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Off-road equipment is one of the most significant sources of nitrogen oxides (NOx) 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 NOx emissions, representing 7% and 4% of PM and NOx 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 engines 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.

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Developing a Model to Quantify Emissions from Heavy-Duty Construction Equipment as Related to Job Site Activity Data

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Acronyms and Abbreviations

40 CFR 1065 or 1065........................Part 1065 of Title 40 of the Code of Federal Regulations
CARB..California Air Resources Board
CE-CERT...College of Engineering-Center for Environmental Research and Technology (University of California, Riverside)
CFR..Code of Federal Regulations
CO..carbon monoxide
CO_2...carbon dioxide
COV..Coefficient of Variation
CVS...constant volume sampling
DOC..diesel oxidation catalyst
DPF...diesel particulate filter
ECM..engine control module
EPA...United States Environmental Protection Agency
FID..flame ionization detector
GFM..gravimetric filter module
g/hp-h...grams per brake horsepower hour
MEL..CE-CERT's Mobile Emissions Laboratory
NMHC...non-methane hydrocarbons
NDIR...Non-Dispersive InfraRed
NDUV...Non-Dispersive Ultraviolet Analyzer
NTE...Not-to-exceed
NO_x..nitrogen oxides
OEM..original equipment manufacturer
PEMS..portable emissions measurement systems
PM...particulate matter
RPM..revolutions per minute
scfm...standard cubic feet per minute
SCR...Selective Catalytic Reduction
SwRI...Southwest Research Institute
Tier 2, 3, or 4.....................................federal emissions standards levels for off-road diesel engines
THC...total hydrocarbons
UCR..University of California at Riverside

Executive Summary

The primary goal of this program was to develop a model to estimate emissions from off-road construction equipment as a function of fuel use. All of the emissions are produced by the combustion of the fuel and the amount of fuel burned is dependent upon the activity of the equipment, i. e. the physical work that the equipment is doing. As the equipment is asked to work harder the engine has to put out more power which requires using more fuel. Electronically controlled engines have an Electronic Control Module (ECM) which controls the speed, fueling rate, horsepower output etc. For diagnostic purposes there is an output jack where an instrument can be attached to read all of the signals from the ECM. While many of the signals are proprietary and can only be interpreted by the Manufacturers instruments, several of the signals which relate to the work that the engine is doing are publicly available. Therefore a secondary goal was to measure these publicly available signals to determine engine response and fuel use for a large subset of off-road equipment for comparison to the responses observed during actual in-use emission testing and estimate the emissions based upon the fuel usage.

Between a 2010 joint program with the California Air Resources Board (CARB) (Durbin, et al., 2013) and Caltrans (Barth, et al., 2012) and a 2012 program with CARB (Johnson, et al., 2013), emissions were measured from 27 pieces of off-road 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 27 pieces of equipment include 7 pieces of Tier 2 equipment, 15 pieces of Tier 3 equipment, and 5 pieces of Tier 4i equipment... 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. Analysis of the data indicated that a model could be developed based upon two modes of operation defined as idle and work and not on specialized physical activity such as trenching, scraping, backfilling, etc...

The data for each piece of equipment was partitioned into idle and non-idle based primarily on the engine speed. The standard idle speed was determined for each vehicle from the dataset and the data was partitioned into mini events where mini events are defined as sections of continuous and uniform activity modes that end when the activity mode changes. The objective of this analysis was to create a tool that can be used to estimate emissions from off-road construction equipment based upon data readily available to the equipment owners. The developed model, Off-Road Equipment Emission Estimator (ORE) model is a stand-alone Excel spreadsheet with a graphical user interface and the ability to load parameter files to facilitate running the model. The inputs to the model are the equipment type (i. e. the emission tier of the engine), fuel consumption, and general equipment activity (i. e. whether the engine is idling or operating at a higher speed because the equipment is performing physical work).

The model is based upon emission factors developed based upon an initial dataset of 27 units of construction equipment which UCR measured the emissions from over the last few years. Outputs from the model are emission estimates for Carbon Dioxide (CO_2), and the regulated pollutants; Carbon Monoxide (CO), Total Hydrocarbons (THC), Oxides of Nitrogen (NO_x), and Particulate Matter (PM) for individual units of construction equipment as well as a fleet defined by individual units of equipment.

In the current program emissions were measured from five pieces of off-road construction equipment to evaluate the robustness of the model. The equipment included one 2013, Tier 4i, 127 hp

backhoe/loader, one 2011 Tier 3, 174 hp bulldozer, one 2011, Tier 3, 171 hp wheel loader, one 2013, Tier 3, 300 hp Excavator, and one 2011 Tier 4i, 316 hp Bulldozer. This equipment was used to evaluate the ability of the model to produce emission estimates in reasonable agreement with measured values. The results of these comparisons indicate that variability in the modeling results for individual equipment result from emission variability within the chosen category groups and that the model results improve greatly when combined across multiple pieces of equipment.

1 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 engines 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 which the equipment is typically operated and what types of operation lead to the greatest sources of emissions.

The development of accurate emissions factors for off-road equipment under in-use conditions remains an 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. 2011, Giannelli et al., 2010, Warila et al., 2013). Frey and coworkers have conducted a number of studies looking at the emissions of construction equipment and how to model their emissions impact (Abolhasani, et al., [2008, 2013], Frey et al., [2003, 2008, 2008a, 2008b, 2010, 2010a], 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 (Cocker, et al., 2004), (Durbin, et al. (2007, 2009, 2009a), Fiest et al. (2008), Johnson, et al. (2008, 2009, 2010, 2011, 2011a), Khalek et al. (2010), Khan, et al. (2012), and Miller, et al. (2006, 2007, 2008)). 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 goal of this study was to develop a model to estimate emissions from off-road construction equipment as a function of fuel consumption and to obtain fuel usage from many pieces of off-road construction equipment. We had emission measurements from 20 pieces of off-road construction equipment, using CFR 1065 compliant PEMS instruments, from the joint 2010 CARB, Caltrans program to which we intended to add emission measurements from five more before developing the model. The gas phase and PM exhaust emissions and the engine work (E-Work) were measured on a second-by-second basis. Concurrently CE-CERT had a 2 million dollar 2012 CARB Air Quality Improvement Program (AQIP) to compare emissions from a hybrid bulldozer to conventional bulldozers and from a hybrid excavator to conventional excavators. The CARB AQIP program used the same equipment as required for this Caltrans project so there was a long delay before we were able to make the required measurements. The emissions data from the seven pieces of equipment from the 2012 CARB AQIP program were added to the 20 pieces from the prior programs before developing the model of emissions as a function of fuel usage. The emissions data from the 5 pieces of construction equipment measured in this program were then used to estimate the robustness of the emissions model.

2 Development of the Off-Road Equipment Emission Estimator (ORE) Model

The objective of creating the ORE (Off-Road Equipment) model was to develop a tool that could be used to estimate emissions from off-road construction equipment based on available data such as equipment type, fuel consumption and general equipment activity. The model is a stand-alone Excel spreadsheet with a graphical user interface and the ability to load parameter files to facilitate running the model.

The model is an emission factor model that was developed based on an initial dataset measured from 27 units of construction equipment and validated on a measured data set of 5 additional units of construction equipment. Outputs from the model are emission estimates for Carbon Dioxide (CO_2), and the regulated pollutants: Carbon Monoxide (CO), Total Hydrocarbons (THC), Oxides of Nitrogen (NO_x) and Particulate Matter (PM) for individual units of construction equipment as well as a fleet defined by individual units of equipment.

This section provides a description of the analysis of the construction equipment data collected for the purpose of model development and the modeling methodology for the ORE model.

2.1 Data Analysis

The modeling dataset was analyzed for the purpose of developing the ORE model and consists of measured data from 27 units of construction equipment of varying equipment type, model year, horse power rating, engine certification standard, and exhaust aftertreatment and powertrain technology (standard and hybrid). The testing of this equipment is described in more detail in Appendix B.

2.1.1 Mode of Operation

The importance of mode of operation was analyzed in the modeling dataset. The test data was partitioned into several operating modes based on video recordings from mounted cameras on the front of the equipment during testing.

The results show that in general, fuel-specific emissions and the fuel consumption rate vary significantly between the idle mode and the other modes identified, but the variance among the other modes which were observed is relatively small. Fuel-specific emissions, and to a lesser extent fuel consumption, did not change very much under the different levels of load which were observed. This can be seen in the examples in Figure 2-1 through Figure 2-5.

For this reason, and the fact that including different operating modes in the model would also require activity information for those modes, which the user is not likely to have, the model utilizes two general modes of operation: idle and work. For the purposes of this modeling work, idle mode is standard idling, as opposed to high idle used for engine power take-off (PTO). Work mode is all non-idle activity with the exception of cold-start and diesel particulate filter (DPF) regeneration events. Cold-start and DPF regeneration events, were excluded from the modeling work because there was limited information to characterize them sufficiently.

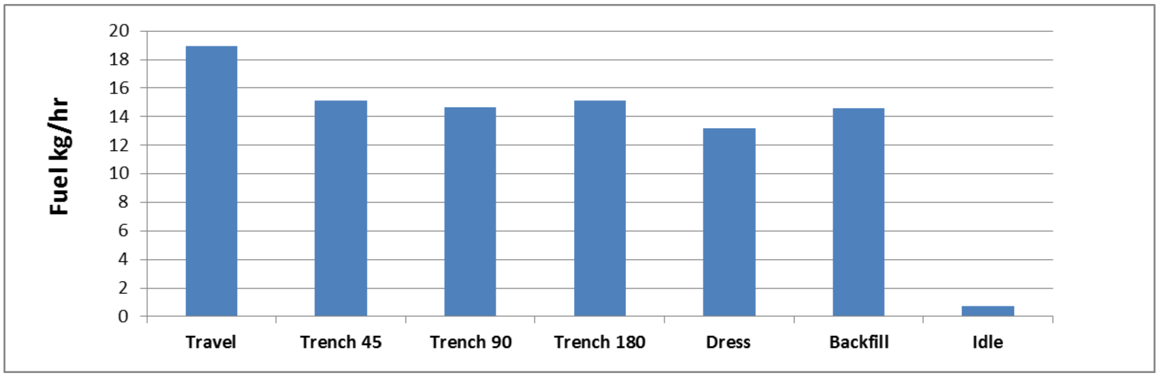

Figure 2-1 Fuel consumption rate by mode of operation for 2011 excavator.

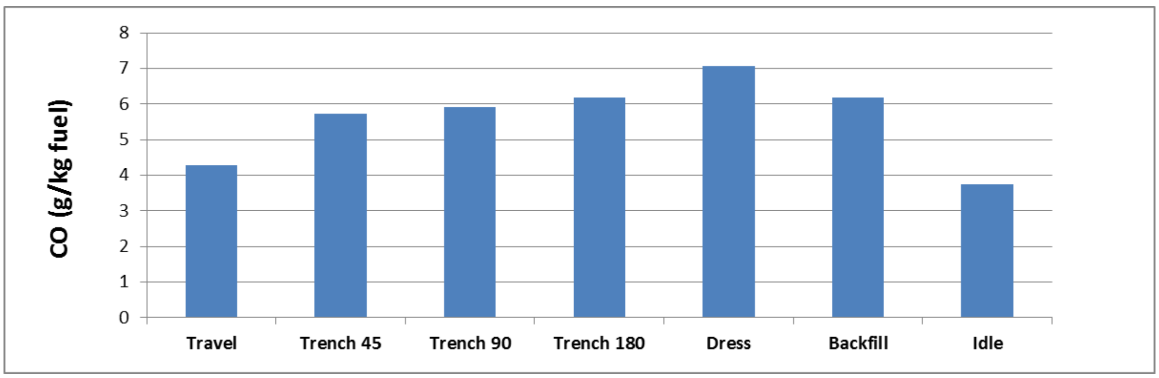

Figure 2-2 Fuel based CO emission by mode of operation for 2011 excavator.

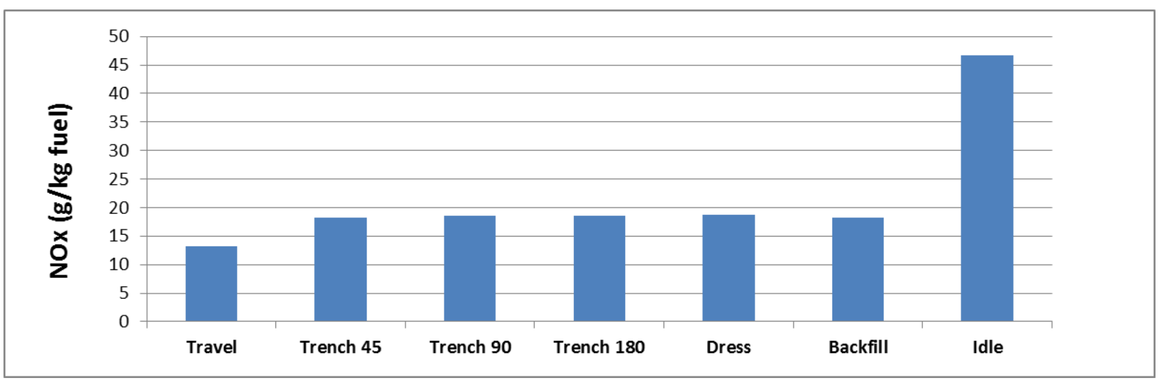

Figure 2-3 Fuel based NO_x emission by mode of operation for 2011 excavator.

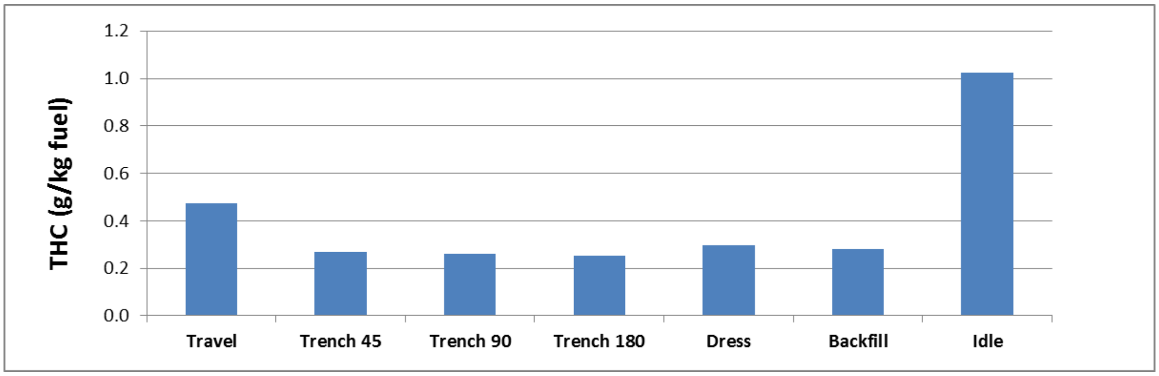

Figure 2-4 Fuel based THC emission by mode of operation for 2011 excavator.

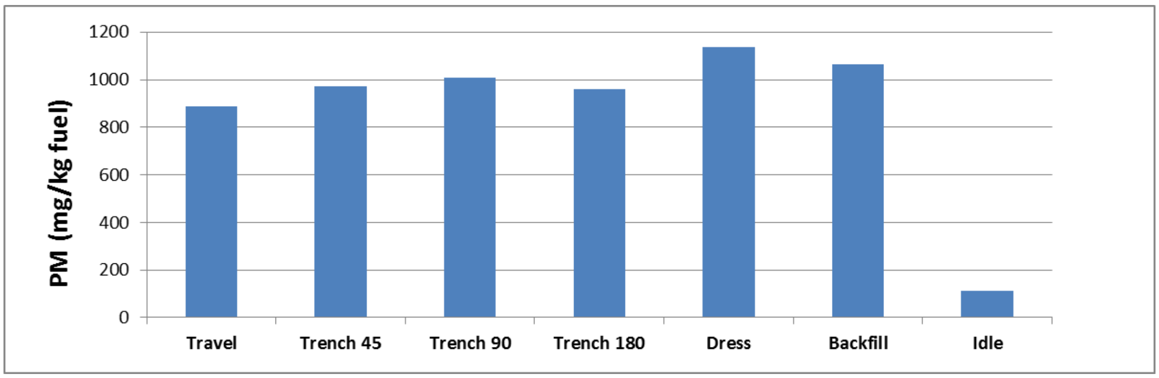

Figure 2-5 Fuel based PM emission by mode of operation for 2011 excavator.

2.1.1.1 Data Partitioning into Mini Events

Since the model is based on two modes of operation defined here, idle and work, and not on specialized activity such as trenching, scraping, backfilling, etc., all of the subsequent data analysis is based on partitioning the test data into idle and non-idle (work) with the exclusion of cold-start and DPF regeneration events.

Data was partitioned into idle and non-idle based primarily on the engine speed. The standard idle speed was determined for each vehicle from the dataset and the data was partitioned into mini events. Mini events are defined as sections of continuous and uniform activity modes that end when the activity mode changes. An example of the data partitioning that was used is presented in Figure 2-6. In this figure, the green indicates idle data and the blue indicates non-idle data. Each continuous section of green or blue data represents one idle or non-idle mini event. Since the model is not a second-by-second model, partitioning the data into mini-events allows for data analysis on a scale similar to that of the model. Results from the analysis of mini events are also not as noisy as trends in second-by-second data.

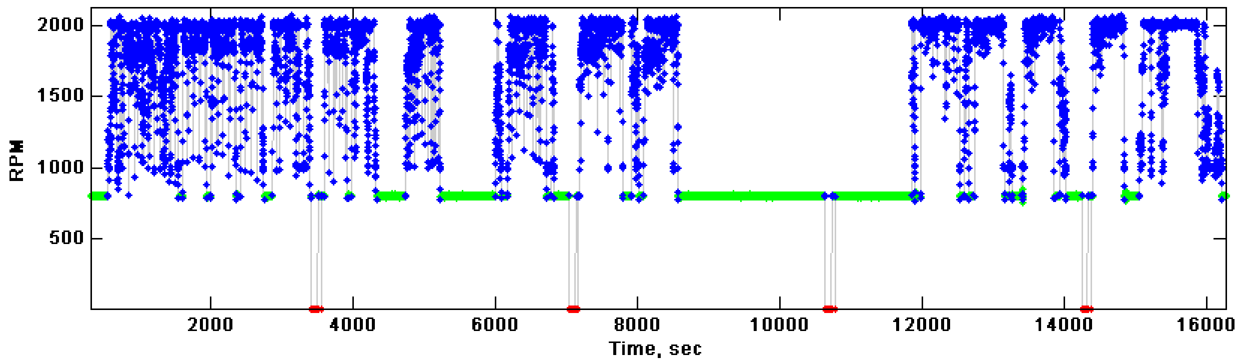

Figure 2-6 Example of data partitioning into mini events. Green indicates idle, blue indicates non-idle, and red is omitted.

2.1.2 Equipment Categories

Equipment categories were developed for use with the model based on the development dataset. The development dataset contains data for 6 equipment types: backhoe, bulldozer, excavator, road grader, scraper, and wheel loader; 3 tier certification standards: Tier 2, Tier 3 and Tier 4 Interim; rated engine power ranging from 92 to 540 hp; and 2 powertrain technologies: standard and hybrid as shown in Table 2-1. Table 2-1 provides an overview of the equipment tested and the parameters that were examined for developing the model.

Table 2-2 presents a matrix of equipment characteristics and the number of units of equipment tested with each characteristic. Emission trends with respect to equipment characteristics and the availability of data were evaluated to determine equipment categories for modeling. This subsection discusses the analysis of equipment characteristics in the model development dataset.

Table 2-1 Construction equipment tested in development dataset

Equipment	Model Year	Type	Unit Tier	HP	Tech Group
1	2007	Backhoe	Tier 2	99	non-hybrid
2	2010	Backhoe	Tier 3	99	non-hybrid
3	2007	Wheel Loader	Tier 3	225	non-hybrid
4	2006	Backhoe	Tier 2	92	non-hybrid
5	2006	Backhoe	Tier 2	99	non-hybrid
6	2009	Wheel Loader	Tier 3	273	non-hybrid
7	2004	Wheel Loader	Tier 2	156	non-hybrid
8	2008	Excavator	Tier 3	520	non-hybrid
9	2006	Scraper	Tier 2	280	non-hybrid
10	2006	Scraper	Tier 2	540	non-hybrid
11	2006	Excavator	Tier 3	269	non-hybrid
12	2003	Bulldozer	Tier 2	338	non-hybrid
13	2008	Road Grader	Tier 3	163	non-hybrid
14	2011	Wheel Loader	Tier 3	171	non-hybrid
15	2010	Road Grader	Tier 3	163	non-hybrid
16	2008	Road Grader	Tier 3	163	non-hybrid
17	2010	Road Grader w/DPF	Tier 3	168	non-hybrid
18	2011	Wheel Loader	Tier 3	171	non-hybrid
19	2010	Scraper	Tier 3	193	non-hybrid
20	2011	Wheel Loader	Tier 3	171	non-hybrid
21	2012	Bulldozer	Tier 4i	204	non-hybrid
22	2011	Bulldozer	Tier 4i	296	hybrid
23	2012	Bulldozer	Tier 4i	347	non-hybrid
24	2012	Bulldozer	Tier 4i	204	non-hybrid
25	2011	Bulldozer	Tier 4i	296	hybrid
26	2007	Excavator	Tier 3	155	non-hybrid
27	2011	Excavator	Tier 3	148	hybrid

Table 2-2 Matrix of equipment tested and selected characteristics

Emission Certification	HP Category	Backhoe	Bulldozer	Excavator	Road Grader	Scraper	Wheel Loader	Grand Total
Tier 2	50-100	3						3
	100-175						1	1
	175-300					1		1
	300-450		1					1
	450-600					1		1
Tier 3	50-100	1						1
	100-175			2	4		3	9
	175-300			1		1	2	4
	450-600			1				1
Tier 4i	175-300		4					4
	300-450		1					1
Grand Total		4	6	4	4	3	6	27

2.1.2.1 Emission Certification Standard

Equipment characteristics were evaluated with respect to idle and non-idle modes of operation since they were determined to be significant predictors of fuel-specific emission rates. Figure 2-7 shows a boxplot of fuel consumption rate by engine certification standards and the operating modes used in the model. Figure 2-8 and Figure 2-9 show boxplots for NO_x and PM fuel-specific emissions by emission certification and mode. In the boxplot, the red center line in the box indicates the median, the box represents the 25th and 75th percentiles, and the whiskers extend to the extreme values not considered outliers which are indicated by red crosses.

Results from the data analysis show that the emission certification standard is a significant predictor for fuel-specific emissions. This is expected since the engines are manufactured to meet these standards. In the case of PM, the Tier 4 Interim engines have a median emission in the non-idle mode of 1.08 x 10^{-3} (kg PM/kg Fuel), as seen in the expanded scale of Figure 2-10, which can be compared to Tier 3 equipment with emission of 1.03 (kg PM/kg Fuel). This represents a 99.9 % reduction in PM emissions and is related to the more stringent Tier 4 Interim PM standards.

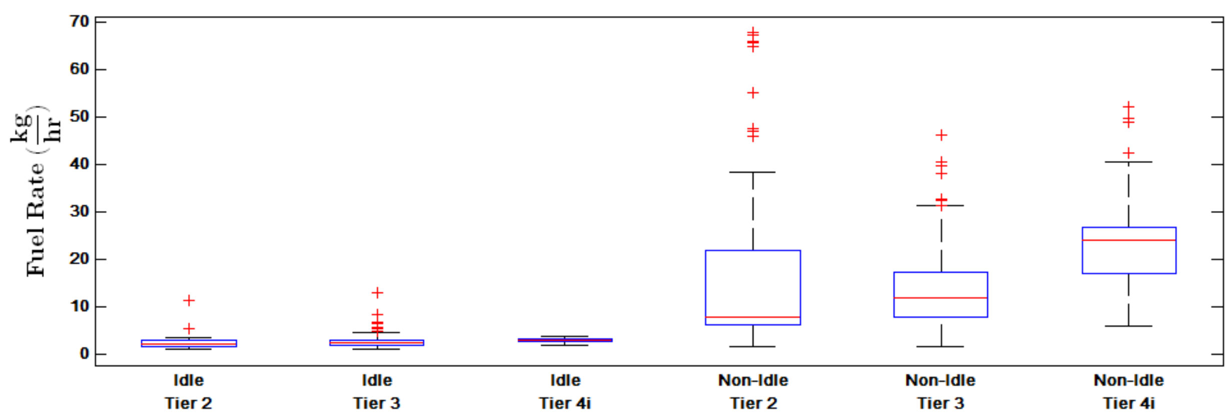

Figure 2-7 Boxplot of fuel rate engine certification standards and mode

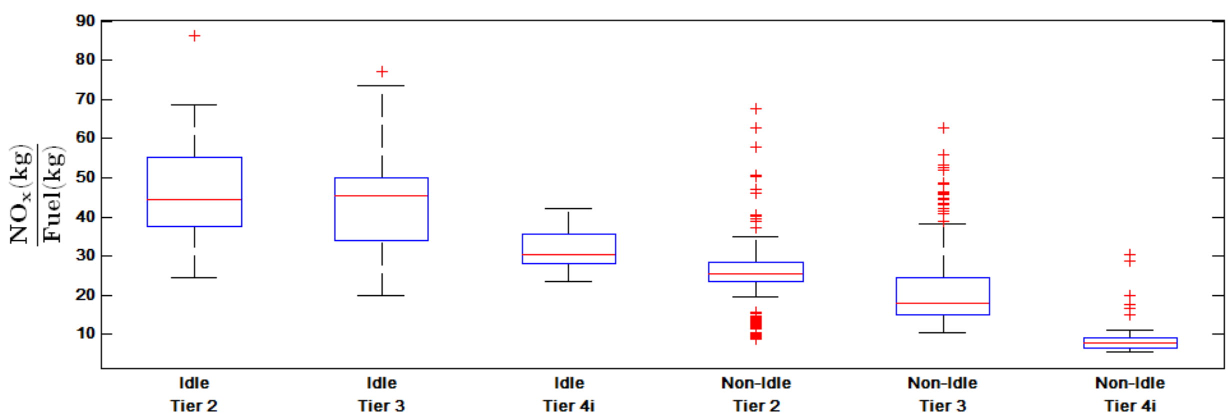

Figure 2-8 Boxplot of NO_x fuel-specific emission by emission certification and mode

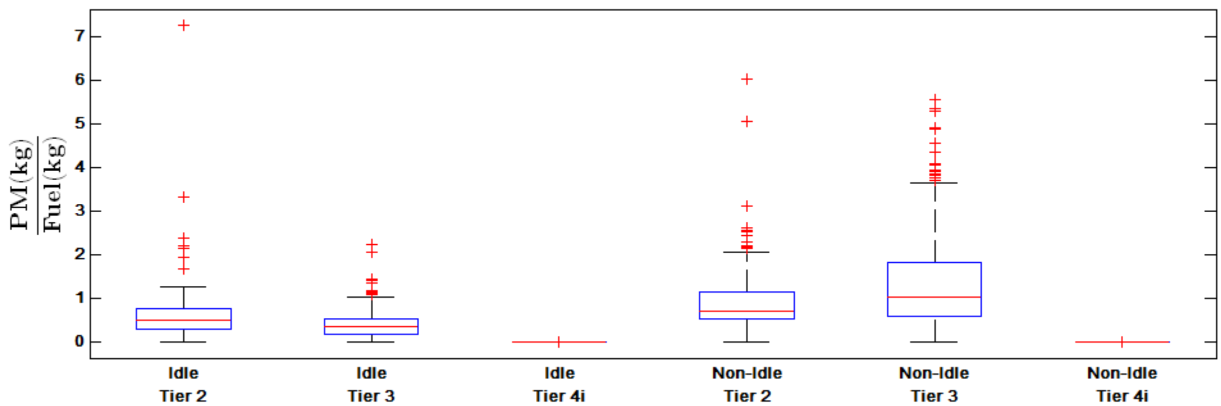

Figure 2-9 Boxplot of PM fuel-specific emission by emission certification and mode

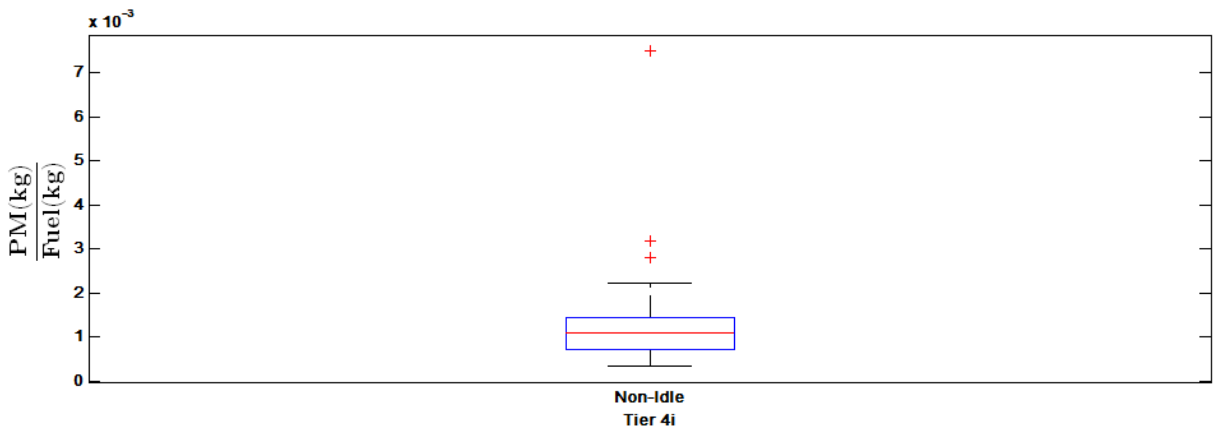

Figure 2-10 Boxplot of PM fuel-specific emission for Tier 4 Interim for the non-idle mode

2.1.2.2 *Aftertreatment Technologies*

The main strategy for meeting Tier 4 PM standards is the use of a Diesel Particulate Filter (DPF). In the case of Tier 4 Interim, DPFs are standard on all equipment and therefore DPFs do not need to be accounted for specifically. In addition to the Tier 4 Interim equipment tested, a Tier 3 unit of equipment with a DPF was also tested. Although this unit is Tier 3, the DPF makes it an extreme outlier with respect to PM emissions (See Appendix A: Non-idle regression for PM). For this reason, equipment categories including DPF technology were implemented in the model for Tier 2 and Tier 3 equipment. These categories are equivalent to their non-DPF counterparts and only contain adjusted PM parameters which reflect the addition of DPF technology.

Similar reasoning could be applied to the aftertreatment technology of SCR (Selective Catalytic Reduction) for NO_x, however no SCR equipped units were tested and therefor this technology is not currently reflected in the model.

2.1.2.3 Rated Engine Power

The rated engine power was evaluated as a predictive parameter for fuel-specific emissions. Figure 2-11 shows that the non-idle fuel consumption rate varied somewhat with rated engine-horsepower as expected since higher horsepower equipment can be loaded more heavily. Figure 2-12 and Figure 2-13 show that variations in NO_x and PM fuel-specific emissions do not show a clear trend with rated engine power for non-idle modes. This trend is also true for the idle mode and therefore engine rated power was not used as a predictive parameter for fuel-specific emissions.

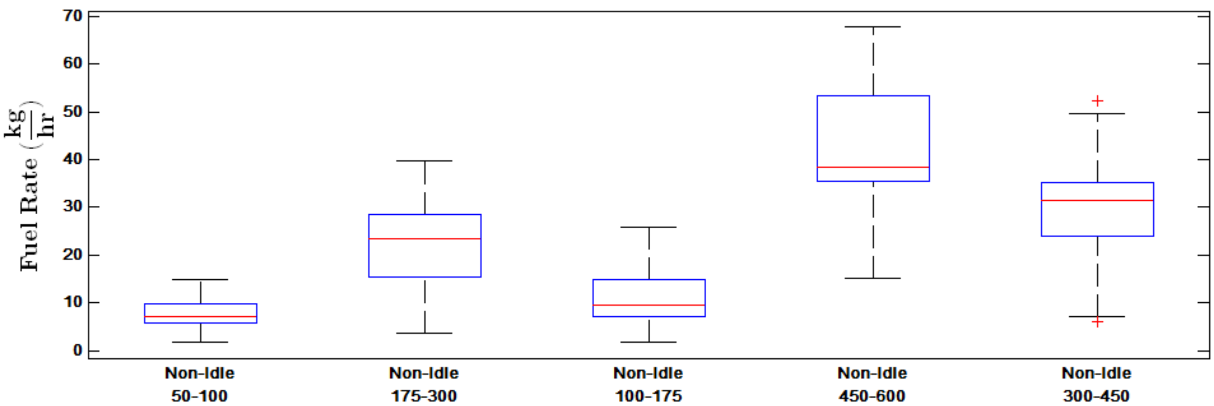

Figure 2-11 Fuel consumption rate by mode and engine rated horsepower.

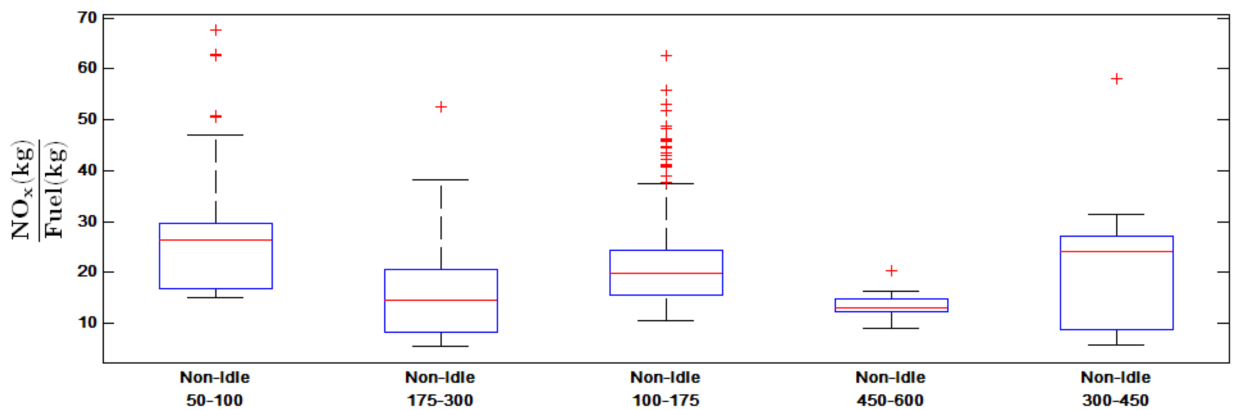

Figure 2-12 NOx fuel-specific emissions by mode and engine rated horsepower.

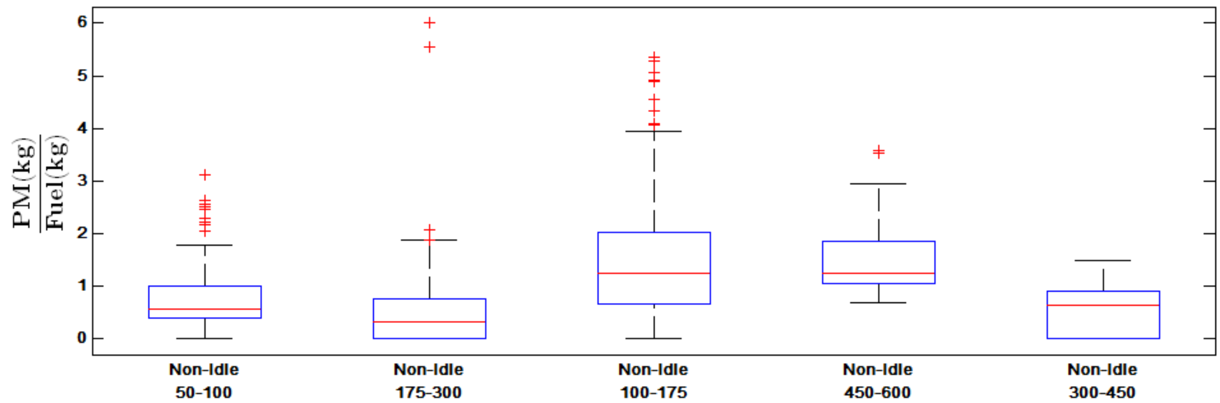

Figure 2-13 PM fuel-specific emissions by mode and engine rated horsepower.

2.1.2.4 Equipment Type

Equipment type was also evaluated as a predictive parameter for fuel-specific emissions. Similar to the case with rated engine power, fuel consumption shows variation by equipment type as seen in Figure 2-14 for Tier 2 equipment and Figure 2-15 for Tier 3 equipment. Tier 4 Interim equipment is not shown here since all of the Tier 4 Interim equipment tested for this project is of a single type (bulldozer). A difference in fuel consumption rate is expected due to the differing activities performed by the different equipment types.

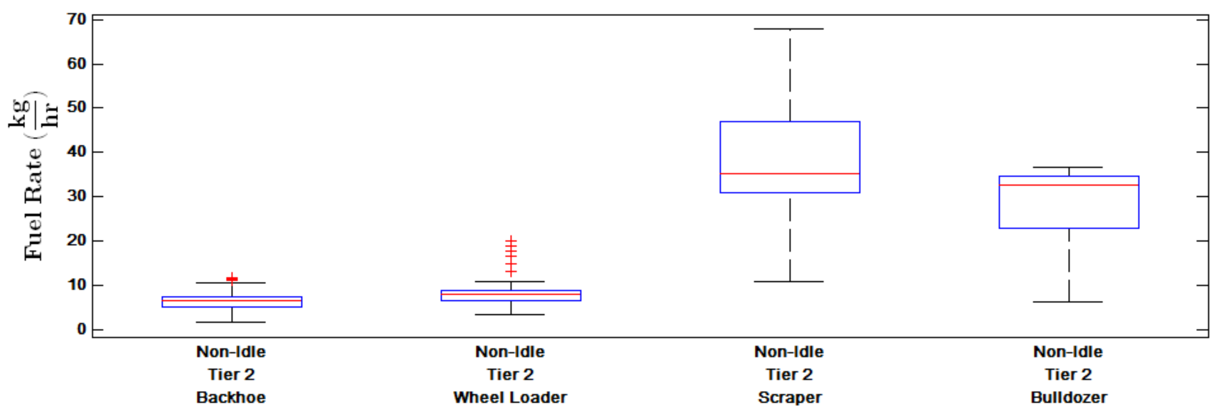

Figure 2-14 Non-idle fuel consumption rate by equipment type for Tier 2 equipment.

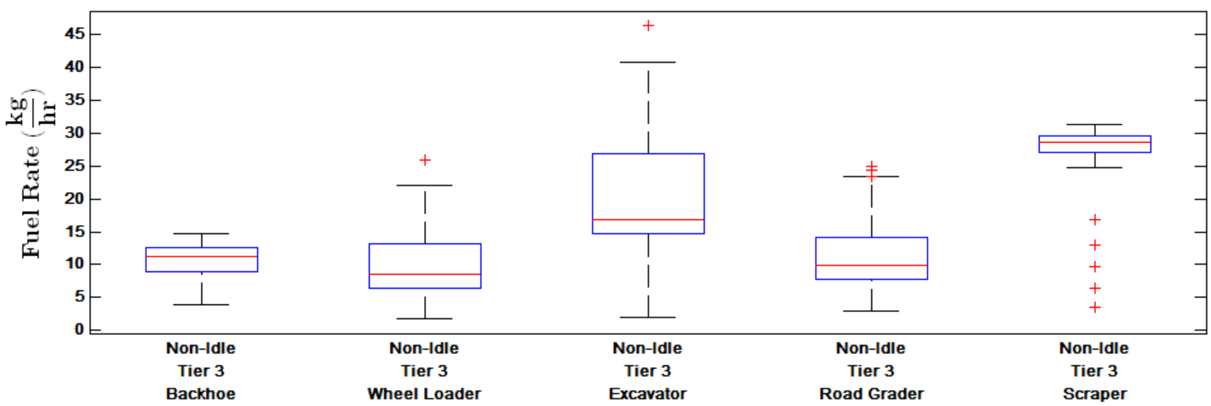

Figure 2-15 Non-idle fuel consumption rate by equipment type for Tier 3 equipment.

Fuel-specific non-idle NO_x emissions did show some variation by equipment type for Tier 2 equipment as seen in Figure 2-16 and Tier 3 equipment as seen in Figure 2-17 as did fuel-specific non-idle PM emissions as seen in Figure 2-19 for Tier 3. Little variation was seen in the fuel-specific non-idle PM emissions for Tier 2 as seen in Figure 2-18.

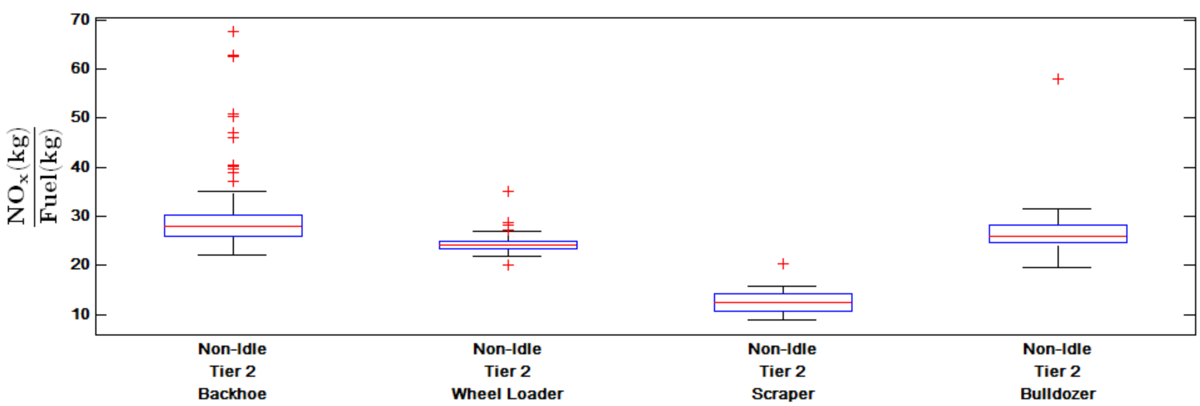

Figure 2-16 Non-idle fuel-specific NO_x emissions by equipment type for Tier 2 equipment.

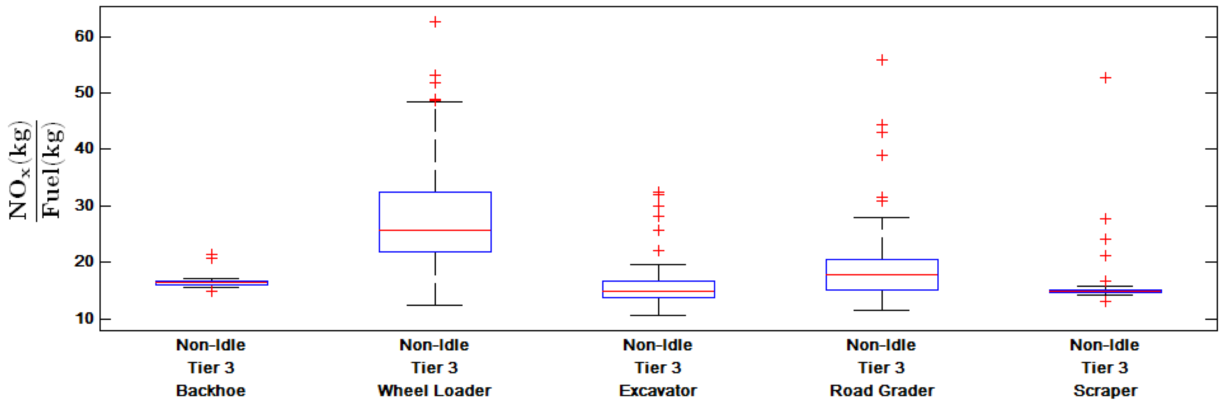

Figure 2-17 Non-idle fuel-specific NO_x emissions by equipment type for Tier 3 equipment.

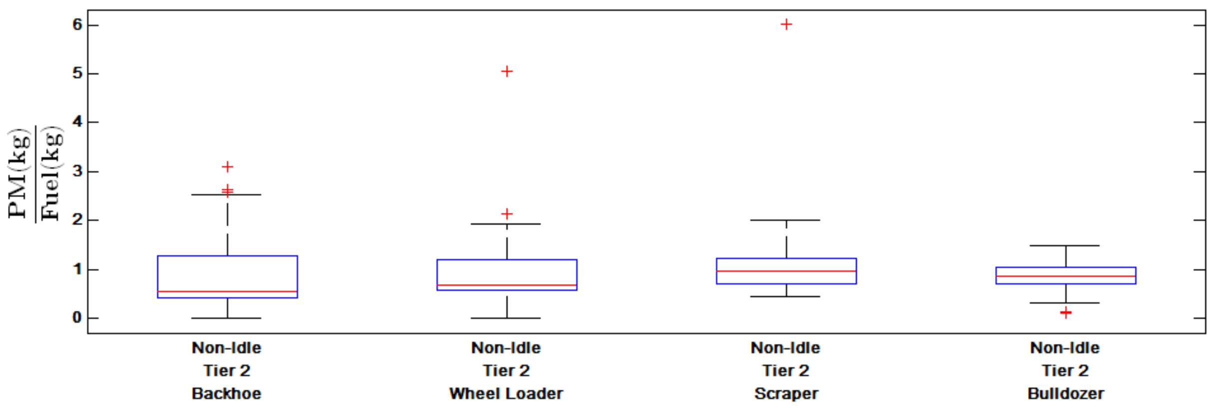

Figure 2-18 Non-idle fuel-specific PM emissions by equipment type for Tier 2 equipment.

