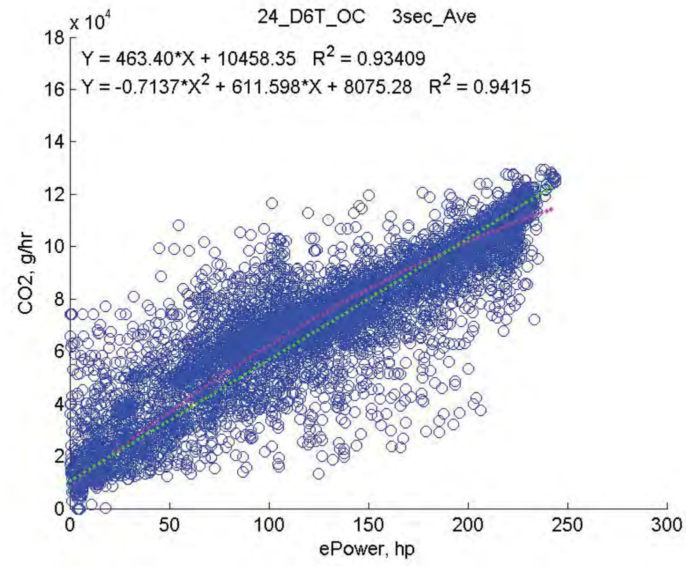

23_D8T_WM 3sec_Ave
x 10^4
Y = 151.95*X + 7685.71 R2 = 0.83441
Y = -0.3189*X2 + 237.704*X + 5760.36 R2 = 0.85474
FC, g/hr
ePower, hp

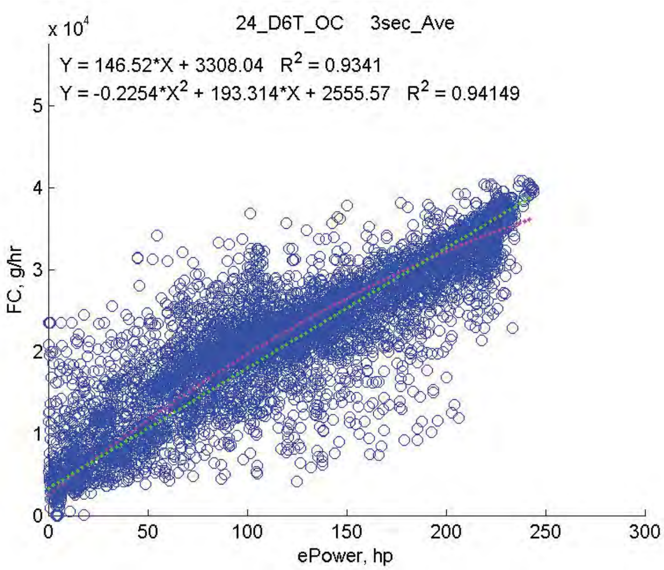

23_D8T_WM 3sec_Ave
Y = 0.01*X + 4.73 R2 = 0.024617
Y = -0.0001*X2 + 0.031*X + 4.26 R2 = 0.033777
NMHC, g/hr
ePower, hp

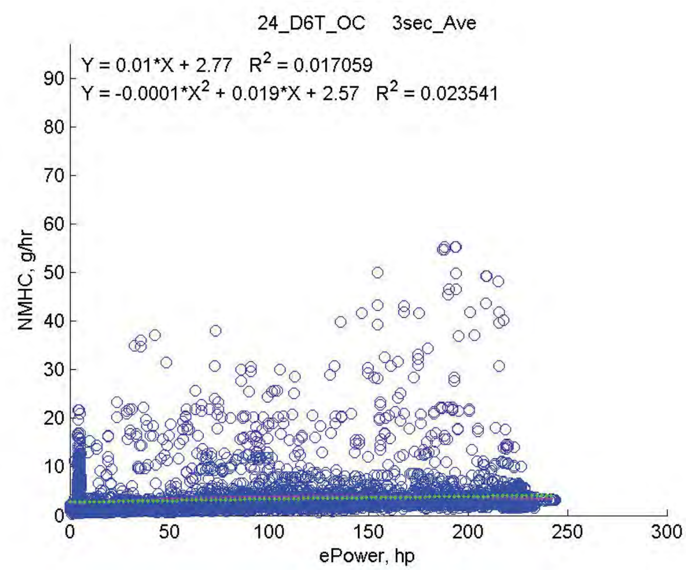

23_D8T_WM 3sec_Ave
Y = 0.81*X + 136.88 R2 = 0.4883
Y = -0.0015*X2 + 1.215*X + 127.84 R2 = 0.49748
NOx, g/hr
ePower, hp

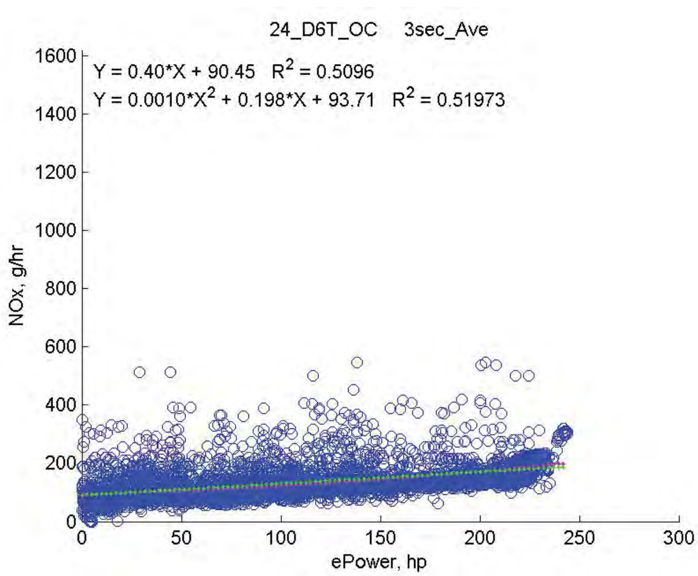

23_D8T_WM 3sec_Ave
Y = 0.01*X + 0.19 R2 = 0.060596
Y = -0.0001*X2 + 0.026*X + -0.27 R2 = 0.13161
PM, g/hr
ePower, hp

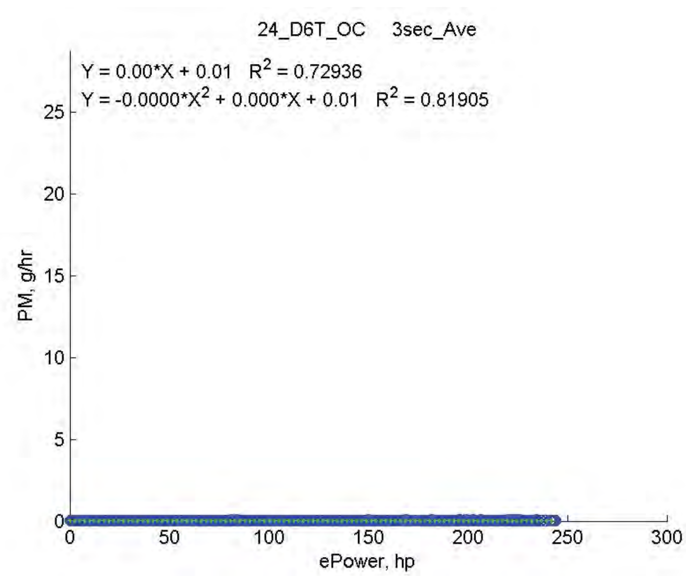

24_D6T_OC 3sec_Ave
Y = -0.08*X + -4.71 R2 = 0.1152
Y = 0.0009*X2 + -0.261*X + -1.79 R2 = 0.16217
CO, g/hr
ePower, hp

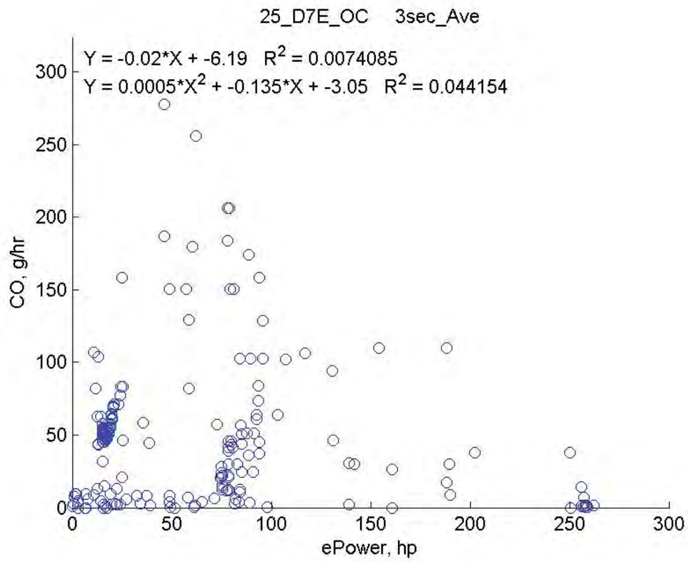

24_D6T_OC 3sec_Ave
x 10^4
Y = 463.40*X + 10458.35 R2 = 0.93409
Y = -0.7137*X2 + 611.598*X + 8075.28 R2 = 0.9415
CO2, g/hr
ePower, hp

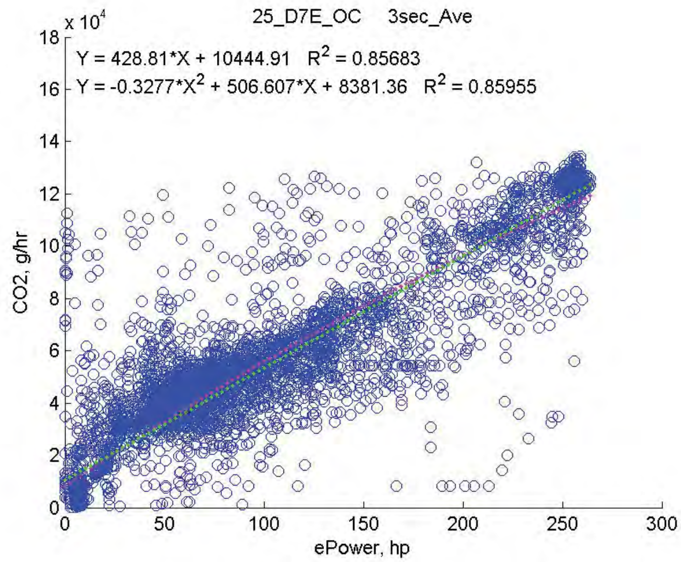

24_D6T_OC 3sec_Ave
x 10^4
Y = 146.52*X + 3308.04 R2 = 0.9341
Y = -0.2254*X2 + 193.314*X + 2555.57 R2 = 0.94149
FC, g/hr
ePower, hp

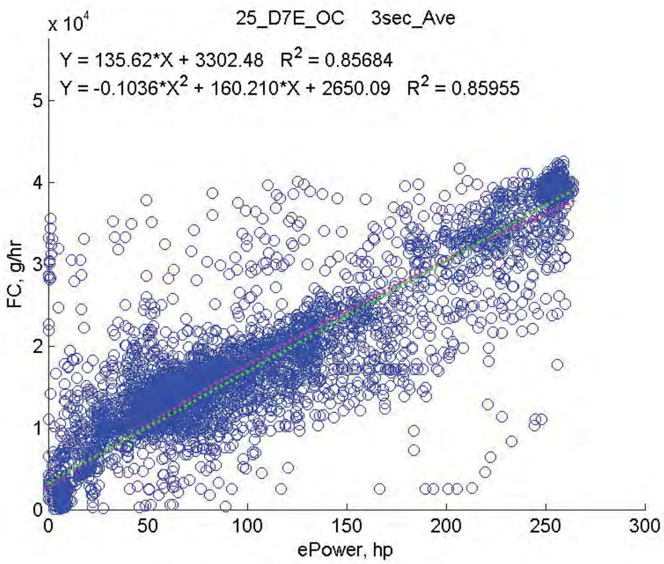

24_D6T_OC 3sec_Ave
Y = 0.01*X + 2.77 R2 = 0.017059
Y = -0.0001*X2 + 0.019*X + 2.57 R2 = 0.023541
NMHC, g/hr
ePower, hp