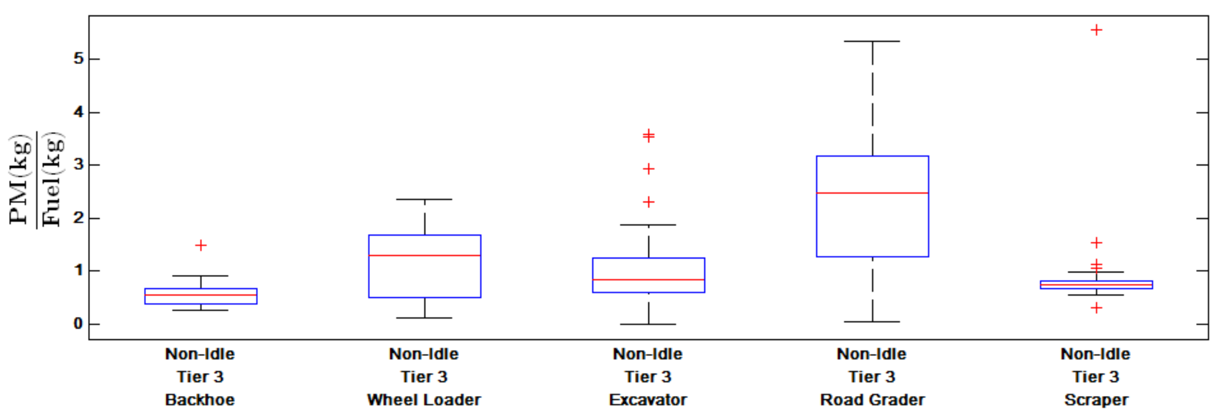

Figure 2-19 Non-idle fuel-specific PM emissions by equipment type for Tier 3 equipment.

For the current version of the construction model, equipment type was not used for characterizing modeling categories. This is primarily since the development dataset was too sparse to properly characterize all combinations of equipment categories based on engine certification and equipment type, and that this level of categorization would limit the models application unless a comprehensive dataset of equipment types was used.

2.1.3 CO2 Emissions

The ORE model estimates CO_2 emissions directly from fuel use. Analysis of the development data shows that the fuel-specific CO_2 emission factors vary with engine emission certification level. This is especially evident with the Tier 4 Interim equipment as can be seen in Figure 2-20.

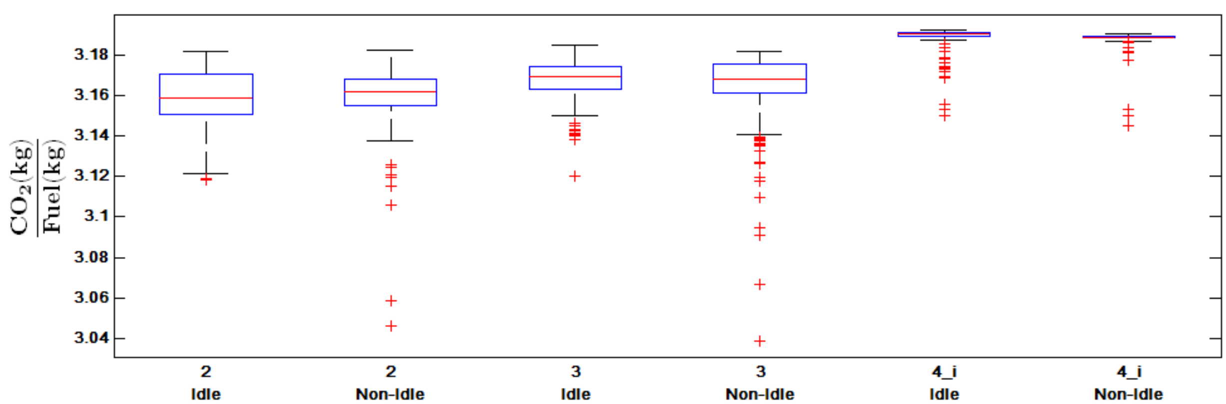

Figure 2-20 CO_2 fuel-specific emission rate by mode and engine certification standard.

2.2 Modeling Methodology

The ORE model estimates emissions by applying fuel based emission factors to the amount of fuel consumed during the idle and work mode of operation. There are two basic calculations that occur in the model: 1) calculations to determine the fuel consumption during both modes of operation, and 2) calculations applying fuel-specific emission factors to the fuel consumed during each mode of operation.

Calculations to determine the amount of fuel consumed during the idle and work modes are based on user inputs and modeling parameters. In equations 1 through 6, the known variables are indicated in blue. Using equations 1 through 3, the amount of time spent at idle can be determined and is given by equation 4 in terms of the known variables. The model uses equations 4, 5 and 6 to determine fuel consumed during the idle and work mode for each piece of equipment.

$$Time_{Total} = Time_{Idle} + Time_{Work} \quad \text{Eq. 1}$$

$$Idle_{Frac} = \frac{Time_{Idle}}{Time_{Total}} \quad \text{Eq. 2}$$

$$Fuel_{Total} = FR_{Idle} \times Time_{Idle} + FR_{Work} \times Time_{Work} \qquad \text{Eq. 3}$$

$$Time_{Idle} = \frac{Fuel_{Total}}{\left(FR_{Idle} + FR_{Work} \times \left(\frac{1}{Idle_{Frac}} - 1\right)\right)} \qquad \text{Eq. 4}$$

$$Fuel_{Idle} = FR_{Idle} \times Time_{Idle} \qquad \text{Eq. 5}$$

$$Fuel_{Work} = Fuel_{Total} - Fuel_{Idle} \qquad \text{Eq. 6}$$

Where

$Time_{Total}, Time_{Idle}, Time_{Work}$	=	Time in mode, (hrs)
$Idle_{Frac}$	=	Fraction of time spent at idle
$Fuel_{Total}, Fuel_{Idle}, Fuel_{Work}$	=	Fuel consumption by mode, (kg)
FR_{Idle}, FR_{Work}	=	Fuel consumption rate by mode, (kg/hr)

The model applies fuel consumed in each mode to fuel-specific emission factors for each mode, as shown in equation 7, to determine mass emissions by mode.

$$Emiss_{mode,pollutant} = EF_{mode,pollutant} \times Fuel_{mode} \qquad \text{Eq. 7}$$

Where

$Emiss_{mode,pollutant}$	=	Mass emission for specified mode and pollutant, (g)
$EF_{mode,pollutant}$	=	Fuel based emission factor for specified mode and pollutant, (g/kg fuel)
$Fuel_{mode}$	=	Fuel consumption for specified mode, (kg)

In addition to the idle and work mode, the framework of the model accommodates parameters for the emissions contributions from cold-start and DPF regeneration events. The development dataset does not provide sufficient information to properly populate these parameters so they are currently set to zero. The emission contribution from cold-start and DPF regeneration events are applied to total emissions only as shown in Equation 8, and are not distributed over the idle and work modes.

$$Emiss_{Total} = Emiss_{Idle} + Emiss_{Work} + Emiss_{ColdStart} + Emiss_{Regen} \qquad \text{Eq. 8}$$

Where

$Emiss_{Total}$	=	Total mass emissions, (kg)
$Emiss_{Idle}$	=	Mass emission from idle mode, (kg)
$Emiss_{Work}$	=	Mass emission from work mode, (kg)
$Emiss_{ColdStart}$	=	Mass emission from cold-start event, (kg)
$Emiss_{Regen}$	=	Mass emission from DPF regeneration event, (g//kg fuel)

The cold-start emission contribution is assumed to occur only one time at the beginning of each equipment activity and is approximated as a constant. Emission contributions from the DPF regeneration event are assumed to occur periodically or continuously depending of the DPF technology and are a function of filter loading and the regeneration scheme. As an approximation, the emission contribution from DPF regeneration events is modeled as a function of fuel consumption in the same way that emissions are modeled in Equation 7. Only PM emissions from DPF regeneration events are considered.

Emissions from individual units of equipment are aggregated to determine fleet emissions. Parameters used by the model for estimating emissions are presented in Table 2-3 and Table 2-54. The emission factors are mapped to equipment category and activity mode in the model using a combination key. For each combination of equipment type and activity mode, several modeling parameters are defined. The model currently contains five equipment types based on three emission certification tier groups: Tier 2, Tier 2 with DPF, Tier 3, Tier 3 with DPF and Tier 4 Interim; and two activity modes: idle and non-idle or work.

Table 2-3 Modeling parameters mapped to idle and work modes

Parameter	Mode	Description
CO_gpkg	Idle, Work	Carbon Monoxide emissions in grams per kilogram fuel
THC_gpkg	Idle, Work	Total Hydrocarbon emissions in grams per kilogram fuel
NOx_gpkg	Idle, Work	Oxides of Nitrogen emissions in grams per kilogram fuel
PM_gpkg	Idle, Work	Particulate Matter emissions in grams per kilogram fuel
Fuel_kgphr	Idle, Work	Fuel consumption rate in kilograms fuel consumed per hour
CO2_gpkg	Idle, Work	Carbon Dioxide emissions in grams CO_2 per kilogram fuel

Table 2-4 Modeling parameters for cold-start and DPF regeneration events

Parameter	Event	Description
CO_g	Cold-Start	Carbon Monoxide emissions in grams per kilogram fuel
THC_g	Cold-Start	Total Hydrocarbon emissions in grams per kilogram fuel
NOx_g	Cold-Start	Oxides of Nitrogen emissions in grams per kilogram fuel
PM_g	Cold-Start	Particulate Matter emissions in grams per kilogram fuel
CO2_g	Cold-Start	Carbon Dioxide emissions in grams CO_2 per kilogram fuel
PM_gpkg	DPF Regeneration	Particulate Matter emissions in grams per kilogram fuel

2.3 Model Calibration

The model was calibrated based on the model development dataset discussed in Appendix B and C consisting of 27 units of construction equipment. Modeling parameters were developed from the data analysis presented in Appendix A and comparison of the model with the development dataset is presented here. Figure 2-21 through Figure 2-24 show calibration results for the 27 units of construction equipment tested in the development dataset. The results of this comparison reflect the variation in emission trends within the equipment category since the model was calibrated to the equipment category and not individual test equipment.

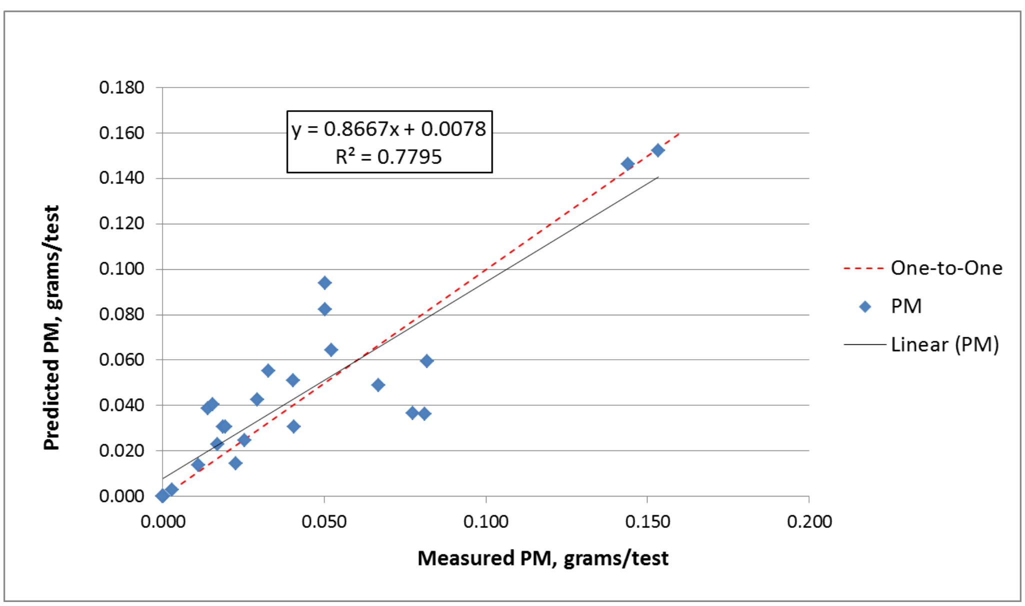

Figure 2-21 PM calibration results for 27 units in development dataset.

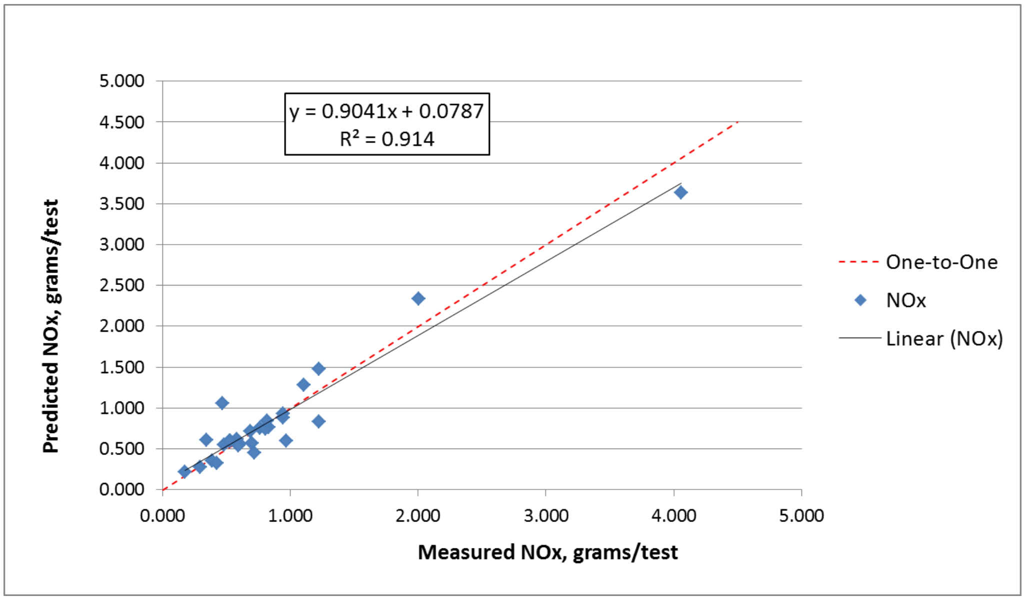

Figure 2-22 NO_x calibration results for 27 units in development dataset.

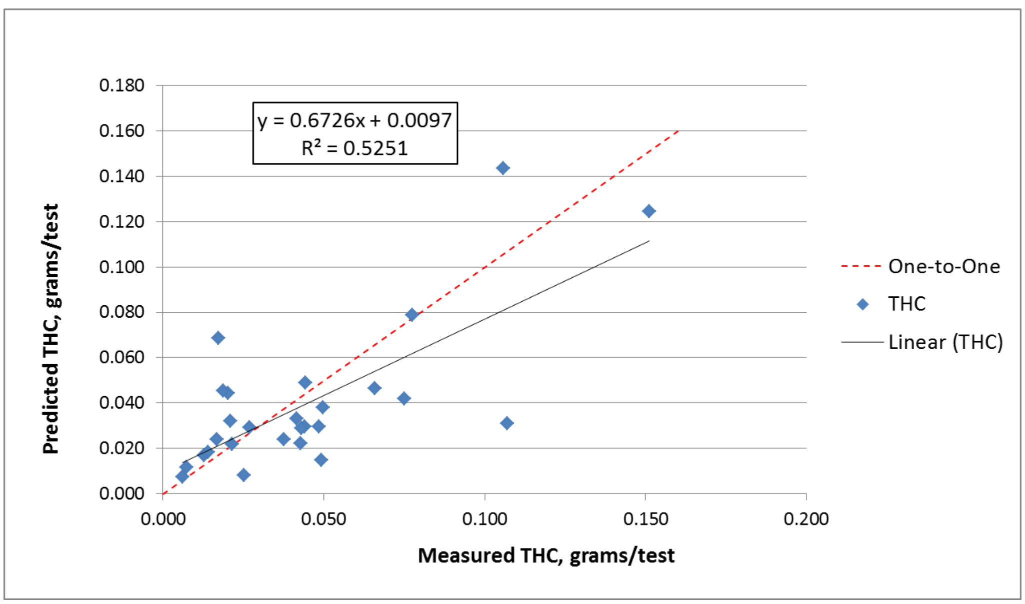

Figure 2-23 THC calibration results for 27 units in development dataset.

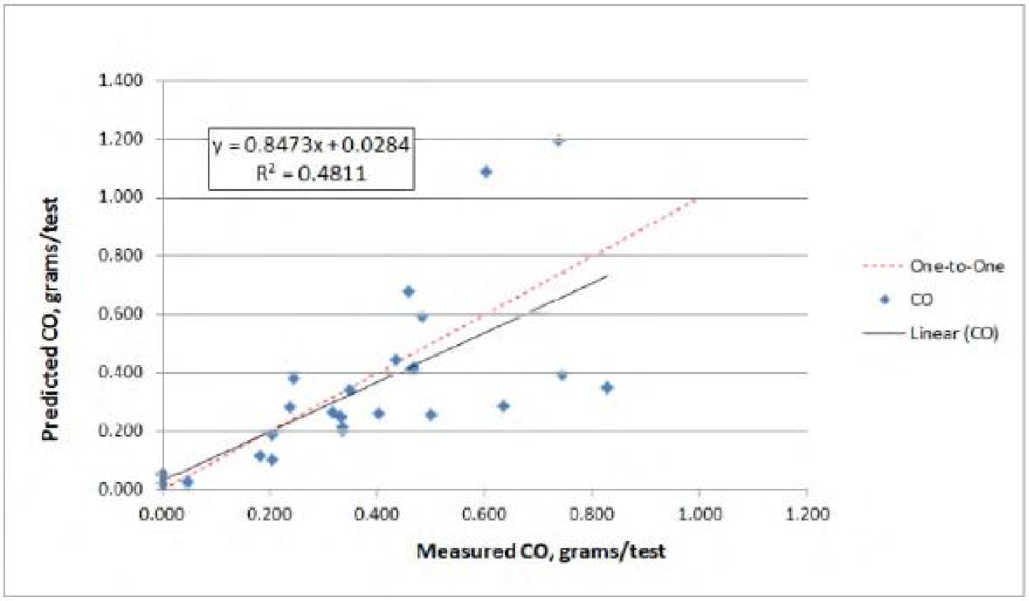

Figure 2-24 CO calibration results for 27 units in development dataset.

Table 2-5 shows the calibration results for the combined test fleet. CO_2 emissions are strongly proportional to fuel consumption and since total fuel consumption is an input parameter, the error in total CO_2 emissions is extremely low as expected. The variation in the idle and work mode fuel consumption is related to variation in the fuel consumption rate for the equipment category for both of these modes and consequently the partitioning of fuel use into both of these modes. This has a negative effect on emission predictions since fuel consumption in each mode is an important parameter for estimating emissions in each mode. The effect on total emissions is small, however, since fuel consumption is relatively small for the idle mode in relation to the work mode. Variations in total emissions estimates are less that 11%, with PM and NO_X being 6.9% and -0.43%.

Table 2-5 Comparison of calibration results in development dataset using categories parameters.

Mode	Error in Mass Emission Estimation (%)					
	Fuel	CO2	CO	THC	NOx	PM
Idle	-10.38	-10.36	8.98	7.38	-13.74	7.38
Work	0.47	0.46	-7.80	-12.53	0.88	6.89
Total	0.00	-0.01	-7.11	-10.83	-0.43	6.90

2.4 Model Validation

The model was validated on a supplemental data set consisting of 5 units of construction equipment discussed in section 3. A general description of the equipment tested is provided in Table 2-6. The validation data set consisted of 3 Tier 3 and 2 Tier 4 Interim units of construction equipment.

Table 2-6 Description of equipment tested for model validation data set.

Equipment	Model Year	Type	Unit Tier	Tech Group
28	2013	Backhoe Loader	4i	non-hybrid
29	2011	Bulldozer	3	non-hybrid
30	2011	Wheel Loader	3	non-hybrid
31	2013	Excavator	3	non-hybrid
32	2011	Bulldozer	4i	non-hybrid

Results from the model validation exercise using the appropriate category parameters are presented in Figure 2-25 through Figure 2-28. Overall fleet results for the validation data set are presented in Table 2-7 and show that variability in the modeling results for individual equipment tests, shown in Figure 2-5 through Figure 2-8, result from emission variability within the chosen category groups. Results from the

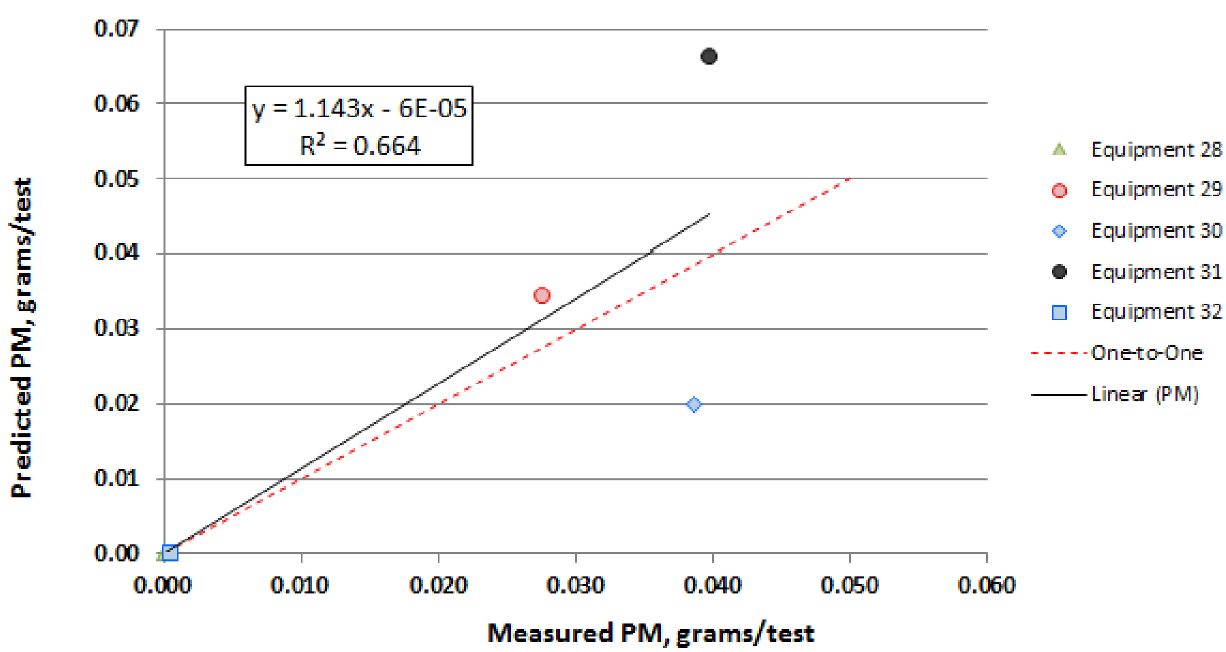

Figure 2-25 Comparison of measured vs. model predicted PM emissions for validation data set.

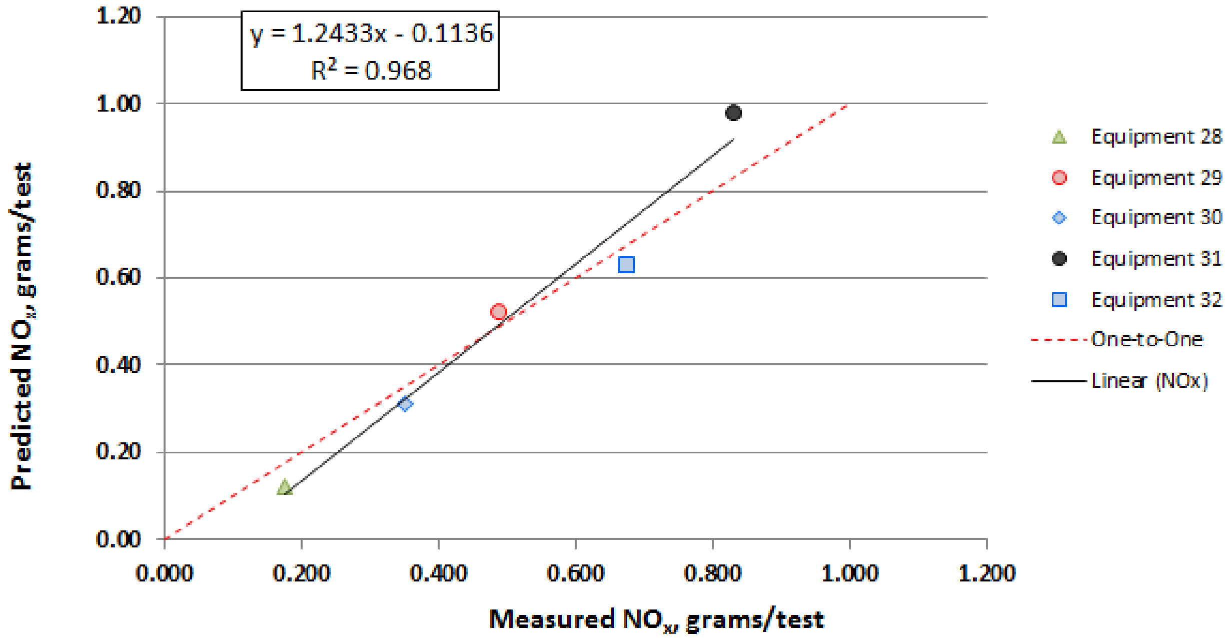

Figure 2-26 Comparison of measured vs. model predicted NO_x emissions for validation data set.

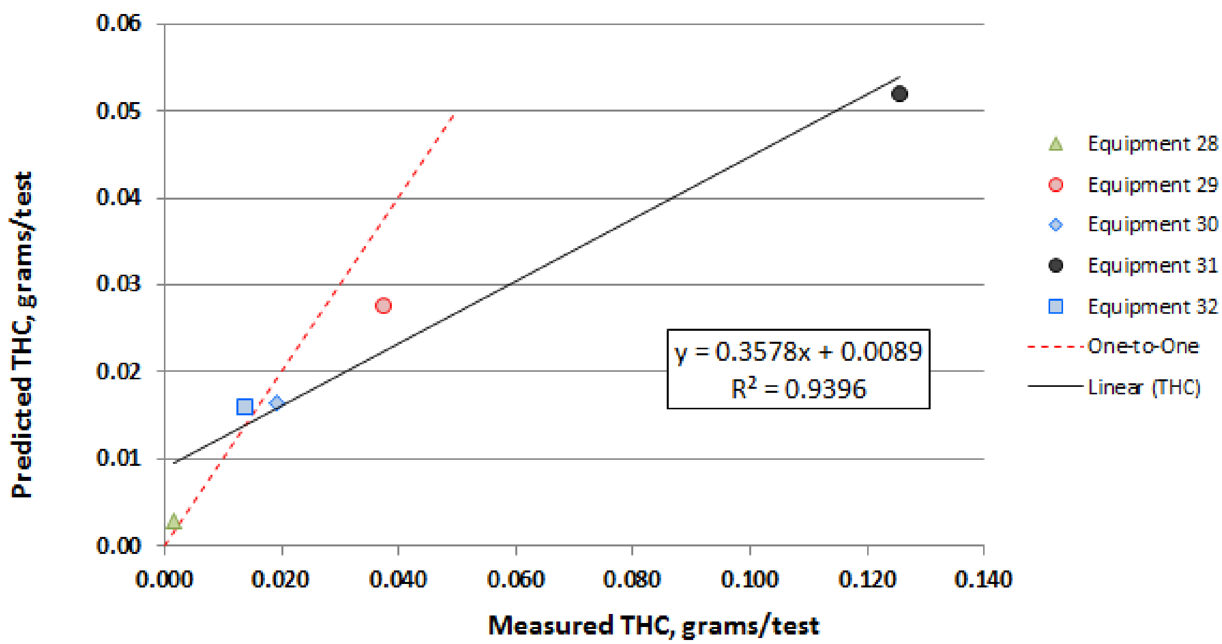

Figure 2-27 Comparison of measured vs. model predicted THC emissions for validation data set.

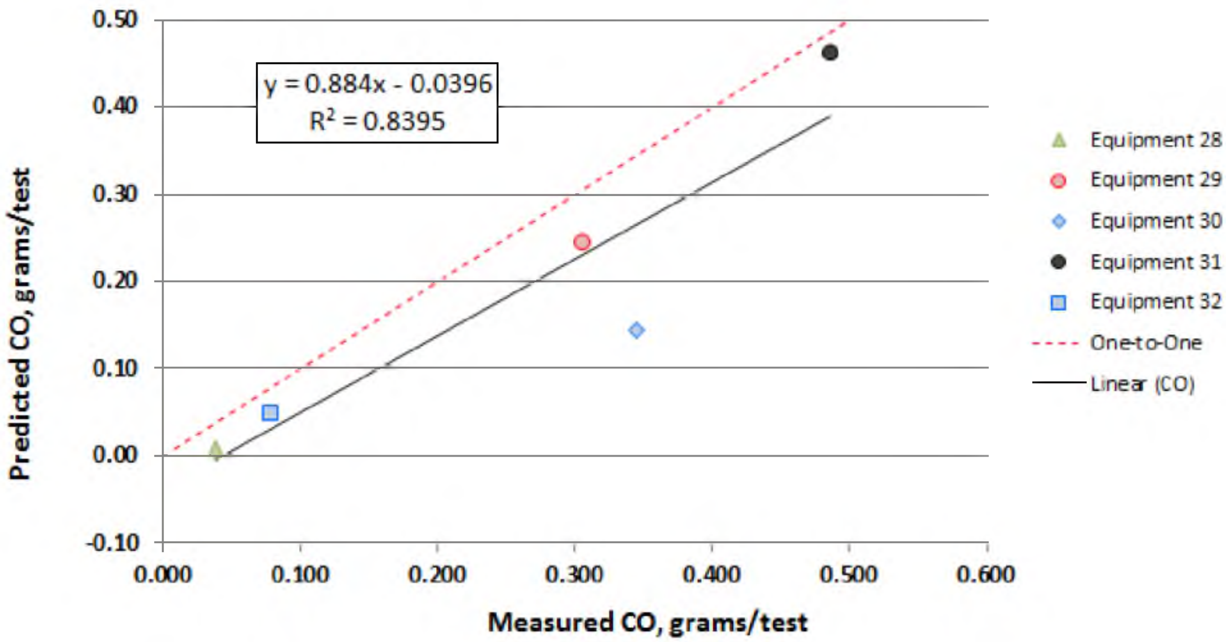

Figure 2-28 Comparison of measured vs. model predicted CO emissions for validation data set.

Table 2-7 Modeling results for validation dataset.

Validation Dataset	CO_2 (kg)	CO (kg)	THC (kg)	NO_x (kg)	PM (kg)
Predicted	610.8	0.908	0.115	2.56	0.121
Actual	611.3	1.251	0.198	2.52	0.106
Error (%)	-0.08	-27.41	-41.72	1.76	14.02

combined equipment tests, shown in Table 2-7, show that model results improve greatly when combined across multiple pieces of equipment; this will, however, depend on the mix of equipment tested.

2.5 Programming the Model

The model was developed in Excel in the form of an .xls workbook containing VBA macros and the four basic worksheets: "About", "Main", "Export" and "EF". The "About" worksheet contains basic model information and credits. The model is run from the "Main" worksheet which contains the model's Graphical User Interface (GUI), presented in Section 2.5.1. Using the GUI, the user can input model run information, load previous model run parameters, execute the model and export the results and model run parameters to an output file. As the model is run, model output data is presented in the GUI on the "Main" worksheet and in the "Export" worksheet. The "EF" worksheet contains the emission factors which support the model. The following section explains the GUI. For detailed information on running the model, please review the "Off-Road Equipment (ORE) – User's Guide"

2.5.1 Graphical User Interface (GUI)

The Graphical User Interface (GUI), presented in Figure 2-29, was developed using ActiveX Controls and visual basic for applications (VBA) standard with Excel software. The GUI provides a user friendly interface for setting up and executing model runs. Model runs consist of single or multiple instances of off-road equipment. For each instance of equipment, an equipment entry is made and a number of model run parameters are defined. The modeled fleet is defined as the combination of all the instances of equipment defined in a run. Instructions for running the ORE model are presented in the "Off-Road Equipment (ORE) Model - User's Guide". An overview of the components of the GUI is presented in Figure 2-29 and the text that follows.

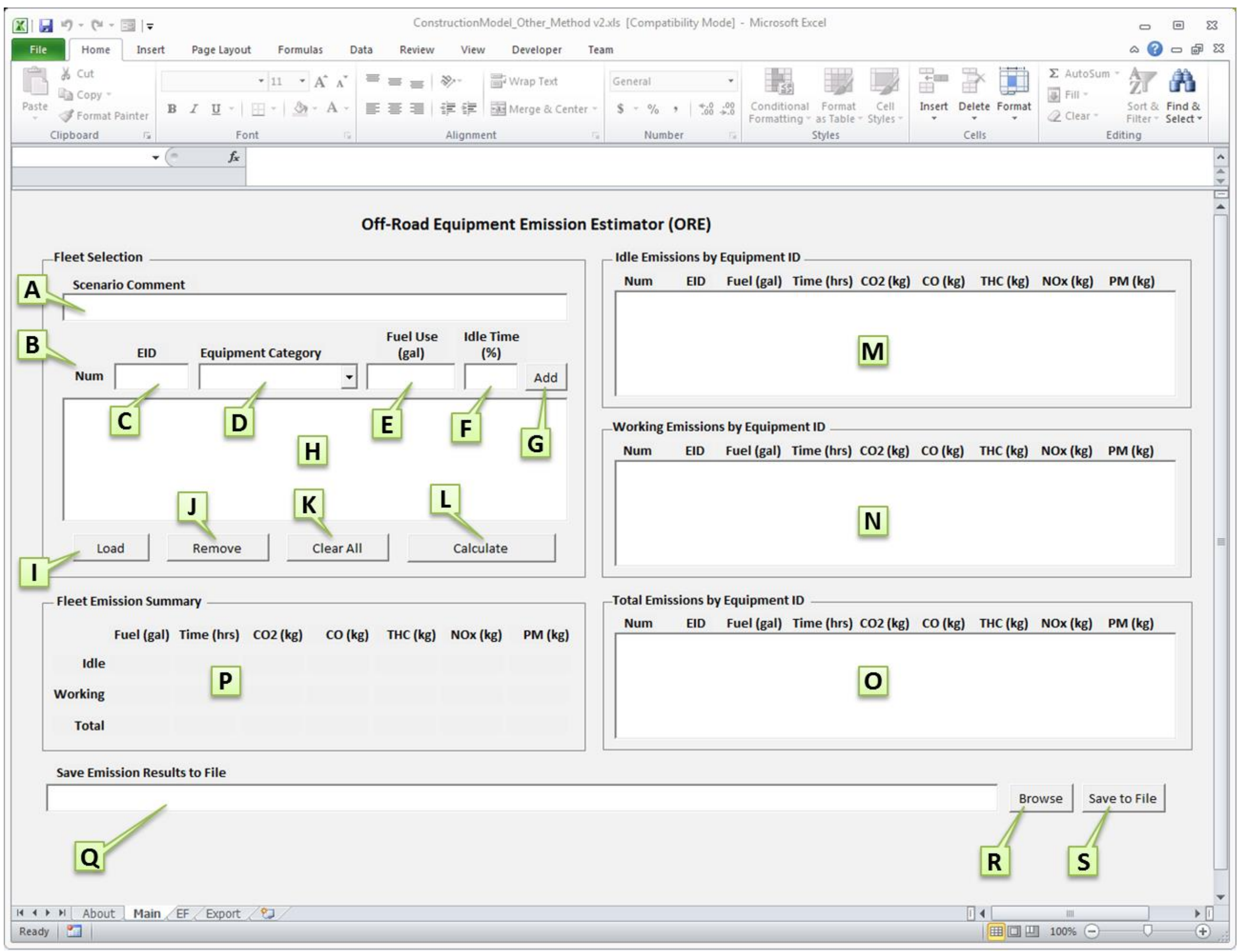

Figure 2-29 ORE GUI overview

A: The scenario comment box provides an area to add commentary for a particular run. This information is passed to the "Export" sheet and saved in the export file.

B: The "Num" column displays a position count provided by the model for each entry of user input data.

C: The "EID" box provides an area to add an alpha-numeric Equipment ID (EID) for an equipment entry.

D: The "Equipment Category" selection box allows the user to choose a particular equipment type (i.e. engine tier category) for an equipment entry.

E: The "Fuel Use" box allows the user to specify the amount of fuel in gallons consumed by each equipment entry during the modeled period of interest.

F: The "Idle Time" box allows the user to specify the percent of time an equipment entry is at idle during the modeled period of interest.

G: The "Add" button adds an equipment entry to the "Fleet Selection" list (labeled H) based on the entry parameters specified in C through F.

H: The "Fleet Selection" list contains the current equipment entries defined in the equipment fleet for the current model run. The equipment fleet can contain several thousand entries. The limit of the GUI to hold equipment entries has not been tested. It is important to note that model runs are based on the fleet information contained in the GUI and not in the export worksheet.

I: The "Load" button allows the user to populate the "Fleet Selection" list from a model run output file which contains information for a fleet of equipment units. In this manner, the user does not have to specify individual entries each time to recreate a model run.

J: The "Remove" button allows the user to remove selected entries from the "Fleet Selection" list. Entries are selected with the mouse and may include one or more entries. Use the Ctrl key to select multiple entries or the Shift key to select a range of entries.

K: The "Clear All" button removes all entries from the "Fleet Selection" list from the GUI. Note that this also removes all data from the "Export" sheet.

L: The "Calculate" button initiates the model run. For the model run, the model iterates through entries in the fleet list box, searches for the appropriate emission factors from the supporting emission factor worksheet "EF", applies those parameters to the entry data and provides the results of that calculation in the GUI in the list sections **M** through **P**. At this time, the "Export" worksheet is also updated with the latest calculated results.

M: This section of the GUI provides individual equipment results for the idle mode portion of activity. The idle mode portion of activity is determined by the % idle time specified by the user and the fuel rate for both the idle and non-idle activity modes for the equipment type.

N: This section of the GUI provides individual equipment results for the non-idle or work mode portion of activity. The work mode portion of activity is determined by the % idle time specified by the user and the fuel rate for both idle and non-idle activity modes for the equipment type.

O: This section of the GUI provides total emissions for individual equipment entries in the fleet. The total emissions for each equipment entry are the idle and work emissions combined for each equipment entry.

P: This section of the GUI provides total emissions for the equipment fleet defined in the run. These emissions are the aggregated results of the total emissions for the individual equipment entries from section **O**.

Q: This box shows the save file path and name which is selected with the "Browse" button **R**.

R: This "Browse" button allows the user to browse for a save file path and name.

S: This button saves the data in the "Export" worksheet to a .csv file added using the GUI "Browse" button **R** and shown in the save file text box **Q**. A file saved in this manner can be used to populate the GUI equipment list entries using the "Load" button **I**.

2.6 Model Expandability

The model was developed on a limited data set and contains estimates for five distinct equipment types based on emission certification standards and aftertreatment technology. Analysis of emission data did show variability in emission trends in the non-idle mode for some equipment categories as defined in the model. This is evident from the data analysis presented in Appendix A. Although there was insufficient data to further break-down the equipment categories in this study, subsequent testing could produce a dataset which could be used to increase the focus of the equipment categories. The emphasis for the model is to estimate the emission performance characteristics of a general equipment category and not a specific piece of equipment.

3 Portable Emissions Measurement System (PEMS) Data

Appendix B provides details of the equipment used over the course of the prior programs, and .the analysis of the data. Appendix C contains summary tables of the integrated results and plots of the modal emissions for all of the PEMS tests used to develop the model discussed in Section 2. The PEMS measurements of engine parameters and emissions are made on a second-by-second basis and the modeler analyzed the second-by-second data to develop the model. This section discusses the additional emission measurements made specifically for this program.

When this project was proposed we had a model based upon emissions data for four backhoes and three wheel loaders obtained under Caltrans project number RTA 65A0197 (Barth, et. al, 2012). We were obtaining additional emissions data under CARB contract #08-315 (Durbin, et al., 2013), which was a joint contract with Caltrans, which would increase the total equipment tested to 20. We proposed to add emission measurements for five additional pieces of equipment to bring the total to 25 before developing the model to broaden the range of engines and equipment. This project started on April 1, 2012 and ended on April 30, 2014. From April 1, 2012 through February 2014 the equipment and/or the personnel required for the emissions measurements were not available. The equipment was being used to measure the emissions from the additional 13 pieces of equipment to complete the CARB program (Durbin, 2013) or the seven pieces of equipment for the CARB AQIP program (Johnson, 2013).

Because of the delay in obtaining the emission measurements from five pieces of equipment it was decided to develop the model based upon the 27 pieces of equipment, 20 from the joint CARB, Caltrans program plus 7 from the CARB AQIP program and then use the measurements from the 5 pieces of equipment to check the robustness of the model. The robustness is discussed in section 2.

Appendix C contains a list of the equipment tested in the prior programs, brief descriptions of the test conditions, tables of integrated data for each piece of equipment, and plots of the modal data for each piece of equipment. Equivalent information for the five pieces of equipment measured in this program is presented in Table 3-1 through Table 3-6 and Figure 3-1 through Figure 3-5.

The local Caterpillar dealer, Johnson Machinery, is located within 1.5 miles from CE-CERT and they have a rental yard with an area where renters can test the equipment. We rented the five pieces of equipment and Don Pacocha operated the equipment on the test plot while Edward O'Neal video the operation and monitored the emissions equipment outputs in real time as the data was sent wirelessly to his computer monitor. Descriptions of the equipment tested are given in Table 3-1.

We attempted to select equipment which differed in some way from the equipment used to develop the model to provide a more robust evaluation of the model, but were limited to what was available on the day we tested. In the modeling dataset there are 4 John Deere Backhoe/Loaders (2006, 92 hp; 2006, 99 hp; 2007, 99 hp; and 2010, 99 hp), 2 conventional Caterpillar Bulldozers (D6T, 2012, 223 hp; D8T, 2011, 316 hp) and 2 hybrid Caterpiller Bulldozers (2012, 296 hp), 1 John Deere Wheel Loader (2007, 225 hp), 1 Komatsu Wheel Loader (2009, 273 hp), 4 Caterpillar Wheel Loaders (one 2004, 156 hp, three 2011, 171 hp), and 4 excavators (1 Caterpillar (2008, 520 hp), 1 Volvo (2006, 269 hp), and 1 conventional Komatsu (2007, 155 hp) and 1 hybrid Komatsu (2012, 148 hp). For the validation dataset we have 1 Caterpillar Backhoe/Loader (2013, 127 hp), 2 Caterpillar Bulldozers (2011, 174 hp, and 2011, 316 hp), 1 Caterpillar Wheel Loader (2011, 171 hp), and 1 Caterpillar Excavator (2013, 300 hp).

The validation dataset backhoe/loader is a different manufacturer and a higher horsepower than the backhoe/loaders in the modeling dataset and is also and a Tier 4i versus the Tier 2 and Tier 3 in the modeling dataset. The D6KXL Caterpillar Bulldozer in the validation dataset has a lower horsepower than the D6T in the modeling dataset. The D8T Caterpillar Bulldozer is physically the same machine in both datasets, but in the modeling dataset the bulldozer was pulling a trash dumpster containing rocks with a load measuring device attached between the dozer and the trash dumpster. The validation dataset wheel loader is presumed to be very similar to the Caterpillar Wheel Loaders in the modeling dataset. The model is slightly different and since the engine label was not visible the engine family and engine horsepower are assumed values. The excavator in the validation dataset has a horsepower between the Caterpillar and the Volvo in the modeling dataset.

For the validation dataset the emission equipment performed without any problems for tests 28, 29, and 31. When there are no problems the AVL Concerto program calculates the modal emissions in g/sec. For test 30 the exhaust flow meter stopped communicating with the computer (labeled as Flow Meter Froze in the tables and figures) after about 30 minutes so the AVL Concerto program did not give valid emissions in g/sec. Since the concentration of pollutants in ppm were recorded the emissions in g/sec were calculated by determining the flow rate per second based upon the displacement of the engine. For test 32 the exhaust flow meter stopped communicating with the computer after about 160 minutes but since there was only about 30 minutes of data after the freeze only the data before the freeze was used for the model validation.

For test 29 the only information the AVL instrumentation read from the Electronic Control Module (ECM) information was the engine rpm. The emissions in g/kg fuel do not require any information from the ECM but %load and power are required to obtain emissions in g/bhp-hr. While this information is not part of the model it is presented in the tables. For this test we estimated the brake specific CO_2 ($bsCO_2$) based upon the measured $bsCO_2$ for the same engine size in the modeling dataset. The power was then calculated from the $bsCO_2$ and this power was used to calculate the g/bhp-hr for the other emissions. For test 31 the AVL instrumentation did not read any of the ECM data so the CAT-ET tool was used to obtain the ECM information.

Table 3-1: Description of Equipment Tested at Johnson Machinery Test plot

Test Count	Date Tested	UCR Name ID	Equipment Owner	Equipment Type	Equipment Model	Engine Family	Year	Tier	Engine Model	Engine Mfg	Rated Power (bhp)	Rated Speed (RPM)	Engine Hours	Lug Curve	Percent Load	Displace-ment (L)
28	3/5/2014	28_450F	Johnson Machinery	Backhoe Loader	450F	DPKXL04.4ML1*	2013	4i	C4.4 ACERT	Perkins	127	2200	76	Yes	Yes	4.4
29	3/6/2014	29_D6KXL	Johnson Machinery	Bulldozer	D6KXL	BPKXL06.6PJ2	2011	3	C6.6 ACERT	Perkins	174	2100	1739	Yes	Yes	6.6
30	3/10/2014	30_928H	Johnson Machinery	Wheel Loader	928H	BPKXL06.6PJ2**	2011	3	C6.6 ACERT	Perkins	171	2000	2436	Yes	No	6.6
31	3/11/2014	31_328DLCR	Johnson Machinery	Excavator	328DLCR	ACPXL07.2ESL	2013	3	C7.2 ACERT	Caterpillar	300	1800	9.8	Yes	Yes	7.2
32	3/12/2014	32_D8Ti	Johnson Machinery	Bulldozer	D8Ti	CCPXL15.2HPA	2011	4i	C15.2 ACERT	Caterpillar	316	2000	1455	Yes	Yes	15.2

* Emission label not photographed, family based on Perkins C4.4 ACERT in CARB certification database.
** Emission label not photographed, family based on Perkins C6.6 ACERT in CARB certification database.