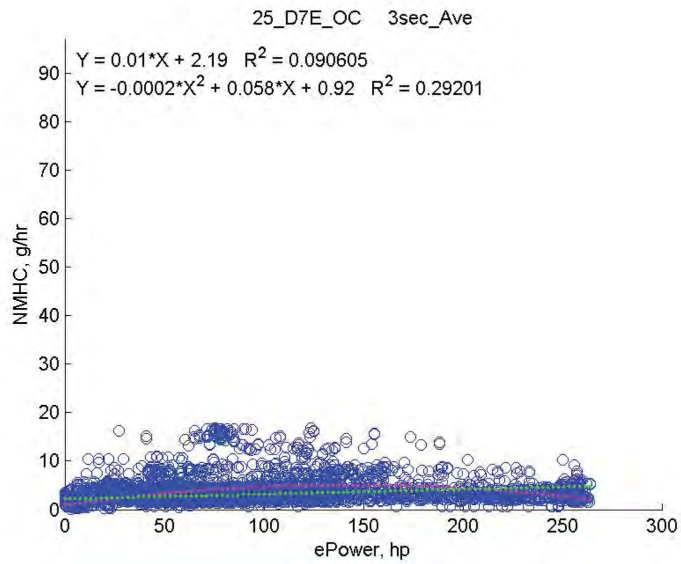

24_D6T_OC 3sec_Ave
Y = 0.40*X + 90.45 R2 = 0.5096
Y = 0.0010*X2 + 0.198*X + 93.71 R2 = 0.51973
NOx, g/hr
ePower, hp

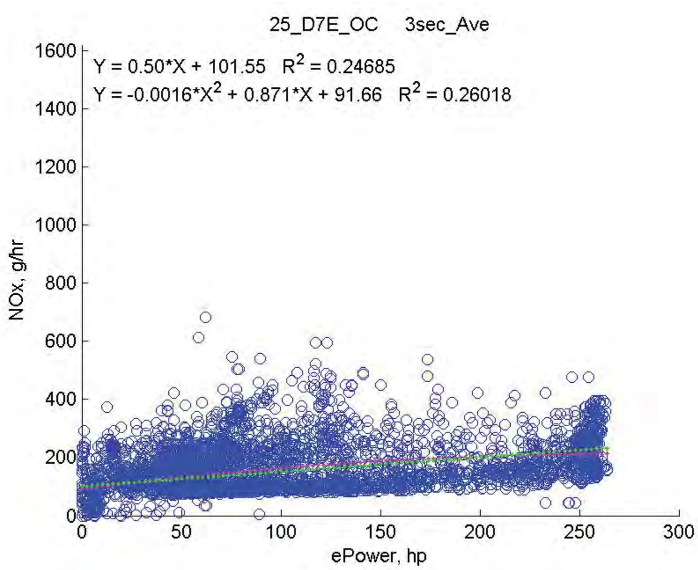

24_D6T_OC 3sec_Ave
Y = 0.00*X + 0.01 R2 = 0.72936
Y = -0.0000*X2 + 0.000*X + 0.01 R2 = 0.81905
PM, g/hr
ePower, hp

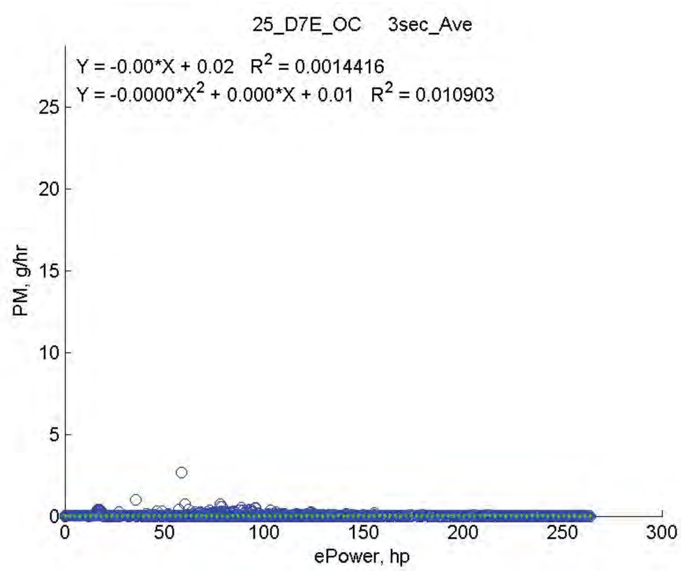

25_D7E_OC 3sec_Ave
Y = -0.02*X + -6.19 R2 = 0.0074085
Y = 0.0005*X2 + -0.135*X + -3.05 R2 = 0.044154
CO, g/hr
ePower, hp

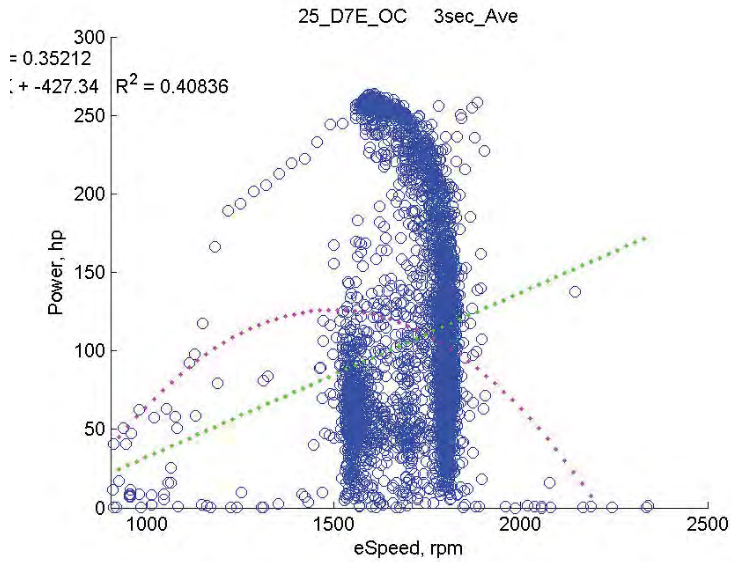

25_D7E_OC 3sec_Ave
x 10^4
Y = 428.81*X + 10444.91 R2 = 0.85683
Y = -0.3277*X2 + 506.607*X + 8381.36 R2 = 0.85955
CO2, g/hr
ePower, hp

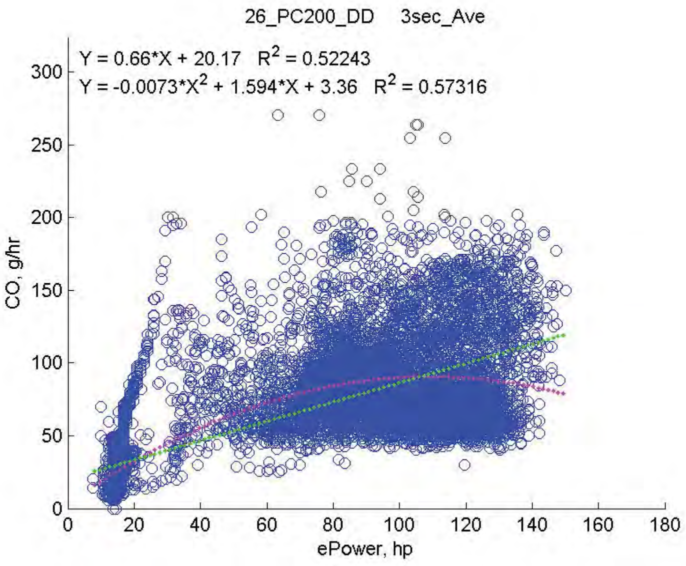

25_D7E_OC 3sec_Ave
x 10^4
Y = 135.62*X + 3302.48 R2 = 0.85684
Y = -0.1036*X2 + 160.210*X + 2650.09 R2 = 0.85955
FC, g/hr
ePower, hp

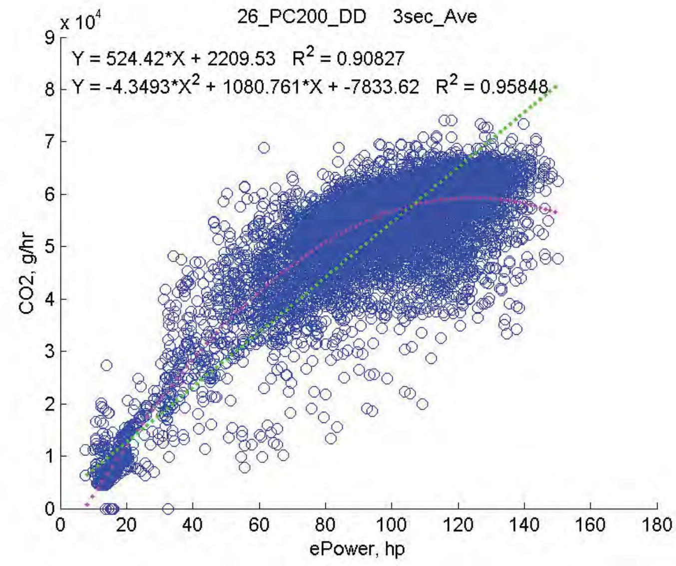

25_D7E_OC 3sec_Ave
Y = 0.01*X + 2.19 R2 = 0.090605
Y = -0.0002*X2 + 0.058*X + 0.92 R2 = 0.29201
NMHC, g/hr
ePower, hp

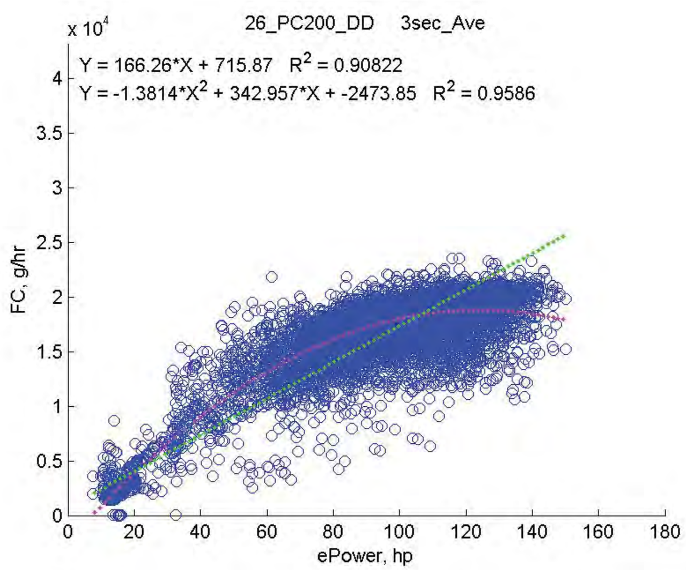

25_D7E_OC 3sec_Ave
Y = 0.50*X + 101.55 R2 = 0.24685
Y = -0.0016*X2 + 0.871*X + 91.66 R2 = 0.26018
NOx, g/hr
ePower, hp

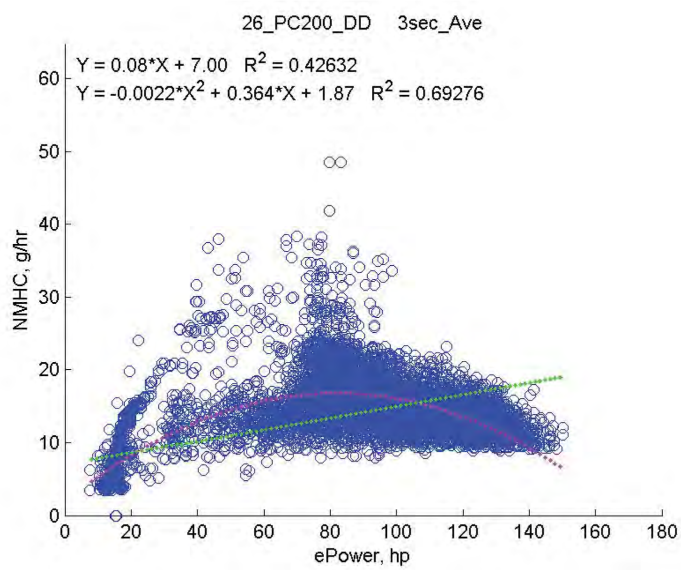

25_D7E_OC 3sec_Ave
Y = -0.00*X + 0.02 R2 = 0.0014416
Y = -0.0000*X2 + 0.000*X + 0.01 R2 = 0.010903
PM, g/hr
ePower, hp