28_450F_2014.3.05

This 2013 Tier 4i Caterpillar backhoe/loader was rented from Johnson Machinery and tested in their rental test plot at 800 E. La Cadena Dr, Riverside, CA. The equipment was operated by CE-CERT's Don Pacocha doing mostly digging with the backhoe for approximately the first hour and backfilling the trench with the loader for approximately the last hour. The PEMS equipment was the AVL M. O. V. E. 493 Gas PEMS[1], the AVL 483 MSS[2], and a Semtech 5 inch flow tube which is the same as used for tests 22_ through _27 in Appendix C. There was 1.7 hours of valid data collected.

Table 3-2: Integrated Emissions for 28_2014.03.05 2013 CAT 450F Tier 4i backhoe/loader

Time (s)			Test Function	Fuel [1]	Power [2]	Torque	Fuel [3]	eLoad	eSpeed	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel) [3]					Brake Specific Emissions (g/bhp)				
Start	Stop	Duration	A-Work	kg/hr	bhp	ft-lb	kg/hr	%	RPM	CO2	CO	NOx	THC	mg PM [4]	CO2	CO	NOx	THC	mg PM [4]	CO2	CO	NOx	THC	mg PM [4]
1250	1644	394	idle 1	2.3	11.3	62.3	2.3	16.8	950	7159	16.7	71.9	1.19	11.55	3147	7.35	31.6	0.52	5.08	635	1.48	6.39	0.11	1.03
1646	2199	553	a) Dig trench	8.4	50.4	134.4	8.0	31.5	1843	25290	29.7	86.4	2.35	33.48	3153	3.70	10.8	0.29	4.17	502	0.59	1.72	0.05	0.66
2200	2806	606	b) Dig trench	12.9	79.1	188.2	12.0	46.2	2200	37927	12.7	111.8	1.26	32.40	3158	1.05	9.3	0.11	2.70	479	0.16	1.41	0.02	0.41
2807	3056	249	idle 2	1.5	7.9	43.6	1.9	11.8	950	6015	4.8	67.7	0.44	6.30	3155	2.50	35.5	0.23	3.31	763	0.61	8.59	0.06	0.80
3057	3251	194	c) Fill trench	12.8	81.3	202.4	12.2	47.0	2105	38372	11.7	108.8	0.99	22.28	3158	0.96	9.0	0.08	1.83	472	0.14	1.34	0.01	0.27
3252	3918	666	d) Fill trench	10.5	75.5	225.5	9.6	48.5	1628	30249	9.5	125.1	0.76	29.47	3158	0.99	13.1	0.08	3.08	401	0.13	1.66	0.01	0.39
3966	7431	3465	e) Fill trench	10.0	65.7	181.3	9.6	40.5	1810	30328	28.2	105.1	0.74	15.54	3155	2.94	10.9	0.08	1.62	461	0.43	1.60	0.01	0.24
1250	7431	6181	Overall Ave	9.4	61.7	170.7	9.0	38.8	1756	28522	22.7	102.9	0.96	20.01	3156	2.51	11.4	0.11	2.21	462	0.37	1.67	0.02	0.32
Idle Average				1.9	9.6	52.9	2.1	14.3	950	6587	10.7	69.8	0.8	8.9	3151	4.9	33.6	0.4	4.2	699	1.0	7.49	0.08	0.91
Idle StDev				0.6	2.4	13.2	0.3	3.6	0	809	8.4	3.0	0.5	3.7	6	3.4	2.8	0.2	1.3	90	0.6	1.56	0.04	0.16
Idle COV				29%	25%	25%	12%	25%	0%	12%	79%	4%	65%	42%	0%	70%	8%	54%	30%	13%	60%	21%	43%	18%
Dig Trench Average				10.6	64.7	161.3	10.0	38.8	2022	31609	21.2	99.1	1.8	32.9	3156	2.4	10.0	0.2	3.4	491	0.4	1.57	0.03	0.54
Dig Trench StDev				3.1	20.3	38.0	2.8	10.4	252	8935	12.0	18.0	0.8	0.8	3	1.9	1.0	0.1	1.0	16	0.3	0.21	0.02	0.18
Dig Trench COV				30%	31%	24%	28%	27%	12%	28%	57%	18%	43%	2%	0%	79%	10%	67%	30%	3%	81%	14%	69%	34%
Fill Trench Average				11.1	74.2	203.1	10.4	45.3	1848	32983	16.5	113.0	0.8	22.4	3157	1.6	11.0	0.1	2.2	445	0.2	1.53	0.01	0.30
Fill Trench StDev				1.5	7.9	22.1	1.5	4.3	241	4667	10.2	10.6	0.1	7.0	2	1.1	2.1	0.0	0.8	39	0.2	0.17	0.00	0.08
Fill Trench COV				13%	11%	11%	14%	9%	13%	14%	62%	9%	17%	31%	0%	69%	19%	3%	36%	9%	73%	11%	10%	27%

[1] ECM reported fuel rate

[2] Power estimated from published lug curve and % load, see detailed work sheet

[3] Carbon balance fuel rate calculation using gaseous PEMS

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

[5] Fuel use by carbon balance

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[1] AVL, M.O.V.E. Gas PEMS https://www.avl.com/c/document_library/get_file?uuid=2928fd26-93b7-4382-9c5b-76649865e650&groupId=10138

[2] AVL Micro Soot Sensor (MSS) https://www.avl.com/micro-soot-sensor

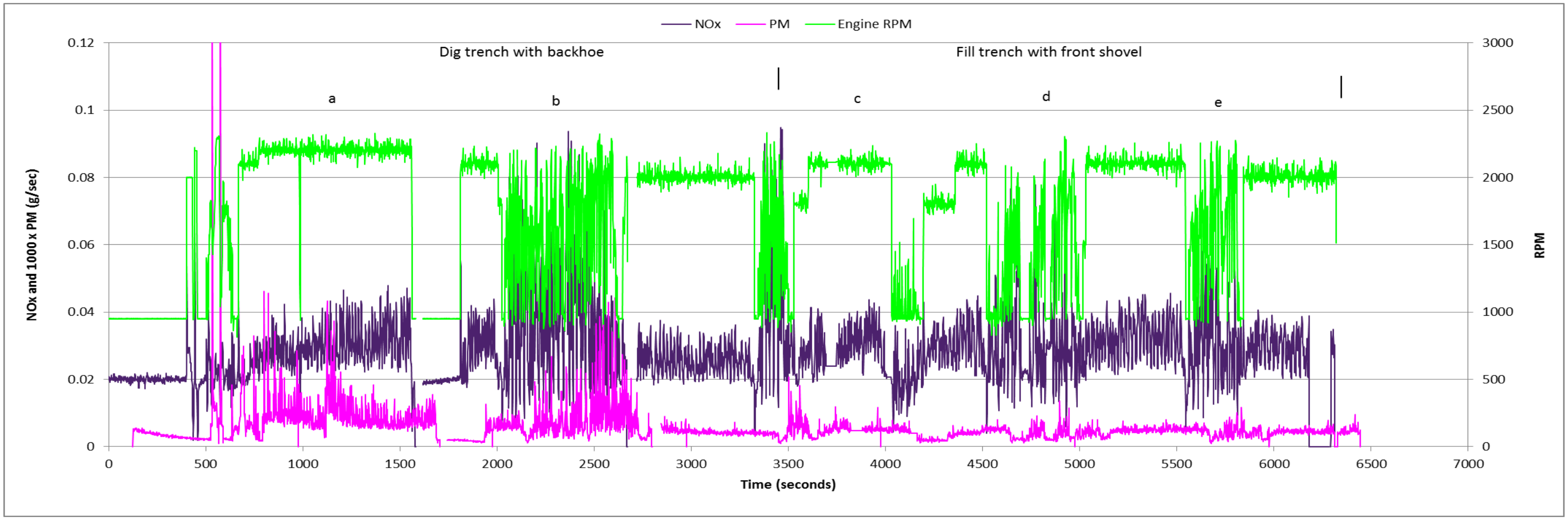

Figure 3-1: Modal Emissions for 28_2014.03.05 2013 CAT 450F Tier 4i backhoe/loader

29_D6 KXL_2014.3.06

This 2011 Tier 3 Caterpillar bulldozer was rented from Johnson Machinery and tested in their rental test plot at 800 E. La Cadena Dr, Riverside, CA. The equipment was operated by CE-CERT's Don Pacocha building and moving dirt piles. The PEMS equipment was the same as used for test 28_. There was 3.1 hours of valid data collected.

Table 3-3: Integrated Emissions for 29_2014.03.06 2011 CAT D6 KXL Tier 3 Bulldozer

Time (s)			Test Function	Fuel [1,2]	Power [2,6]	Torque [2]	Fuel [3]	eLoad [2]	eSpeed	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel) [3]					Brake Specific Emissions (g/bhp)				
Start	Stop	Duration	A-Work	kg/hr	bhp	ft-lb	kg/hr	%	RPM	CO2	CO	NOx	THC	mg PM [4]	CO2	CO	NOx	THC	mg PM [4]	CO2	CO	NOx	THC	mg PM [4]
1610	1796	186	idle 1	NR	7.4	NR	2.5	NR	749	7806	30.9	93.1	3.62	860	3136	12.39	37.4	1.45	346	1061	4.20	12.66	0.49	117.0
1797	2262	465	a) Push loose pile	NR	84.9	NR	12.8	NR	1806	40197	213.9	179.0	14.40	21986	3130	16.65	13.9	1.12	1712	473	2.52	2.11	0.17	258.9
2263	2369	106	idle 2	NR	6.2	NR	2.1	NR	750	6555	25.2	106.6	3.83	144	3135	12.06	51.0	1.83	69	1059	4.07	17.23	0.62	23.2
2370	4545	2175	b) Move pile, full blade	NR	59.2	NR	13.1	NR	2088	41108	121.4	199.3	14.36	11386	3142	9.28	15.2	1.10	870	694	2.05	3.37	0.24	192.3
4548	4717	169	idle 3	NR	5.9	NR	2.0	NR	750	6288	23.1	103.1	3.43	84	3136	11.54	51.4	1.71	42	1060	3.90	17.38	0.58	14.1
4718	5534	816	c) Move pile, full blade	NR	43.6	NR	9.5	NR	2081	29960	95.1	146.9	12.51	10071	3140	9.96	15.4	1.31	1056	687	2.18	3.37	0.29	230.8
5535	6159	624	idle 4	NR	5.8	NR	2.0	NR	750	6117	24.4	99.4	3.53	59	3134	12.53	50.9	1.81	30	1060	4.24	17.21	0.61	10.3
6160	7547	1387	d) Rebuild pile, full blade	NR	45.3	NR	10.1	NR	2092	31670	103.1	169.9	15.53	9716	3139	10.22	16.8	1.54	963	699	2.28	3.75	0.34	214.5
7548	7740	192	idle 5	NR	5.6	NR	1.9	NR	750	5935	23.8	98.6	4.05	67	3133	12.57	52.0	2.14	35	1060	4.25	17.60	0.72	11.9
7741	9679	1938	e) Rebuild pile, full blade	NR	52.7	NR	11.7	NR	2088	36620	112.4	173.0	14.82	10539	3141	9.64	14.8	1.27	904	694	2.13	3.28	0.28	199.9
9680	10370	690	idle 6	NR	5.7	NR	1.9	NR	750	6092	24.8	98.3	3.68	57	3134	12.75	50.6	1.89	29	1060	4.31	17.10	0.64	10.0
10371	12439	2068	f) Clean up, light work	NR	49.5	NR	10.9	NR	2085	34196	119.7	174.2	14.46	11540	3138	10.98	16.0	1.33	1059	691	2.42	3.52	0.29	233.2
1610	12439	10829	Overall Ave	NR	62.6	NR	9.8	NR	1835	30630	101.8	163.2	12.55	9388	3139	10.43	16.7	1.29	962	489	1.63	2.61	0.20	149.9
Idle Average				NR	6.1	NR	2.1	NR	750	6466	25.4	99.8	3.7	211.8	3135	12.3	48.9	1.8	92	1060	4.2	16.5	0.61	31.1
Idle StDev				NR	0.6	NR	0.2	NR	0.5	690	2.8	4.6	0.2	319.2	1.1	0.4	5.7	0.2	125	0.8	0.2	1.9	0.08	42.4
Idle COV				NR	11%	NR	11%	NR	0.1%	11%	11%	5%	6%	151%	0.0%	4%	12%	12%	136%	0.1%	3.6%	11.5%	12.4%	136%
Full Blade Push Average				NR	50.2	NR	11.1	NR	2087	34839	108.0	172.3	14.3	10428	3140	9.8	15.6	1.3	948	694	2.2	3.4	0.29	209.4
Full Blade Push StDev				NR	7.2	NR	1.6	NR	4.9	5044	11.4	21.4	1.3	722	1.2	0.4	0.9	0.2	81	5.1	0.1	0.2	0.04	17.0
Full Blade Push COV				NR	14%	NR	14%	NR	0.2%	14%	11%	12%	9%	7%	0.0%	4%	6%	14%	9%	0.7%	4.4%	6.1%	14.4%	8.1%

[1] ECM reported fuel rate

[2] Not reported by ECM

[3] Carbon balance by hand calculation

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

[5] BSCO2 = 0.001*RPM^2 -3.111*RPM+2830.4

[6] Calculated from BSCO2

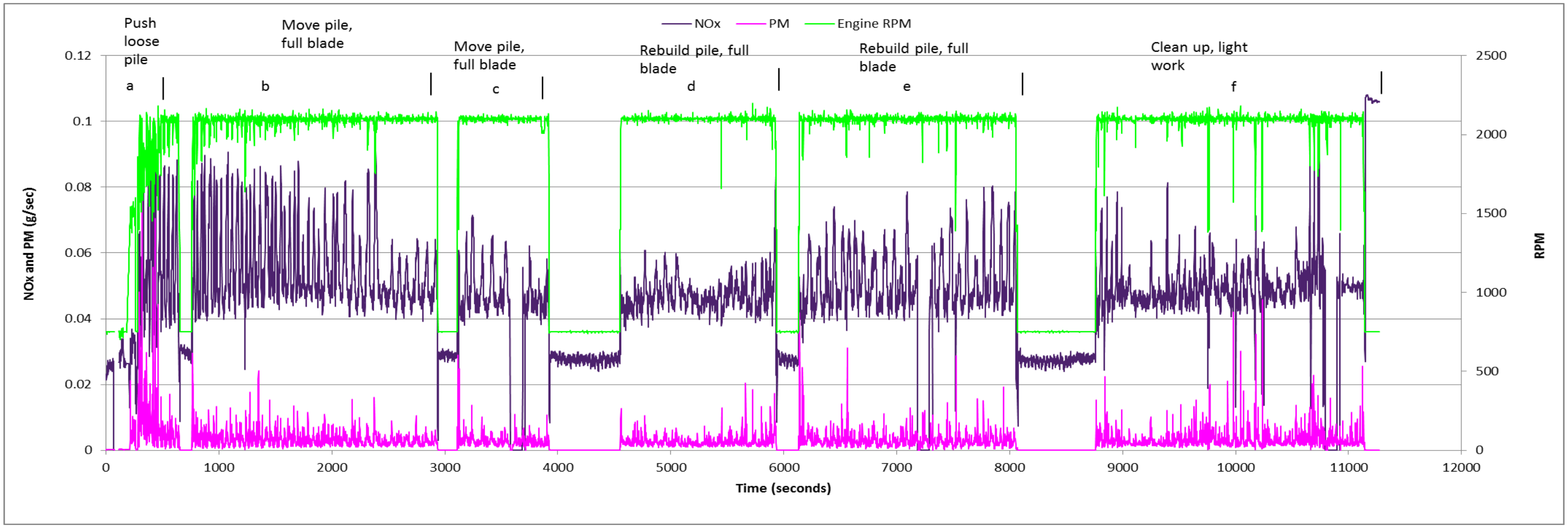

Figure 3-2: Modal Emissions for 29_2014.03.06 2011 CAT D6 KXL Tier 3 Bulldozer

30_928H_2014.3.10

This 2011 Tier 3 Caterpillar 928H wheel loader was rented from Johnson Machinery and tested in their rental test plot at 800 E. La Cadena Dr, Riverside, CA. The equipment was operated by CE-CERT's Don Pacocha moving dirt with full bucket, ½ full bucket, and doing light clean up. The PEMS equipment was the same as used for test 28_ and 29_. There was 2.9 hours of valid data collected.

Table 3-4: Integrated Emissions for 30_2014.03.10 2011 CAT 928H Tier 3 Wheel Loader

Time (s)			Test Function	Fuel[1]	Power[2]	Torque	Fuel[3]	eLoad	eSpeed	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel)[3]					Brake Specific Emissions (g/bhp)				
Start	Stop	Duration	A-Work	kg/hr	bhp	ft-lb	kg/hr	%	RPM	CO2	CO	NOx	THC	mg PM[4]	CO2	CO	NOx	THC	mg PM[4]	CO2	CO	NOx	THC	mg PM[4]
1675	2199	524	a) Light clean up	9.0	52.8	162	7.1	34.1	1407	22192	112	132	9.58	18889	3131	15.9	18.6	1.35	2665	420	2.13	2.50	0.18	357
2200	3260	1060	b) Heavy work	10.2	58.6	167	8.5	35.3	1662	26424	178	149	9.74	26825	3123	21.1	17.6	1.15	3171	451	3.05	2.54	0.17	458
3261	3982	721	idle 1	1.6	6.8	41	2.1	9.5	838	6485	25	97	3.54	930	3136	12.0	47.0	1.71	450	953	3.65	14.29	0.52	137
3983	5203	1220	c) Heavy work	9.9	59.4	183	6.7	35.9	1587	21047	158	121	7.19	27792	3120	23.5	17.9	1.07	4119	354	2.66	2.03	0.12	468
5204	5678	474	idle 2	1.5	6.3	39	1.9	9.2	834	5861	31	89	4.62	892	3126	16.5	47.4	2.46	476	929	4.89	14.09	0.73	141
5679	7492	1813	d) 1/2 bucket loads	7.3	40.9	134	5.4	25.6	1459	16954	125	112	6.94	21485	3120	23.0	20.6	1.28	3953	415	3.06	2.73	0.17	525
7493	10569	3076		Flow meter froze, no valid data																				
10570	12385	1815	e) Heavy Work	11.4	70.6	200	7.8	41.9	1736	24328	152	129	7.30	9011	3126	19.5	16.6	0.94	1158	345	2.15	1.83	0.10	128
12386	12959	573	idle 3	1.3	6.6	42	2.1	9.8	830	6536	28	105	3.52	243	3133	13.4	50.6	1.69	116	992	4.25	16.01	0.53	37
12999	13136	137	f) Lift empty bucket	11.4	70.9	173	7.5	46.0	1595	23337	152	164	6.79	4657	3125	20.3	21.9	0.91	624	329	2.14	2.31	0.10	66
13187	13418	231	g) Lift full bucket	7.7	45.9	136	5.5	32.7	1235	17201	94	165	5.42	2077	3130	17.2	29.9	0.99	378	374	2.06	3.58	0.12	45
13491	13789	298	idle 4	1.7	7.6	46	2.2	10.7	839	6866	29	106	3.42	388	3134	13.0	48.5	1.56	177	907	3.77	14.04	0.45	51
13790	14970	1180	h) light work	12.1	73.7	190	8.0	45.4	1857	25026	163	134	7.55	8922	3125	20.4	16.7	0.94	1114	339	2.21	1.82	0.10	121
14971	15300	329	idle 5	1.6	6.6	42	2.1	9.8	830	6526	25	109	3.13	234	3136	12.0	52.3	1.50	112	992	3.81	16.56	0.48	36
1418	15300	13882	Overall Ave	6.0	47.1	142	5.9	30.1	1440	18151	118	120	6.59	13609	3053	19.8	20.2	1.11	2289	385	2.50	2.54	0.14	289
Idle Average				1.5	6.8	42	2.1	9.8	834	6455	27	101	3.6	537	3133	13.4	49.2	1.79	266	954	4.07	15.00	0.54	80
Idle stdev				0.2	0.5	2.4	0.1	0.6	4.2	365	2.5	8.2	0.6	347	4.0	1.8	2.2	0.39	181	38	0.51	1.19	0.11	54
COV				11.4%	7.1%	5.7%	5.6%	5.7%	0.5%	5.7%	9.2%	8.1%	15.6%	64.6%	0.1%	13.6%	4.6%	21.8%	68.1%	4.0%	12.5%	8.0%	20.4%	67.2%
Light Work Average				10.6	63.3	176	7.5	39.7	1632	23609	138	133	8.6	13905	3128	18.1	17.7	1.1	1889	380	2.2	2.2	0.1	239
Light Work stdev				2.2	14.8	19.7	0.7	8.0	318	2004	35.8	1.4	1.4	7048	4.1	3.2	1.3	0.3	1096	56.9	0.1	0.5	0.1	167
COV				21.1%	23.3%	11.2%	8.6%	20.2%	19.5%	8.5%	26%	1.1%	16.8%	51%	0.1%	17.6%	7.6%	25.2%	58.0%	15.0%	2.8%	22%	39.4%	69.9%
Heavy Work Average				10.5	62.9	184	7.7	37.7	1662	23933	163	133	8.1	21210	3123	21.4	17.4	1.1	2816	383	2.6	2.1	0.1	351
Heavy Work stdev				0.8	6.7	16.5	0.9	3.6	75	2710	14.0	14.3	1.4	10575	3.3	2.0	0.7	0.1	1512	58.9	0.5	0.4	0.0	193
COV				7.8%	10.6%	9.0%	11.3%	9.6%	4.5%	11.3%	8.6%	10.8%	17.9%	50%	0.1%	9.4%	3.9%	10.2%	53.7%	15.4%	17.2%	17%	24.9%	55.1%

[1] ECM reported fuel rate

[2] Power estimated from published lug curve and % load, see detailed work sheet

[3] Carbon balance fuel rate by hand calculation

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

[5] Fuel use by carbon balance

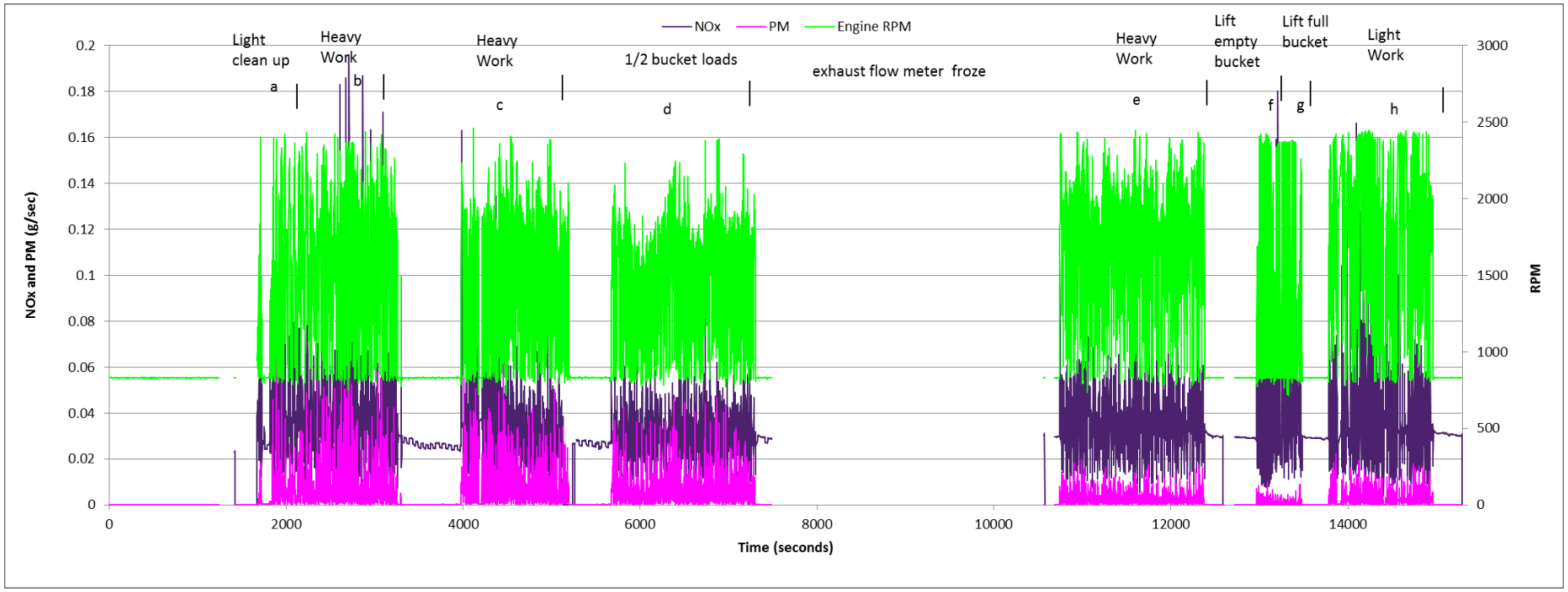

Figure 3-3: Modal Emissions for 30_2014.03.10 2011 CAT 928H Tier 3 Wheel Loader

31_328DLCR_2014.3.11

This 2013 Tier 4i Caterpillar 328DLCR Excavator was rented from Johnson Machinery and tested in their rental test plot at 800 E. La Cadena Dr, Riverside, CA. The equipment was operated by CE-CERT's Don Pacocha digging trench with 45 and 90º swings, filling trench with 45, 90 and 180 º swings, walking with small buckets to fill trench, and walking to pack down the dirt. The PEMS equipment was the same as used for test 28_, 29_, and 30_. There was 3.1 hours of valid data collected.

Table 3-5: Integrated Emissions for 31_2014.03.11 2013 CAT 328DLCR Tier 3 Excavator

Time (s)			Test Function	Fuel[1]	Power[2]	Torque	Fuel[3]	eLoad	eSpeed	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel)[3]					Brake Specific Emissions (g/bhp)				
Start	Stop	Duration	A-Work	kg/hr	bhp	ft-lb	kg/hr	%	RPM	CO2	CO	NOx	THC	mg PM[4]	CO2	CO	NOx	THC	mg PM[4]	CO2	CO	NOx	THC	mg PM[4]
58	1732	1674	a) Digging, 45⁰	20.7	182.2	509.6	25.1	63.8	1901	78808	216	370	48.7	18265	3139	8.58	14.7	1.94	727	433	1.18	2.03	0.27	100
1733	2103	370	idle 1	6.4	28.8	147.9	3.7	19.9	1025	11661	53	99	12.6	9119	3141	14.18	26.7	3.40	2456	404	1.83	3.44	0.44	316
2104	3470	1366	b) Digging, 90⁰	21.6	191.4	538.7	26.9	67.3	1881	84633	234	416	49.5	16773	3142	8.69	15.5	1.84	623	442	1.22	2.17	0.26	88
3636	4016	380	idle 2	6.7	29.8	151.6	3.8	20.1	1029	11822	54	99	12.7	9634	3139	14.43	26.2	3.37	2558	397	1.83	3.31	0.43	324
4017	4188	171	c) Fill, 90⁰	19.7	175.9	500.0	22.4	62.1	1786	70364	190	304	50.3	14498	3136	8.46	13.6	2.24	646	400	1.08	1.73	0.29	82
4189	4273	84	idle 3	5.6	44.6	179.6	5.4	20.0	1313	16983	66	164	18.7	1434	3170	12.35	30.6	3.49	268	381	1.48	3.67	0.42	32
4274	6104	1830	d) Fill, 45⁰	20.5	185.0	513.6	23.8	64.6	1910	74792	220	341	51.1	17387	3138	9.23	14.3	2.15	729	404	1.19	1.85	0.28	94
6105	6213	108	idle 4	7.3	32.4	156.5	4.1	20.7	1062	13014	62	102	15.0	12617	3178	15.21	24.9	3.66	3081	402	1.92	3.14	0.46	390
6214	7391	1177	e) Fill 180⁰	8.7	72.8	246.5	10.1	30.1	1413	31755	112	201	27.8	8945	3132	11.08	19.8	2.75	882	436	1.54	2.75	0.38	123
7392	9551	2159	f) Clean up	20.7	190.2	530.3	23.9	66.6	1886	74950	209	340	51.8	16837	3139	8.74	14.2	2.17	705	394	1.10	1.79	0.27	89
9552	9732	180	idle 5	5.3	37.0	167.5	4.8	20.0	1162	15311	56	160	16.8	1920	3176	11.56	33.1	3.49	398	414	1.51	4.32	0.46	52
9733	10801	1068	g) Walking/Packing	19.6	238.8	656.8	25.1	83.0	1908	78690	146	313	64.7	10259	3141	5.83	12.5	2.58	409	330	0.61	1.31	0.27	43
10802	11091	289	idle 6	6.9	25.4	140.3	3.6	19.6	950	11156	48	106	12.5	9595	3129	13.52	29.8	3.52	2691	439	1.90	4.18	0.49	378
58	11091	11033	Overall Ave	17.3	159.7	458.2	20.5	57.5	1735	64363	179	307	44.5	14554	3137	8.70	15.0	2.17	709	403	1.12	1.92	0.28	91
Idle Average				6.4	33.0	157	4.2	20.1	1090	13324	57	122	14.7	7387	3156	13.5	28.5	3.49	1909	406	1.74	3.68	0.45	249
Idle stdev				0.8	6.9	14.2	0.7	0.4	129.0	2330	6.6	31.3	2.6	4596	21.5	1.4	3.1	0.10	1240	20	0.20	0.48	0.03	163
COV				12.2%	20.9%	9.1%	17.0%	1.9%	11.8%	17.5%	11.6%	25.8%	17.6%	62.2%	0.7%	10.1%	11.0%	3.0%	64.9%	4.8%	11.3%	13.0%	6.2%	65.5%
Digging Average				21.1	186.8	524	26.0	65.5	1891	81720	225	393	49.1	17519	3140	8.6	15.1	1.9	675	437	1.2	2.1	0.3	93.9
Digging stdev				0.7	6.6	20.6	1.3	2.5	14	4119	13.2	32.7	0.5	1055	2.3	0.1	0.5	0.1	74	6.7	0.0	0.1	0.0	8.9
COV				3.2%	3.5%	3.9%	5.0%	3.8%	0.8%	5.0%	6%	8.3%	1.1%	6%	0.1%	0.9%	3.4%	3.9%	11.0%	1.5%	2.4%	5%	2%	10%
Filling Average				16.3	144.6	420	18.8	52.3	1703	58970	174	282	43.1	13610	3135	9.6	15.9	2.4	753	413	1.3	2.1	0.3	99.7
Filling stdev				6.6	62.3	150.4	7.5	19.2	259	23673	55.4	73.0	13.2	4290	3.3	1.3	3.4	0.3	120	19.6	0.2	0.6	0.1	20.8
COV				40.6%	43.1%	35.8%	40.1%	36.8%	15.2%	40.1%	31.9%	25.9%	30.7%	32%	0.1%	14.1%	21.3%	13.5%	15.9%	4.8%	19.1%	27%	19%	21%

[1] ECM reported fuel rate

[2] Power estimated from published lug curve and % load, see detailed work sheet

[3] Carbon balance fuel rate by hand calculation

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

[5] Fuel use by carbon balance

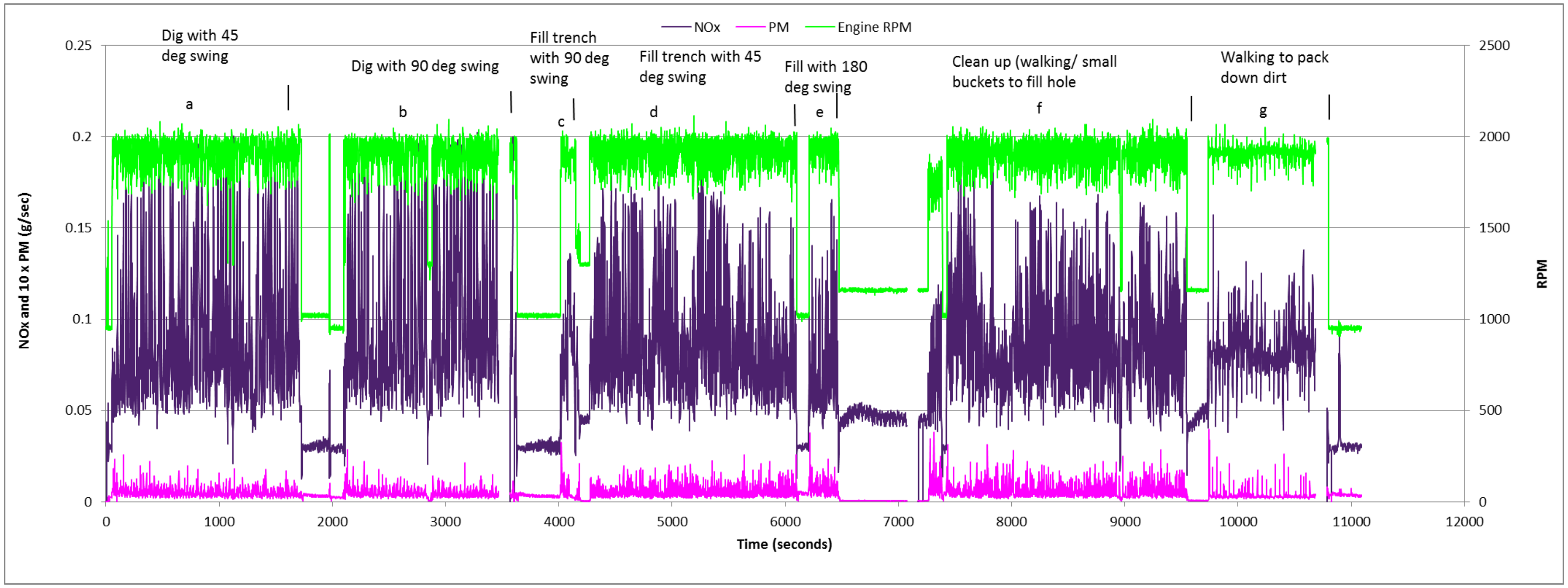

Figure 3-4: Modal Emissions for 31_2014.03.11 2013 CAT 328DLCR Tier 3 Excavator

32_D8Ti_2014.03.12

This 2011 Tier 4i Caterpillar D8Ti Bulldozer was rented from Johnson Machinery and tested in their rental test plot at 800 E. La Cadena Dr, Riverside, CA. The equipment was operated by CE-CERT's Don Pacocha digging trench with 45 and 90º swings, filling trench with 45, 90 and 180 º swings, walking with small buckets to fill trench, and walking to pack down the dirt. The PEMS equipment was the same as used for test 28_, 29_, 30_ and 31_. There was 2.9 hours of valid data collected.

Table 3-6: Integrated Emissions for 32_2014.03.12 2011 CAT D8Ti Tier 4i Bulldozer

Time (s)			Test Function	Fuel[1]	Power[2]	Torque	Fuel[3]	eLoad	eSpeed	Time Specific Emissions (g/hr)					Fuel Specific Emissions (g/kgfuel)[3]					Brake Specific Emissions (g/bhp)				
Start	Stop	Duration	A-Work	kg/hr	bhp	ft-lb	kg/hr	%	RPM	CO2	CO	NOx	THC	mg PM[4]	CO2	CO	NOx	THC	mg PM[4]	CO2	CO	NOx	THC	mg PM[4]
1187	1213	26	idle 1	4.2	6.1	46	4.9	14.4	699	15454	5.7	203	1.73	265	3157	1.17	41.5	0.35	54.08	2519	0.93	33.11	0.28	43.15
1214	1420	206	not specified	6.5	16.7	83	9.2	8.4	1000	29060	79.8	142	10.16	1255	3143	8.63	15.3	1.10	135.68	1738	4.77	8.47	0.61	75.05
1421	1445	24	idle 2	3.7	4.7	35	4.3	10.7	700	13686	9.9	151	5.68	974	3152	2.28	34.9	1.31	224.33	2924	2.11	32.35	1.21	208.12
1446	1458	12	not specified	14.6	64.5	196	13.9	27.5	1308	43716	146.2	293	14.72	1577	3140	10.50	21.0	1.06	113.27	678	2.27	4.54	0.23	24.44
1459	1846	387	idle 3	3.8	5.3	36	4.4	11.1	709	13968	22.6	157	5.82	192	3148	5.08	35.3	1.31	43.25	2630	4.25	29.50	1.10	36.14
1847	2530	683	a) Full cut	36.6	212	599	41.7	67.1	1796	131779	34.2	307	9.74	1095	3158	0.82	7.4	0.23	26.24	622	0.16	1.45	0.05	5.17
2531	2853	322	idle 4	3.4	4.2	31	3.9	10.0	703	12165	7.7	119	1.23	14.6	3156	1.99	30.8	0.32	3.77	2874	1.81	28.06	0.29	3.44
2854	3580	726	b) Rear claw ripping	38.4	223	627	42.5	71.1	1846	134205	32.4	304	6.07	88.6	3158	0.76	7.2	0.14	2.08	601	0.15	1.36	0.03	0.40
3581	3621	40	idle 5	3.6	4.9	34	4.0	9.4	725	12630	7.3	115	1.17	18.5	3156	1.81	28.8	0.29	4.62	2594	1.49	23.67	0.24	3.80
3622	4182	560	b) Rear claw ripping	40.1	224	612	43.5	70.9	1957	137353	28.2	316	5.15	75.5	3158	0.65	7.3	0.12	1.74	613	0.13	1.41	0.02	0.34
4183	4264	81	idle 6	3.6	5.3	35	3.9	9.6	718	12354	7.9	113	1.16	16.6	3156	2.01	28.8	0.30	4.25	2339	1.49	21.36	0.22	3.15
4265	4644	379	b) Rear claw ripping	37.5	201	548	38.8	64.5	1978	122393	30.0	279	3.72	67.0	3158	0.77	7.2	0.10	1.73	608	0.15	1.38	0.02	0.33
4645	4922	277	idle 7	3.3	3.5	26	2.6	8.6	703	8174	9.4	77	0.70	14.1	3153	3.64	29.9	0.27	5.46	2309	2.67	21.88	0.20	4.00
4923	6672	1749	c) Full blade push	34.0	186	472	34.4	65.8	2081	108756	31.2	276	4.06	82.4	3158	0.91	8.0	0.12	2.39	586	0.17	1.49	0.02	0.44
6673	7158	485	idle 8	3.3	3.6	27	3.6	8.6	702	11335	7.4	110	1.02	10.8	3156	2.07	30.6	0.29	2.99	3167	2.08	30.73	0.29	3.00
7159	8247	1088	d) Push pile, full blade	29.6	151	375	28.1	56.6	2110	88706	24.0	242	4.50	61.6	3158	0.85	8.6	0.16	2.19	588	0.16	1.60	0.03	0.41
8248	8377	129	idle 9	3.9	7.1	35	1.9	9.5	736	5955	2.4	47	0.41	14.0	3157	1.25	24.8	0.22	7.43	840	0.33	6.60	0.06	1.98
8378	8670	292	e) Light pushing	28.8	129	314	28.9	49.2	2147	91286	24.8	227	4.51	83.2	3158	0.86	7.9	0.16	2.88	706	0.19	1.76	0.03	0.64
8671	8759	88	idle 10	3.7	4.3	30	4.5	9.1	716	14354	9.7	133	1.35	16.8	3156	2.13	29.3	0.30	3.69	3352	2.27	31.17	0.32	3.91
8760	9343	583	e) Light pushing	26.7	134	378	26.8	44.8	1902	84618	21.5	210	4.26	54.7	3158	0.80	7.8	0.16	2.04	631	0.16	1.57	0.03	0.41
9344	9566	222	idle 11	3.2	3.4	26	3.9	8.6	700	12262	8.2	116	0.89	14.8	3156	2.10	29.8	0.23	3.82	3588	2.39	33.90	0.26	4.34
9567	12637	3070		Flow meter froze, no valid data																				
12638	12657	19	idle 12	4.0	5.8	41	4.4	10.7	728	13912	19.6	149	2.08	2.6	3151	4.44	33.7	0.47	0.59	2379	3.35	25.42	0.36	0.45
12658	14701	2043	f) Back dragging area	23.8	110	294	25.1	39.7	1886	79326	29.0	218	5.22	41.3	3157	1.15	8.7	0.21	1.64	718	0.26	1.97	0.05	0.37
14702	14886	184	idle 13	3.3	3.8	28.1	4.4	9.0	704	13912	9	132	1.0	11.9	3156	1.98	29.9	0.23	3	3664	2.30	34.68	0.27	3.14
1187	14886	13699	Overall Ave	19.2	127.4	343.6	25.9	45.6	1675	81842	26	226	4.6	155	3158	1.00	8.7	0.18	6	642	0.20	1.77	0.04	1.21
Idle Average				3.6	4.8	33	3.9	9.9	711	12320	10	125	1.9	120	3155	2.5	31.4	0.45	28	2706	2.11	27.11	0.39	24.5
Idle stdev				0.3	1.1	6.1	0.8	1.6	12.3	2621	5.4	38.1	1.8	269	2.7	1.2	4.1	0.39	61	727	1.00	7.63	0.35	56.8
COV				8.6%	23.6%	18.3%	21.3%	16.0%	1.7%	21.3%	56.0%	30.6%	94.8%	223.5%	0.1%	48.2%	13.1%	85.1%	221.2%	26.9%	47.3%	28.1%	89%	232.0%
Rear Claw Ripping Average				38.7	216.1	596	41.6	68.8	1927	131317	30	300	5.0	77	3158	0.7	7.2	0.12	1.8	608	0.1	1.4	0.0	0.36
Rear Claw Ripping stdev				1.3	12.9	42.3	2.5	3.7	71.3	7887	2.1	19.3	1.2	11	0.1	0.1	0.1	0.02	0.2	6	0.01	0.02	0.00	0.04
COV				3.3%	6.0%	7.1%	6.0%	5.4%	3.7%	6.0%	7%	6.4%	23.8%	14%	0.0%	9.5%	0.8%	19.7%	11.0%	1.0%	9%	2%	19%	10%
Full Blade Push Average				31.8	168	423	31.3	61.2	2096	98731	28	259	4.3	72	3158	0.9	8.3	0.14	2.3	587	0.2	1.5	0.0	0.43
Full Blade Push stdev				3.1	24.6	69	4.5	6.4	20	14178	5.1	25	0.3	15	0.0	0.0	0.4	0.03	0.1	1.4	0.0	0.1	0.0	0.03
COV				9.9%	14.6%	16.3%	14.4%	10.5%	1.0%	14.4%	19%	9.5%	7.2%	20%	0.0%	4.2%	4.9%	21.5%	6.1%	0.2%	4.0%	5%	22%	5.9%
Light Pushing Average				27.8	132	346	27.8	47.0	2025	87952	23	219	4.4	69	3158	0.8	7.8	0.16	2.5	668	0.2	1.7	0.0	0.53
Light Pushing stdev				1.4	3.3	45	1.5	3.1	173	4715	2.4	12	0.2	20	0.1	0.0	0.0	0.00	0.6	52.5	0.0	0.1	0.0	0.17
COV				5.2%	2.5%	12.9%	5.4%	6.6%	8.5%	5.4%	10.2%	5.6%	4.1%	29%	0.0%	4.9%	0.3%	1.3%	24.0%	7.9%	12.7%	8%	7%	32%

[1] ECM reported fuel rate

[2] Power estimated from published lug curve and % load, see detailed work sheet

[3] Carbon balance fuel rate by hand calculation

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

[5] Fuel use by carbon balance

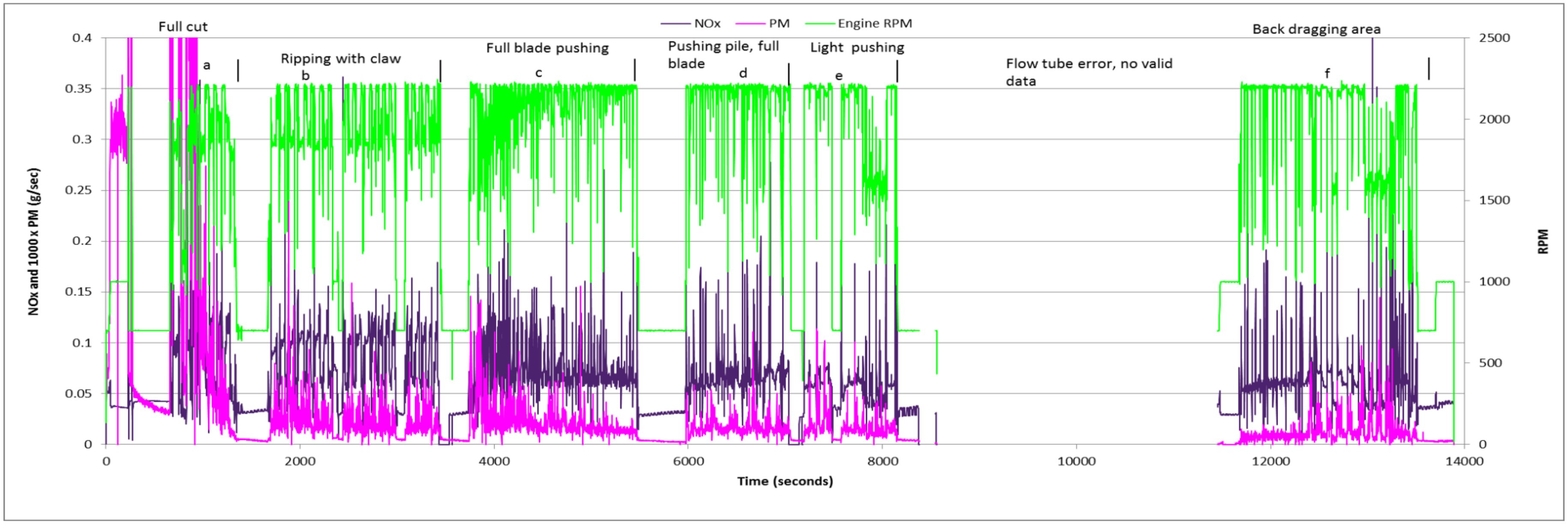

Figure 3-5: Modal Emissions for 32_2014.03.12 2011 CAT D8Ti Tier 4i Bu

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4 Appendices

A Regression Analysis of Model Development Dataset

This section presents regression analysis that was performed on the model development dataset. Data was partitioned into mini-events as discussed in Section 2.1.1 and regressions were performed by equipment category as defined by mode and engine certification standard. Regression results for individual tests are presented in the legend following each equipment description. The variable "b1" presented in the legend is the regression coefficient of a line constrained through the origin and the R^2 value is an adjusted measure for the goodness of fit. For this analysis, regressions were constrained through the origin since the expectation is that without fuel consumption, no emissions are produced. The solid black line is a regression through all of the test data matching the category criteria. For reference purposes, the solid magenta line indicates the ratio of the cumulative emission by cumulative fuel.

A.1 Idle Emissions

A.1.1 Tier 2

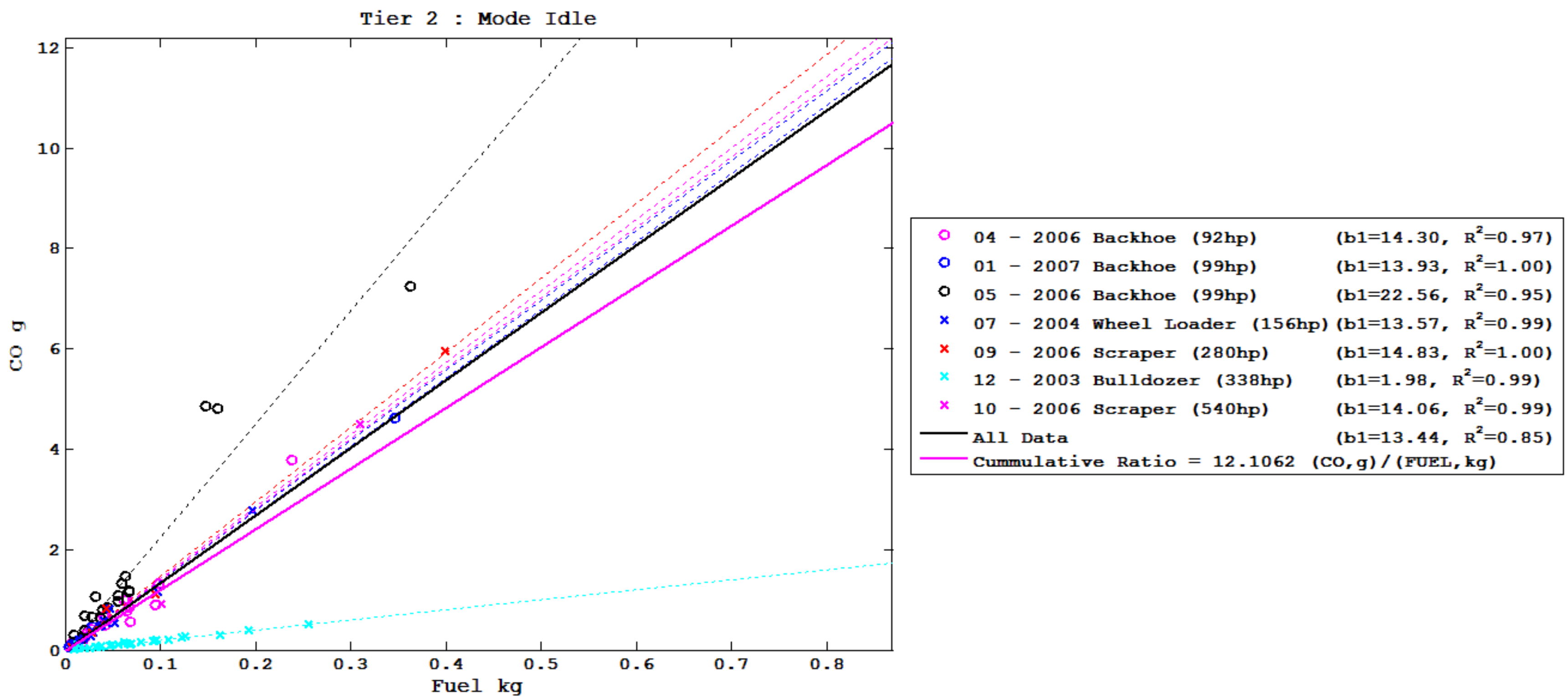


Figure A-1: Tier 2 CO Idle Emissions

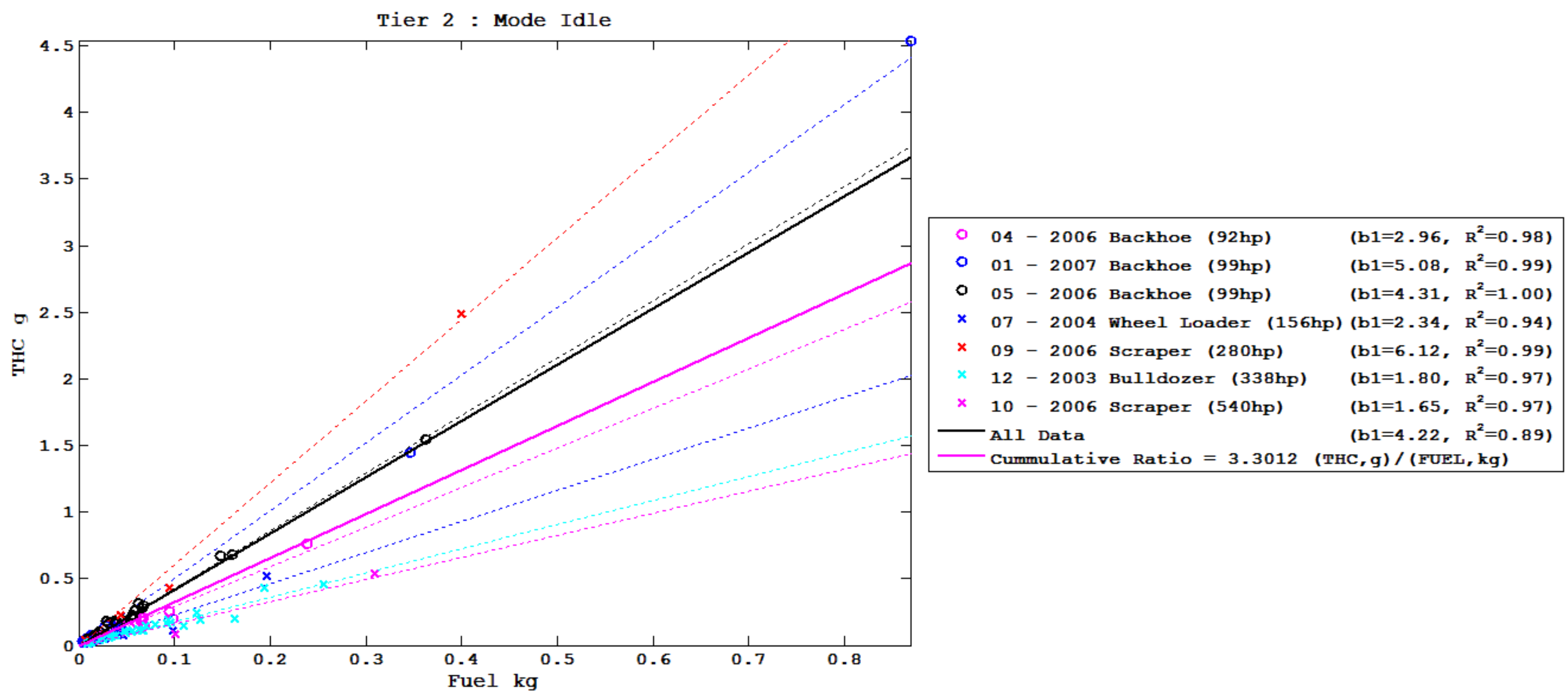


Figure A-2: Tier 2 THC Idle Emissions

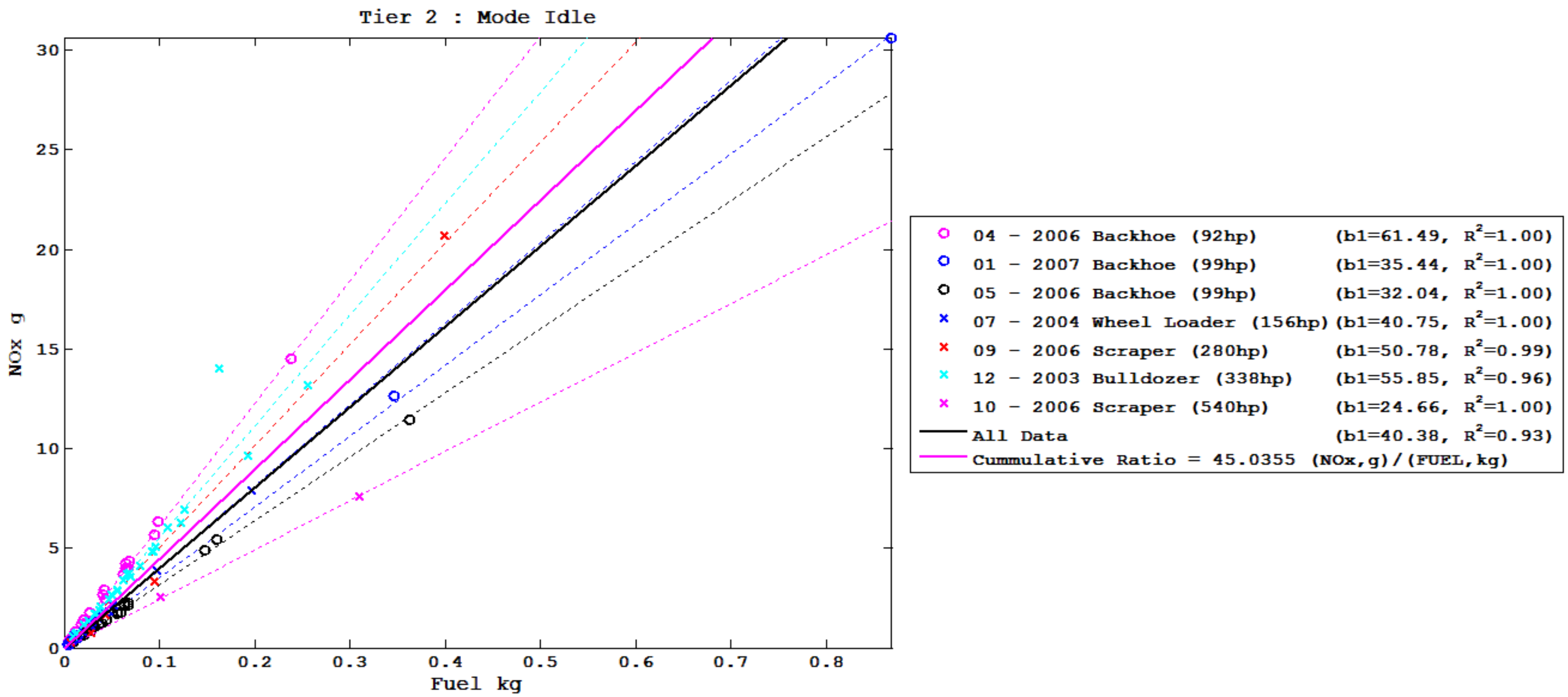


Figure A-3: Tier 2 NO_x Idle Emissions

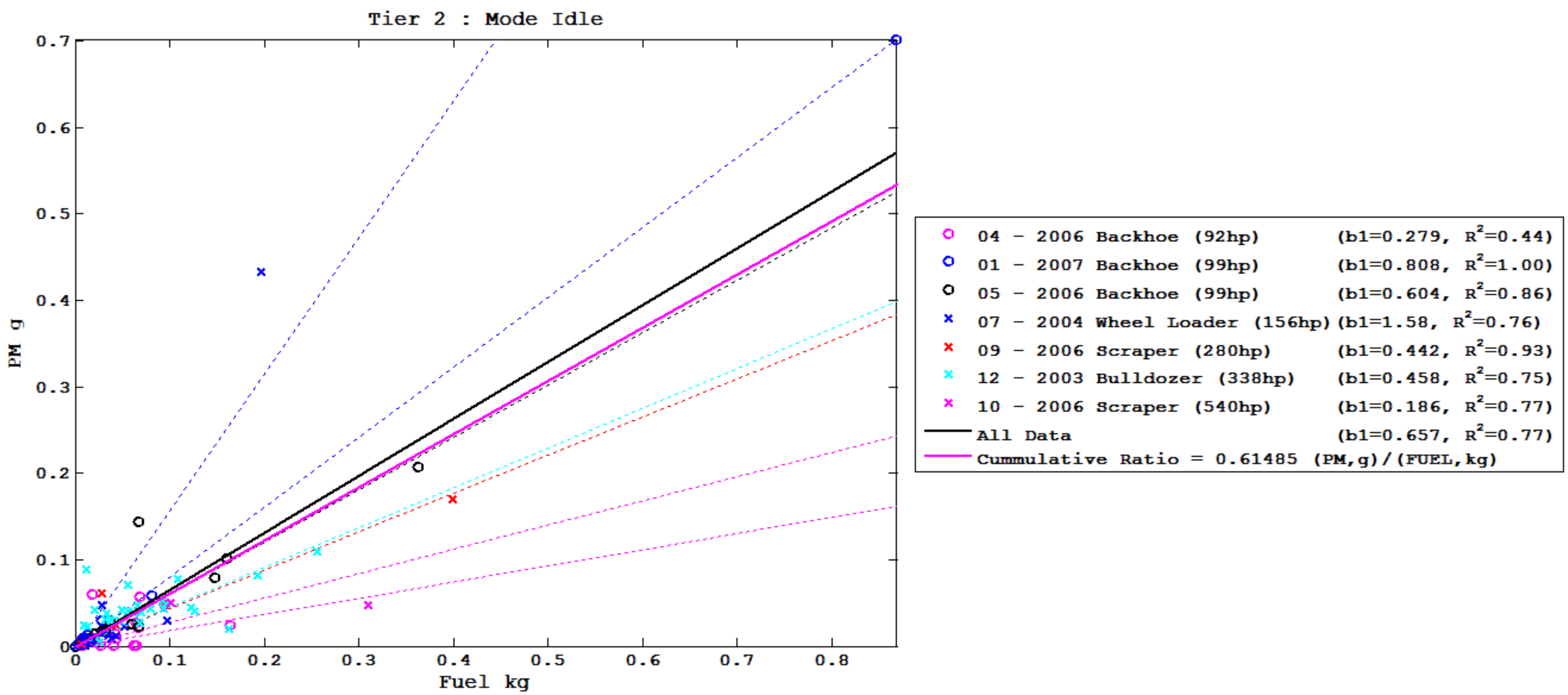


Figure A-4: Tier 2 PM Idle Emissions

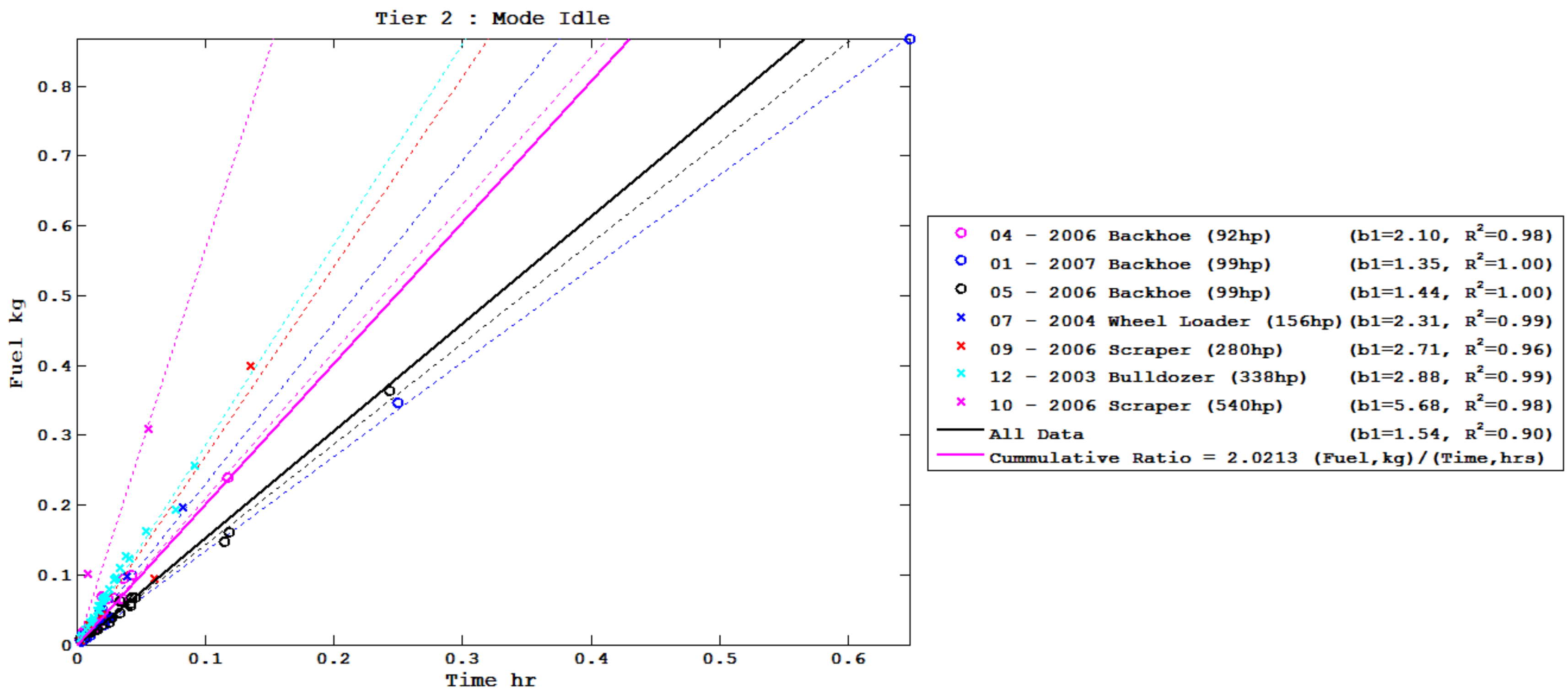


Figure A-5: Tier 2 Fuel Use

A.1.2 Tier 3

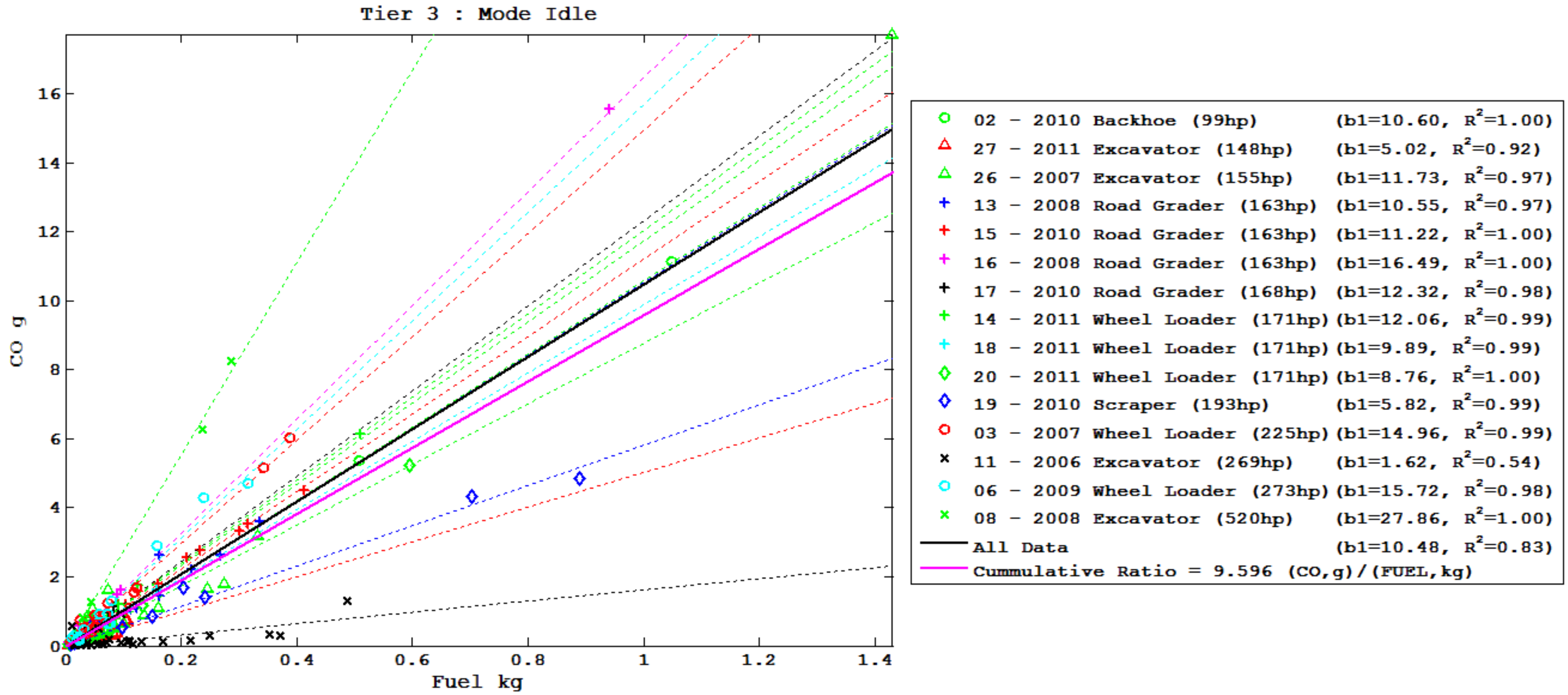


Figure A-6: Tier 3 CO Idle Emissions

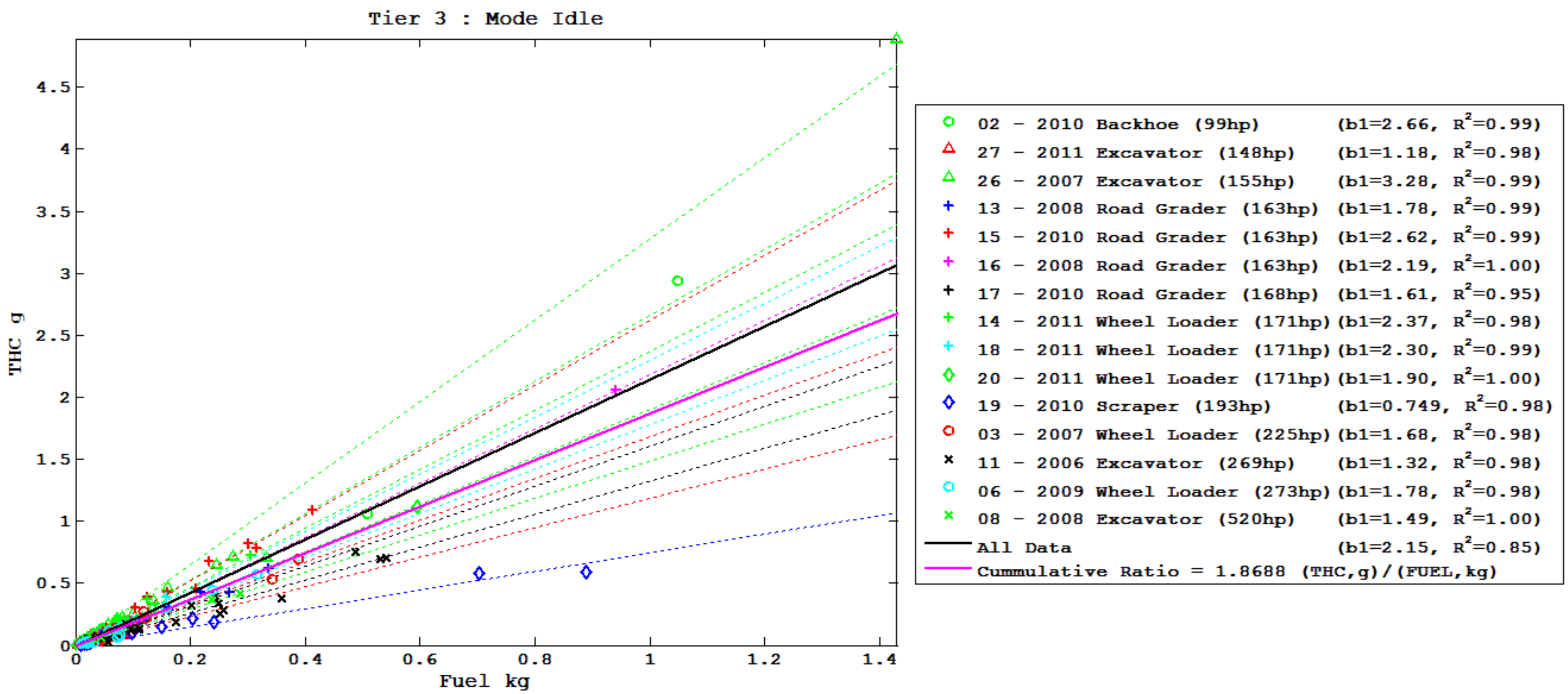


Figure A-7: Tier 3 THC Idle Emissions

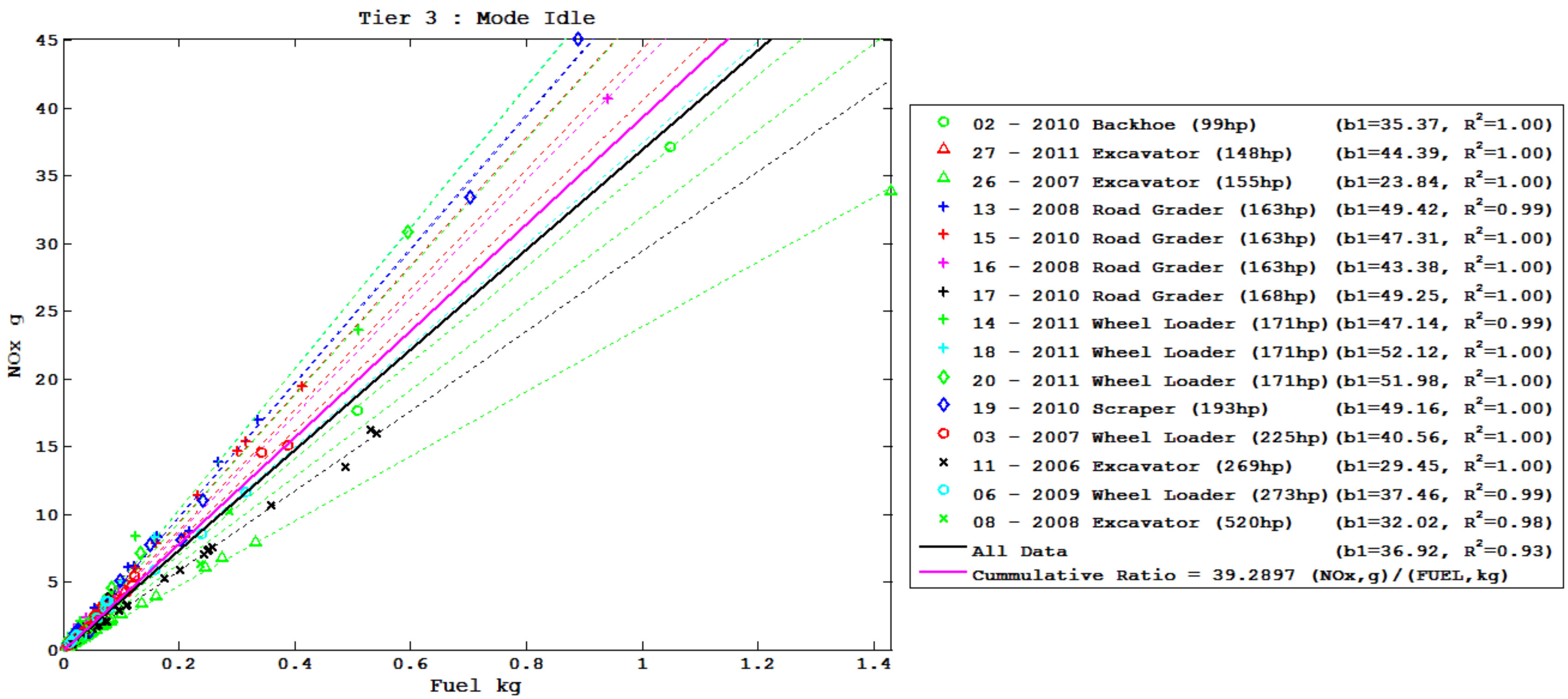


Figure A-8: Tier 3 NO_x Idle Emissions

9

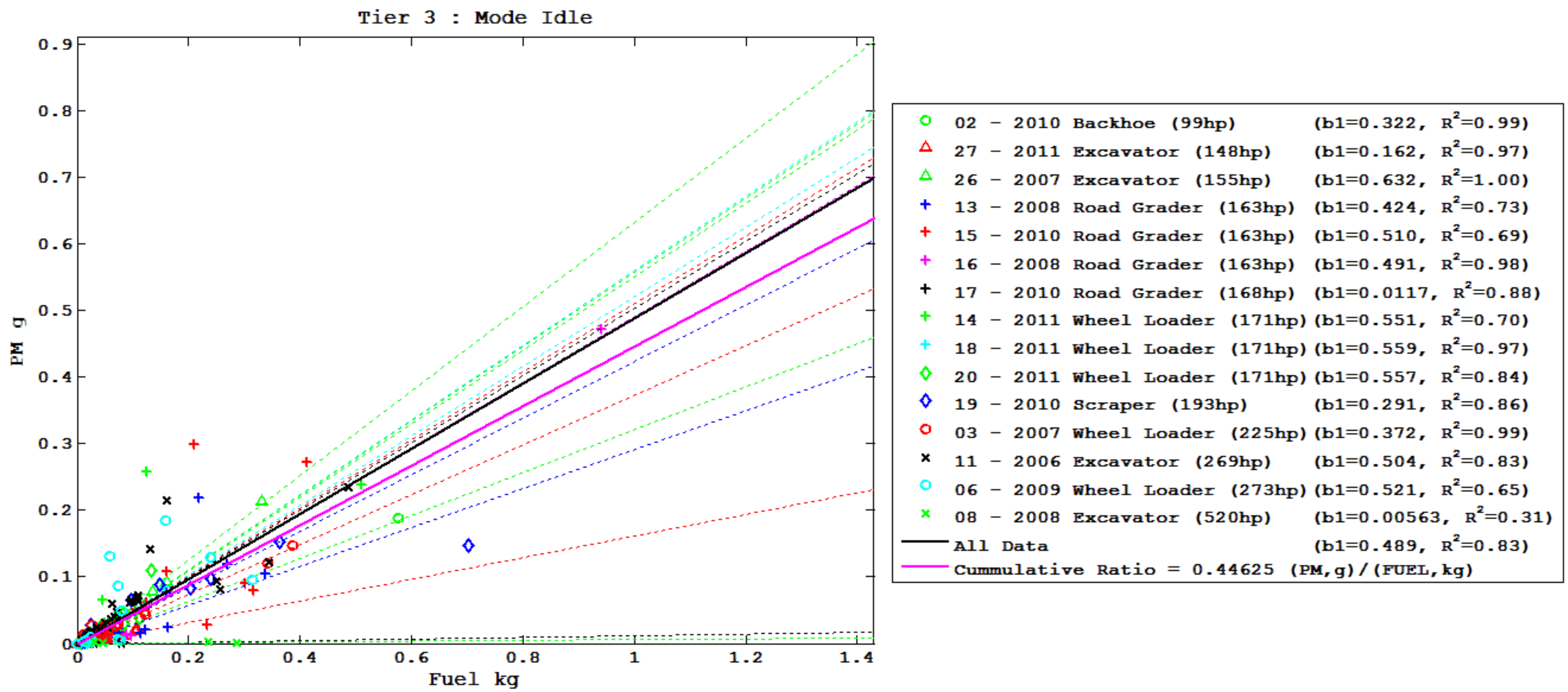


Figure A-9: Tier 3 PM Idle Emissions

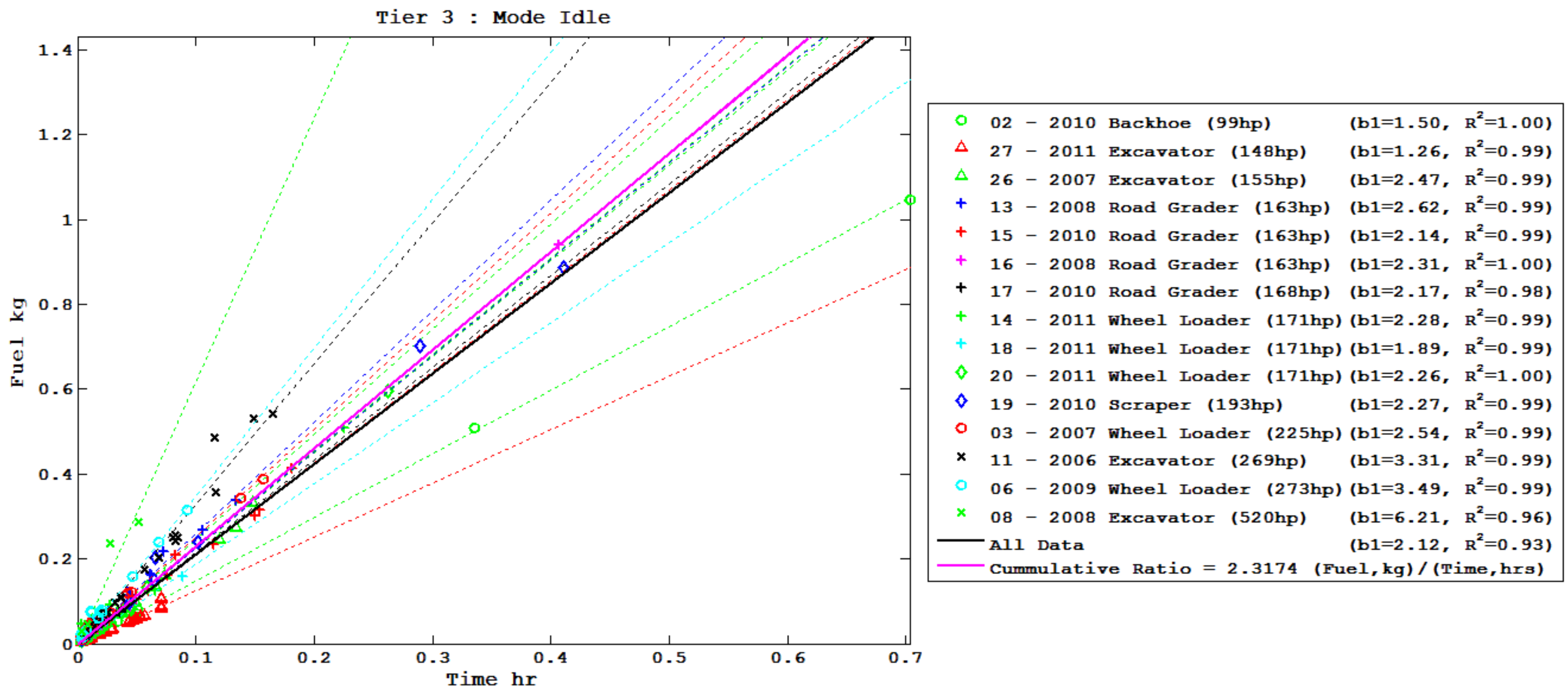


Figure A-10: Tier 3 Fuel Use

A.1.3 Tier 4i

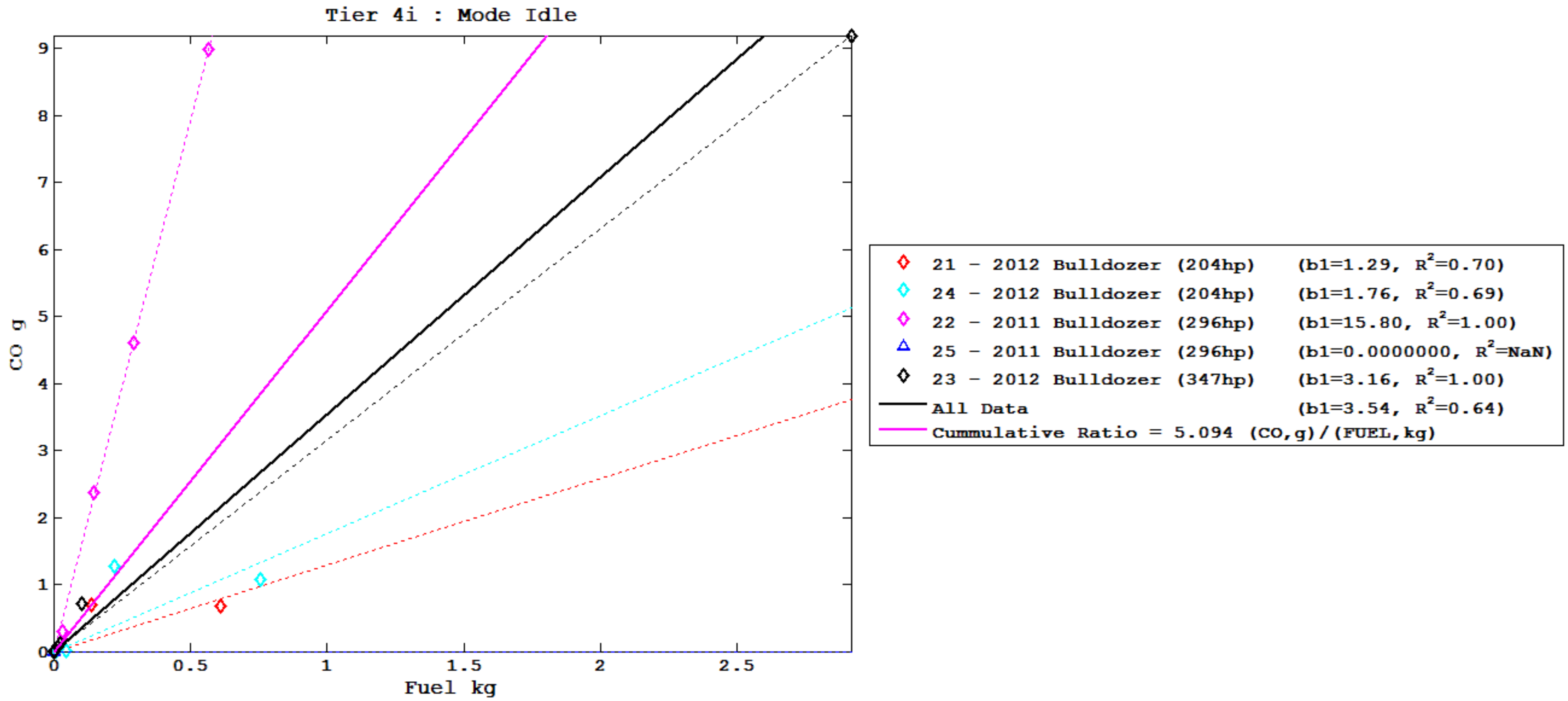


Figure A-11: Tier 4i CO Idle Emissions

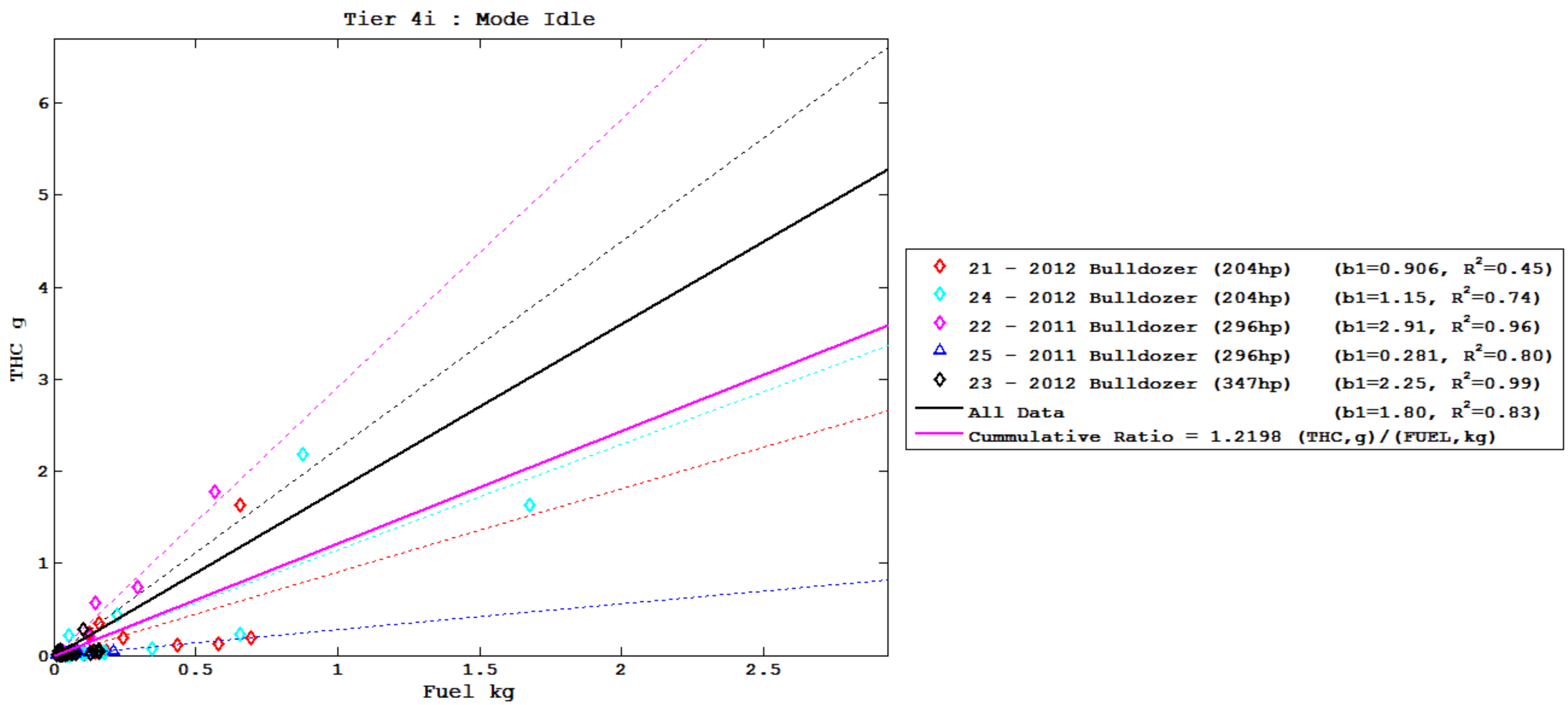


Figure A-12: Tier 4i THC Idle Emissions

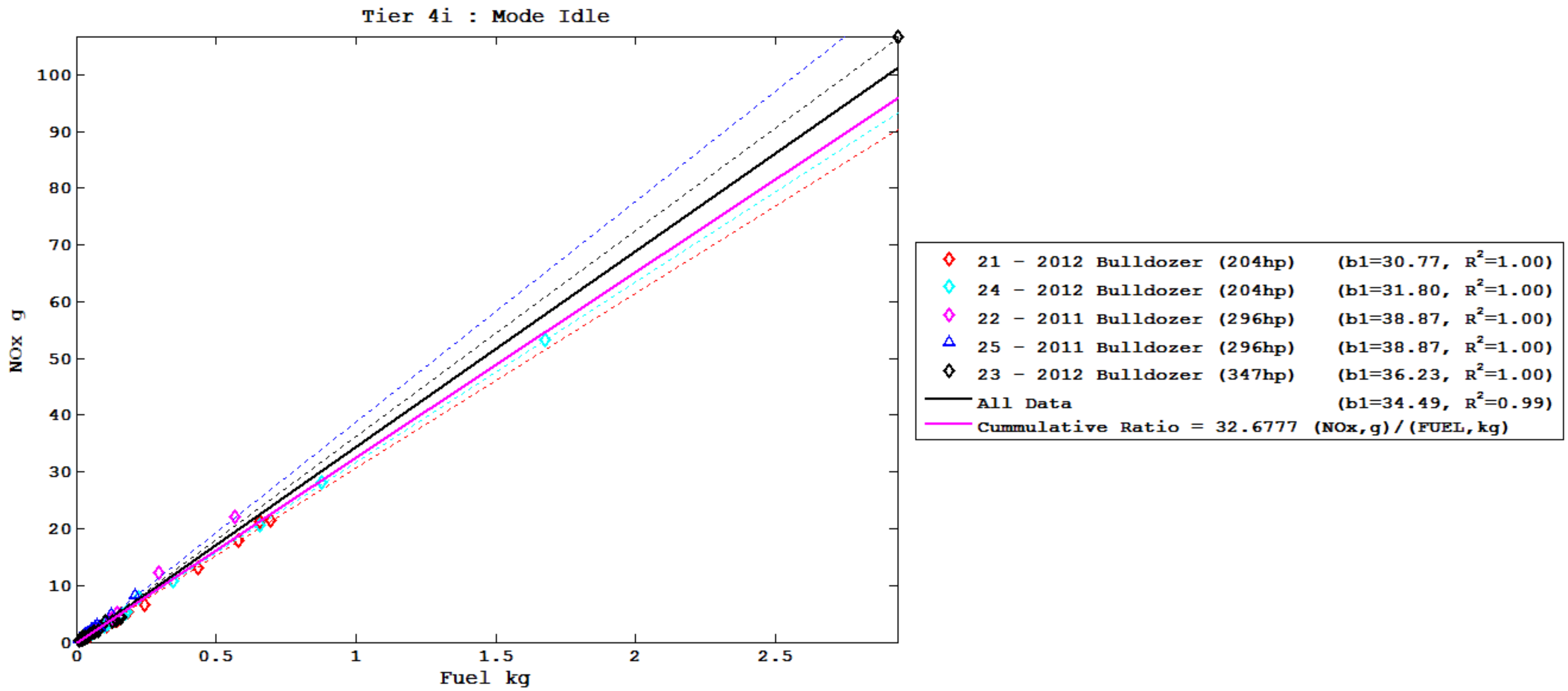


Figure A-13: Tier 4i NO_x Idle Emissions

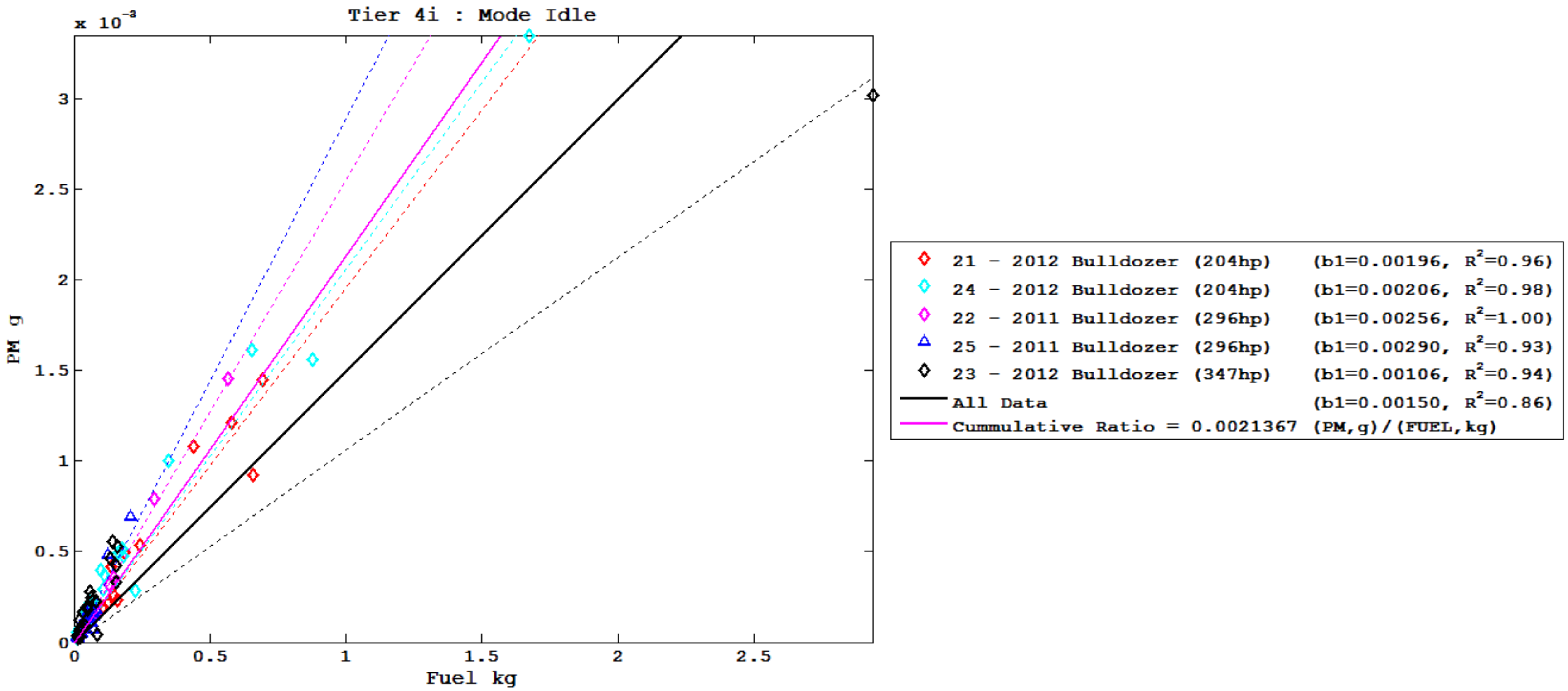


Figure A-14: Tier 4i PM Idle Emissions

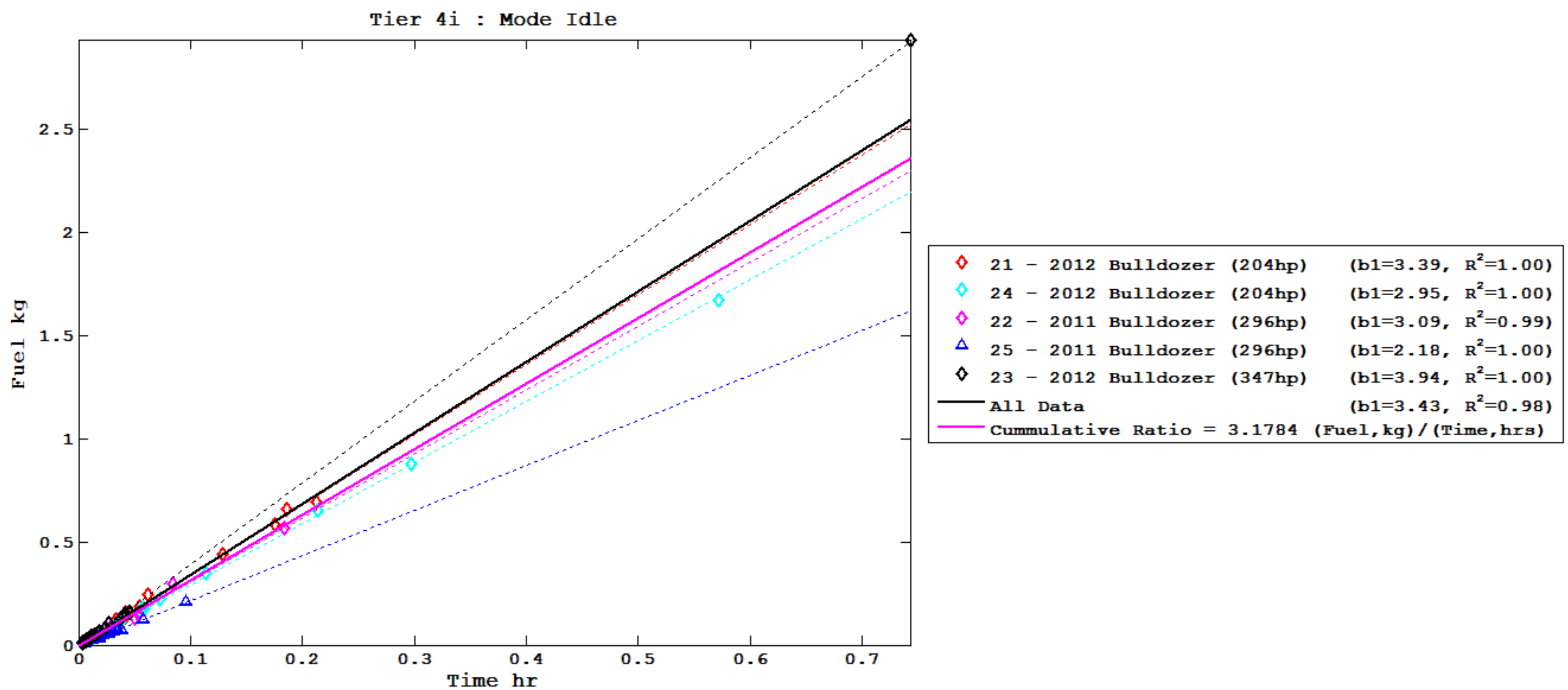


Figure A-15: Tier 4i Fuel Use

A.2 Non-Idle Emissions

A.2.1 Tier 2

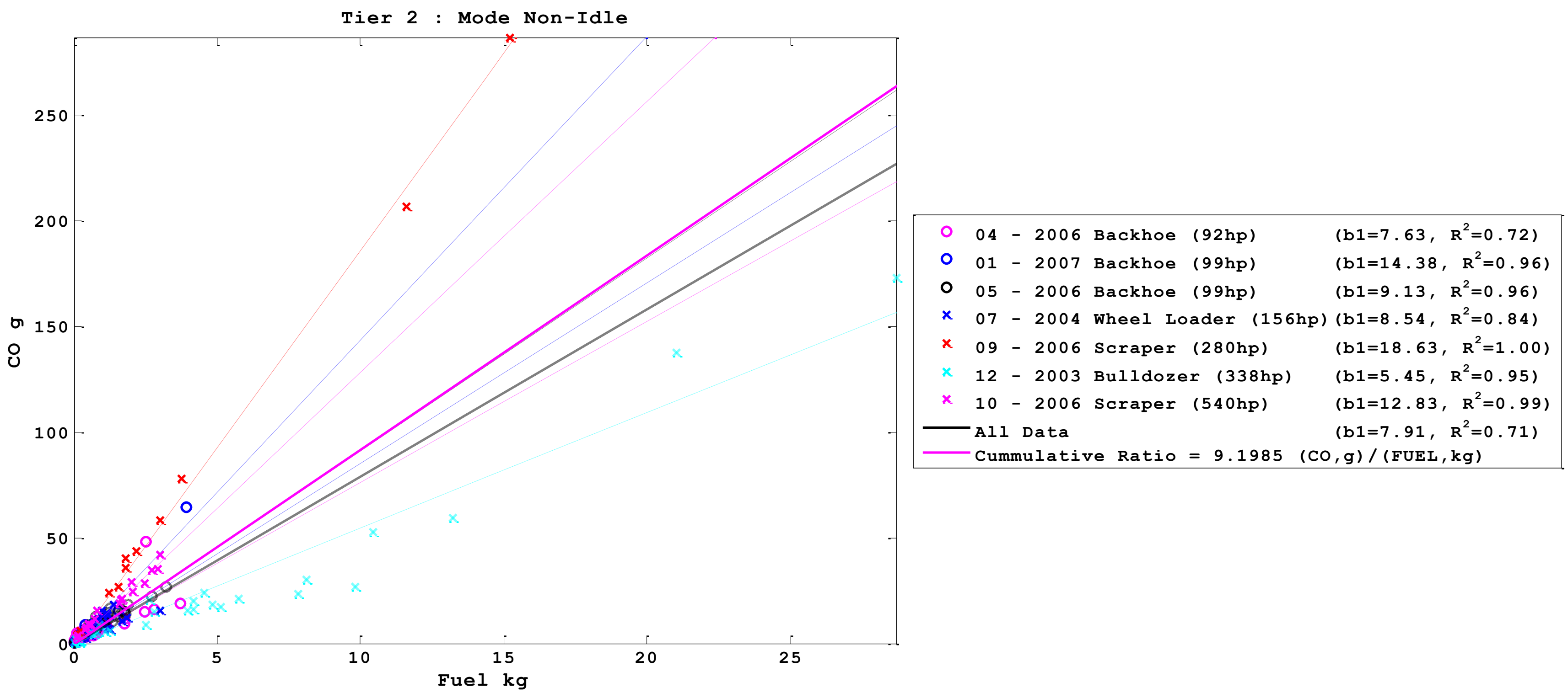


Figure A-16: Tier 2 CO Non-Idle Emission

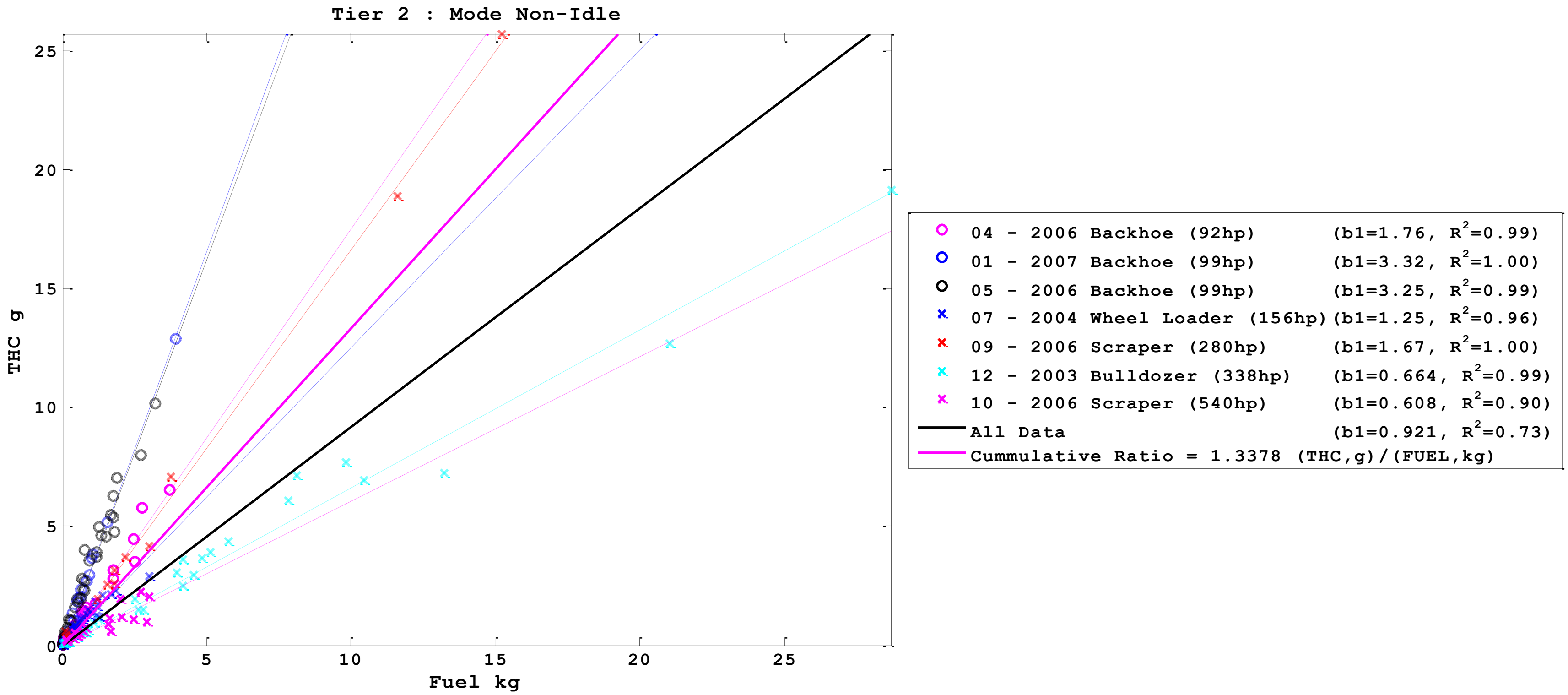


Figure A-17: Tier 2 THC Non-Idle Emissions

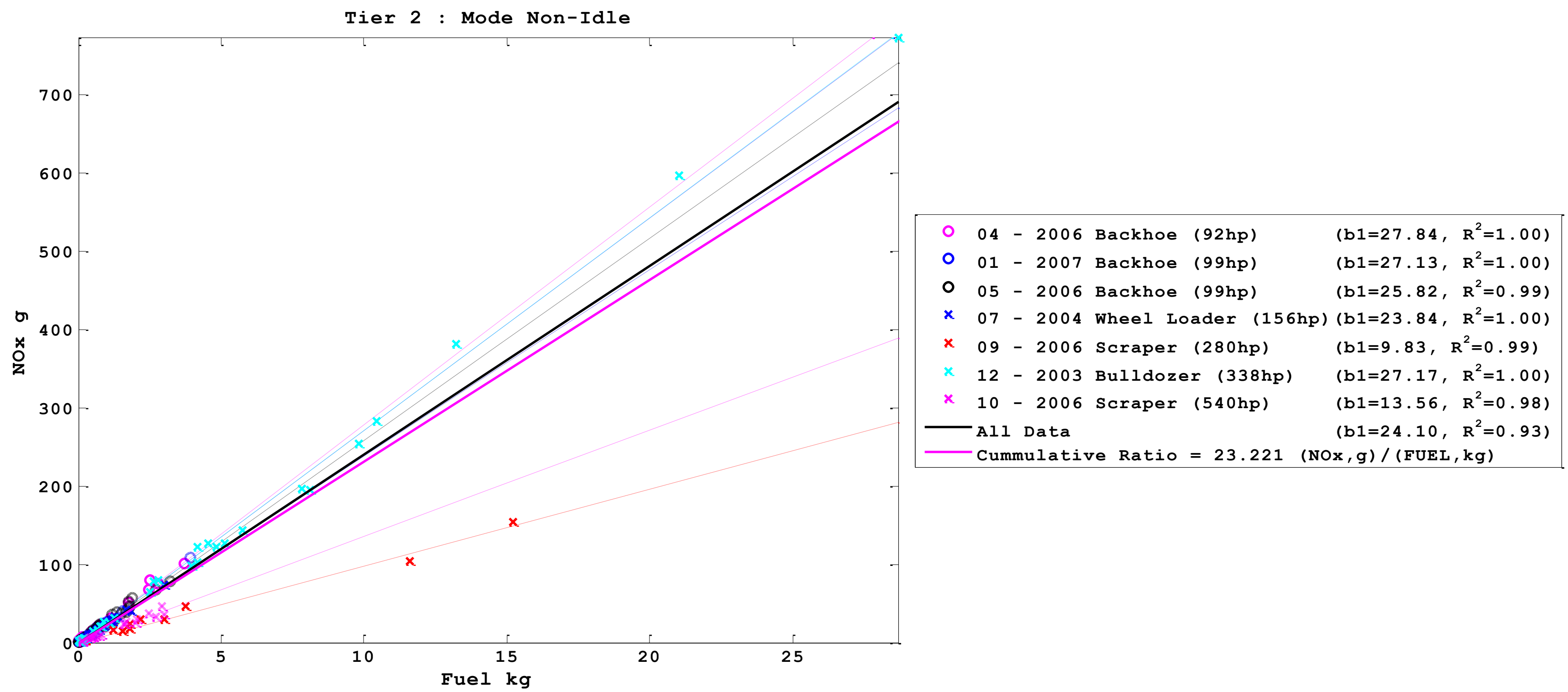


Figure A-18: Tier 2 NO_x Non-Idle Emissions

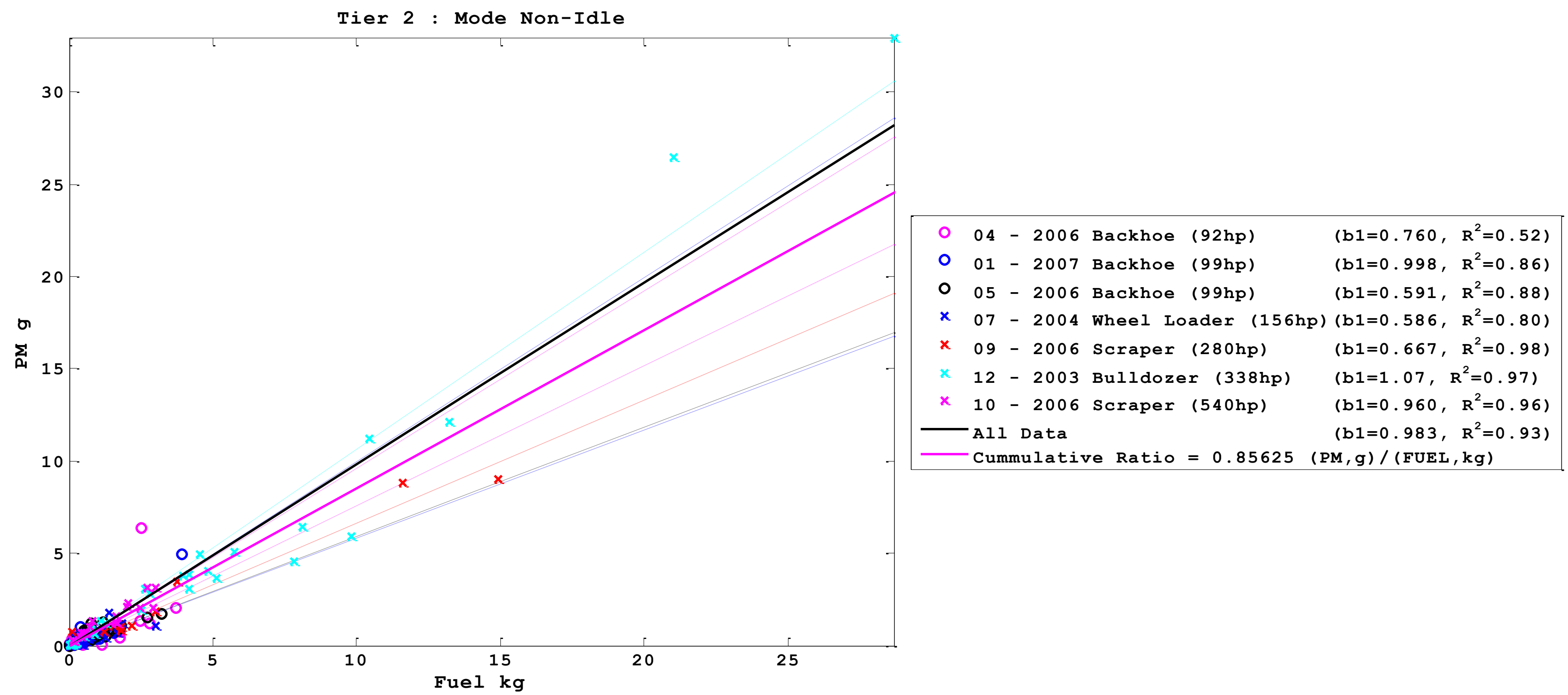


Figure A-19: Tier 2 PM Non-Idle Emissions

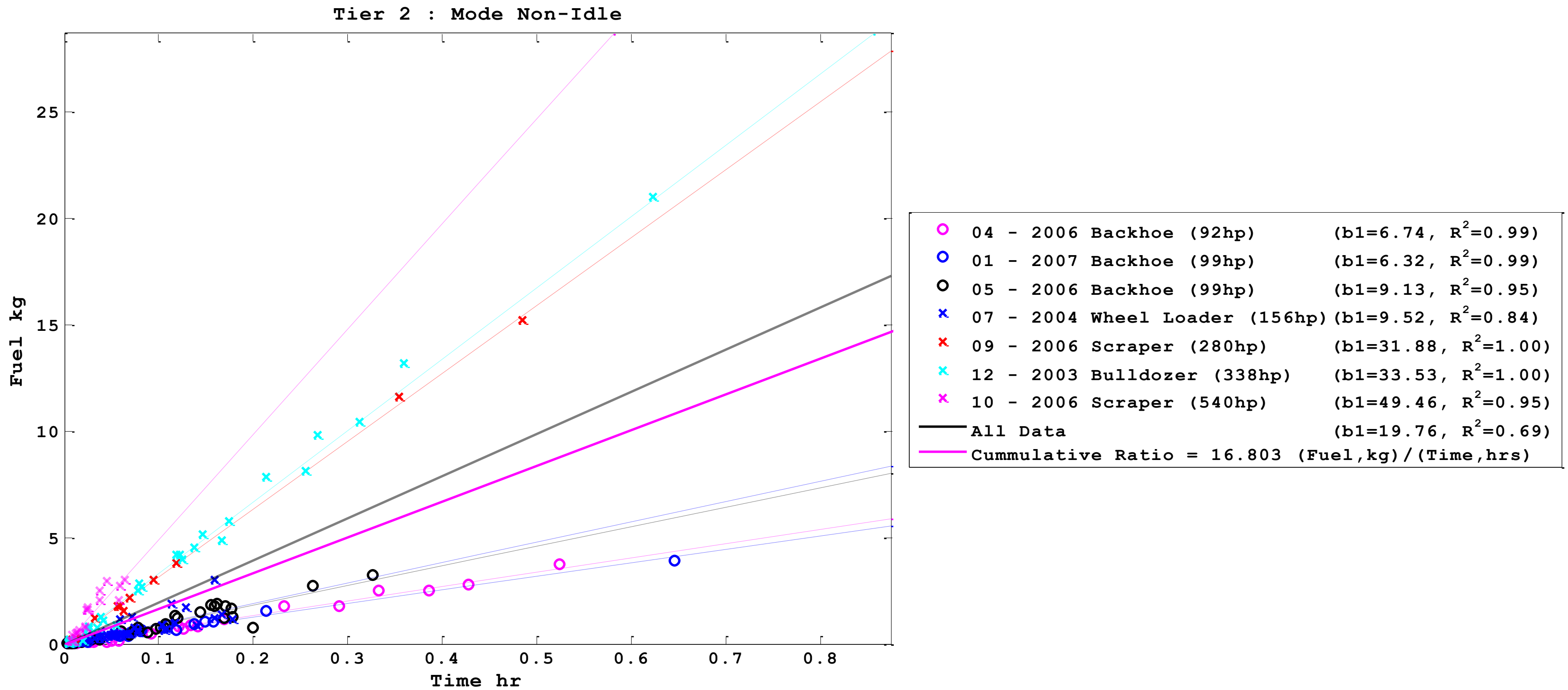


Figure A-20: Tier 2 Fuel Use

A.2.2 Tier 3

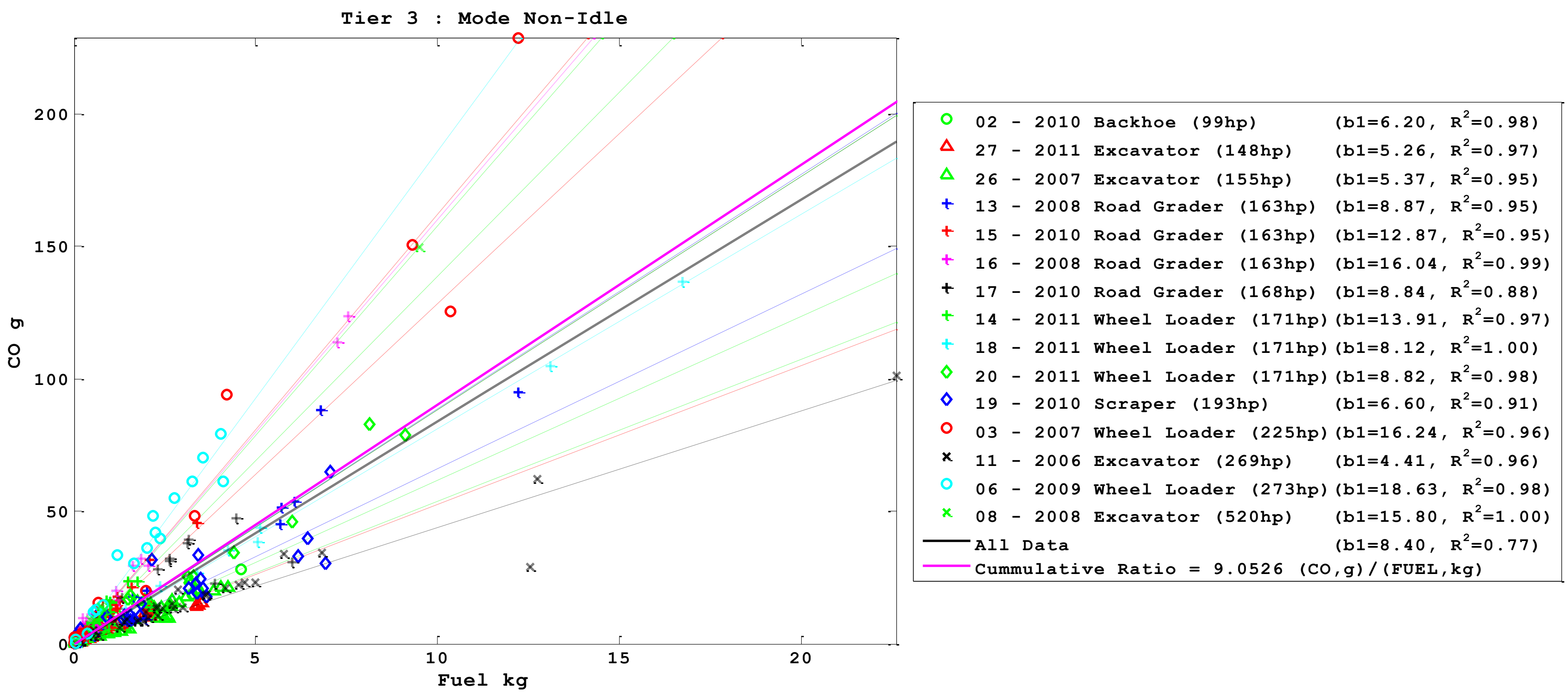


Figure A-21: Tier 3 CO Non-Idle Emissions

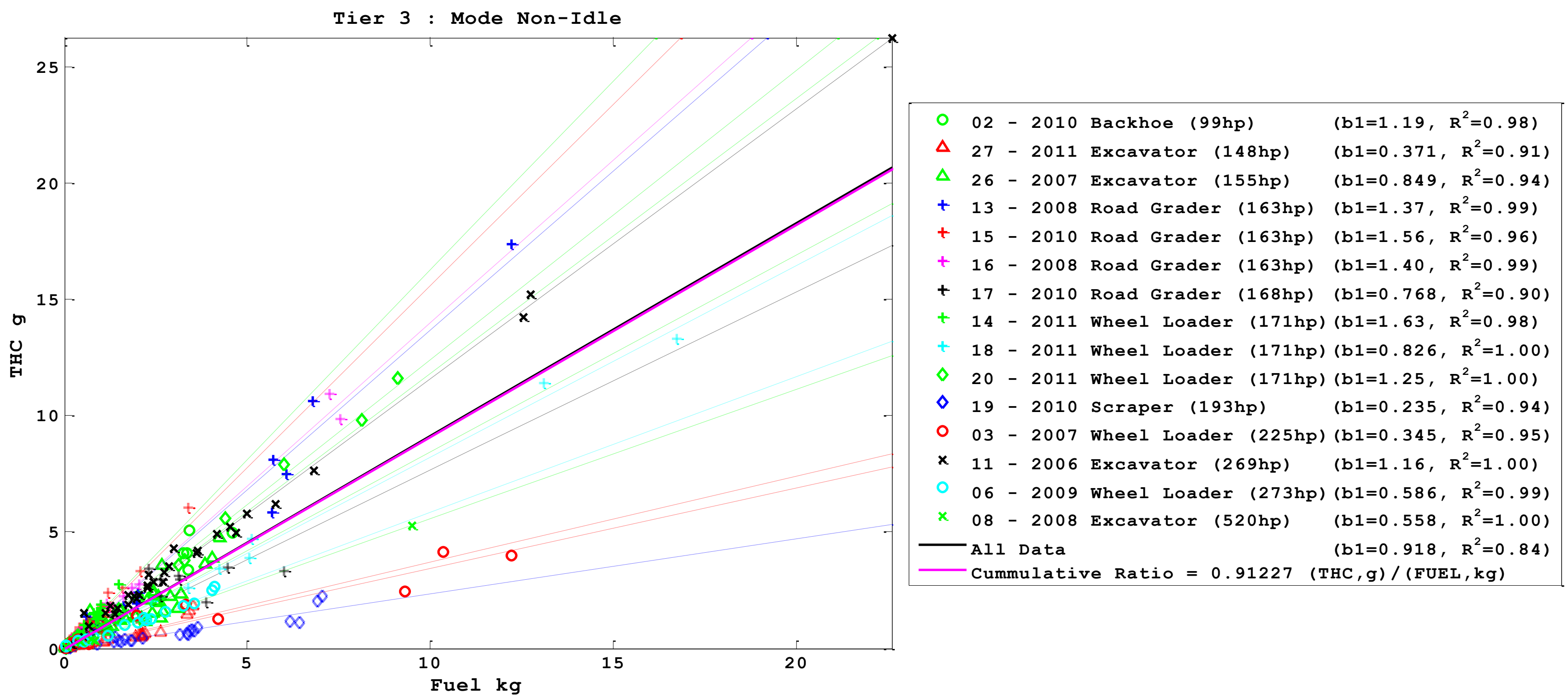


Figure A-22: Tier 3 THC Non-Idle Emissions

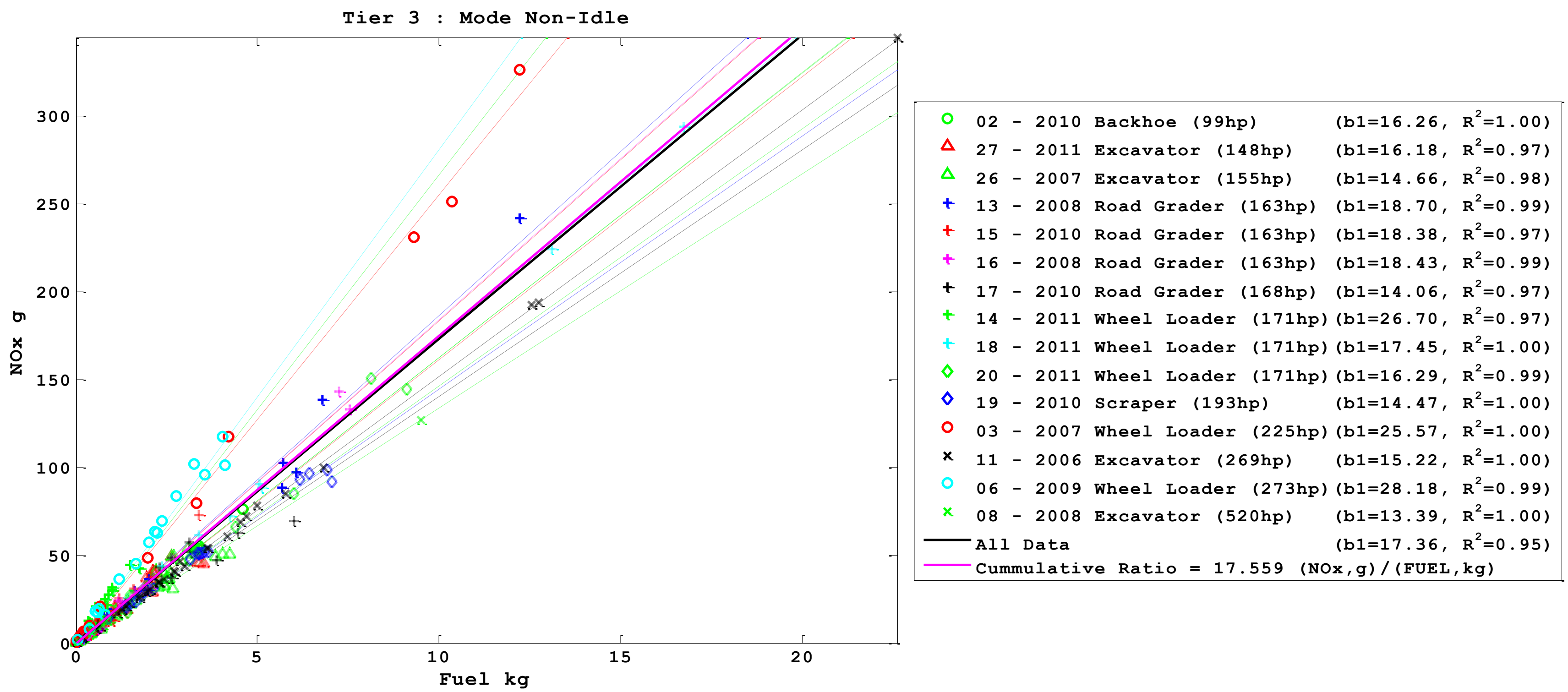


Figure A-23: Tier 3 NO_x Non-Idle Emissions

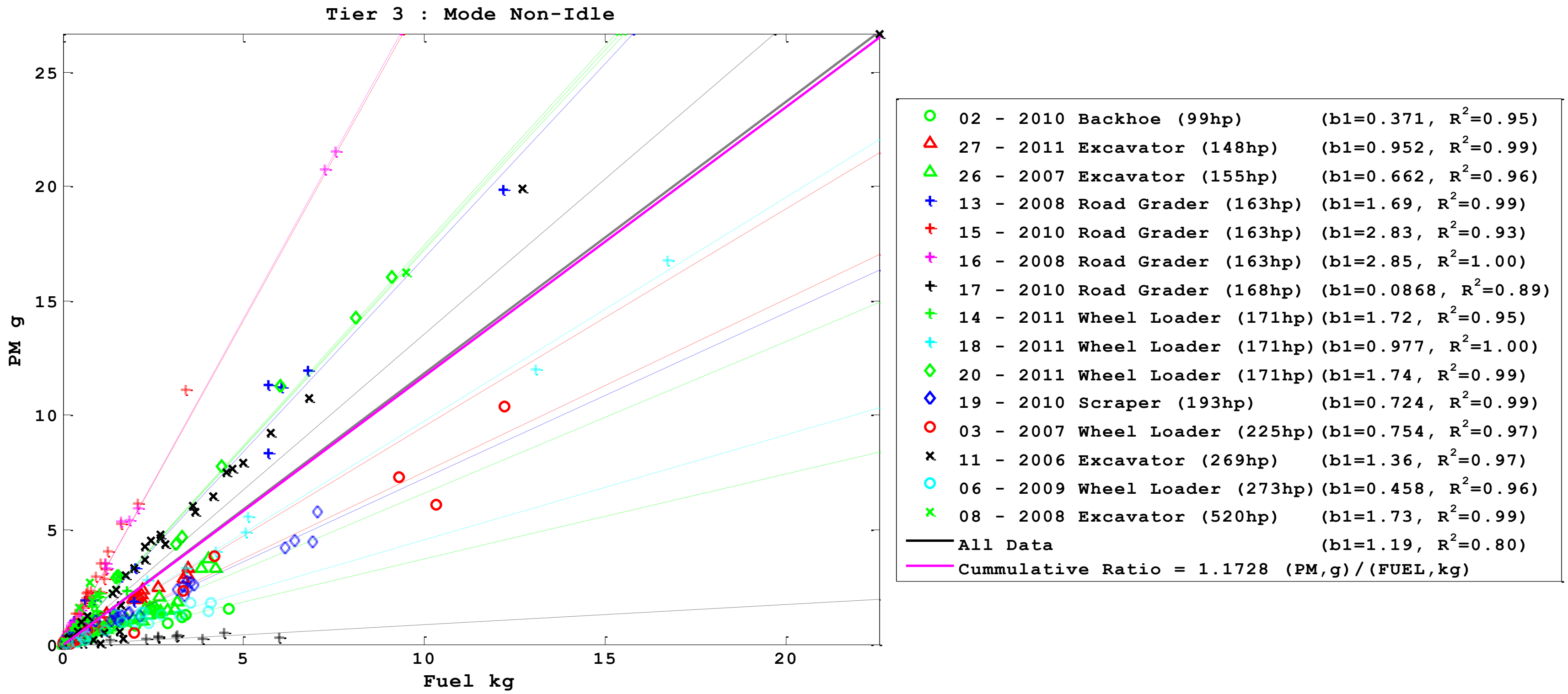


Figure A-24: Tier 3 PM Non-Idle Emissions

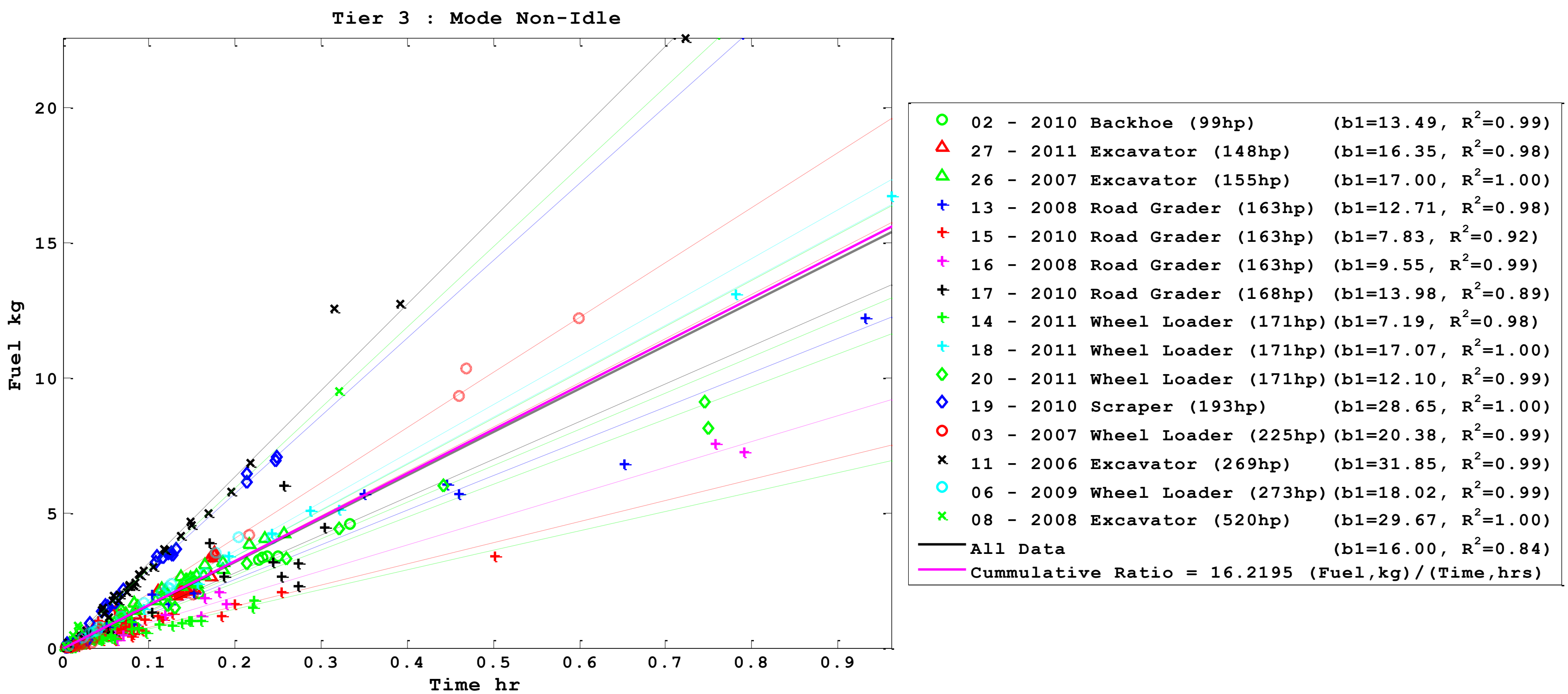


Figure A-25: Tier 3 Fuel Use

A.2.3 Tier 4i

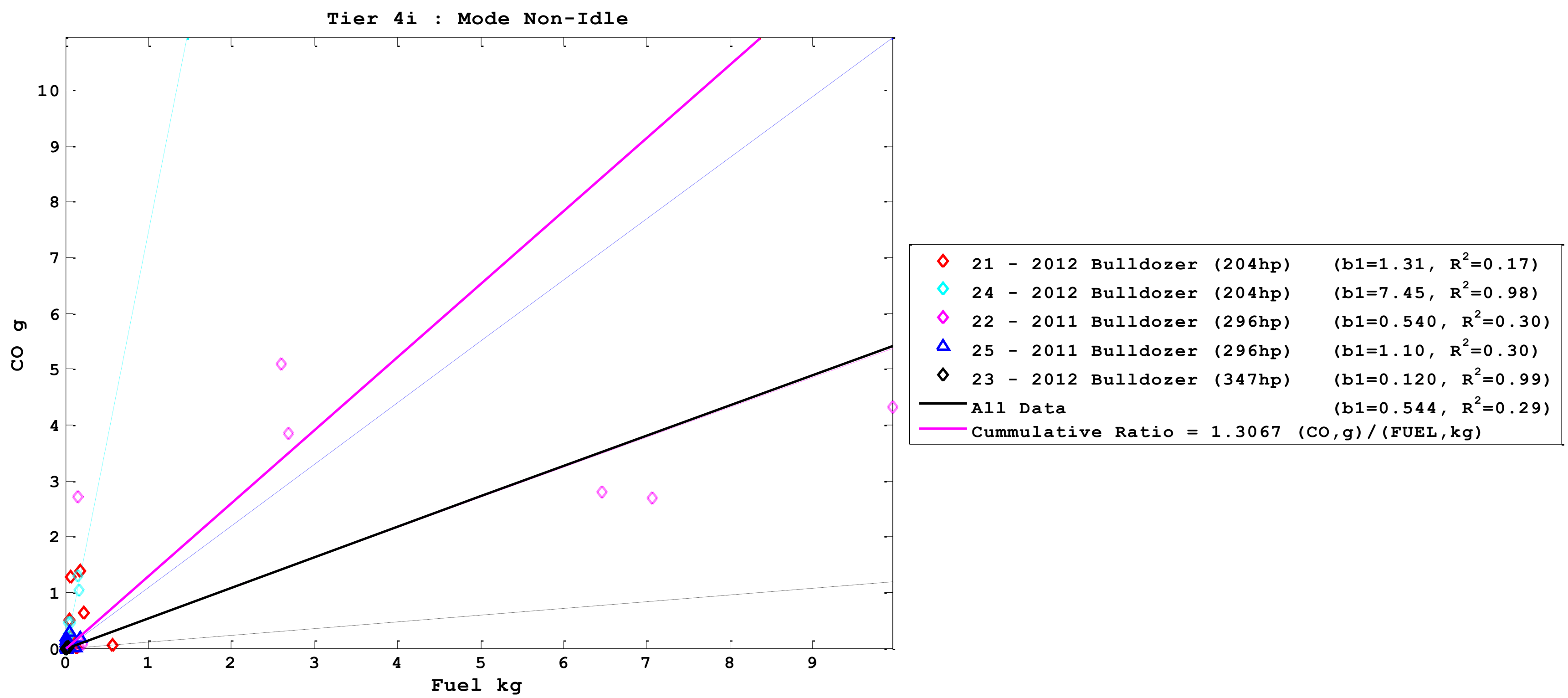


Figure A-26: Tier 4i CO Non-Idle Emissions

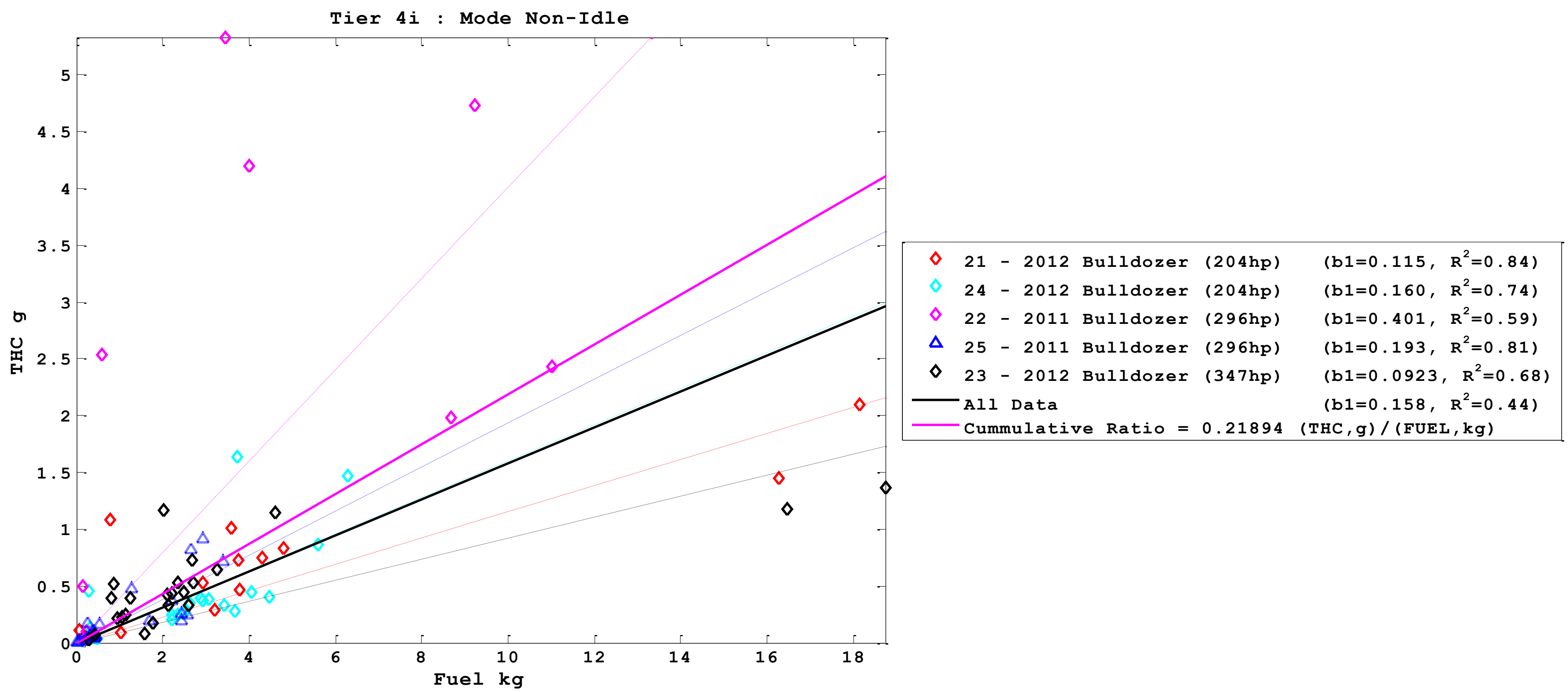


Figure A-27: Tier 4i THC Non-Idle Emissions

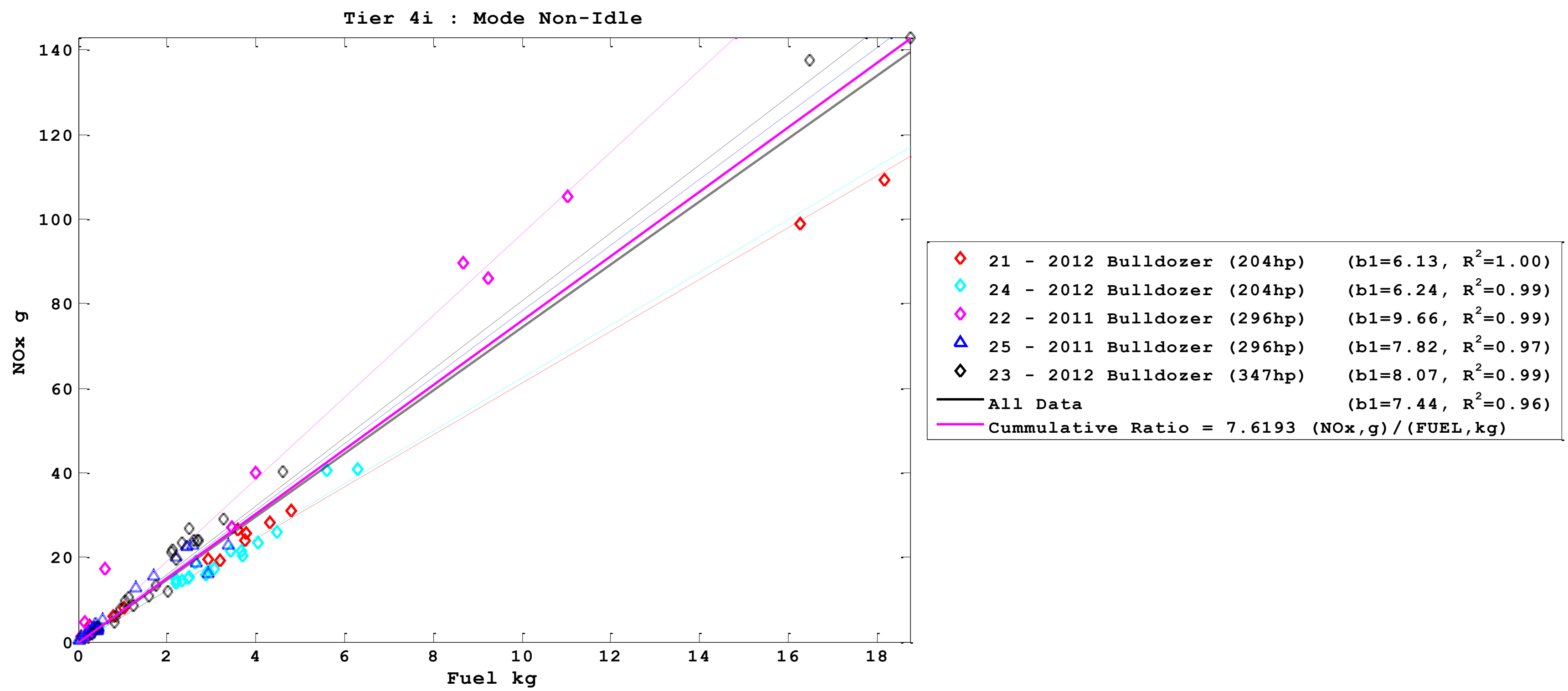


Figure A-28: Tier 4i NO_x Non-Idle Emissions

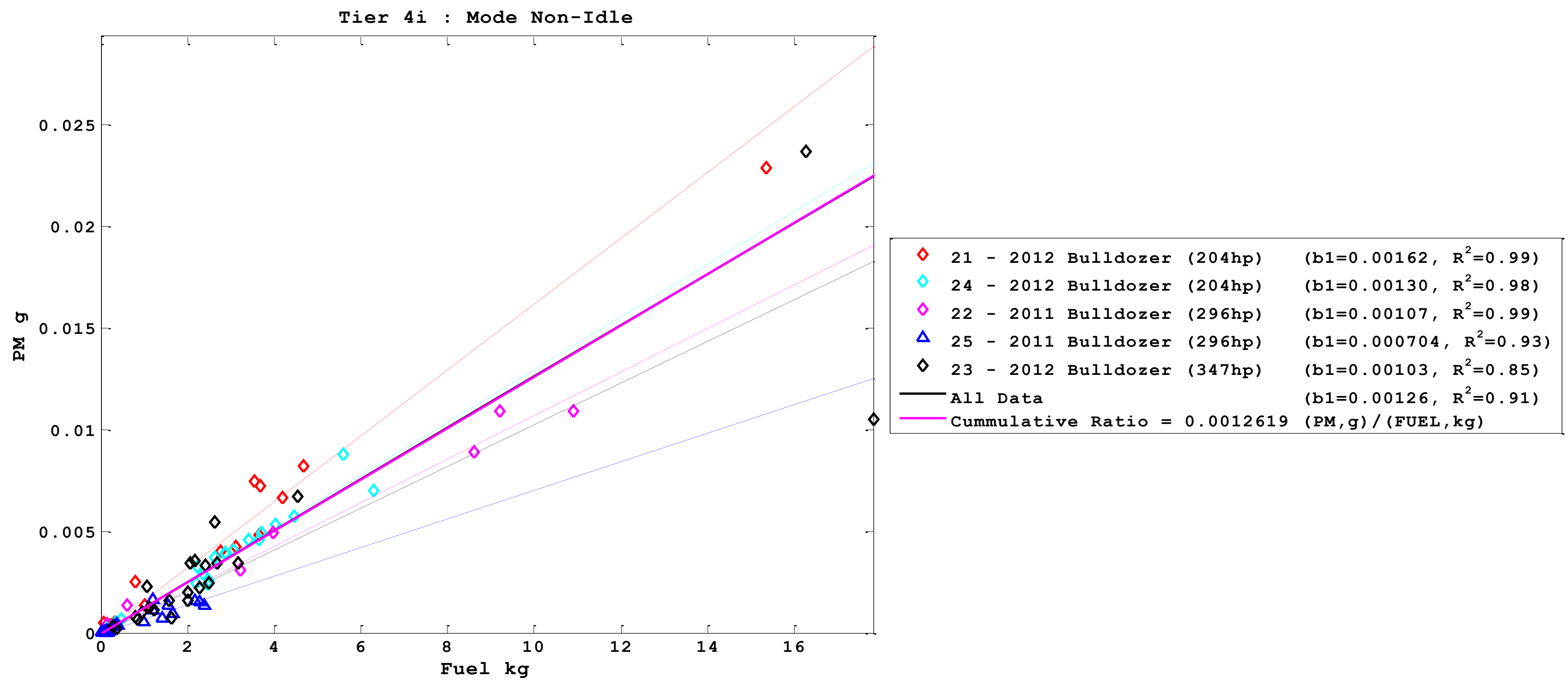


Figure A-29: Tier 4i PM Non-Idle Emissions

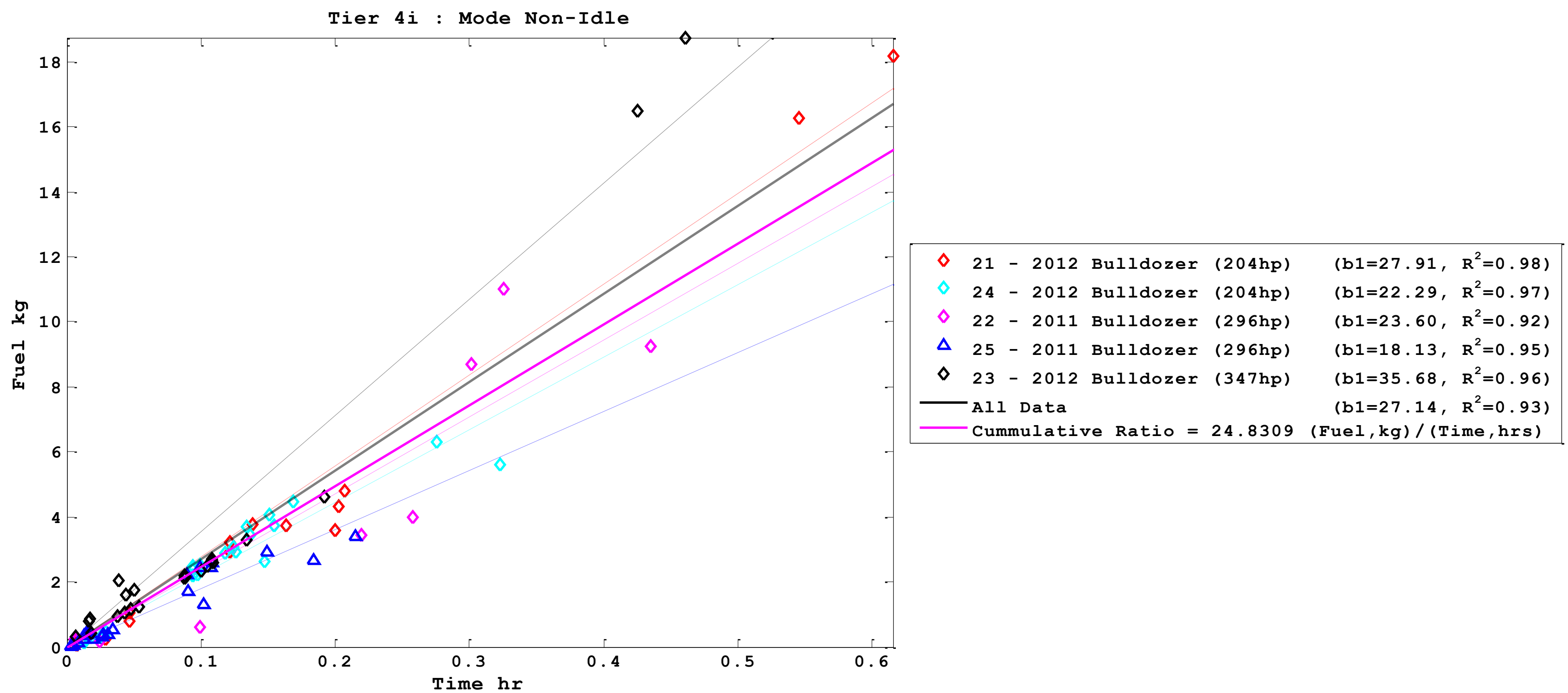


Figure A-30: Tier 4i Fuel Use

B Experimental Procedures

B.1 PEMS Emissions measurement systems

Over the course of the previous test programs, 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[3]. 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 B-1 shows the Semtech DS unit.

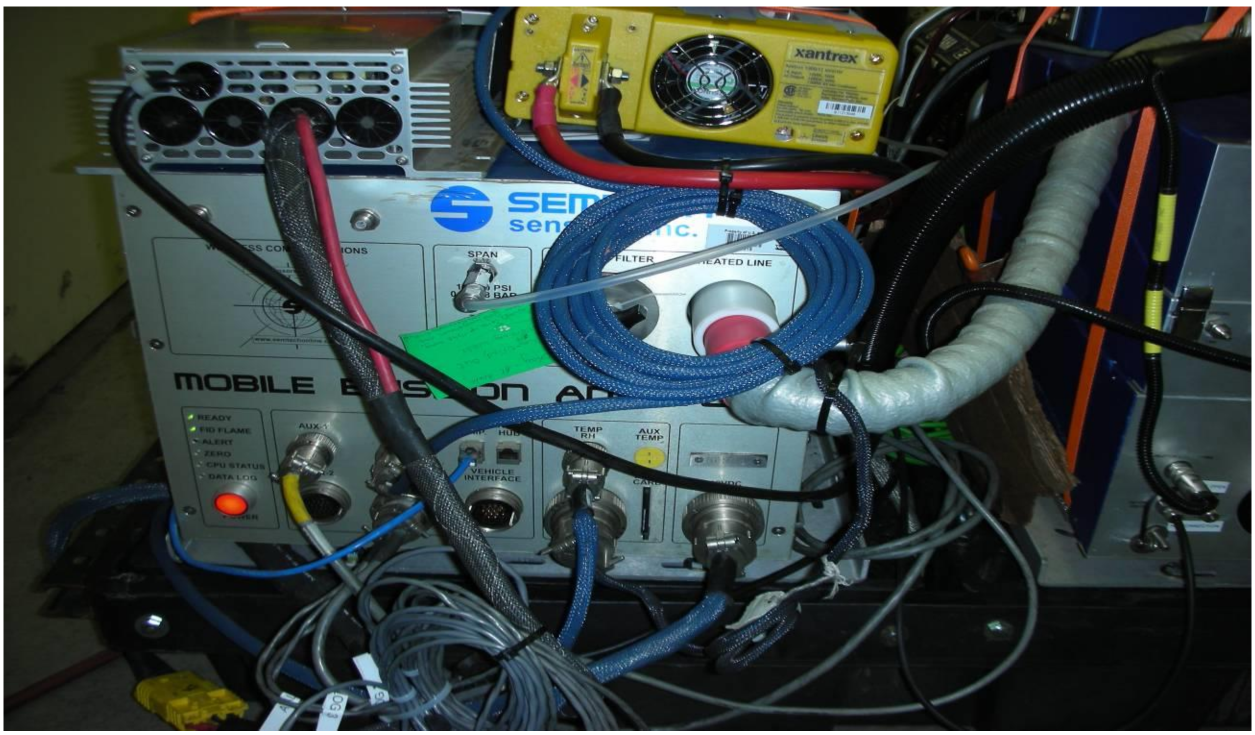


Figure B-1: Picture of Semtech DS PEMS

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

[3] Semtech DS analyzer http://www.sensors-inc.com/

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 B-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 B-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 B-3 is a picture of the MSS and gravimetric filter unit.

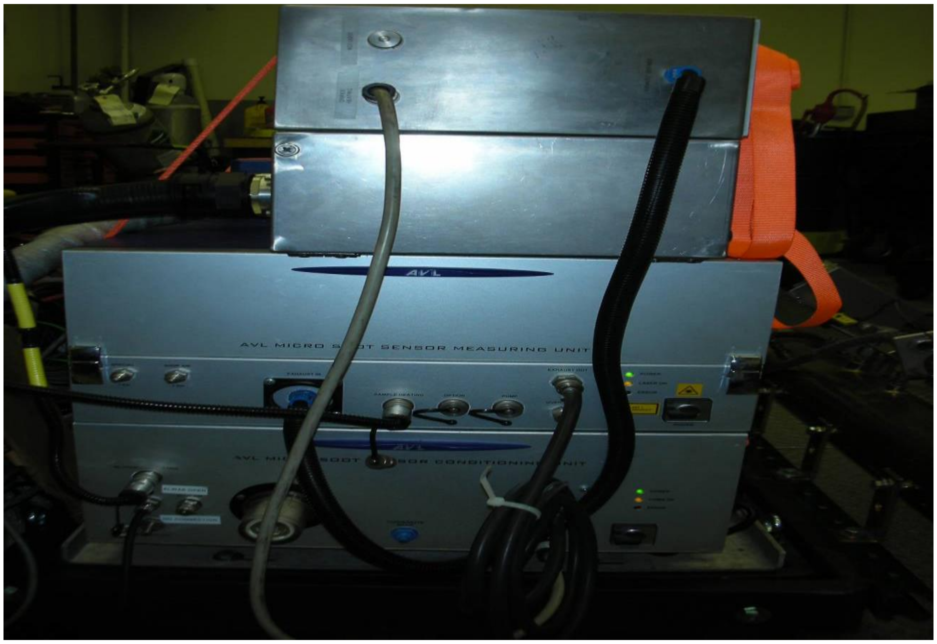


Figure B-3: Picture of AVL Micro Soot Sensor with Gravimetric Filter Box on Top

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 B-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.

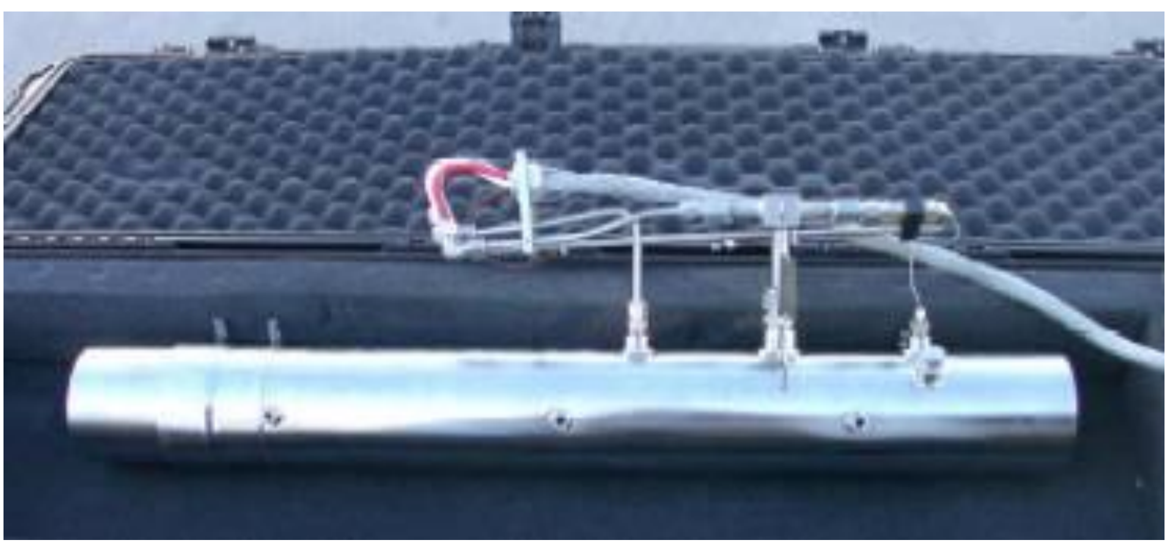


Figure B-4: Picture of Semtech DS Exhaust Flow Meter

B.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 B-5 is a picture of the generator.

Figure B-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 B-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 B-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 Yamaha generator. Figure B-7 is of the new platform. This same equipment and mounting was used for the 5 tests added during the current program.