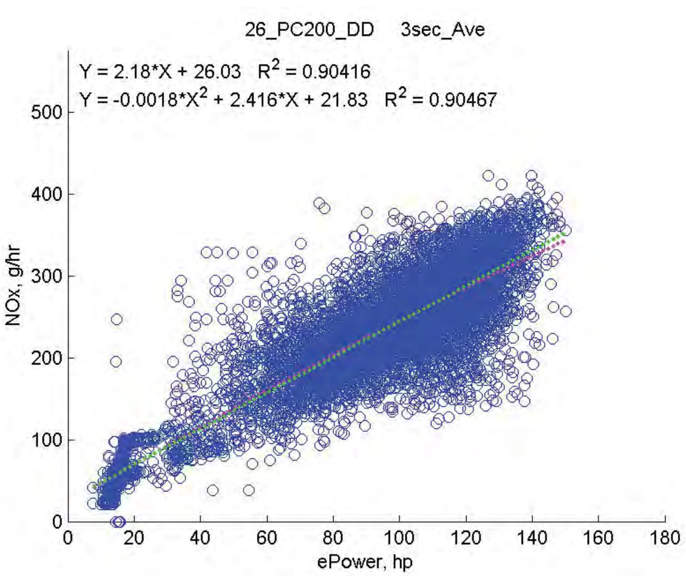

25_D7E_OC 3sec_Ave
= 0.35212
+ -427.34 R^2 = 0.40836
Power, hp
eSpeed, rpm
300
250
200
150
100
50
0
1000
1500
2000
2500

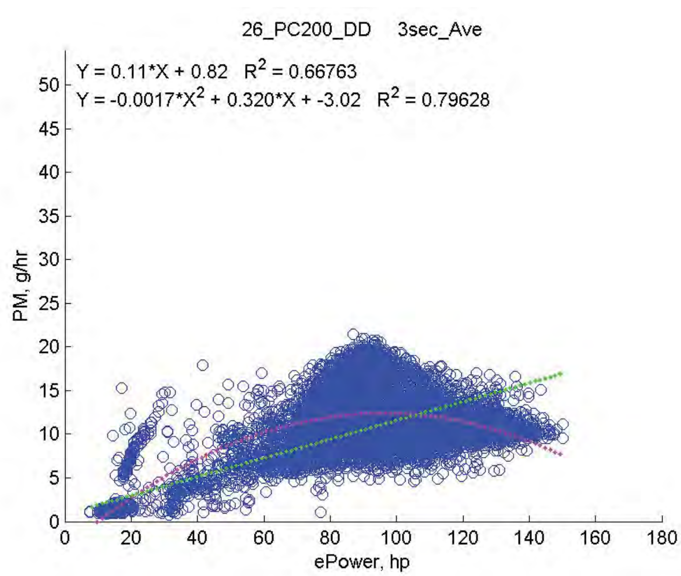

26_PC200_DD 3sec_Ave
Y = 0.66*X + 20.17 R^2 = 0.52243
Y = -0.0073*X^2 + 1.594*X + 3.36 R^2 = 0.57316
CO, g/hr
ePower, hp

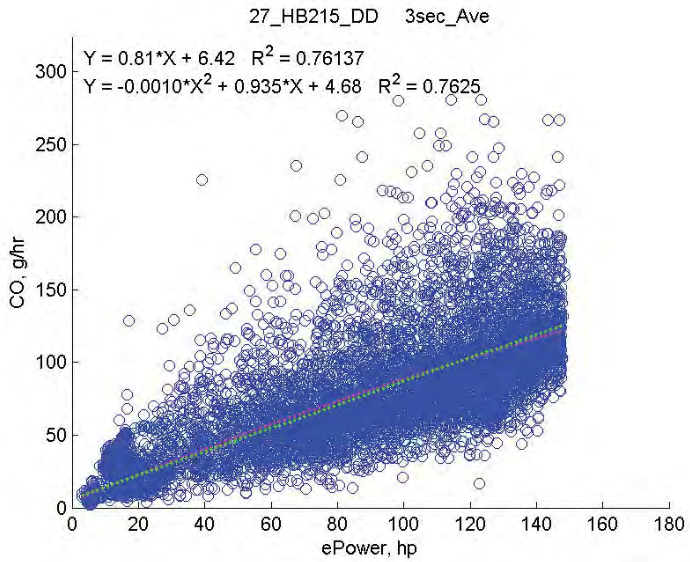

26_PC200_DD 3sec_Ave
x 10^4
Y = 524.42*X + 2209.53 R^2 = 0.90827
Y = -4.3493*X^2 + 1080.761*X + -7833.62 R^2 = 0.95848
CO2, g/hr
ePower, hp

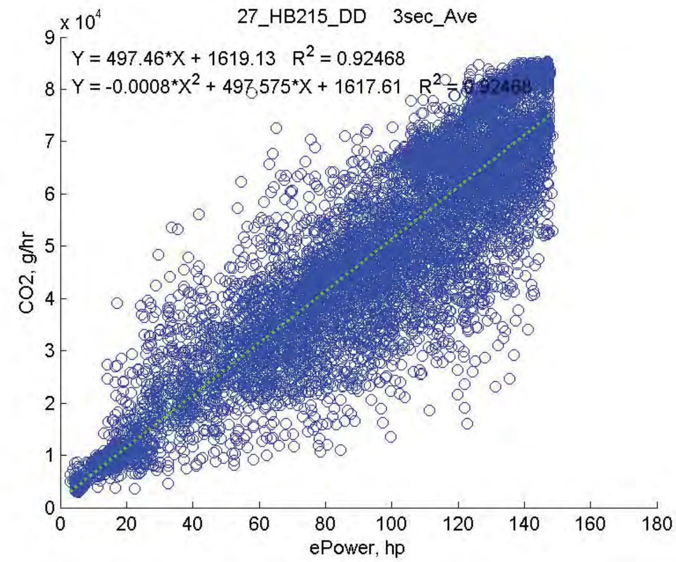

26_PC200_DD 3sec_Ave
x 10^4
Y = 166.26*X + 715.87 R^2 = 0.90822
Y = -1.3814*X^2 + 342.957*X + -2473.85 R^2 = 0.9586
FC, g/hr
ePower, hp

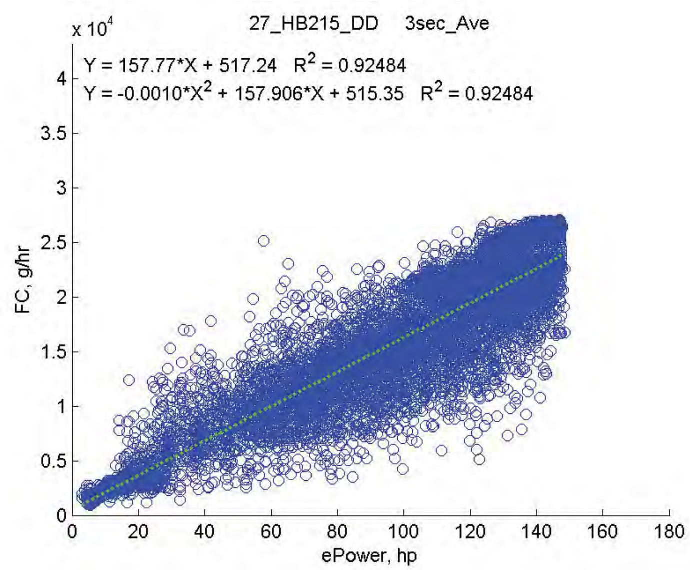

26_PC200_DD 3sec_Ave
Y = 0.08*X + 7.00 R^2 = 0.42632
Y = -0.0022*X^2 + 0.364*X + 1.87 R^2 = 0.69276
NMHC, g/hr
ePower, hp

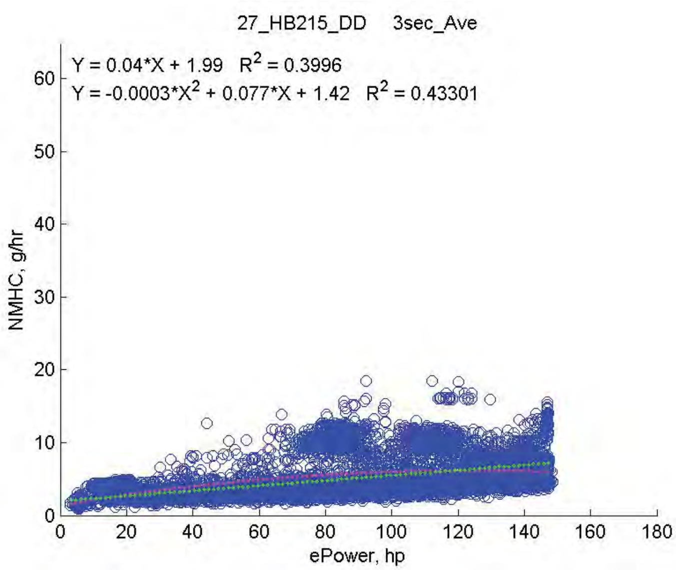

26_PC200_DD 3sec_Ave
Y = 2.18*X + 26.03 R^2 = 0.90416
Y = -0.0018*X^2 + 2.416*X + 21.83 R^2 = 0.90467
NOx, g/hr
ePower, hp

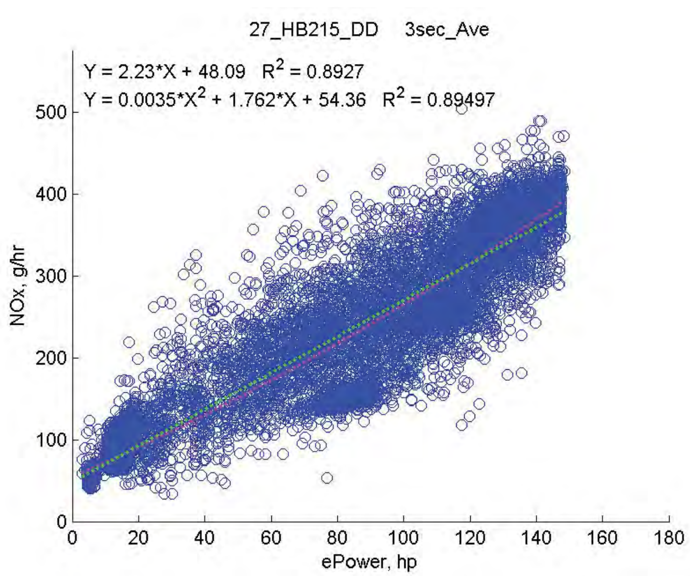

26_PC200_DD 3sec_Ave
Y = 0.11*X + 0.82 R^2 = 0.66763
Y = -0.0017*X^2 + 0.320*X + -3.02 R^2 = 0.79628
PM, g/hr
ePower, hp

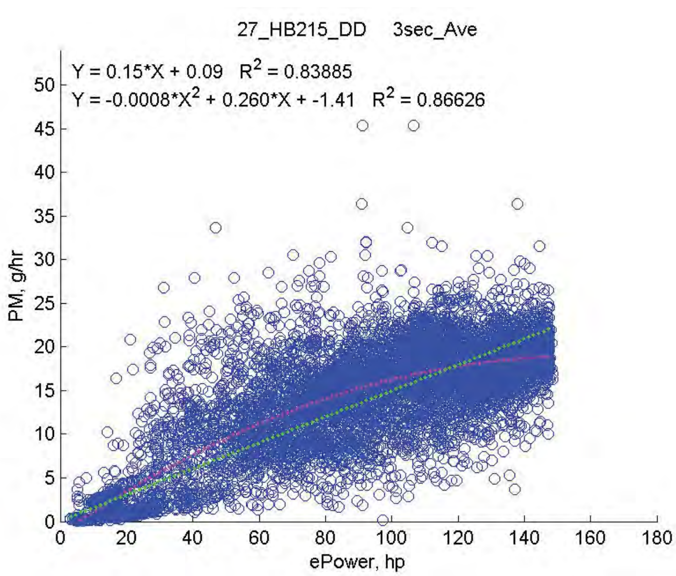

27_HB215_DD 3sec_Ave
Y = 0.81*X + 6.42 R^2 = 0.76137
Y = -0.0010*X^2 + 0.935*X + 4.68 R^2 = 0.7625
CO, g/hr
ePower, hp