Figure B-7: Platform with emission measurement equipment used for the last seventeen tests

Pictures of some of the tested equipment, with the emission measurement analyzers in place, are presented in Figure B-8 through Figure B-13.

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

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

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

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

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

Figure B-13: Caterpillar D6T Bulldozer at Johnson Machinery Test Site

B.3 Preliminary Validation Testing

The use of a PEMS system complaint with the specification in 40 CFR Part 1065 is an important element of a program to measure emissions from in-use vehicles or equipment. 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 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 B-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 B-1: List of instruments evaluated as part of the 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 the projects. 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 the projects. See upgrades section for description of version changes. The table reflects the latest version as of conclusion of test No. 27.

Table B-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 B-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 B-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).

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 UCR's engine dynamometer (satisfying the 1065.920 test) with a 10.8L 2006 Cummins ISM engine equipped with exhaust gas recirculation (EGR). The bsNO_x certification of this 2.68 g/kWh (2.0 g/hp-h) and represents the same bsNO_x level used during validation of PEMS. The other two correlations were conducted on road with the MEL, utilizing UCR's house 2001 Freightliner heavy duty truck and a 2010 compliant SCR equipped low NO_x duty on-road truck.

Table B-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.

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 the Measurement Allowance program. This includes, a trip from Riverside, CA to San Diego, CA and back, a trip from Riverside, CA to the Coachella Valley, CA and back and a trip in the local Riverside, CA area. 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.

Table B-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	$T_{dew,meas} < T_{dew,spec} + 2.0\ ^\circ C$	**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

Table B-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).

B.4 PAMS Activity Measurement System

Activity for off-road equipment includes both physical work (P-work) and engine work (E-work). The physical work represents what is being pushed, lifted, or dug; and how it is done. The E-work is the engine response to the load imposed by the P-work. The E-work is captured with real time ECM and GPS data loggers.

For the CARB AQIP program the E-work was obtained using a beta version of the UniCAN Pro and GPS data logging system and the physical work was captured with video cameras (See Figure B-14). The AQIP program required developing specific test cycles to obtain a more representative comparison of conventional and hybrid equipment, which is why video cameras were used to monitor typical operations. The UniCAN PRO is a self-contained J1939 ECM interface and data logging tool. It is rated for high temperatures and includes an integrated GPS. It was configured to start logging with key-on and stop logging with key-off. The UniCAN tool did not communicate with the CAT or Komatsu equipment out of the box, but with UCR development, the UniCAN was upgraded to send specific J1939 request messaging with 100 percent reliability. This tool as well as HEM data loggers were used to obtain E work for the Caltrans program.