27_HB215_DD 3sec_Ave
x 10^4
Y = 497.46*X + 1619.13 R^2 = 0.92468
Y = -0.0008*X^2 + 497.575*X + 1617.61 R^2 = 0.92468
CO2, g/hr
ePower, hp


27_HB215_DD 3sec_Ave
x 10^4
Y = 157.77*X + 517.24 R^2 = 0.92484
Y = -0.0010*X^2 + 157.906*X + 515.35 R^2 = 0.92484
FC, g/hr
ePower, hp


27_HB215_DD 3sec_Ave
Y = 0.04*X + 1.99 R^2 = 0.3996
Y = -0.0003*X^2 + 0.077*X + 1.42 R^2 = 0.43301
NMHC, g/hr
ePower, hp


27_HB215_DD 3sec_Ave
Y = 2.23*X + 48.09 R^2 = 0.8927
Y = 0.0035*X^2 + 1.762*X + 54.36 R^2 = 0.89497
NOx, g/hr
ePower, hp


27_HB215_DD 3sec_Ave
Y = 0.15*X + 0.09 R^2 = 0.83885
Y = -0.0008*X^2 + 0.260*X + -1.41 R^2 = 0.86626
PM, g/hr
ePower, hp

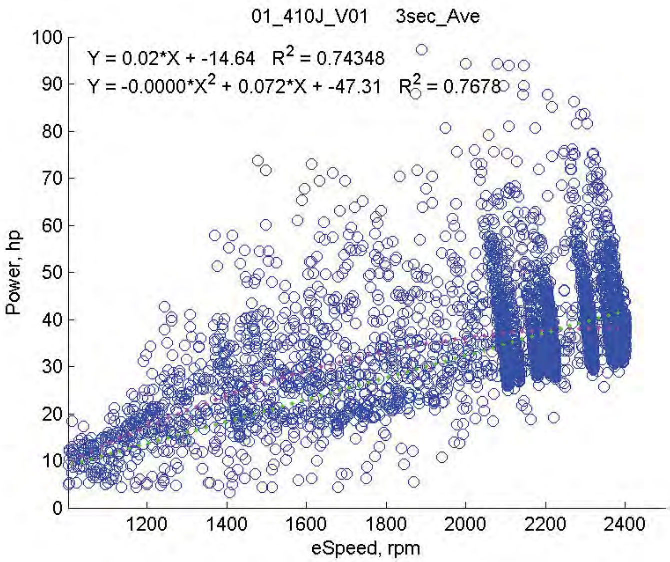
Appendix C. Detailed Modal Power vs RPM Figures

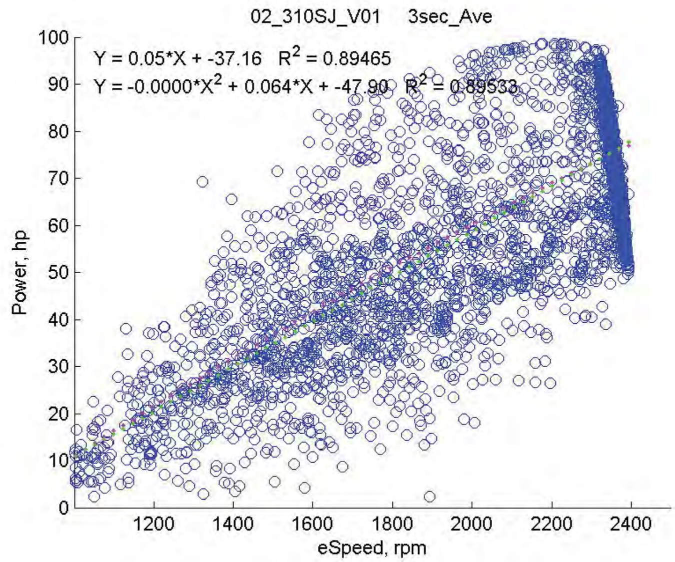
Time alignment between power and RPM is important to understand where an engine operates relative to its lug curve. Both the power and engine speed have similar response times of 100 ms. To compare the power versus rpm data with the emissions versus power the prepared figures of power vs engine speed were also filtered using a three second median filter.

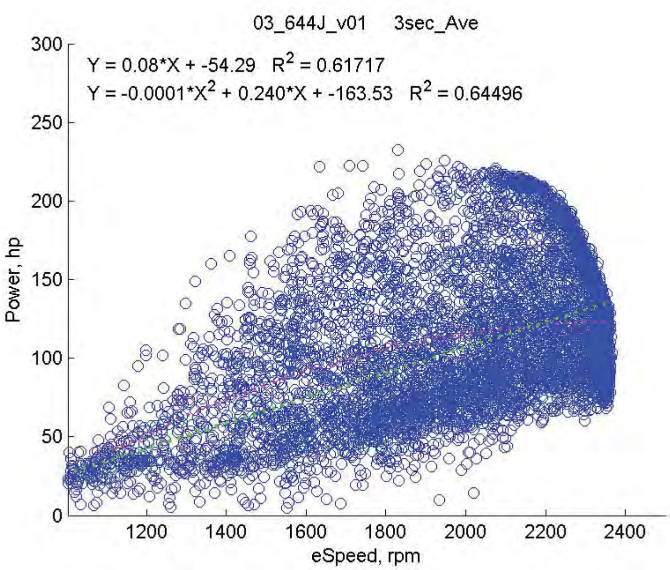
A moving average of three seconds was implemented in MATLAB using the function called "MEDFILT1". MEDFILT1 is a one dimensional median filter function in MATLAB (see MATLAB user manual). The filter uses the median calculation between the points not an average. The three second median filter was used (n=3) for all the real-time power and engine speed signals presented in the figures in Appendix 10.0.

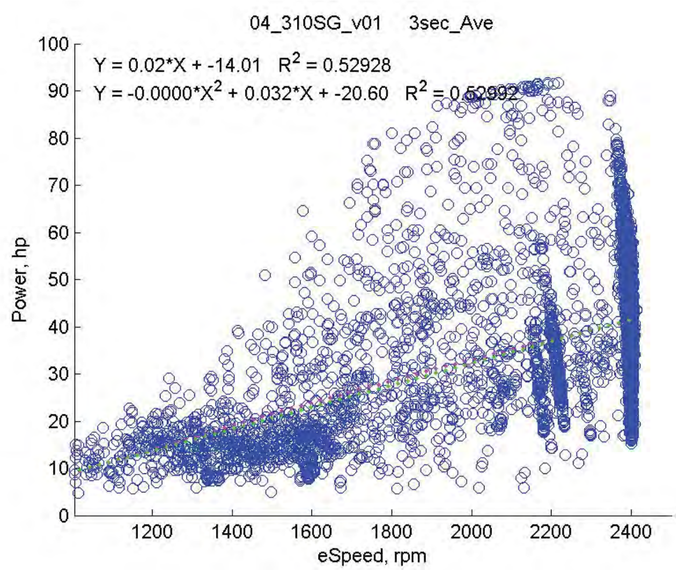
The least squared regression best fit coefficients in each figure were analyzed using MATLAB's "polyfit" command. The Polyfit command finds the coefficients of a polynomial P(X) of degree N that fits the data Y best in a least-squares sense. P is a row vector of length N+1 containing the polynomial coefficients in descending powers, P(1)*X^N + P(2)*X^(N-1) +...+ P(N)*X + P(N+1) (MATLAB user manual). For this analysis the order of the coefficients used were N = 1 and N = 2, representing a linear and polynomial fit, respectively. In addition to the regression equation for a linear and polynomial fit, the goodness of fit is also shown on each figure with the R^2 term.

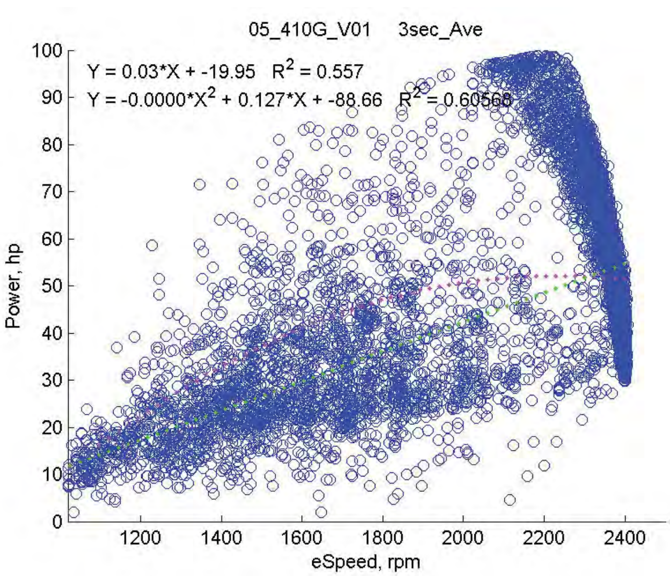
The least squared regression equations do not have significant meaning, but can be used to look at trends between units.

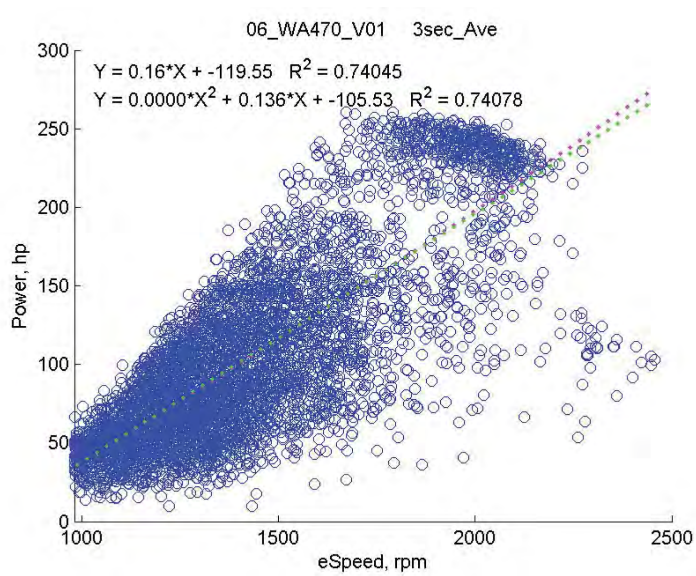

01_410J_V01 3sec_Ave
Y = 0.02*X + -14.64 R^2 = 0.74348
Y = -0.0000*X^2 + 0.072*X + -47.31 R^2 = 0.7678
Power, hp
eSpeed, rpm
0
10
20
30
40
50
60
70
80
90
100
1200
1400
1600
1800
2000
2200
2400

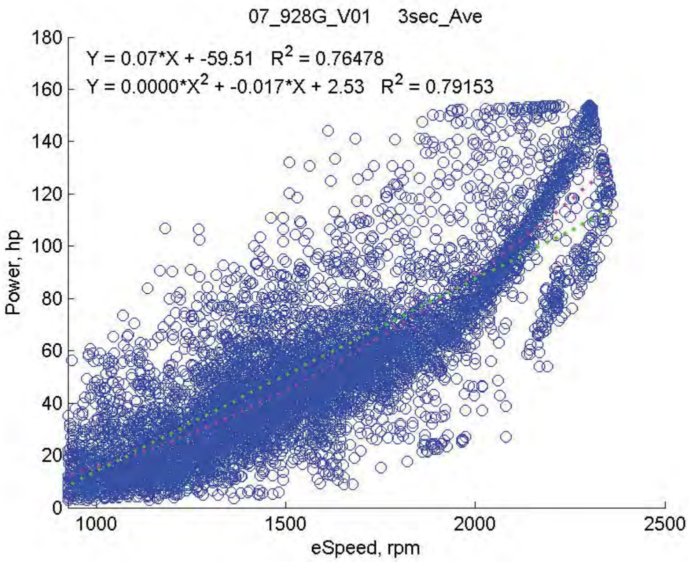

02_310SJ_V01 3sec_Ave
Y = 0.05*X + -37.16 R^2 = 0.89465
Y = -0.0000*X^2 + 0.064*X + -47.90 R^2 = 0.89533
Power, hp
eSpeed, rpm
0
10
20
30
40
50
60
70
80
90
100
1200
1400
1600
1800
2000
2200
2400