Table B-4 shows the GPS and ECM real-time channels recorded. All of the channels in the list were requested, but only the black highlighted names were obtained. Percent torque (friction, actual, and reference) is not available on most units, thus percent load was recorded instead.

Figure B-14: Activity measurement tools ECM, GPS, and time lapse video on the D7E

Table B-4: Real time data logging GPS and ECM data recorded

ECM Datalogging Configuration			
DATE	Altitude [m]	AccelPosition [%]	ThrottlePosition [%]
TIME	Latitude [deg]	EngineLoad [%]	BarometricPressure [kPa]
GPS_Second	Longitude [deg]	PercentDriverDemandTorque [%]	BoostPressure [kPa]
GPS_Minute	Valid_Fix	PercentActualTorque [%]	IntakeManifoldTemperature [°C]
GPS_Hour	Satellites	EngineSpeed [RPM]	EngineAirInletPressure [kPa]
GPS_Year	DOC_Tpost_C [C]	PercentFrictionTorque [%]	
GPS_Month	DPF_Tpost_C [C]	EngineCoolantTemperature [°C]	
GPS_Day	DOC_Tpre_C [C]	FuelTemperature [°C]	
Heading [deg]	DPF_delP [kPa]	OilTemperature [°C]	
Speed_kmh [km/h]	DPF_status	FuelRate [L/h]	

B.5 Emissions Data Analysis

B.5.1 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 is an important element of the data analysis. The first step in the data analysis is to determine a reliable method to time align the data. Time alignment is 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 B-15 through Figure B-17 show the time alignment for the testing of the John Deere 410J backhoe loader. CO versus raw PM is plotted in Figure B-18 on a smaller time scale to more clearly show the time alignment obtained using this methodology.

B-5-2 Correcting PM data

The emissions for THC, CO, NO, and CO_2, in grams 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.

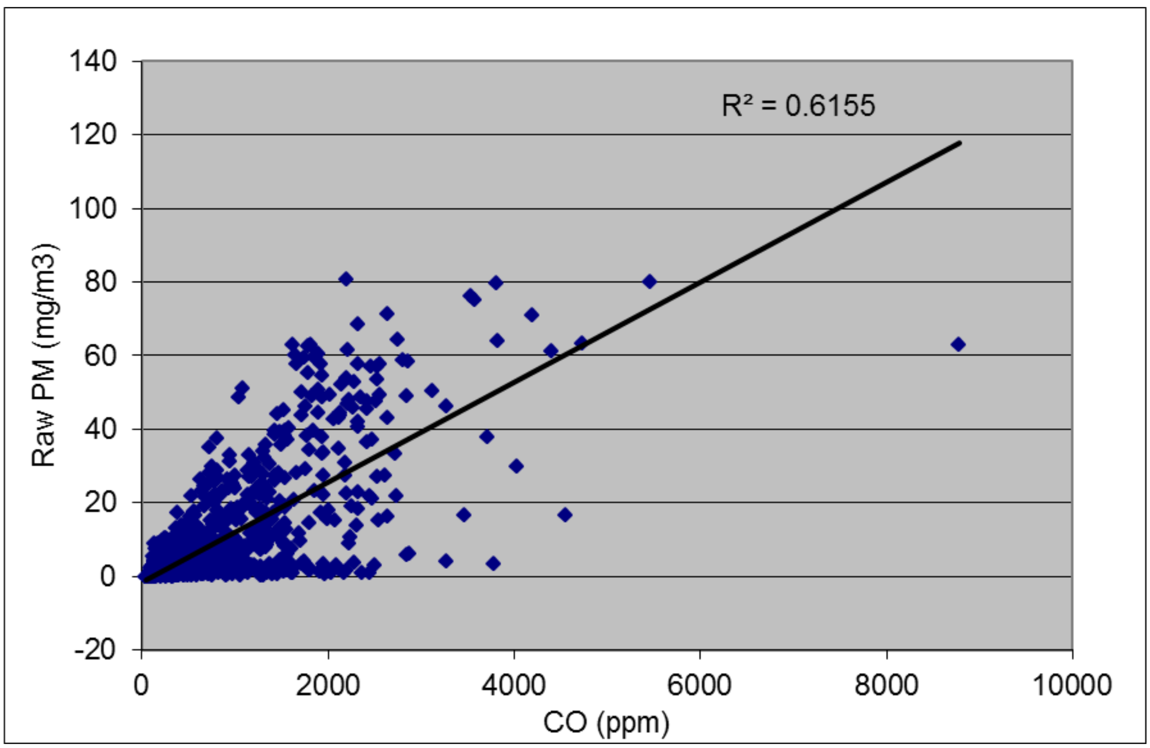


Figure B-15: Plot of time aligned raw PM versus CO for John Deere 410J

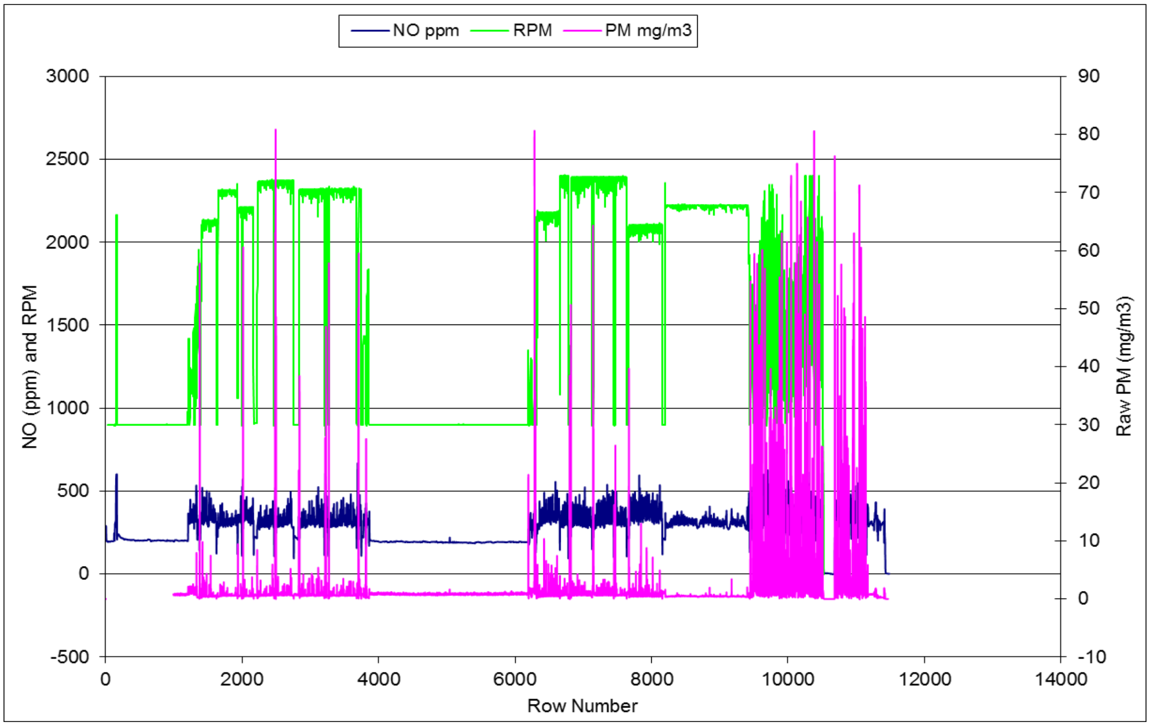


Figure B-16: Plot of NO, RPM, and PM versus Row Number for John Deere 410J

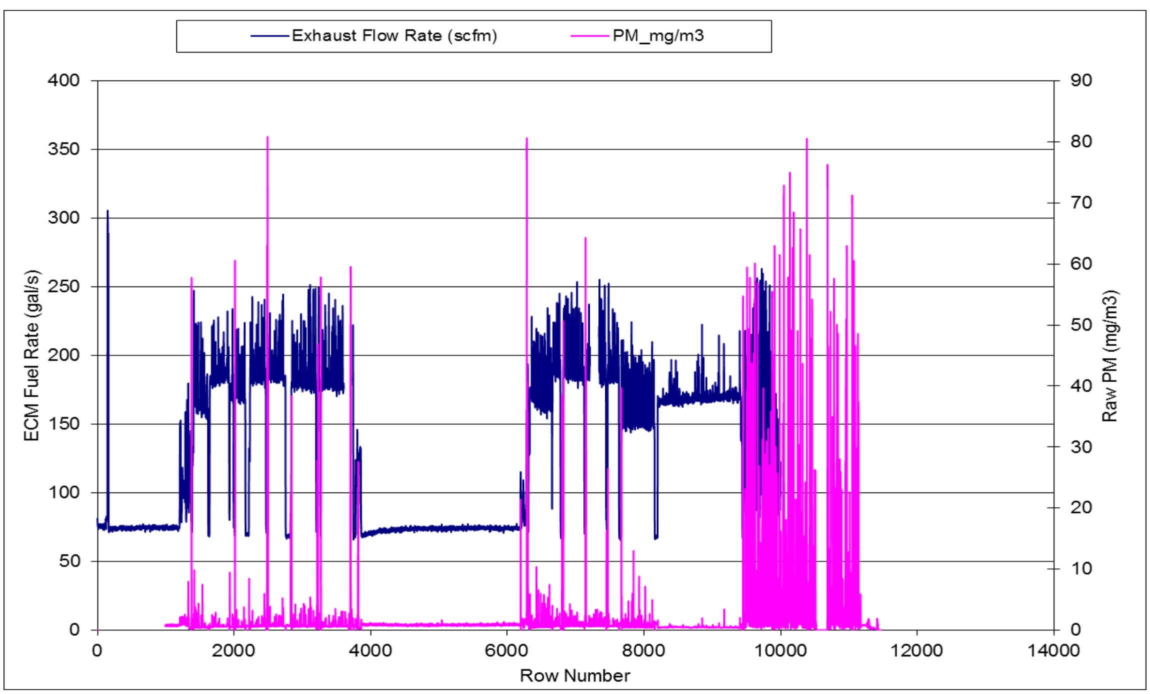


Figure B-17: Modal exhaust flow rate and raw PM concentration for John Deere 410J

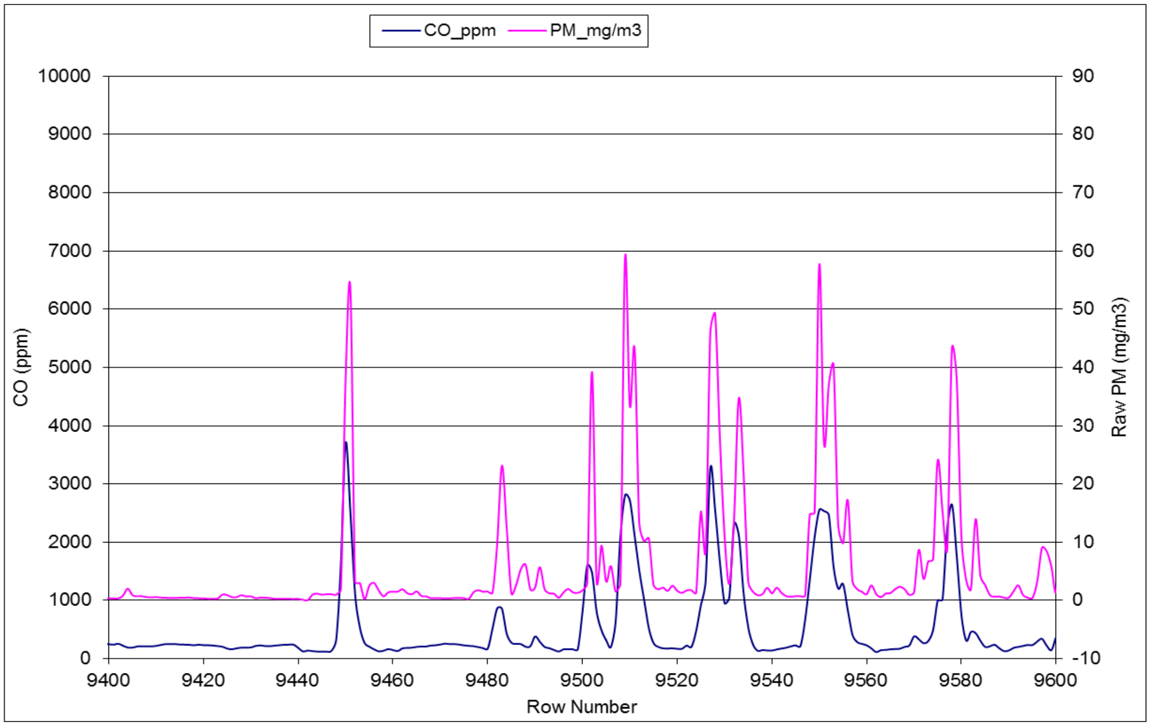


Figure B-18: Plot of CO and Raw PM versus Row Number for John Deere 410J

B.5.2 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 B-19 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.

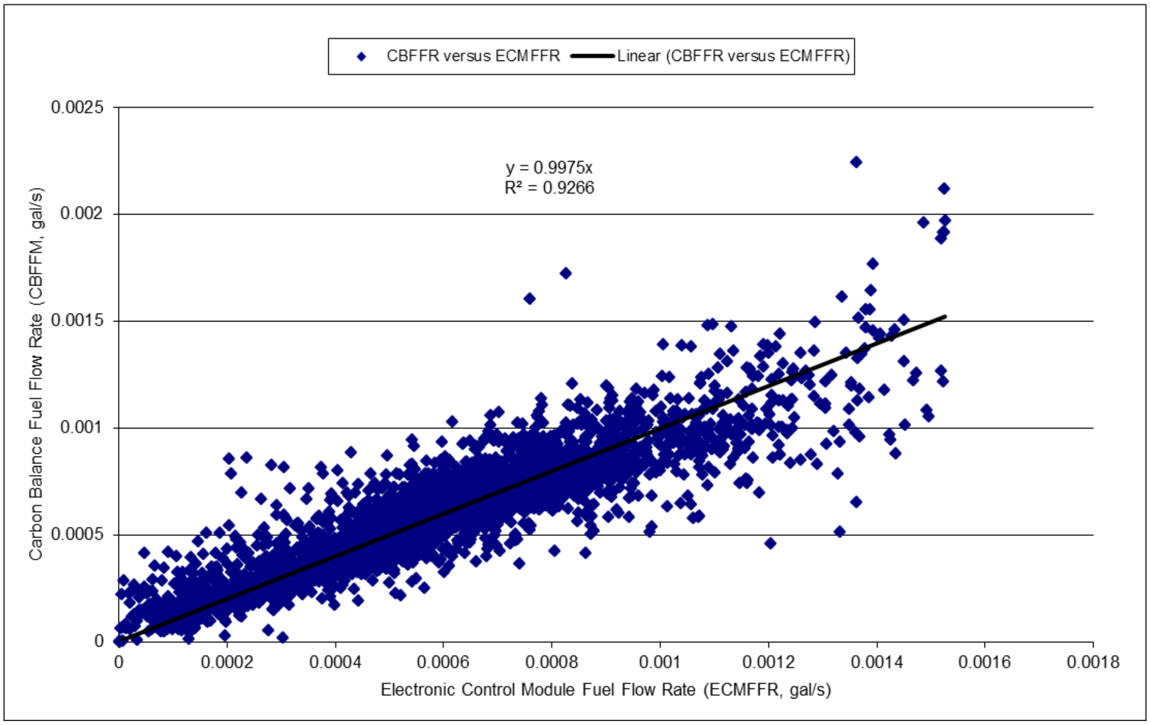


Figure B-19: Correlation of carbon balance and ECM fuel rate for the John Deere 410J

B.5.3 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 the CARB I-Use Emissions from Diesel Off-Road Equipment report (Durbin, 2013) 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.

B.5.3.1 Estimating lug curve from published lug curve

When a lug curve is available, the following method is 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 B-20 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 B-21 shows the lookup table that was developed for this engine following the above procedure. The blue points in Figure B-21 represent points that were extrapolated. The highest two points in Figure B-21 were estimated via extrapolation from the official curve in Figure B-20.

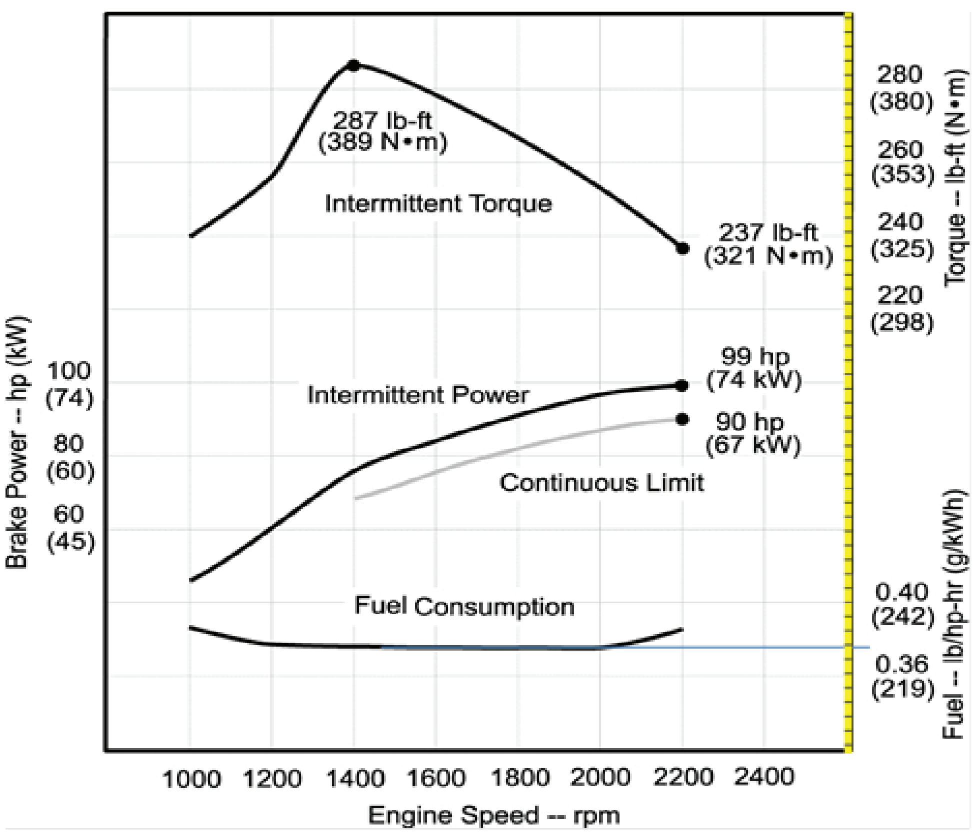
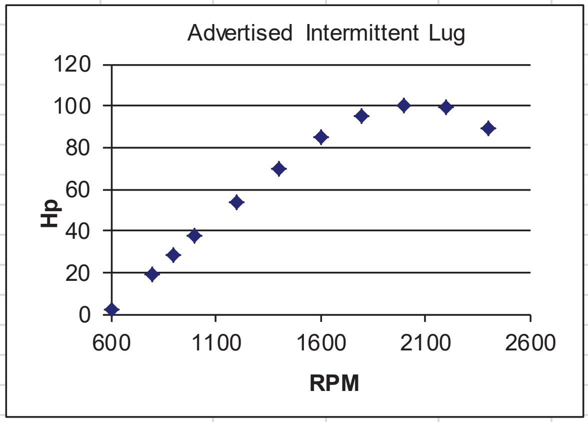


Figure B-20: Lug curve for the John Deere 410J engine

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 B-21: Lookup table for determining power of a John Deere 410J engine

For each RPM value, the Vlookup function is used to determine the maximum Hp from the table in Figure B-21. This value is 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 C Table C-1 through Table C-28. The manufacturers maximum power rated bsFC is 228 g/kWhr from 1200 to 2000 RPM, see Figure B-20. 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 B-22. 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 C Table C-14 through Table C-20. The idle emissions were mostly high > 800 g/kWhr. As such, the reasonable $bsCO_2$ results suggest the selected lug curves are reasonable.

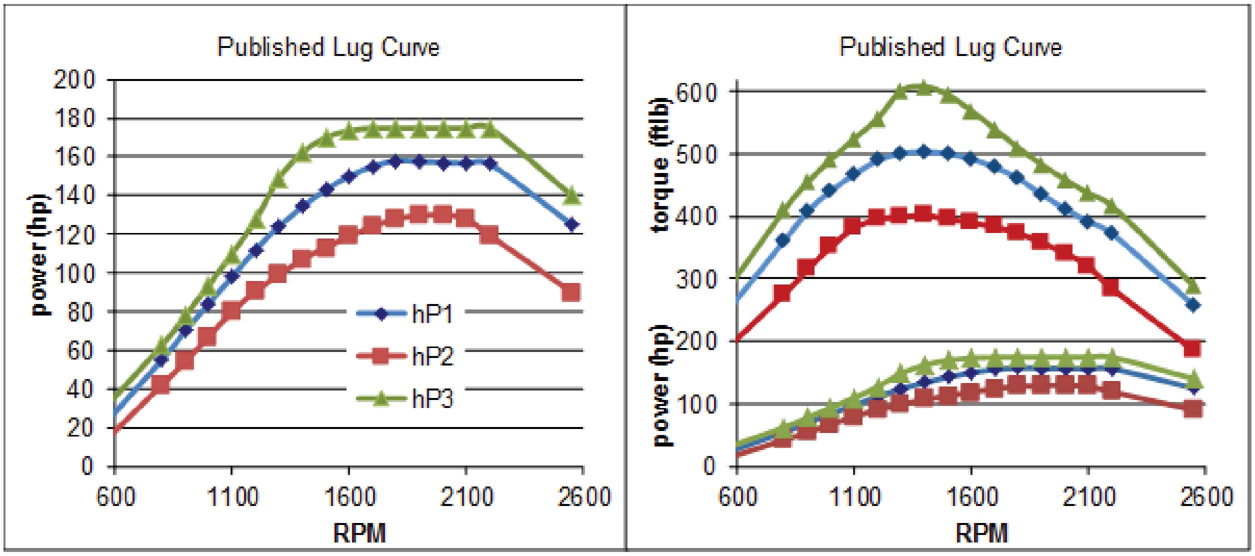


Figure B-22: Caterpillar ACERT 6.6 liter engine published lug curve.