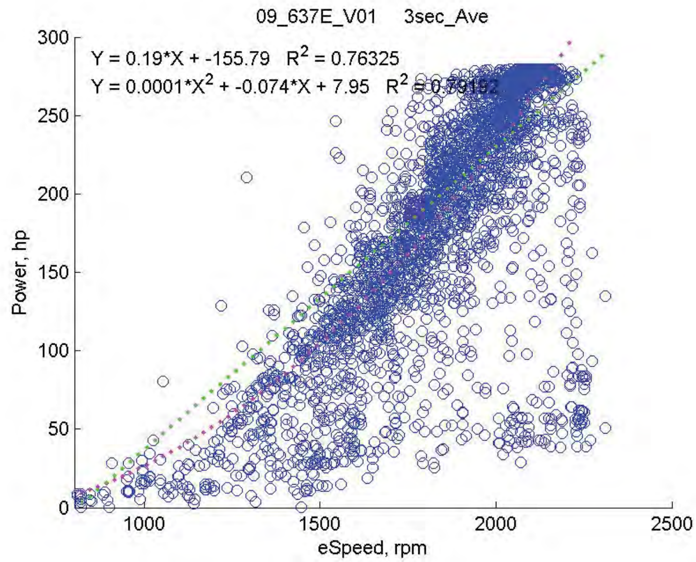

03_644J_v01 3sec_Ave
Y = 0.08*X + -54.29 R^2 = 0.61717
Y = -0.0001*X^2 + 0.240*X + -163.53 R^2 = 0.64496
Power, hp
eSpeed, rpm
0
50
100
150
200
250
300
1200
1400
1600
1800
2000
2200
2400

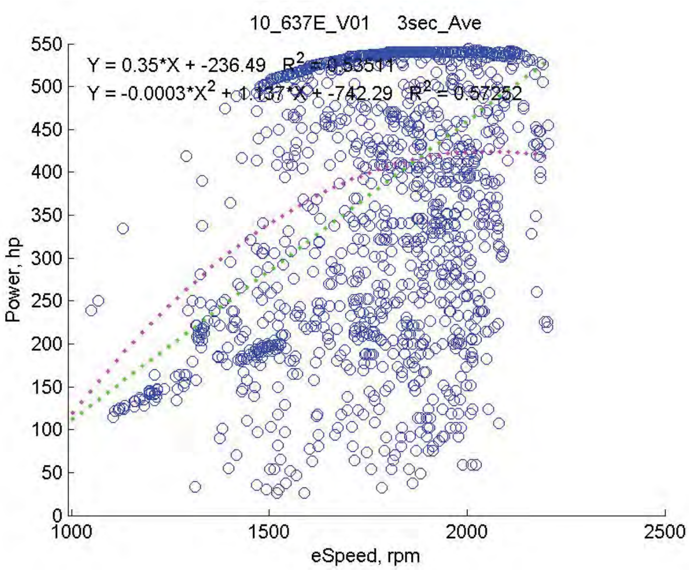

04_310SG_v01 3sec_Ave
Y = 0.02*X + -14.01 R^2 = 0.52928
Y = -0.0000*X^2 + 0.032*X + -20.60 R^2 = 0.52992
Power, hp
eSpeed, rpm
0
10
20
30
40
50
60
70
80
90
100
1200
1400
1600
1800
2000
2200
2400

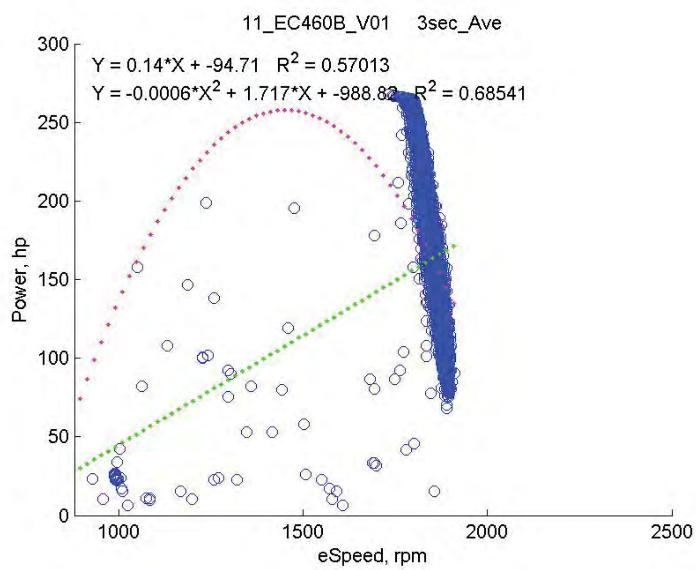

05_410G_V01 3sec_Ave
Y = 0.03*X + -19.95 R^2 = 0.557
Y = -0.0000*X^2 + 0.127*X + -88.66 R^2 = 0.60568
Power, hp
eSpeed, rpm
0
10
20
30
40
50
60
70
80
90
100
1200
1400
1600
1800
2000
2200
2400

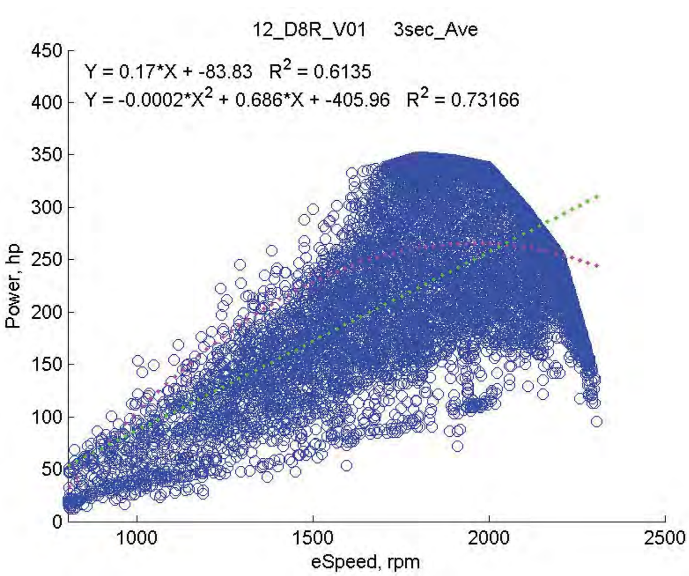

06_WA470_V01 3sec_Ave
Y = 0.16*X + -119.55 R^2 = 0.74045
Y = 0.0000*X^2 + 0.136*X + -105.53 R^2 = 0.74078
Power, hp
eSpeed, rpm
0
50
100
150
200
250
300
1000
1500
2000
2500

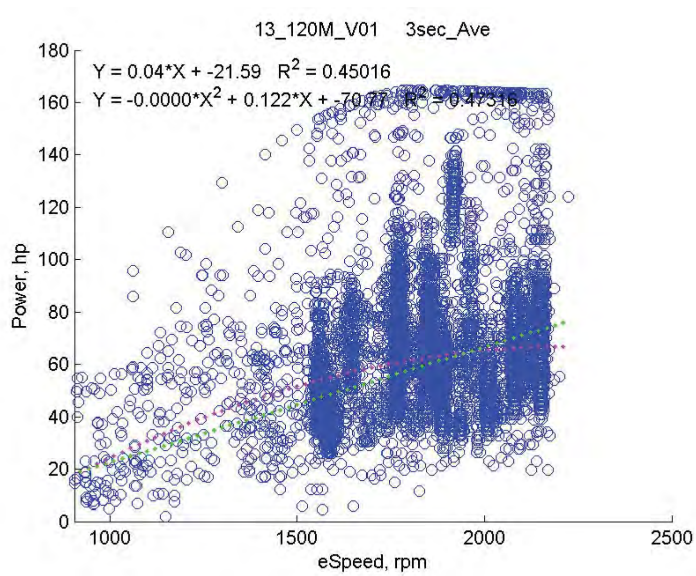

07_928G_V01 3sec_Ave
Y = 0.07*X + -59.51 R^2 = 0.76478
Y = 0.0000*X^2 + -0.017*X + 2.53 R^2 = 0.79153
Power, hp
eSpeed, rpm

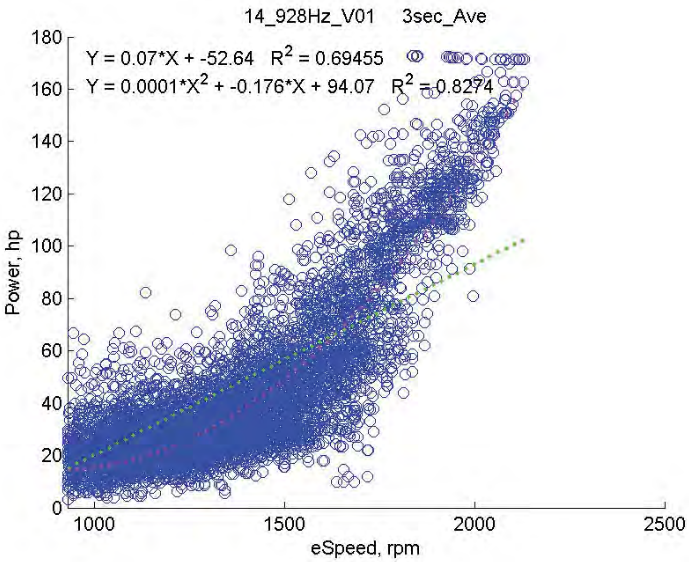

09_637E_V01 3sec_Ave
Y = 0.19*X + -155.79 R^2 = 0.76325
Y = 0.0001*X^2 + -0.074*X + 7.95 R^2 = 0.79152
Power, hp
eSpeed, rpm

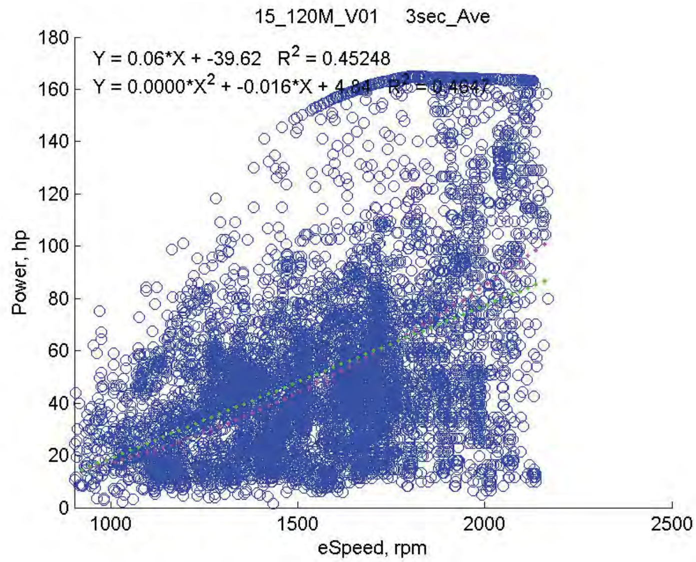

10_637E_V01 3sec_Ave
Y = 0.35*X + -236.49 R^2 = 0.53511
Y = -0.0003*X^2 + 1.137*X + -742.29 R^2 = 0.57252
Power, hp
eSpeed, rpm