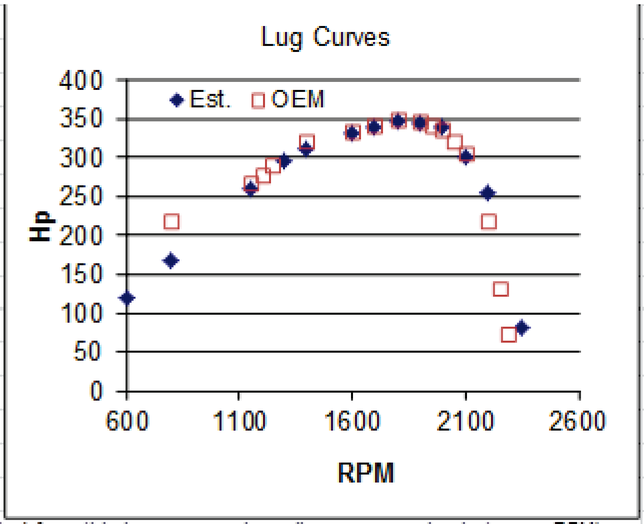
B.5.3.2 Estimating lug curve from rated power and peak torque

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 B-23 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 B-23: Lug curve used for the Caterpillar D8R bulldozer 3406E engine (unit #12)

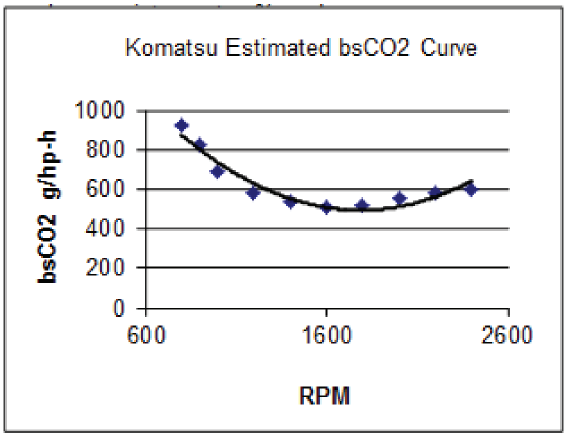
B.5.3.3 Estimating lug curve from brake specific fuel consumption

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 B-24, 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 B-24: 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 C Table C-7. 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 B-24 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).

B.5.4 Work

For construction equipment, two different types of work are 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 can then be calculated.

B.6 Data collection and reduction

The integrated analysis 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 B-5 lists the total valid data utilized for the development of the model. 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 B-5. The model was developed based upon the analysis of the second by second data over the valid data regions in

Table B-5.

Table B-5: Total valid integrated data over which the second by second data was used to develop the model

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

B.6.1 Emissions Measurements

The PEMS equipment utilized in this research was compliant with federal test methods for I n-use testing (40 CFR 1065) for the gaseous and PM systems. The gaseous PEMS is UCR's AVL gaseous PEMS called M.O.V.E... The PM PEMS was UCR's AVL 494 system. An exhaust flow meter designed and manufactured by Sensors, Inc. was used with the M.O.V.E. system.

B.6.1.1 Gaseous PEMS

The specific AVL M.O.V.E. measurement principles are listed below for each pollutant:

- Oxides of nitrogen (NO and NO_2) – non-dispersive ultraviolet radiation (NDUV). The NO_x value is calculated from NO and NO_2 and reported on a NO_2-equivalent basis.
- Carbon Monoxide (CO) – non-dispersive infrared radiation (NDIR)
- Carbon Dioxide (CO_2) – NDIR
- Total Hydrocarbons (THC) – flame ionization detection (FID)
- Non-methane Hydrocarbons (NMHC) – not available, but is a calculated value and reported using NMHC = 0.98*THC

The THC is measured wet and all the others are measured dry and are corrected for moisture content through post processing for the AVL M.O.V.E... The gaseous data is measured as a concentration and is time aligned and flow weighted to the exhaust flow for total mass reporting. All time alignment and flow weighting is performed as part of the post processor system for the PEMS.

The THC instrument requires a source of FID fuel that is a blend of hydrogen and helium. UCR used an external FID fuel bottle that is sufficiently sized for several weeks of testing to prevent possible THC data loss during operation.

B.6.1.2 PM PEMS

The PM PEMS measurement system selected was AVL's 483 micro soot sensor (MSS) in conjunction with their gravimetric filter module (GFM) option. The combined system is called the AVL 494 PM system, and was released in mid-2010. The instrument measures the modulated laser light absorbed by particles from an acoustical microphone. The measurement principle (called photo-acoustic) is directly related to elemental carbon (EC) mass (also called soot), and has been found to be robust and to have good agreement with the reference gravimetric method for EC dominated PM.

The MSS 483 measurement principal does not detect total PM mass, since soluble organic fractions, ash, inorganic, sulfates and nitrates are not detected. As such AVL introduced the GFM and a post processor that utilizes the filter and a soluble organic fraction (SOF) and Sulfate model to estimate total PM from the soot and gravimetric filter measurements. At a minimum, one gravimetric filter is sampled per day and continuous PM concentration is recorded at 1 Hz. The combined MSS+GFM system recently received approval by EPA as a total PM measurement solution for in-use compliance testing, thus making it one of the few 1065 compliant PM PEMS systems.

B.6.1.3 Flow meter

The exhaust flow meter (EFM) used was Sensors Inc's High Speed EFM (HS-EFM) The EFM works with the wide range of exhaust flows and dynamics of transient vehicle testing. The exhaust flow uses differential pressure as its measurement principle. An appropriate exhaust flow meter was selected to match the displacement of the engine being tested.

B.6.1.4 Data Collected

Pollutant emissions real time and integrated data

- NO_x (measured as NO and NO_2 and summed for NO_x)
- PM (MSS 494 based PM)
- THC
- CO
- CO_2

Engine parameter real time and integrated data

- Engine speed (revolutions per minute, rpm)
- Engine intake air temperature (only with ECM if broadcast)
- Engine intake manifold air pressure (only with ECM if broadcast)
- Engine exhaust temperature
- Engine exhaust mass flow rate
- Engine fuel consumption (only with ECM if broadcast)
- Engine % load (only with ECM)

Other real time and integrated data

- Ambient temperature
- Relative humidity
- Barometric pressure
- Date/time stamp
- GPS position, speed, elevation, and others

B.7 Engine/Equipment Inspection

Proper equipment operation is a critical element to ensure good results for the emissions testing. Some of the equipment tested was new, with only a few hours of accumulation, and others were older, with up to a thousand or more hours accumulated. Prior experience has shown that in-service equipment that is not operating correctly will not provide good emissions benefit comparisons. Thus, it was critical to make sure the equipment was operating properly. This was accomplished through a series of inspections.

The engines and equipment were inspected visually just prior to emissions testing to collect data about conditions that might affect engine emissions. Engines were checked for visible exhaust leaks, and other problems that could affect or jeopardize results, such as excessive fuel or oil leaks.

B.8 Quality Control

Quality control is necessary for any measurement campaign and is especially important for field PEMS emissions testing. The quality control checks are broken down into evaluations of gaseous, PM, exhaust flow and other measurements. For each category a series of Standard Operating Procedures (SOP) were developed for proper and consistent operation based on the best recommended practices in the PEMS industry. These SOP's cover checks and verifications for the equipment which include pre-test, setup and installation, equipment start up, in-use, and post-test.

B.8.1 AVL M.O.V.E

The gaseous PEMS software comes with built in QC procedures for all their gaseous measurements (CO, CO2, NO_2, NO, and THC). These include daily pre- and post-test zero, span and audit gaseous emissions checks. All zero check calibrations are performed on zero gas to help improve the quality of the data.

Gaseous analyzer linearity is required by 1065 on a monthly basis. UCR has an in-house 1065 audited gas divider that is used to perform this procedure. In addition, leak checks are performed for each setup change or other change to the plumbing system. Sample filters are replaced as needed and different system pressures are monitored prior to testing to prevent invalidating a test due to a failed component. The gaseous PEMS system has a system ready indicator that lets the user know that the system is ready for operation, and this is verified prior to its use.

B.8.2 AVL PM PEMS 494 (MSS+GFM)

The PM system requires verification of its micro soot signal and gravimetric filter system. The micro soot sensor detection system has a calibration procedure that is used to maintain consistency between testing campaigns. The PM calibration procedure is performed prior to each testing campaign. In addition, routine linearity checks are performed along with each calibration, as recommended by the manufacturer. The daily checks include leak checks, pollution window level checks, and zero checks. Daily leak checks are performed due to potential issues with leaks around the GFM system.

The UCR filter weighing chamber meets 1065 requirements and was maintained throughout the course of this testing effort. The requirements include calibration of balance temperature, pressure, and relative humidity. The UCR micro balance is certified annually by an outside source and was valid during the course of this testing operation.

B.8.3 Sensors, Inc. EFM

The manufacturer recommends that the exhaust flow meter be recertified twice a year. Experience has shown that the EFM accuracy is similar to UCR's mobile emissions laboratory (MEL) CVS by difference method. It is expected that the accuracy of the EFM does not tend to drift over time. Thus, an in-house verification was performed against UCR's MEL both prior to testing and after all testing had been completed. The UCR MEL is routinely verified using propane verifications. The flow check provided a good metric that the EFM did not drift or deviate from its starting calibration over the course of the emissions measurement task.

B.8.4 Other Information

Other measurements that were verified included ambient temperature, RH, and barometric pressure. These measurement systems were verified against local airport records for accuracy. No additional calibrations or verifications were performed, except their annual calibration.

B.9 Data Processing

B.9.1 AVL M.O.V.E.

All gaseous, exhaust flow, ECM, and ambient data were analyzed and post processed using the manufacturer's supplied post processors. The calculation methods used were suitable for in-use off-road regulations. This included NO_x humidity correction factors that follow CFR40 Part 1065.670. For other calculations, such as time alignment, the manufacturer's recommendation and in-house experience were used. At any point data can be re-analyzed and time alignment issues corrected since the raw data is un-affected.

B.9.2 AVL PM 494 PEMS

The AVL MSS+GFM system is a relatively new system and the post processor is still evolving. As such, all data were processed with the latest version of the post processor called "Concerto". The total PM measurement system can be configured to utilize THC, exhaust temperature, fuel sulfur levels, and other parameters for total PM mass modeling. PM, as reported by the MSS system, gravimetric filter mass, and the total PM mass (MSS + modeled), is provided when possible. The gravimetric filters were weighed using UCR's standard practices for gravimetric filters and balance conditions following 40 CFR 1065.

C Summary of Tests 1 through 27 used for Model Development

Table C-1: Equipment Tested in Previous Programs

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	Dis-place-ment (L)
1	12/03/10	1_410J	RDO	Backhoe	Deere	410J	2007	2	7JDXL04.5062	4045TT095	99	2200	1182	Published	yes	4.5
2	12/07/10	2_310SJ	RDO	Backhoe	Deere	310SJ	2010	3	AJDXLO6.8106	4045HT054	99	2250	242	Published	yes	6.8
3	12/08/10	3_644J	RDO	Wheel loader	Deere	644J	2007	3	7JDXL06.8101	6068HDW69	225	2200	1735	Published	yes	6.8
4	12/09/10	4_310SG	RDO	Backhoe	Deere	310SG	2006	2	6JDXL04.5062	4045TT089	92	2300	2599	Published	yes	4.5
5	12/10/10	5_410G	RDO	Backhoe	Deere	410G	2006	2	6JDXL04.5062	4045TT093	99	2200	946	Published	yes	4.5
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	11.04
7	02/10/11	7_928G	Riverside County	Wheel loader	Caterpillar	928G	2004	2	n/a	3056E	156	2300	2294	Published	yes	6.6
8	3/17/2011	8_345D	Sukut	Excavator	Caterpillar	345D	2008	3	n/a	C13	520	2100	tbd	none	no	12.5
9	4/20/2011	9_637E	Riverside County	Scraper	Caterpillar	637E	2006 (Rebuild)	2	n/a	C9 637D	280	2200	>10000	Published	yes	8.8
10	04/21/11	10_637E	Riverside County	Scraper	Caterpillar	637E	2006 (Rebuild)	2	n/a	C15 IND (LHX14568)	540	2100	>10000	Published	yes	15.2
11	05/04/12	11_EC360B	Waste Management	Excavator	Volvo	EC360B	2006	3	6VSXL12 .1CE3	D12DEBE3	269	1700	5233	Published	yes	12.1
12	05/14/12	12_D8R	Waste Management	Bulldozer	Caterpillar	D8R	2003	2	3CPXL14.6ESK	3406E	338	2000	17149	Published	yes	14.8
13	10/16/12	13_120M	Riverside County	Grader	Perkins	120M	2008	3	8PKXL06.6PJ1	C6.6	163	2200	3815	Published	yes	6.6
14	10/17/12	14_928Hz	Riverside County	Wheel loader	Caterpillar	928Hz	2011	3	APKXL06.6PJ2	C6.6	171	2200	289	Published	yes	6.6
15	10/18/12	15_120M	Riverside County	Grader	Caterpillar	120M	2010	3	APKXL06.6PJ1	C6.6	163	2200	1308	Published	yes	6.6
16	10/22/12	16_120M	Riverside County	Grader	Perkins	120M	2008	3	8PKXL06.6PJ1	C6.6	163	2200	2706	Published	yes	6.6
17	10/23/12	17_120M_DPF	Riverside County	Grader	Caterpillar	120M_DPF	2010	3	APKXL06.6PJ1	C6.6	168	2200	952	Published	yes	6.6
18	10/29/12	18_928Hz	Riverside County	Wheel loader	Caterpillar	928Hz	2011	3	APKXL06.6PJ2	C6.6	171	2200	345	Published	yes	6.6
19	10/30/12	19_613G	Riverside County	Scraper	Caterpillar	613G	2010	3	APKXL06.6PJ1	C6.6	193	2200	439	Published	yes	6.6
20	10/31/12	20_928Hz	Riverside County	Wheel loader	Caterpillar	928Hz	2011	3	APKXL06.6PJ2	C6.6	171	2200	242	Published	yes	6.6
21	11/13/12	21_D6T_JM	Johnson Machinery	Bulldozer	Caterpillar	D6T	2012	4i	CCPXL0903HPB	ACERT C9.3	223	2000	24	Estimated	yes	9.3
22	12/04/12	22_D7E_WM	Waste Management	Bulldozer	Caterpillar	D7E	2011	4i	BCPXL09.3HPA	ACERT C9.3	296	2200	296	Estimated	yes	9.3
23	12/06/12	23_D8T-JM	Johnson Machinery	Bulldozer	Caterpillar	D8T	2012	4i	CCPXL15.2HPA	ACERT C15	316	2000	32	Estimated	yes	15
24	12/11/12	24_D6T_OC	Orange County	Bulldozer	Caterpillar	D6T	2012	4i	CCPXL0903HPB	ACERT C9.3	223	2000	44	Estimated	yes	9.3
25	12/12/12	25_D7E_OC	Orange County	Bulldozer	Caterpillar	D7E	2011	4i	BCPXL09.3HPA	ACERT C9.3	296	2200	589	Estimated	yes	9.3
26	03/01/13	26_PC200	Diamond D	Excavator	Komatsu	PC200	2007	3	7KLXL0409AAC	SAA6D107E-1	155	2000	2097	Published	yes	4.5
27	02/28/13	27_HB215	Diamond D	Excavator	Komatsu	HB215	2012	3	BKLXL0275AAG	SAA4D107E-1	148	2000	245	Published	yes	6.7

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 a 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 C-2 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

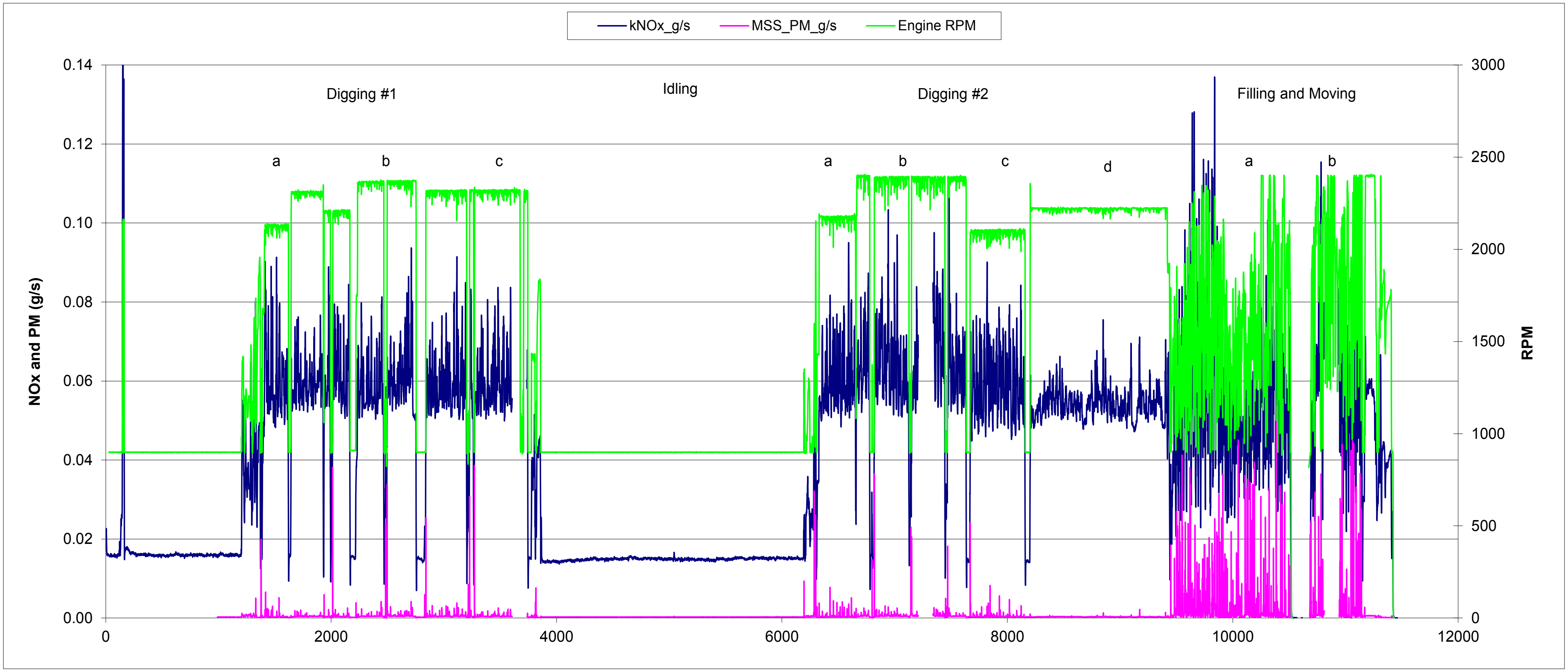


Figure C-1: Modal emissions for 01_410J John Deere 2007 Tier 2 backhoe

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 C-3: 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

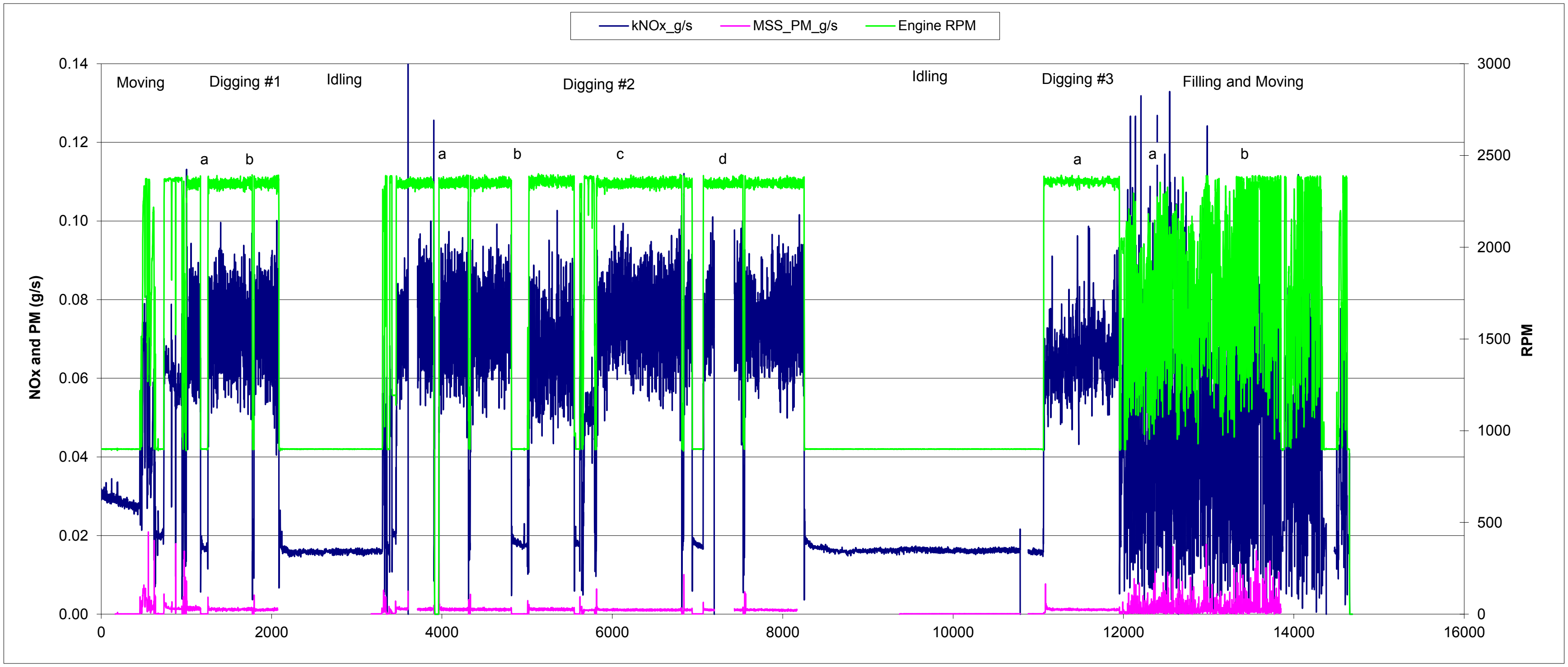


Figure C-2: Modal emissions for 02_310SJ John Deere 2010 Tier 3 backhoe

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 C-4: 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
[7] Overall not included

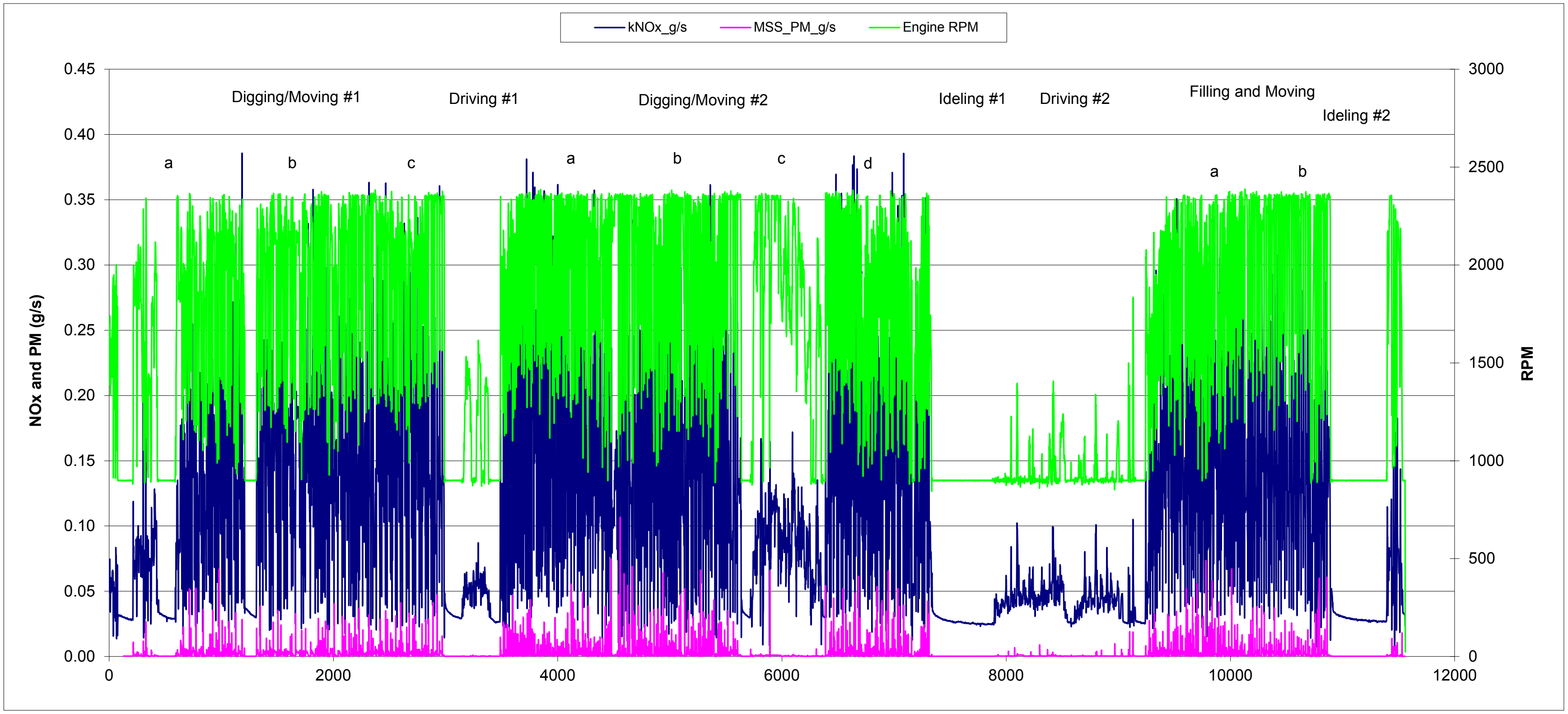


Figure C-3: Modal emissions for 03_644J John Deere 2007 Tier 3 wheel loader

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 C-5: 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

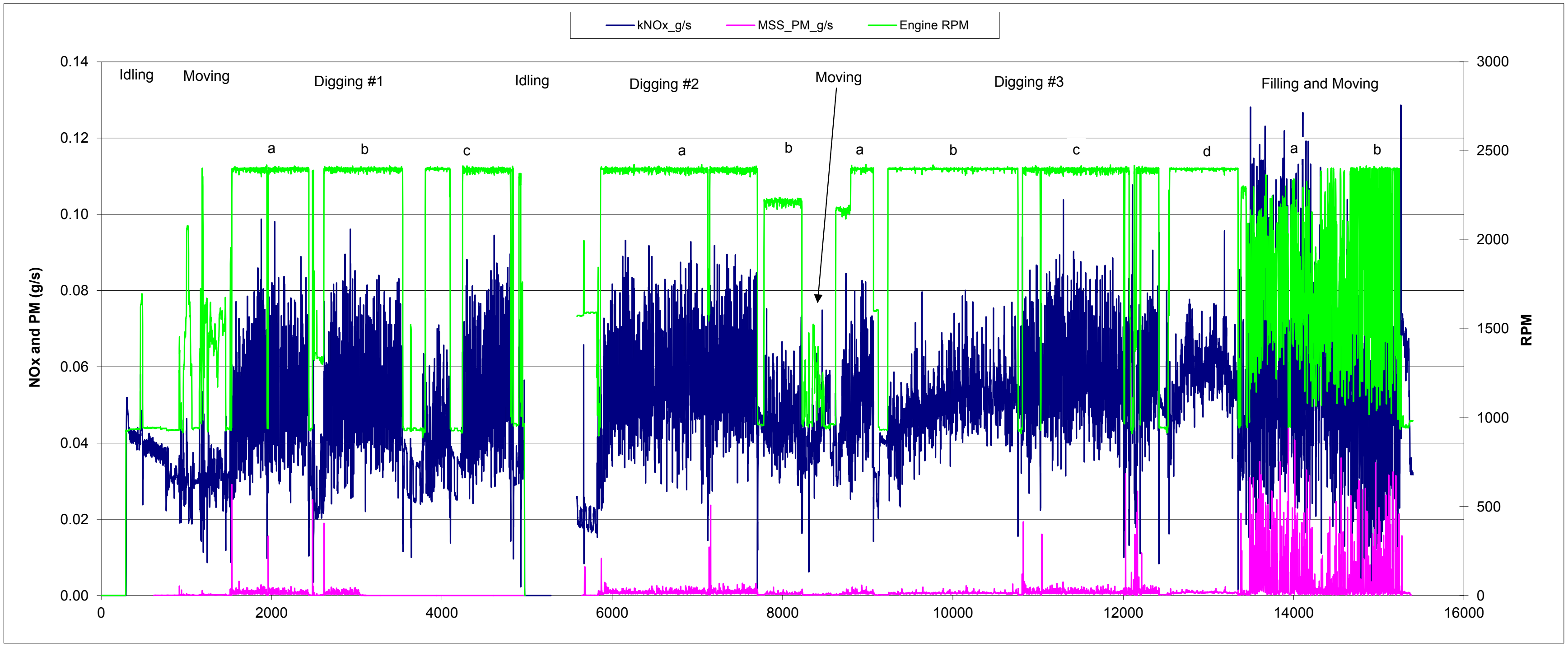


Figure C-4: Modal emissions for 04_310SG John Deer 2006 Tier 2 backhoe

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 C-6: 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

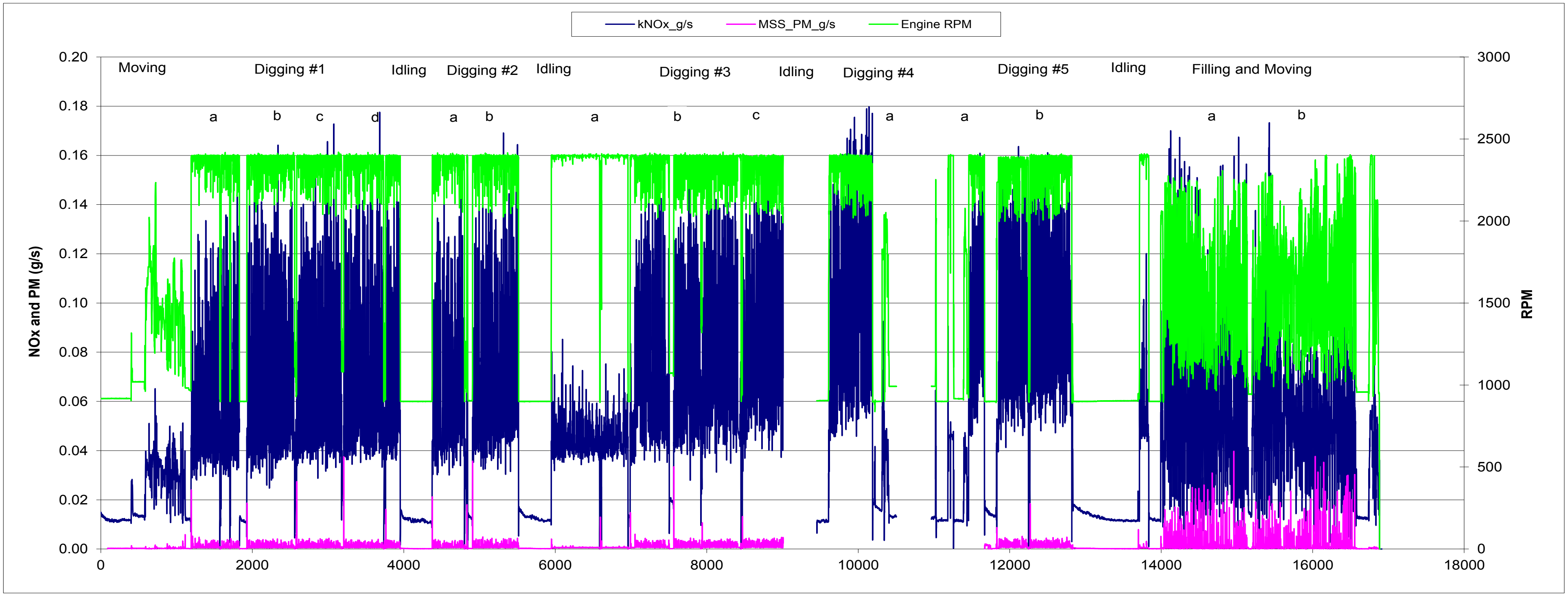


Figure C-5: Modal emissions for 05_410G John Deer 2006 Tier 2 backhoe

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 C-7: 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

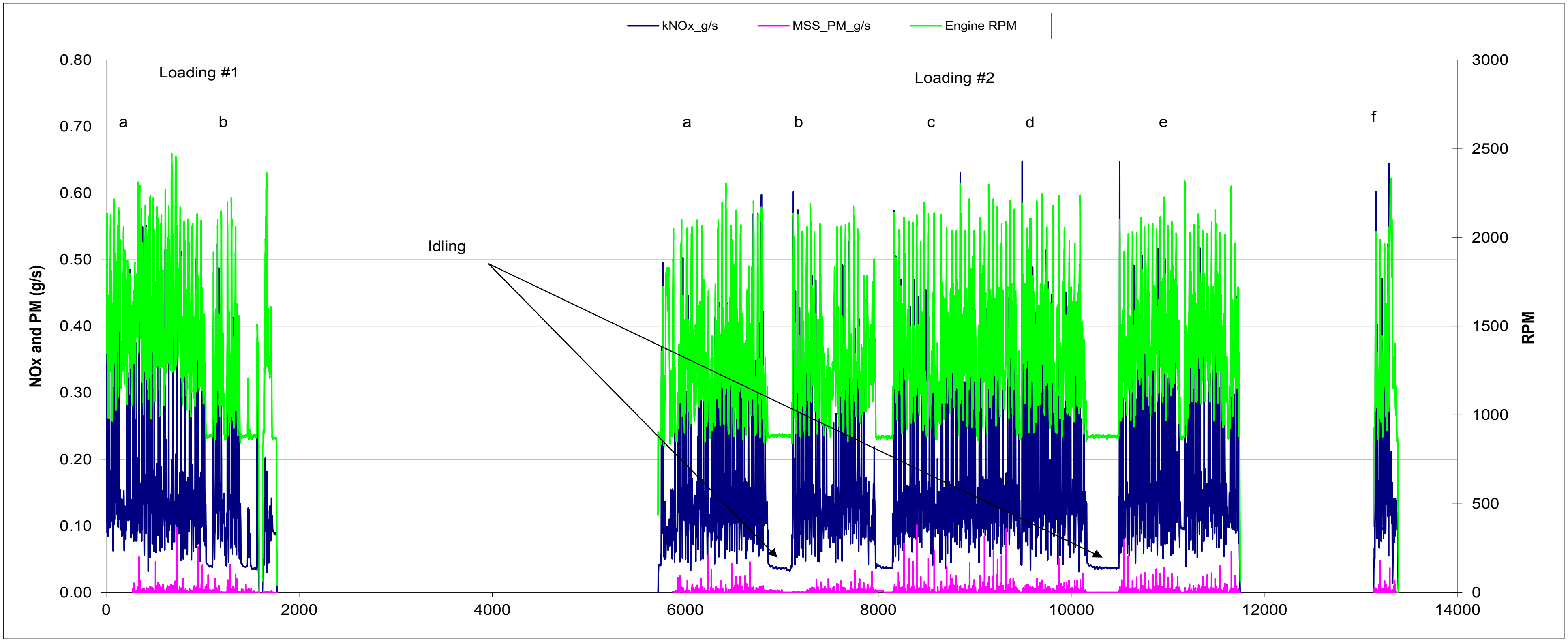


Figure C-6: Model emissions for 06_WA470-6 Komatsu 2009 Tier 3 wheel loader

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 C-8: 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

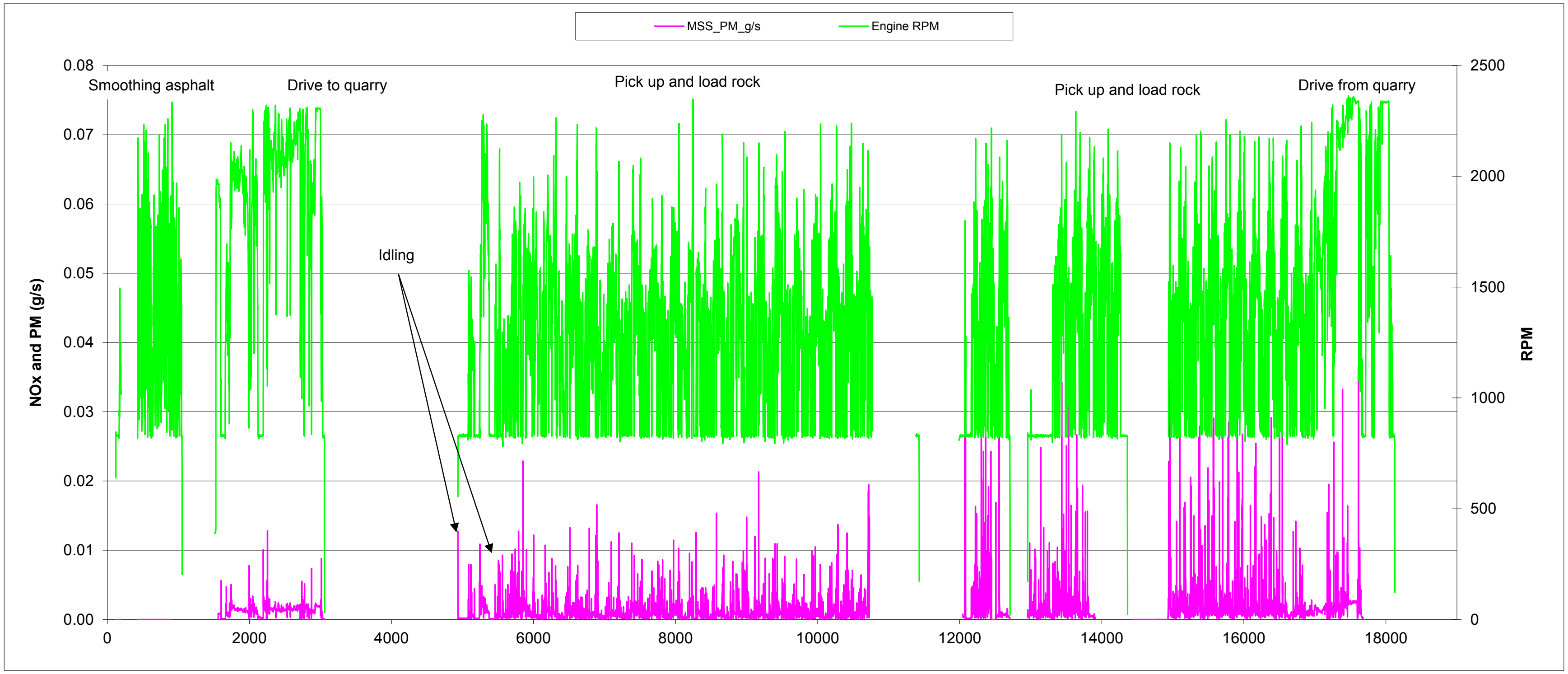


Figure C-7: Modal emissions for 07_928G 2004 CAT Tier 2 wheel loader

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 C-9: 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

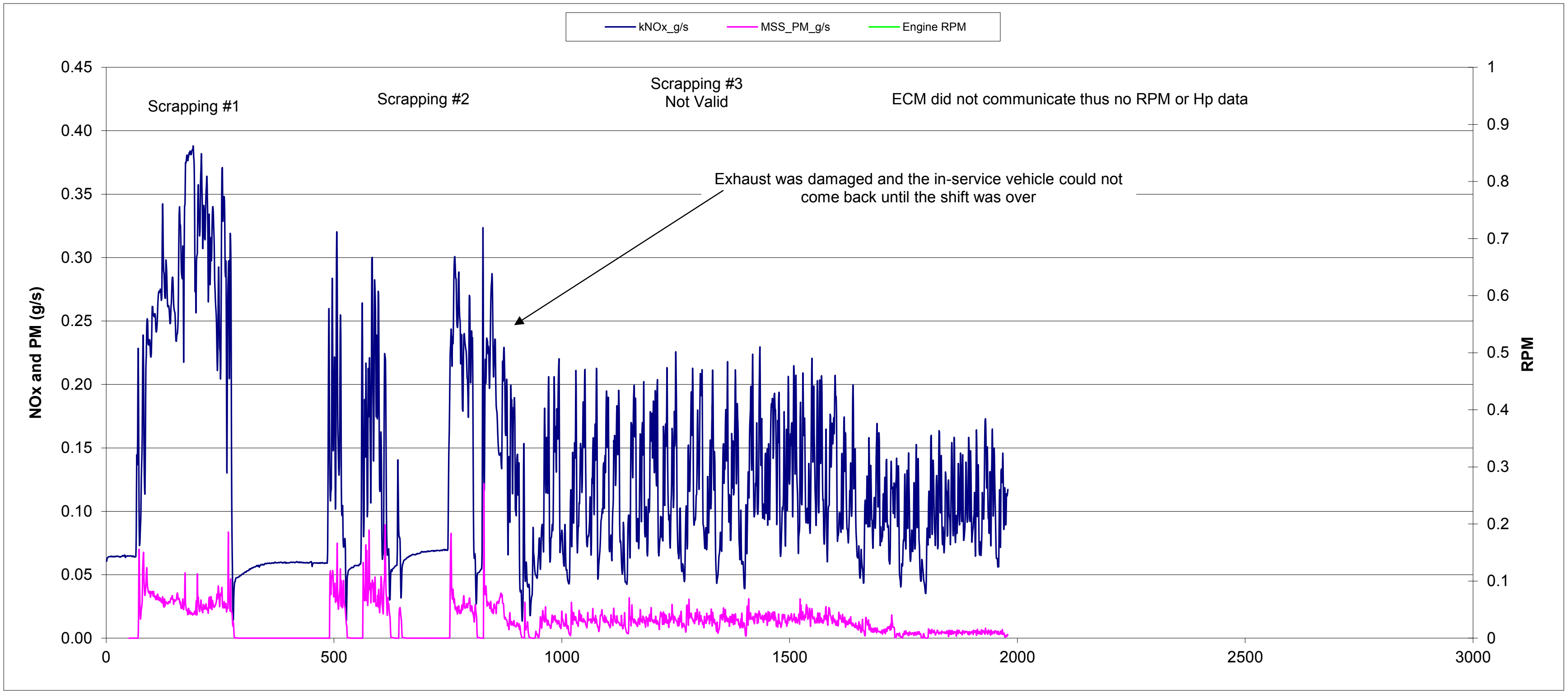


Figure C-8: Modal emissions for 08_345 CAT 2008 tier 3 excavator

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 C-10: 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

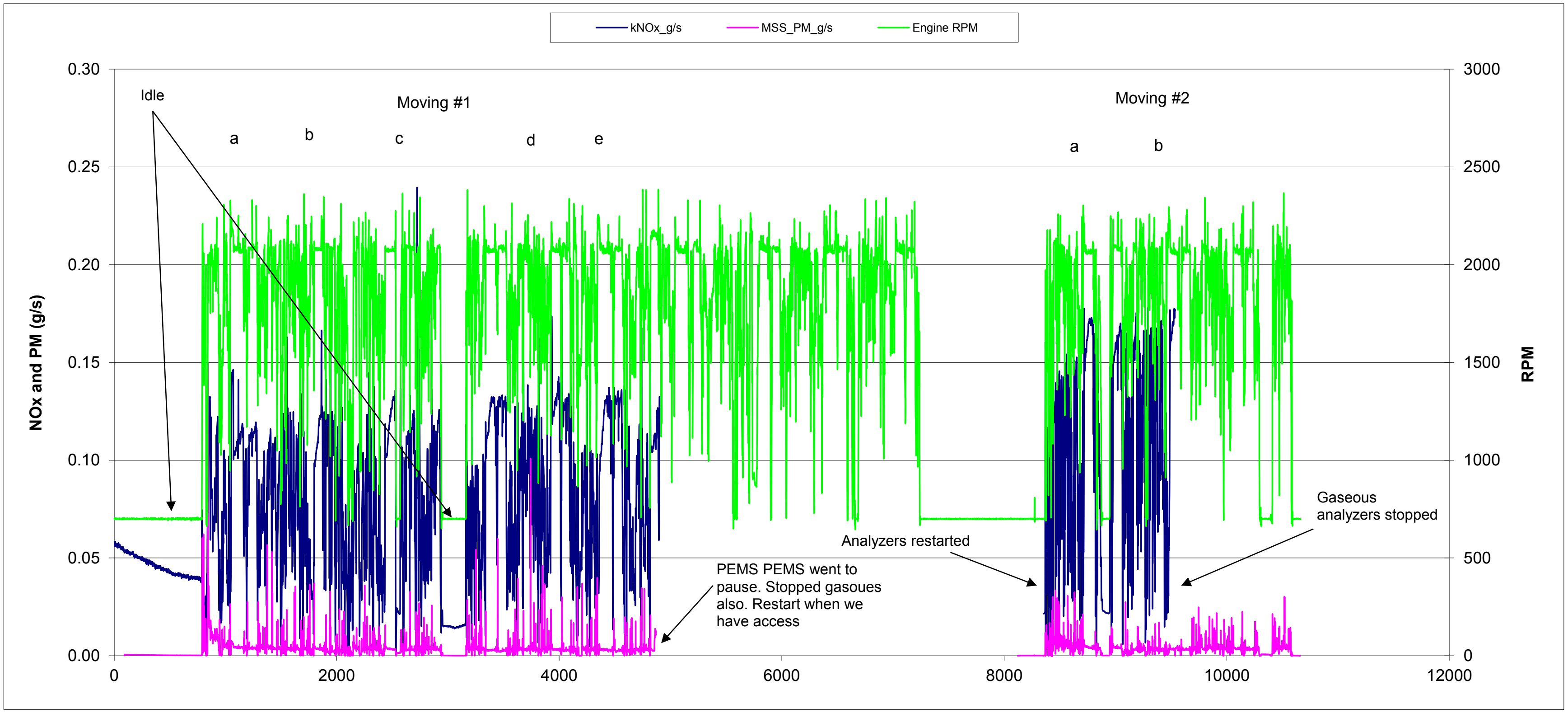


Figure C-9: Modal emissions for 09_637E CAT 2006 C9 (rebuilt) tier 2 scraper

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 C-11: 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