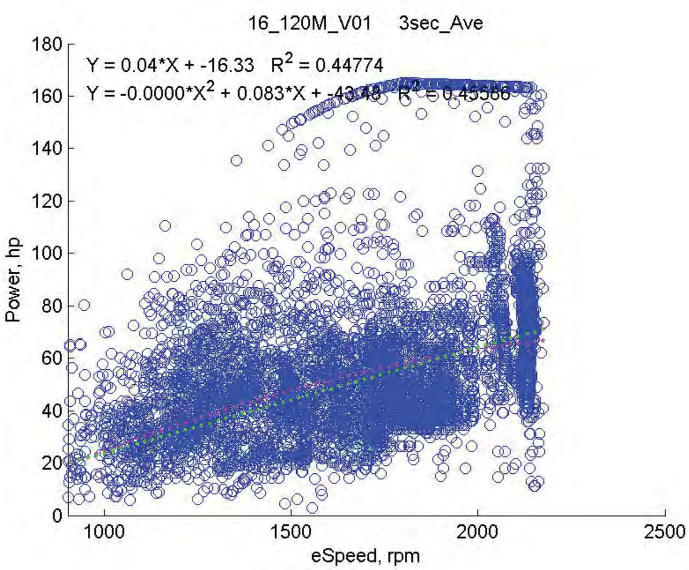

11_EC460B_V01 3sec_Ave
Y = 0.14*X + -94.71 R^2 = 0.57013
Y = -0.0006*X^2 + 1.717*X + -988.82 R^2 = 0.68541
Power, hp
eSpeed, rpm

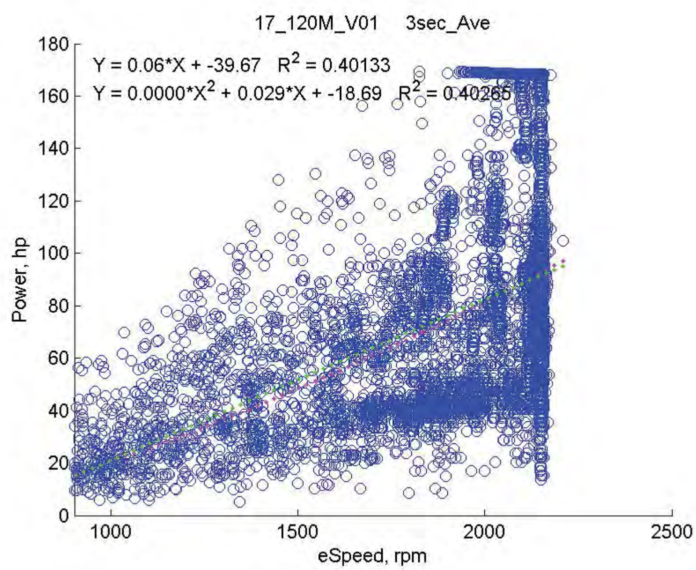

12_D8R_V01 3sec_Ave
Y = 0.17*X + -83.83 R^2 = 0.6135
Y = -0.0002*X^2 + 0.686*X + -405.96 R^2 = 0.73166
Power, hp
eSpeed, rpm

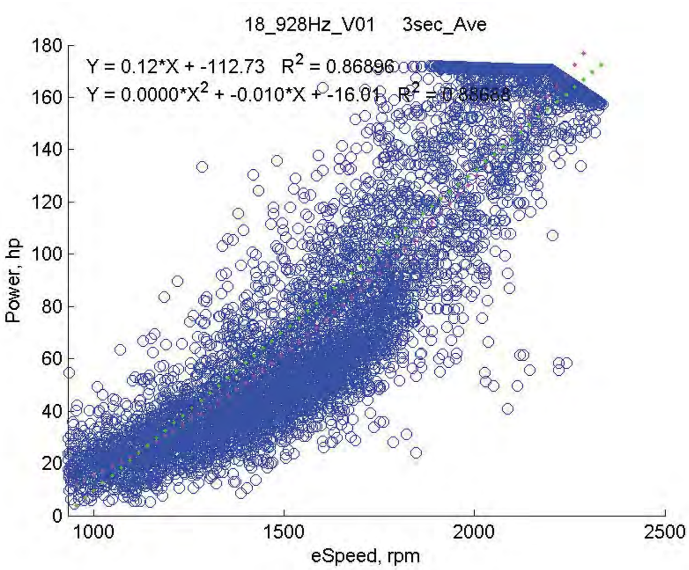

13_120M_V01 3sec_Ave
Y = 0.04*X + -21.59 R^2 = 0.45016
Y = -0.0000*X^2 + 0.122*X + -70.77 R^2 = 0.47316
Power, hp
eSpeed, rpm

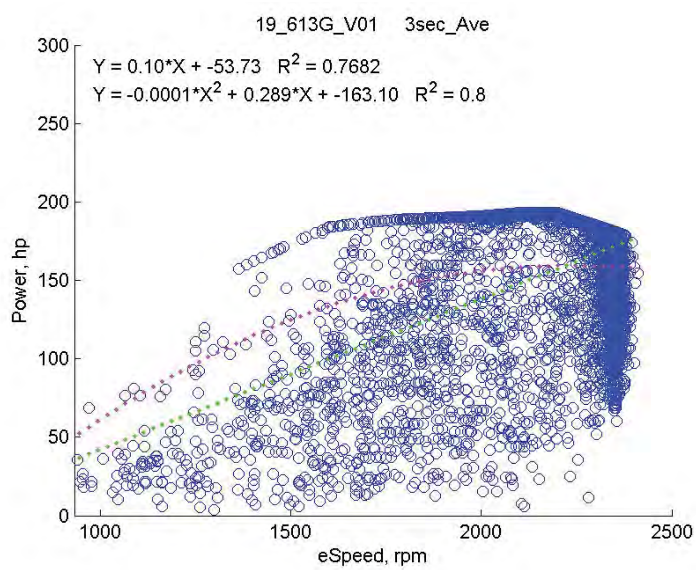

14_928Hz_V01 3sec_Ave
Y = 0.07*X + -52.64 R^2 = 0.69455
Y = 0.0001*X^2 + -0.176*X + 94.07 R^2 = 0.8274
Power, hp
eSpeed, rpm

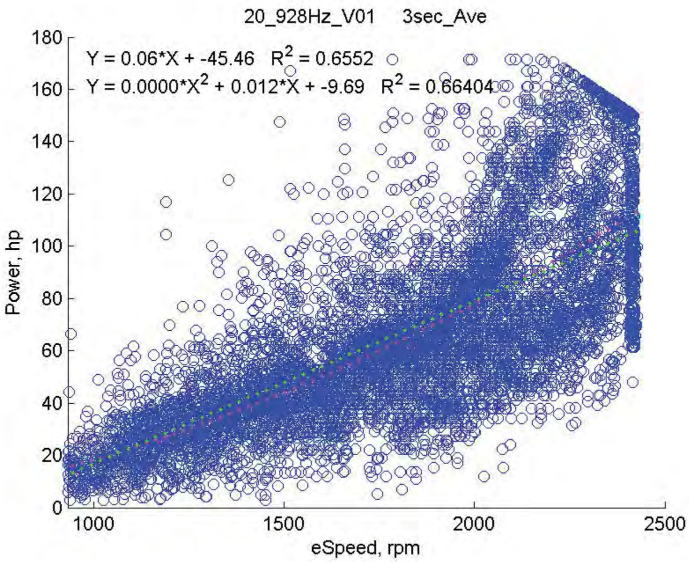

15_120M_V01 3sec_Ave
Y = 0.06*X + -39.62 R^2 = 0.45248
Y = 0.0000*X^2 + -0.016*X + 4.84 R^2 = 0.4647
Power, hp
eSpeed, rpm

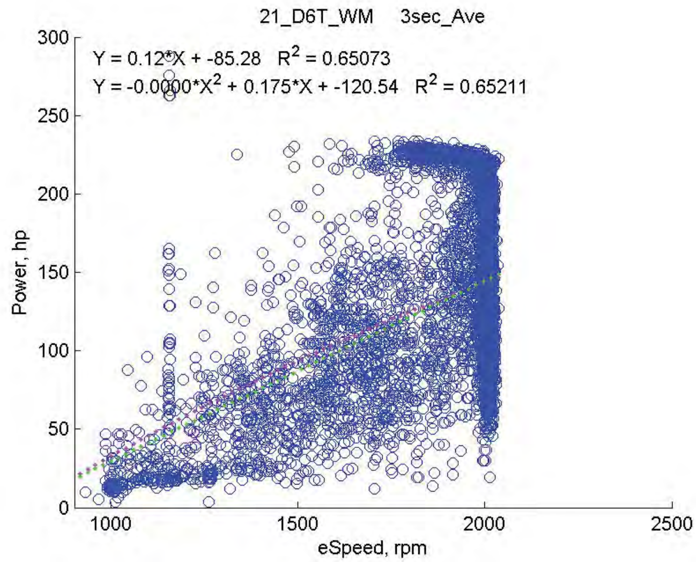

16_120M_V01 3sec_Ave
Y = 0.04*X + -16.33 R^2 = 0.44774
Y = -0.0000*X^2 + 0.083*X + -43.48 R^2 = 0.45566
Power, hp
eSpeed, rpm

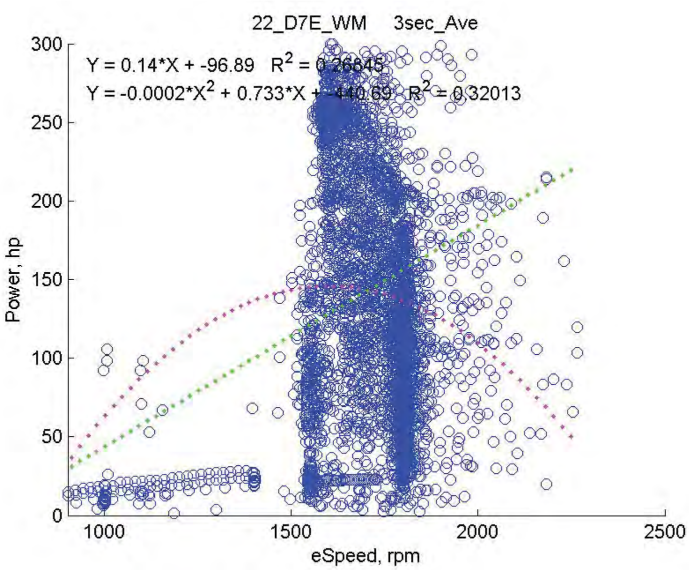

17_120M_V01 3sec_Ave
Y = 0.06*X + -39.67 R^2 = 0.40133
Y = 0.0000*X^2 + 0.029*X + -18.69 R^2 = 0.40265
Power, hp
eSpeed, rpm

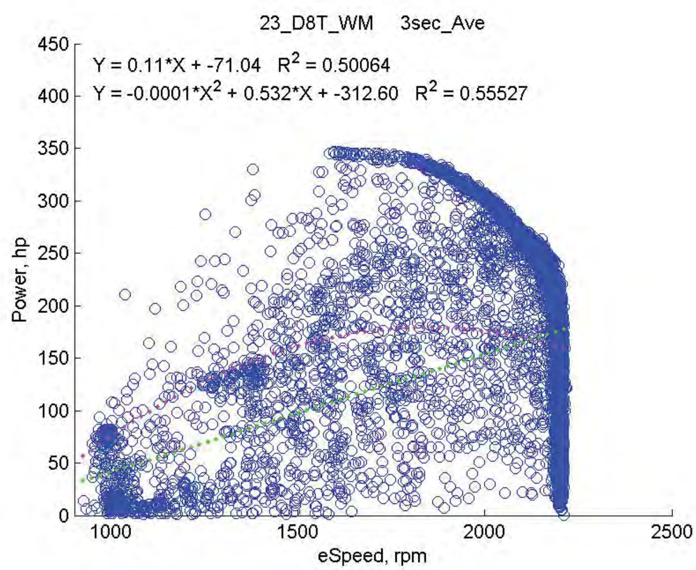

18_928Hz_V01 3sec_Ave
Y = 0.12*X + -112.73 R^2 = 0.86896
Y = 0.0000*X^2 + -0.010*X + -16.01 R^2 = 0.86868
Power, hp
eSpeed, rpm

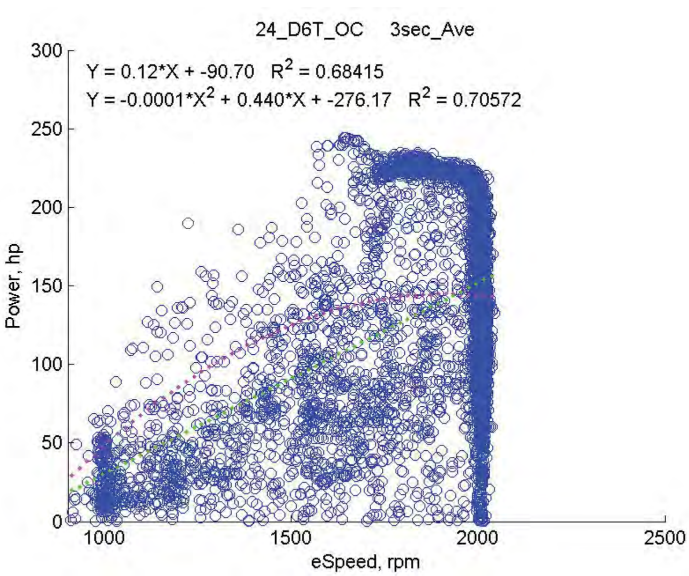

19_613G_V01 3sec_Ave
Y = 0.10*X + -53.73 R^2 = 0.7682
Y = -0.0001*X^2 + 0.289*X + -163.10 R^2 = 0.8
Power, hp
eSpeed, rpm

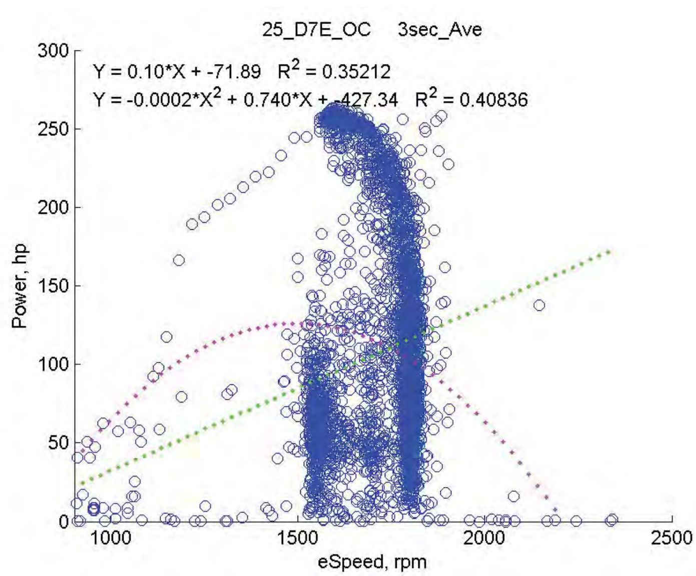

20_928Hz_V01 3sec_Ave
Y = 0.06*X + -45.46 R^2 = 0.6552
Y = 0.0000*X^2 + 0.012*X + -9.69 R^2 = 0.66404
Power, hp
eSpeed, rpm

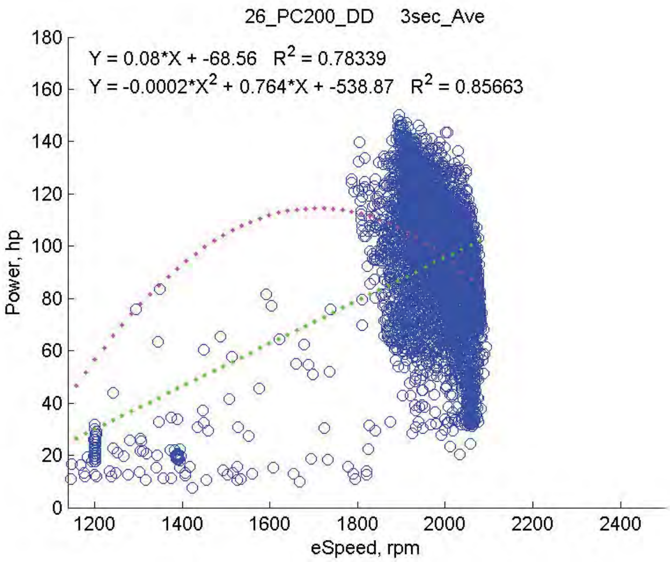

21_D6T_WM 3sec_Ave
Y = 0.12*X + -85.28 R^2 = 0.65073
Y = -0.0000*X^2 + 0.175*X + -120.54 R^2 = 0.65211
Power, hp
eSpeed, rpm

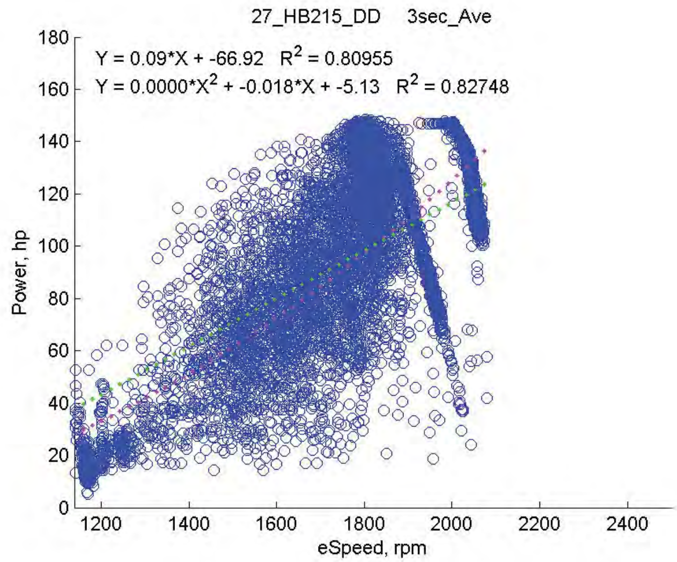

22_D7E_WM 3sec_Ave
Y = 0.14*X + -96.89 R^2 = 0.26845
Y = -0.0002*X^2 + 0.733*X + -440.69 R^2 = 0.32013
Power, hp
eSpeed, rpm


23_D8T_WM 3sec_Ave
Y = 0.11*X + -71.04 R^2 = 0.50064
Y = -0.0001*X^2 + 0.532*X + -312.60 R^2 = 0.55527
Power, hp
eSpeed, rpm


24_D6T_OC 3sec_Ave
Y = 0.12*X + -90.70 R^2 = 0.68415
Y = -0.0001*X^2 + 0.440*X + -276.17 R^2 = 0.70572
Power, hp
eSpeed, rpm


25_D7E_OC 3sec_Ave
Y = 0.10*X + -71.89 R^2 = 0.35212
Y = -0.0002*X^2 + 0.740*X + -427.34 R^2 = 0.40836
Power, hp
eSpeed, rpm


26_PC200_DD 3sec_Ave
Y = 0.08*X + -68.56 R2 = 0.78339
Y = -0.0002*X2 + 0.764*X + -538.87 R2 = 0.85663
Power, hp
eSpeed, rpm
180
160
140
120
100
80
60
40
20
0
1200
1400
1600
1800
2000
2200
2400


27_HB215_DD 3sec_Ave
Y = 0.09*X + -66.92 R2 = 0.80955
Y = 0.0000*X2 + -0.018*X + -5.13 R2 = 0.82748
Power, hp
eSpeed, rpm
180
160
140
120
100
80
60
40
20
0
1200
1400
1600
1800
2000
2200
2400

Appendix D. Predicted Emissions at 50% and 80% Load on a g/hp-hr Basis

Appendix – Predicted Emissions at 50% and 80% Load on a g/hp-hr Basis

NO_x emissions

The predicted emissions at 50% and 80% of load for various horsepower categories and emission Tiers (i.e., 2, 3, and 4i) are presented in Figure 11-1 on a g/hp-hr basis. For these plots, the predicted values for all pieces of equipment within each category are averaged for each bar. The error bars represent the standard deviation of the average values for all equipment within each category. On a g/hp-h basis the data for the individual categories shows that NO_x emissions are comparable to the certification levels at the 50% and 80% hp levels for the Tier 2 and Tier 3 equipment. On a g/hp-h basis, the Tier 2 equipment showed lower emissions than the Tier 3 equipment for the 50-100 hp and 100-175 hp categories, but not for the 175-300 categories. Interestingly, while the Tier 4 equipment showed lower emissions for the 300-450 category, the emissions for the Tier 4 equipment in the 175-300 hp category were comparable to those of the Tier 2 equipment in the category. In both cases, the Tier 4 equipment did not show the order of magnitude differences that are seen from just a straight comparison of the emissions standards.

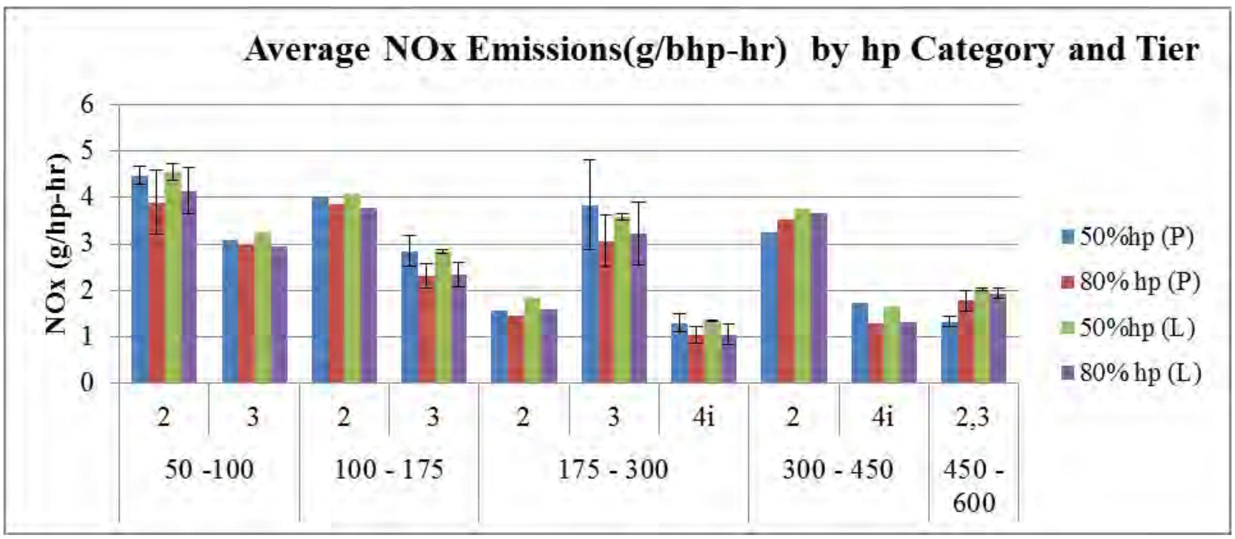


Figure 11-1 Average estimated NO_x emissions g/hp-h

PM emissions

The average predicted PM emissions at the 50% and 80% hp levels for the various hp and emission Tier categories in the fleet are presented in Figure 11-2 on a g/hp-hr basis. On a g/hp-h basis the data show that PM emissions are generally comparable to the certification levels at the 50% and 80% hp levels, with the PM emissions for Tier 4 equipment with aftertreatment systems being significantly lower than those for the Tier 2 and Tier 3 categories. The PM emissions for the two pieces of equipment in the 450-600 hp category exceeded the certification standards.

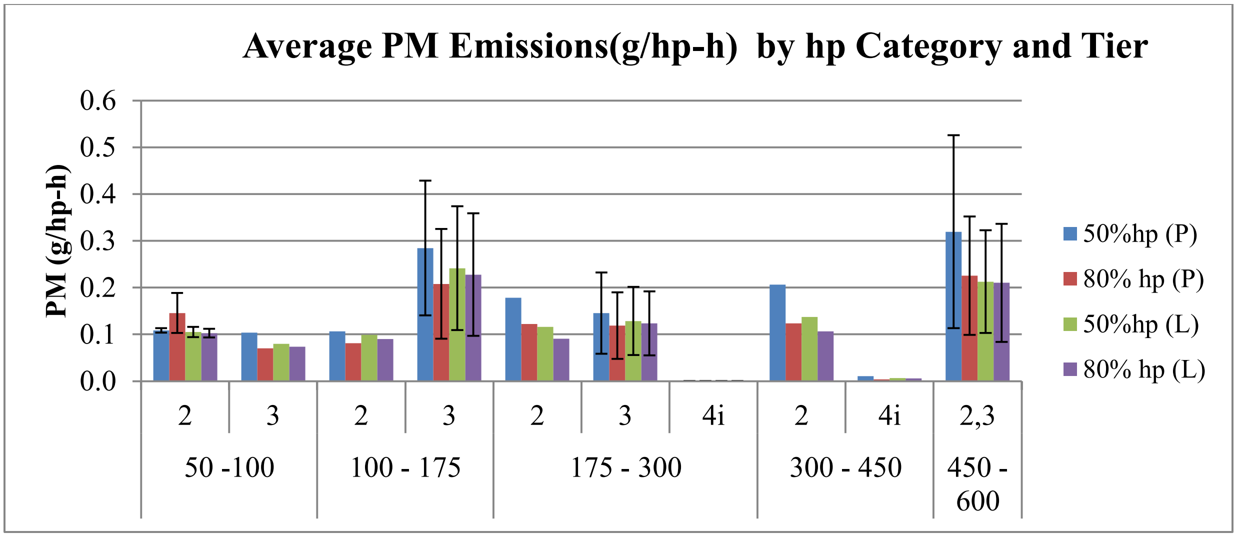


Figure 11-2 Average estimated PM emissions g/hp-h

THC and NMHC emissions

The average predicted THC emissions at the 50% and 80% hp levels for the various hp and emission Tier categories in the fleet are presented in Figure 11-3 on a g/hp-hr basis. On a g/hp-h basis, as shown in the bottom figure, the data show that THC emissions are relatively low, and for the certification categories that are based on a combined NO_x + NMHC standard, that the THC emissions make a relatively small contribution in relation to the NO_x emissions. The THC emissions show reductions in emissions for the Tier 3 equipment compared to the Tier 2 equipment for some categories (e.g., 175-300 and 50-100 hp), but not for others (e.g., the 100-175 hp category). The Tier 4 equipment shows the lowest THC emissions.

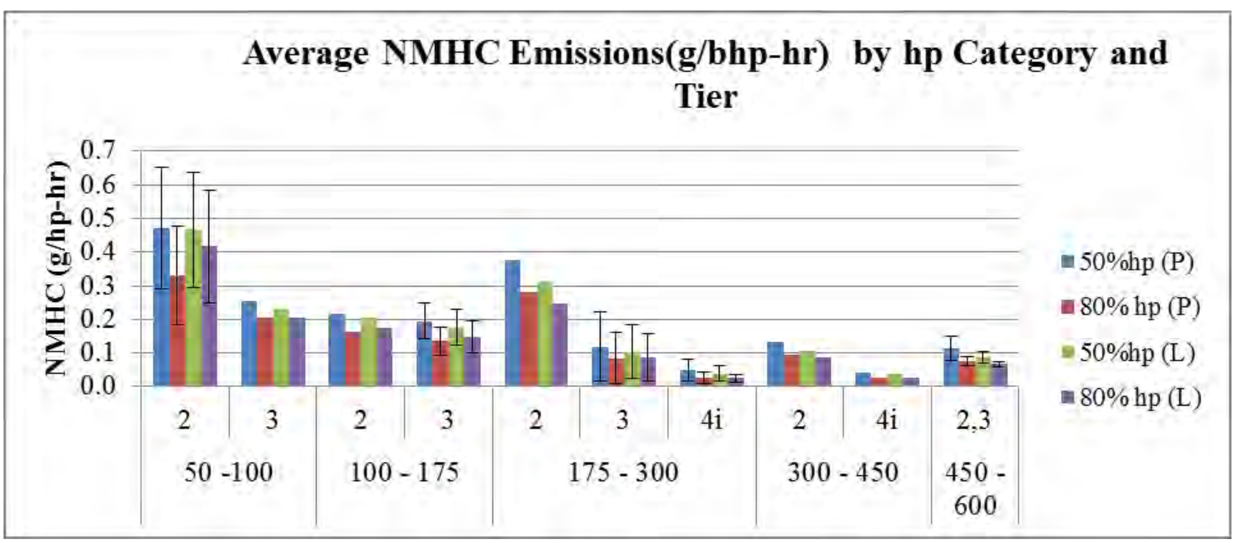


Figure 11-3 Average estimated NMHC emissions in g/hp-h

CO emissions

The average predicted CO emissions at the 50% and 80% hp levels for the various hp and emission Tier categories in the fleet are presented in **Error! Reference source not found.** on a g/hp-hr basis. On a g/hp-h basis, the data show that CO emissions are below the emissions standards except for the Tier 2 equipment in the 175-300 hp category.

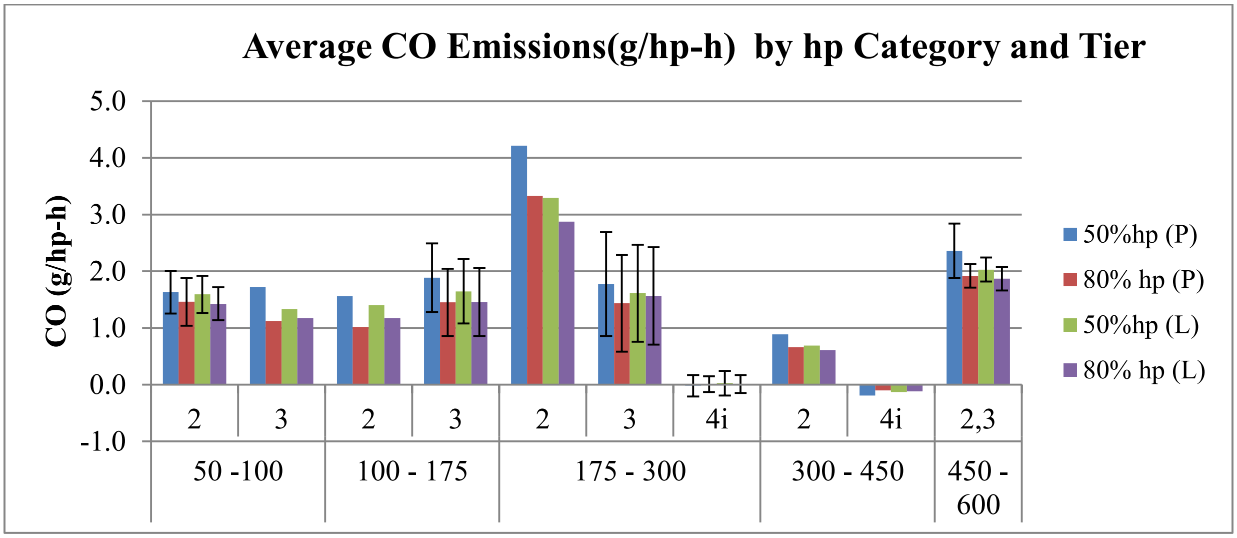


Figure 11-4 Average estimated CO emissions in g/hp-h

CO_2 emissions

The average predicted CO_2 emissions and FE at the 50% and 80% hp levels for the various hp and emission Tier categories in the fleet are presented in Figure 11-5 and Figure 11-6, respectively, on a g/hp-hr basis. On a g/hp-h basis, the data show that CO_2 emissions are approximately constant for equipment with horsepowers between 50 and 300. The Tier 4i in the 300-450 hp category also had CO_2 emissions at approximately the same level as the lower horsepower engines, while the Tier 2 and 3 engines in the 300-600 hp category had significantly lower CO_2 emissions. The trends for FE are similar to those for CO_2 in the exhaust.

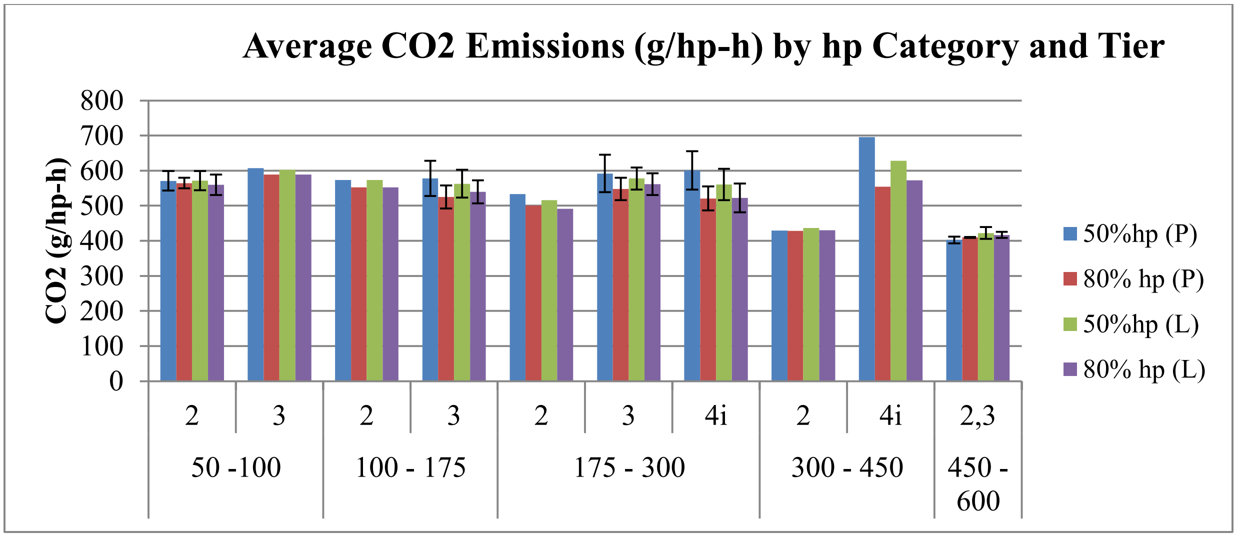


Figure 11-5 Average estimated CO_2 emissions in g/hp-hr

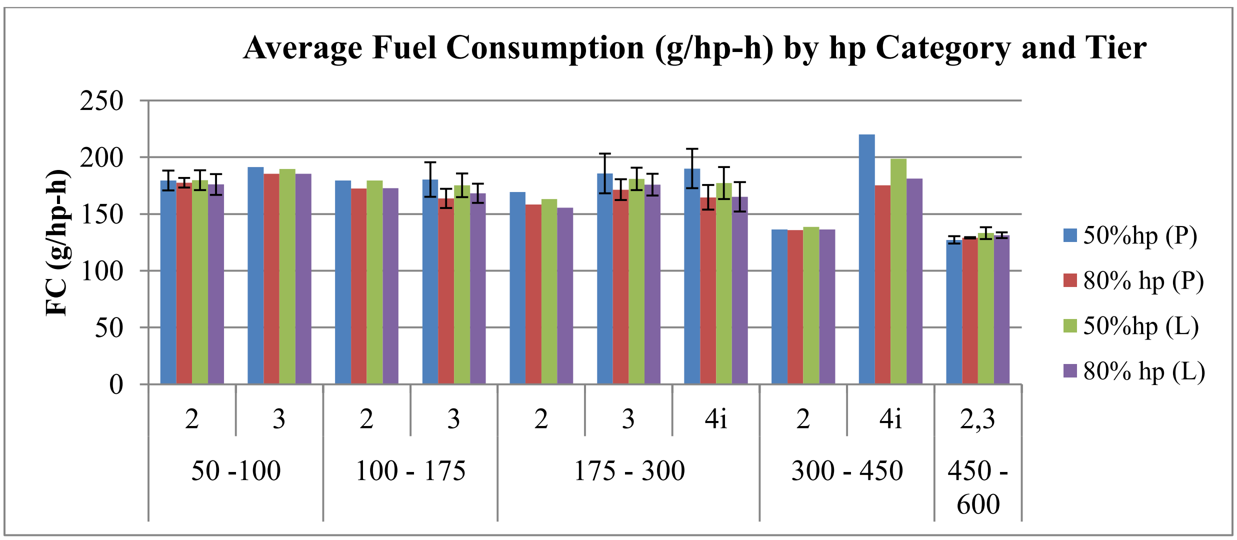


Figure 11-6 Average estimated Fuel Consumption in g/hp-h