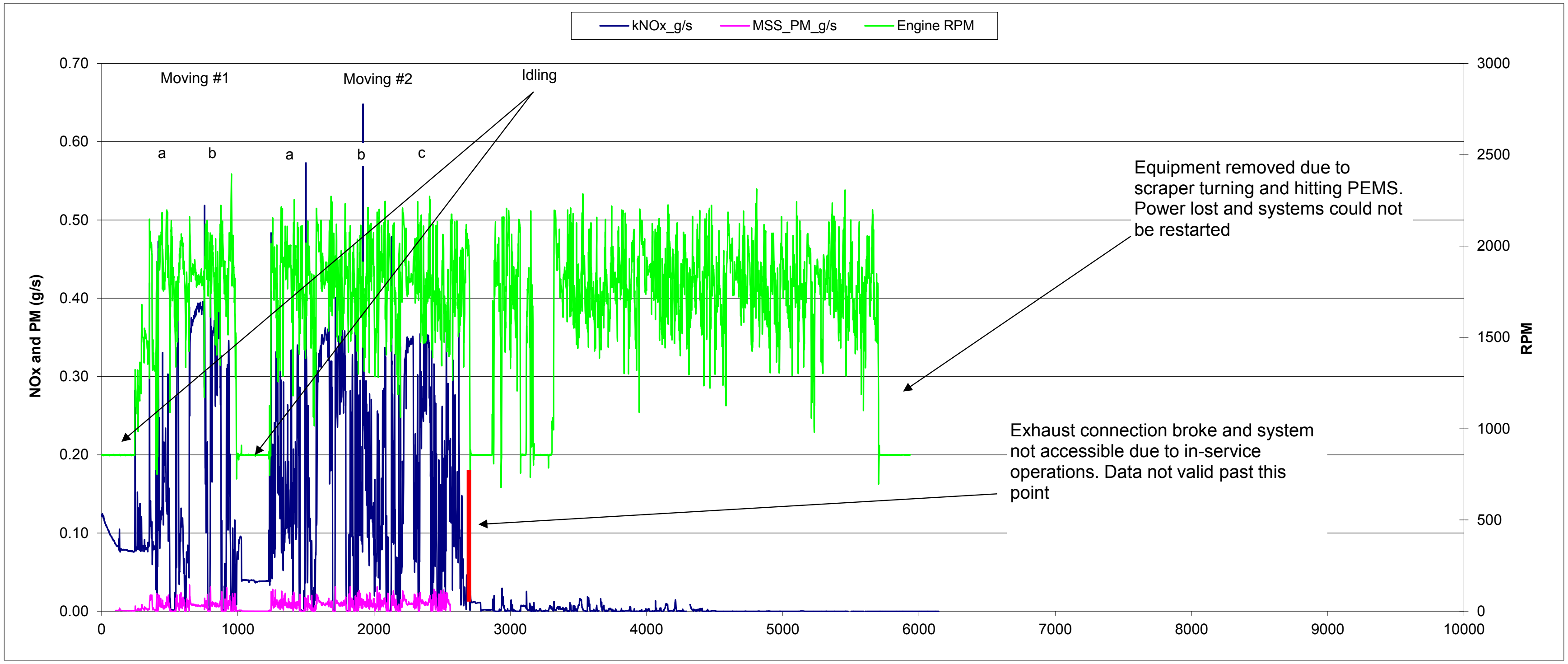


Figure C-10: Modal emissions for 10_637E 2006 CAT C15 (rebuilt) tier 2 scraper

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 C-12: 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

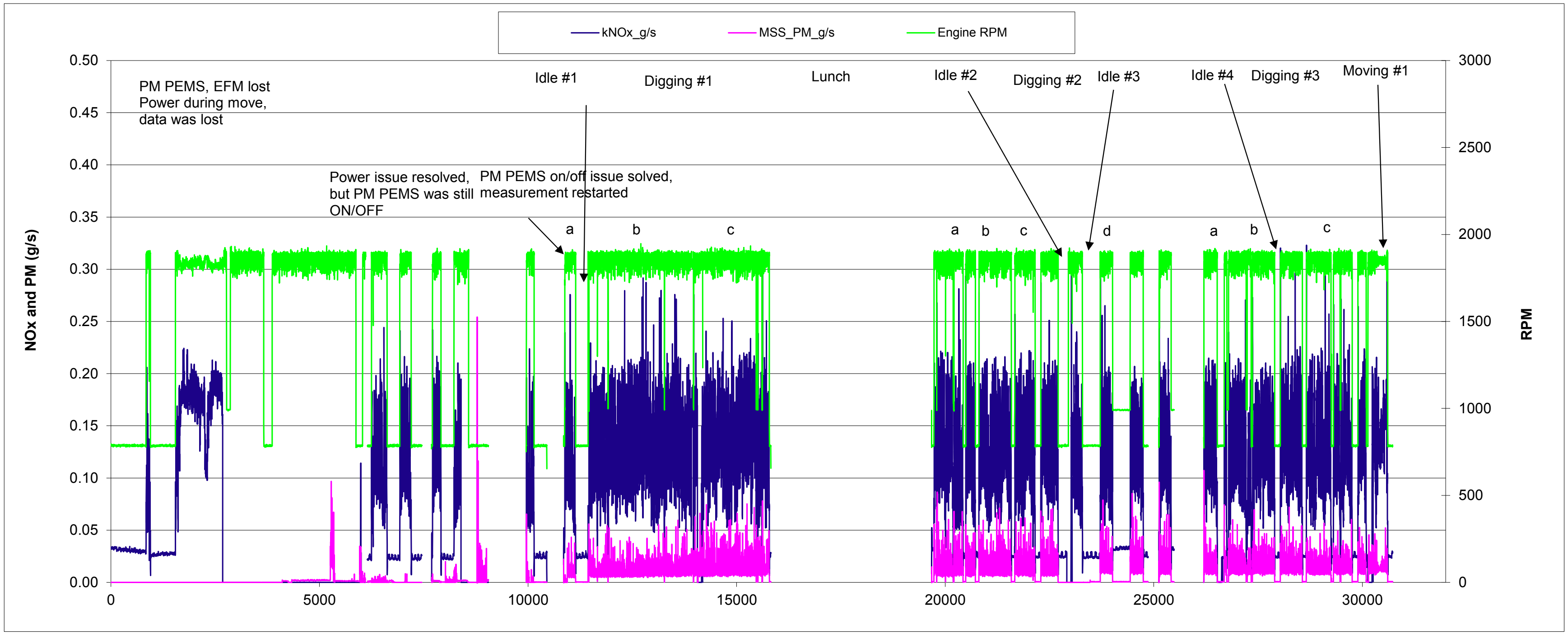


Figure C-11: Modal emissions for 11_E460B/c Volvo 2006 tier 3 excavator

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 C-13: 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%

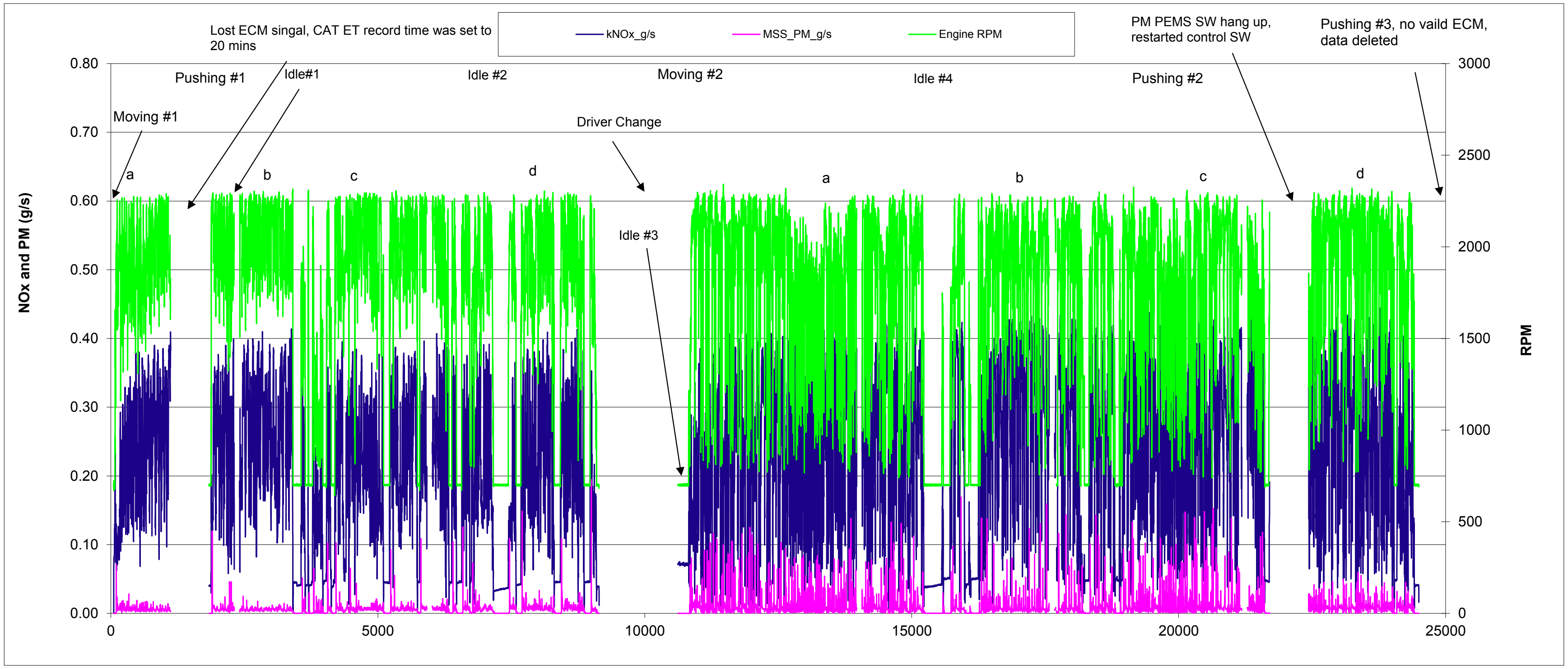


Figure C-12: Modal emissions for 12_D8R CAT 2003 tier 2 bulldozer

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 C-14: 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%

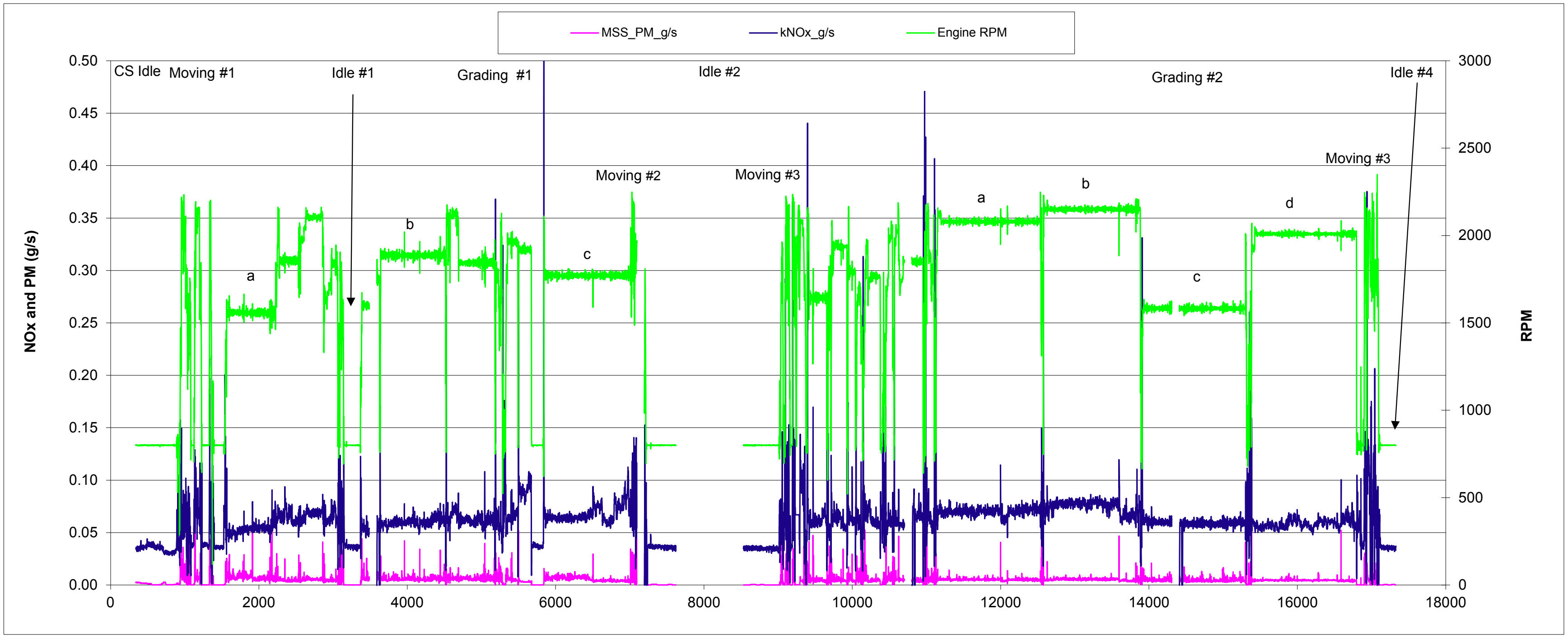


Figure C-13: Modal emissions for 13_120M_101G 2008 CAT tier 3 grader

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 C-15: 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

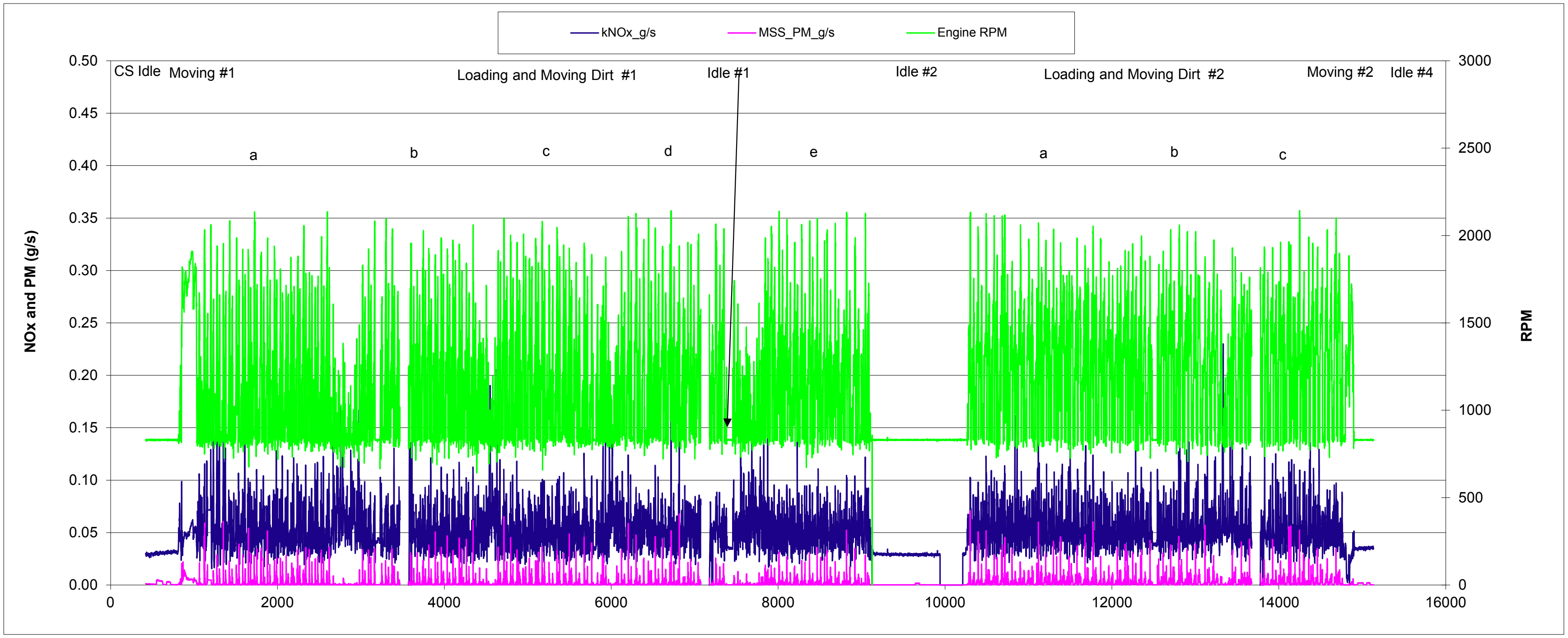


Figure C-14: Modal emissions f for 14_928Hz_72P CAT 2011 tier 3 wheel loader

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 C-16: 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 C-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 C-17: 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

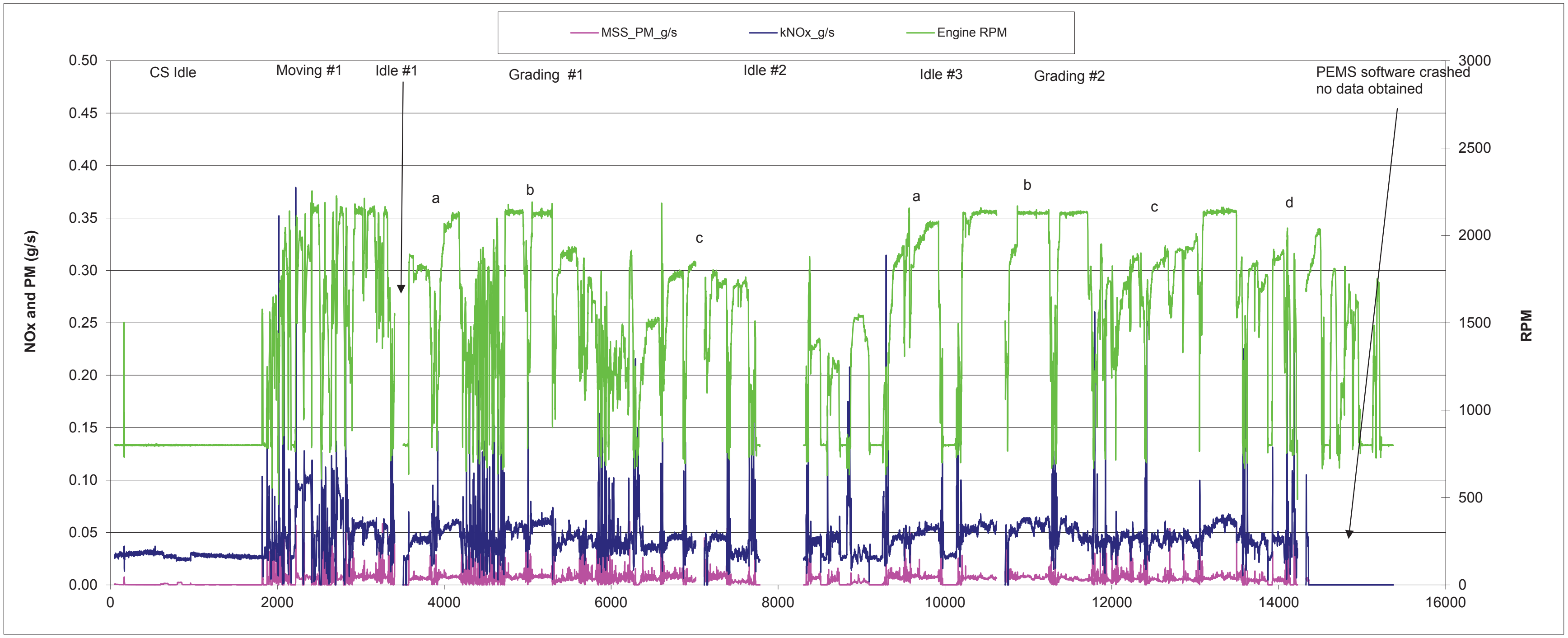


Figure C-16: Modal emissions for 16_120M_97G 2008 CAT tier 3 grader

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 C-18: 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

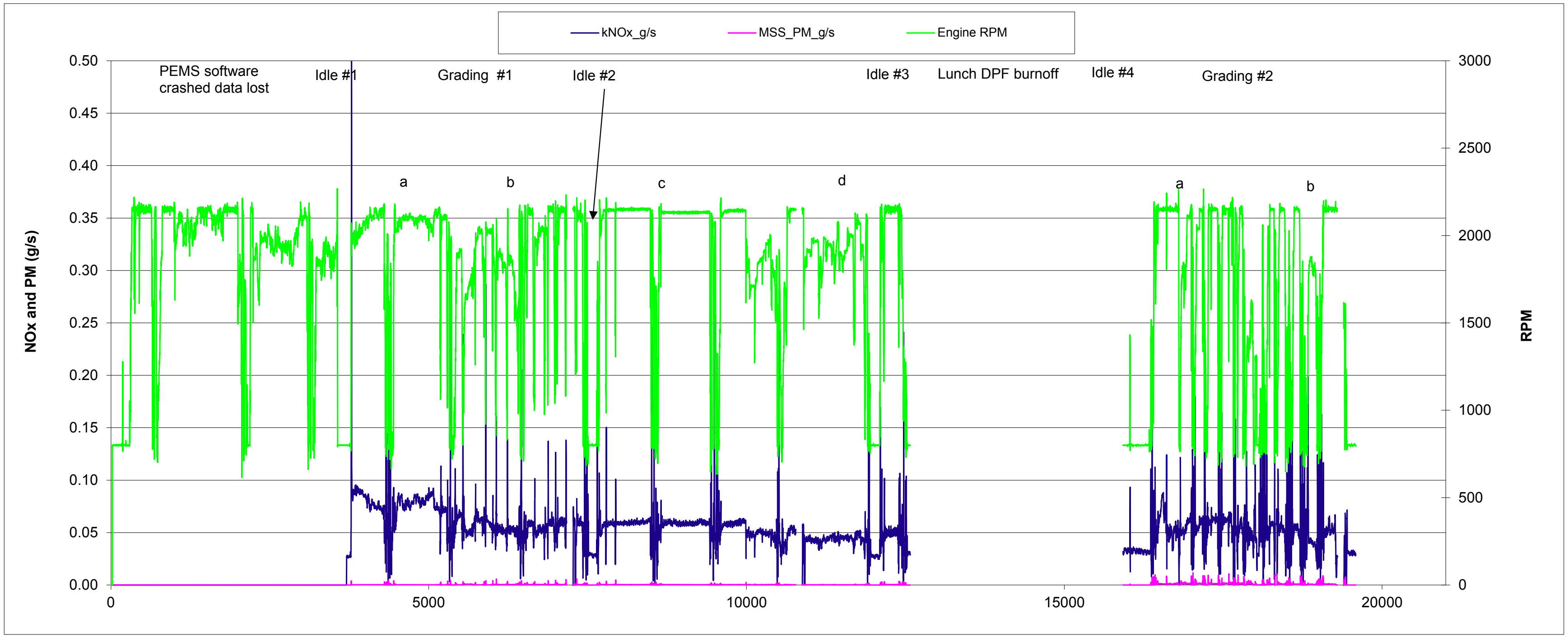


Figure C-17: Modal emissions for 17_120M_106G_DPF 2008 CAT tier 3 grader

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 C-19: 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
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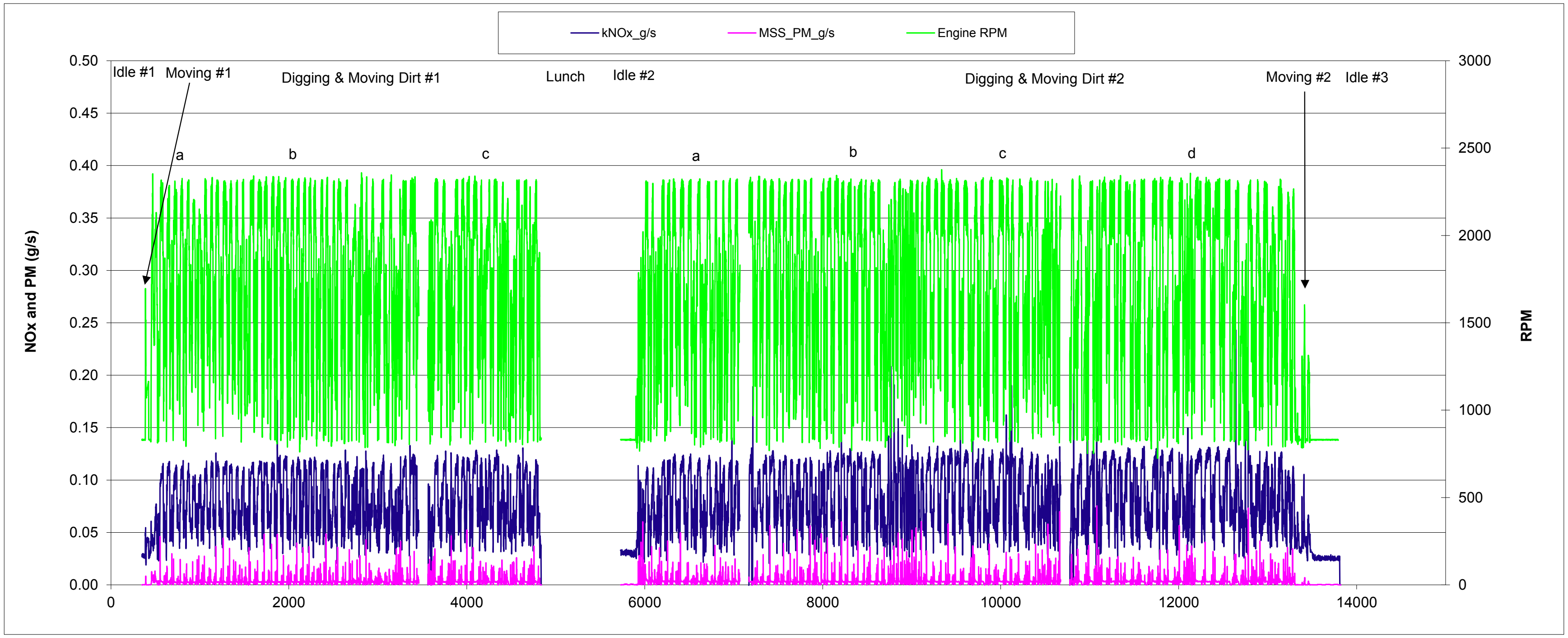

Figure C-18: Modal emissions for 18_928Hz_70P 2011 CAT tier 3 wheel loader

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 C-20: 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

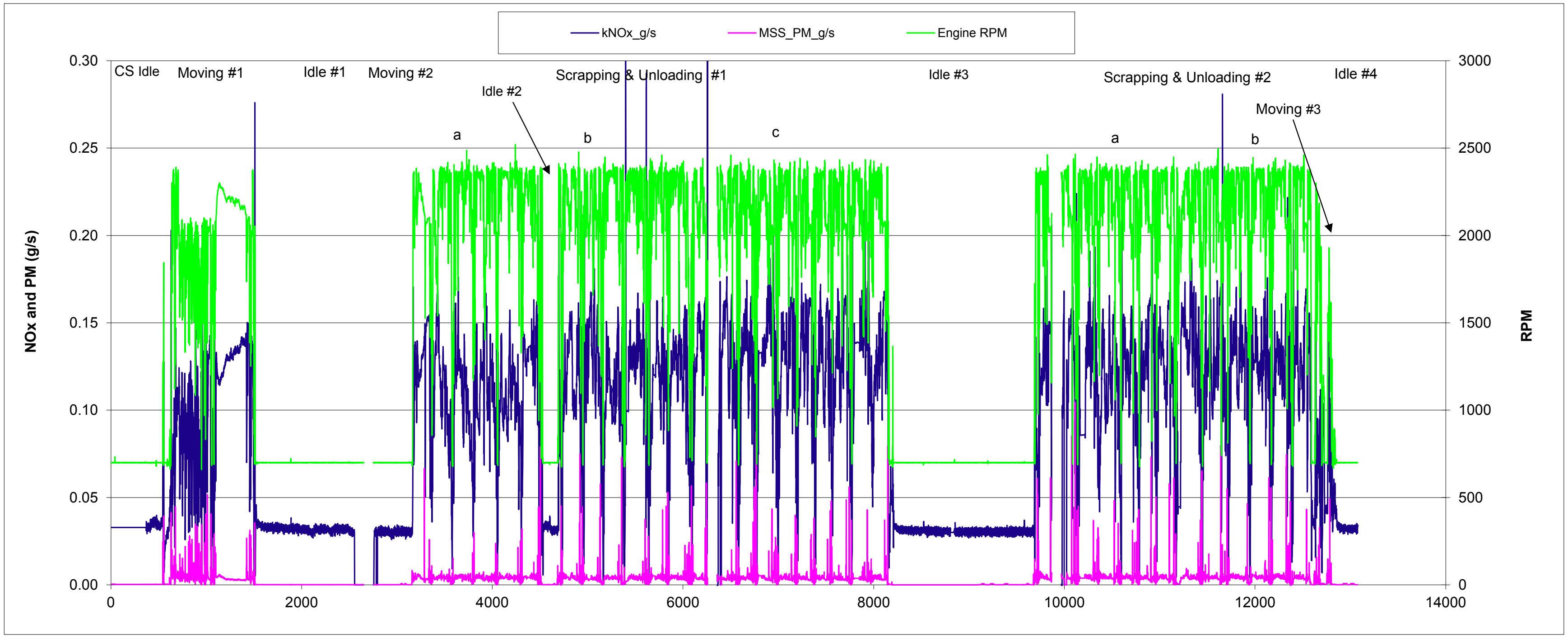

Figure C-19: Modal emissions for 19_613G_10W 2010 CAT tier 3 scraper

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 C-21: 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

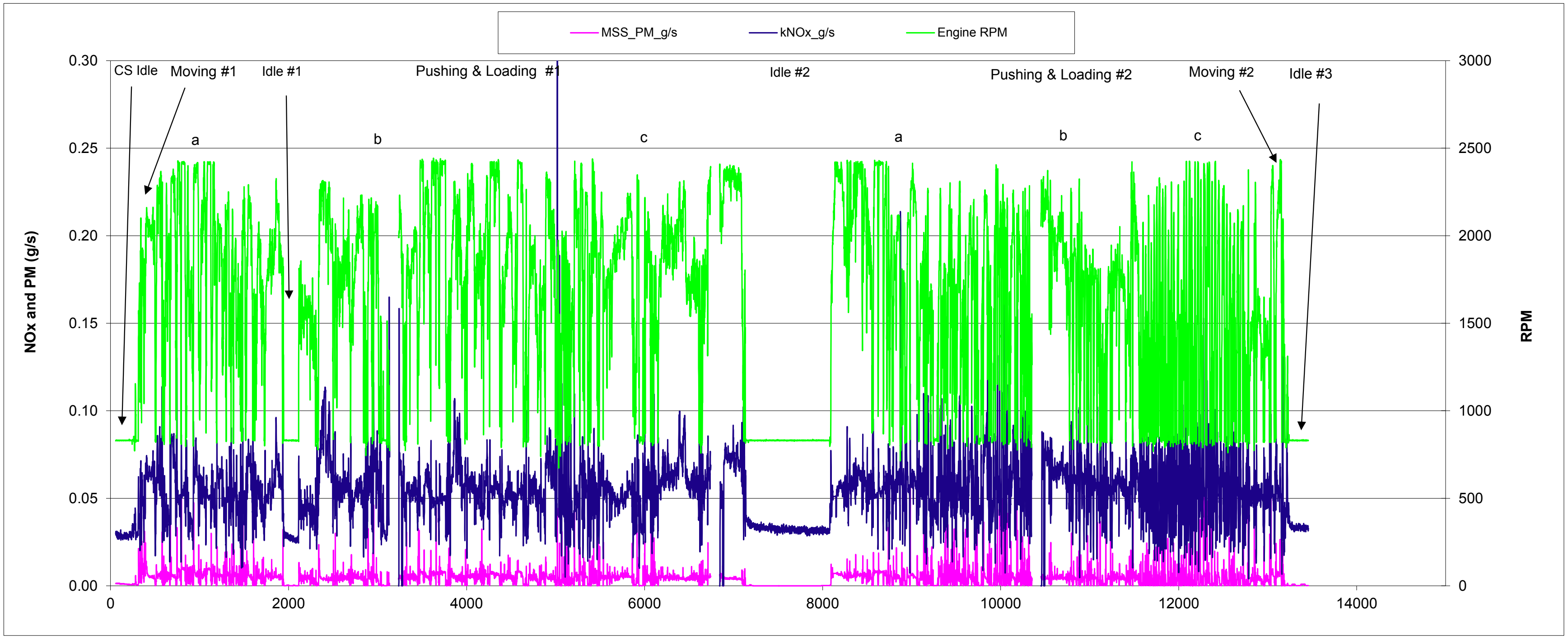

Figure C-20: Modal emissions for 20_928Hz_71P 2011 CAT tier 3 wheel loader

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 C-22: 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	mg 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

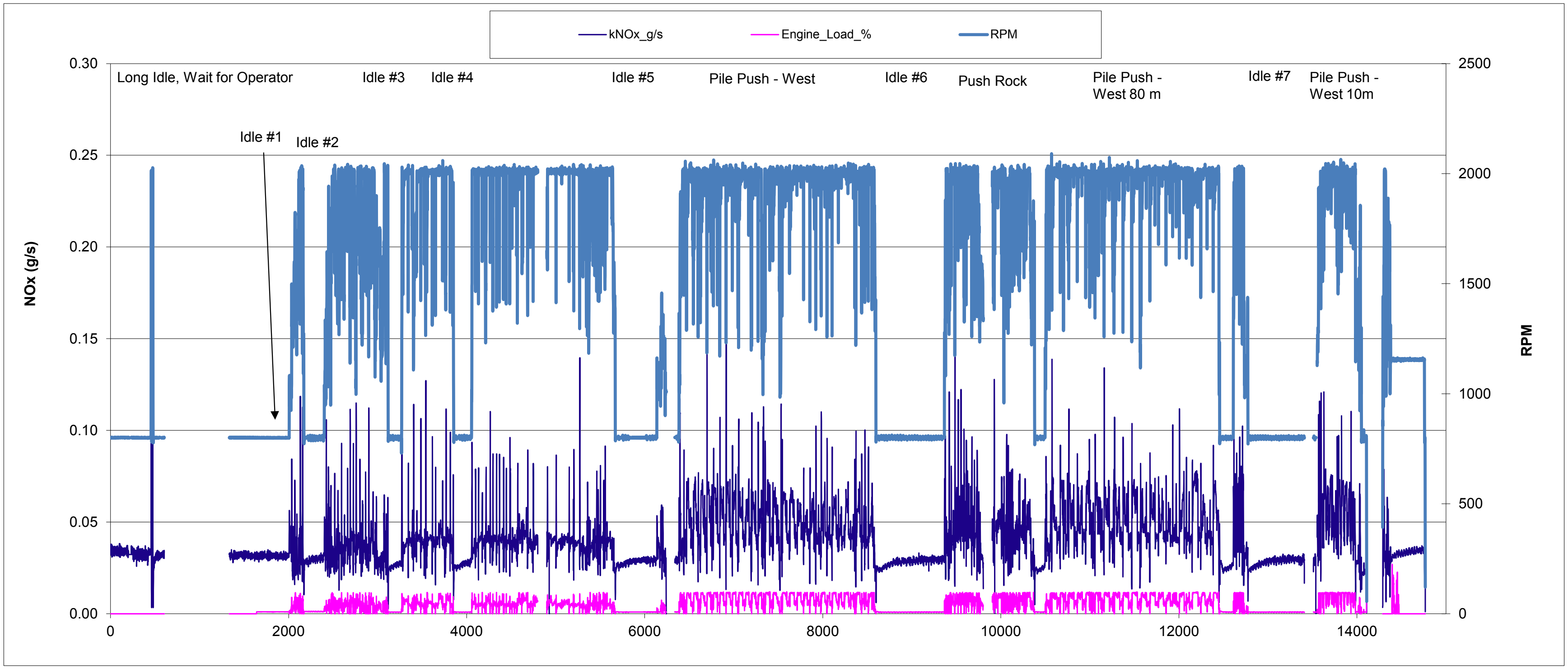

Figure C-21: Modal emissions for 21_D6T_JM 2012 CAT tier 4i bulldozer

22_D7E_WM: 2012.12.04

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.

Table C-23: 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

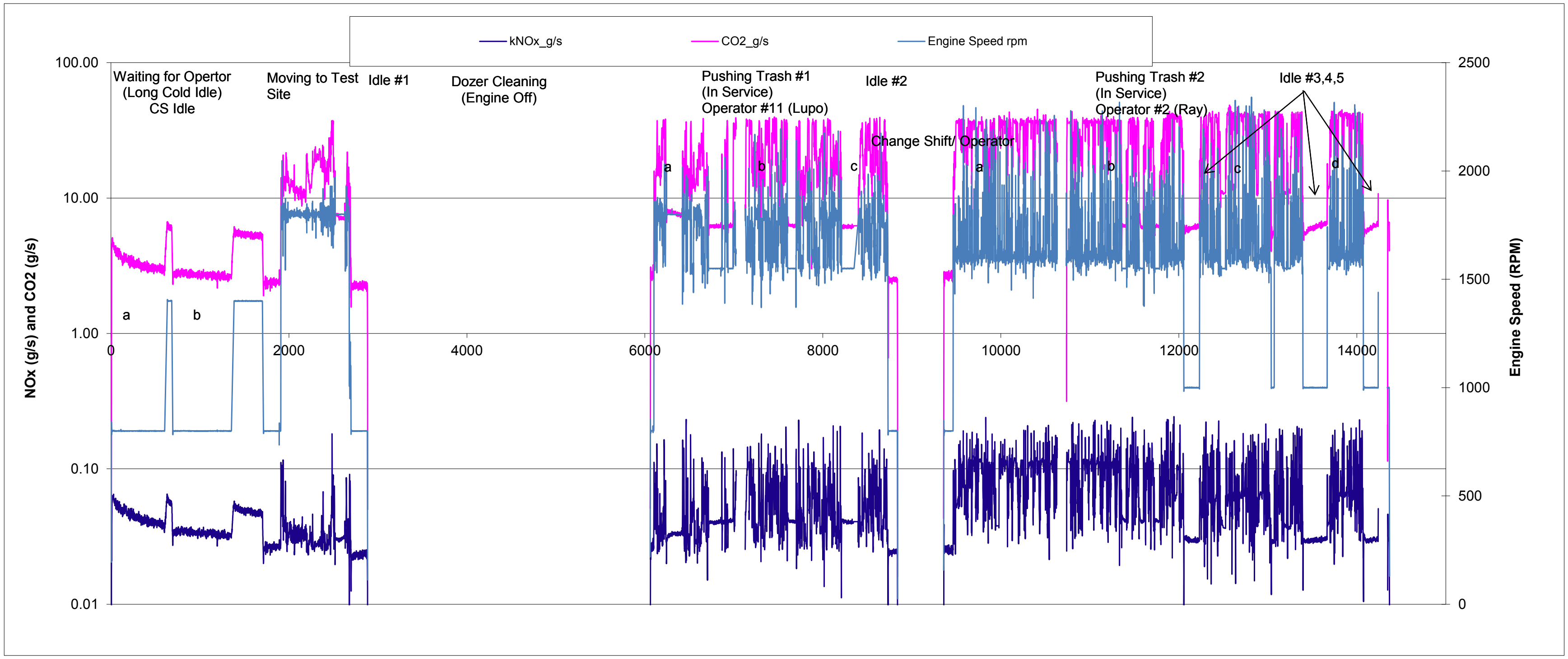

Figure C-22: Modal emissions for 22_D7E_WM 2011 CAT tier 4i bulldozer

23_D8T_JM: 2012.12.06

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.

Table C-24: 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	CO2	CO	NOx	THC	mg PM [3]	CO2	CO	NOx	THC	mg PM [3]	CO2	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.

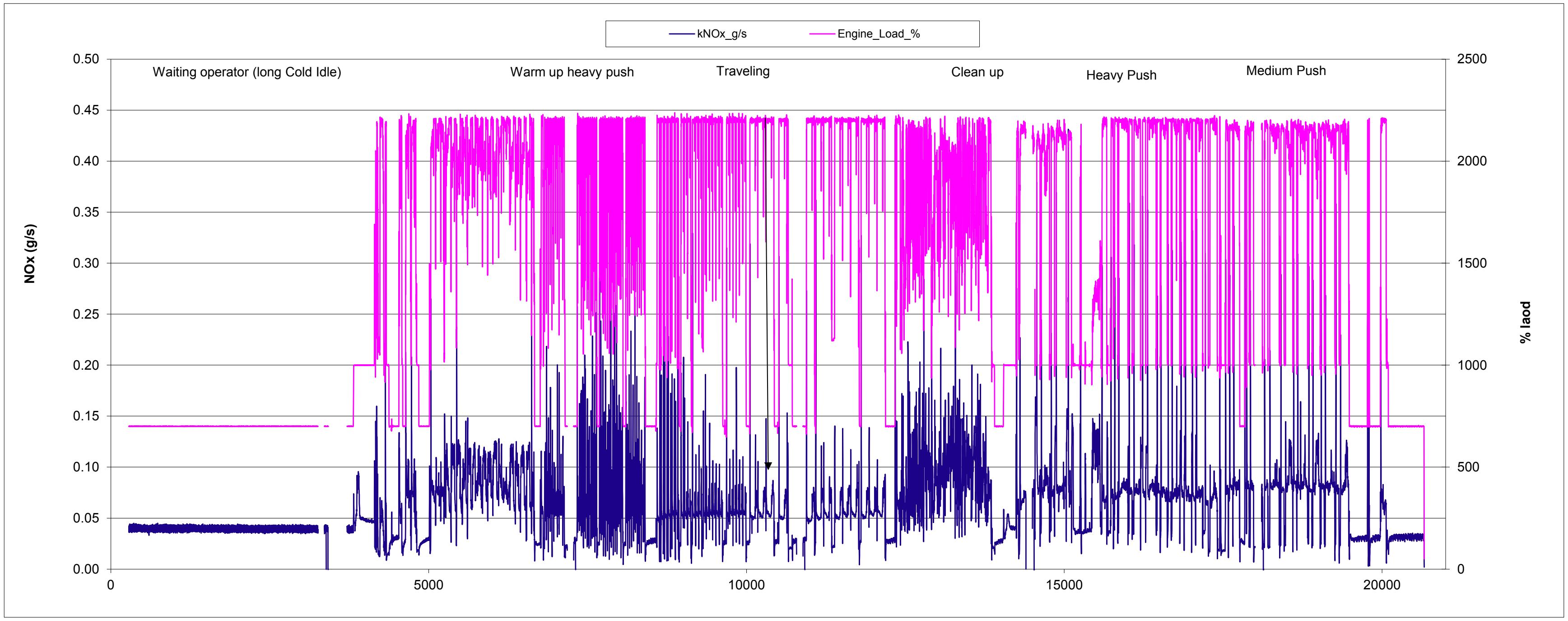

Figure C-23: Modal emissions for 23_D8T_JM 2012 CAT tier 4i bulldozer

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 C-25: 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

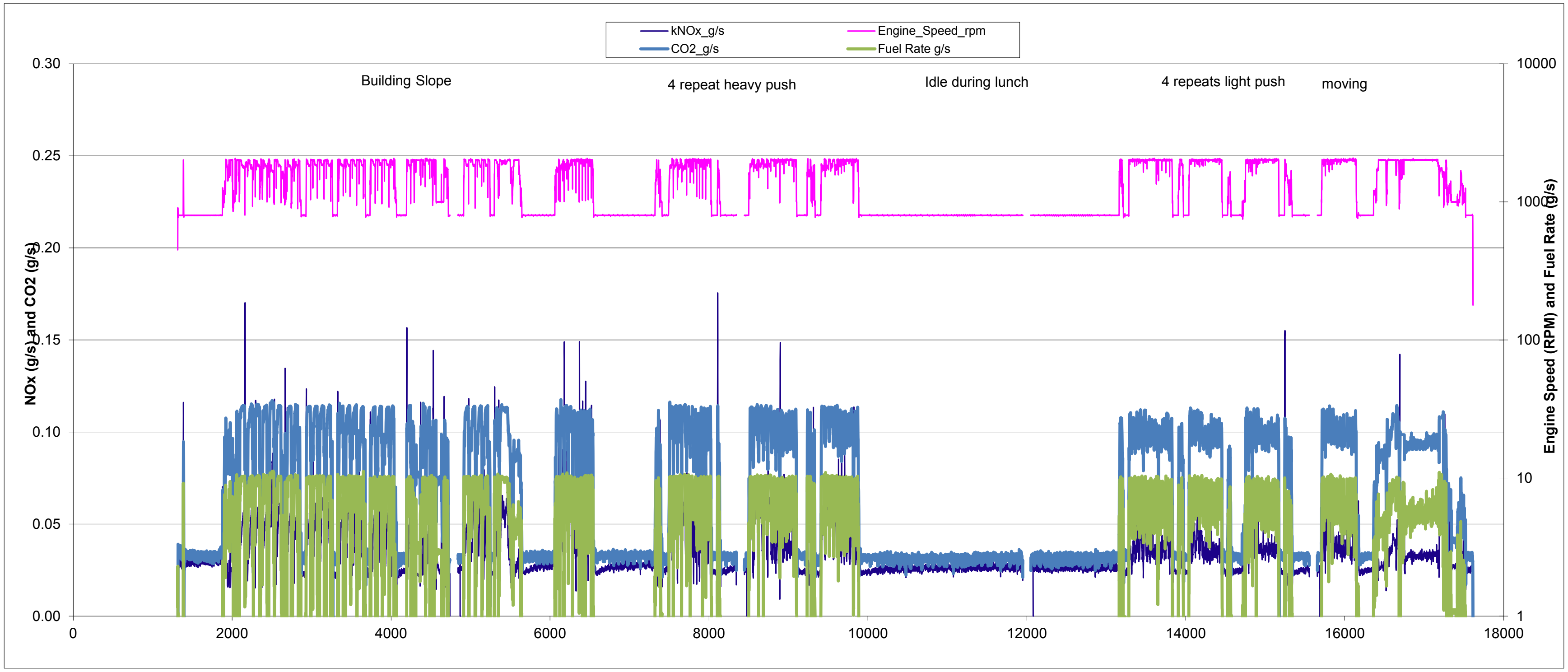

Figure C-24: Modal emissions for 24_D6T_OC 2012 CAT tier 4i bulldozer

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 C-26: 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

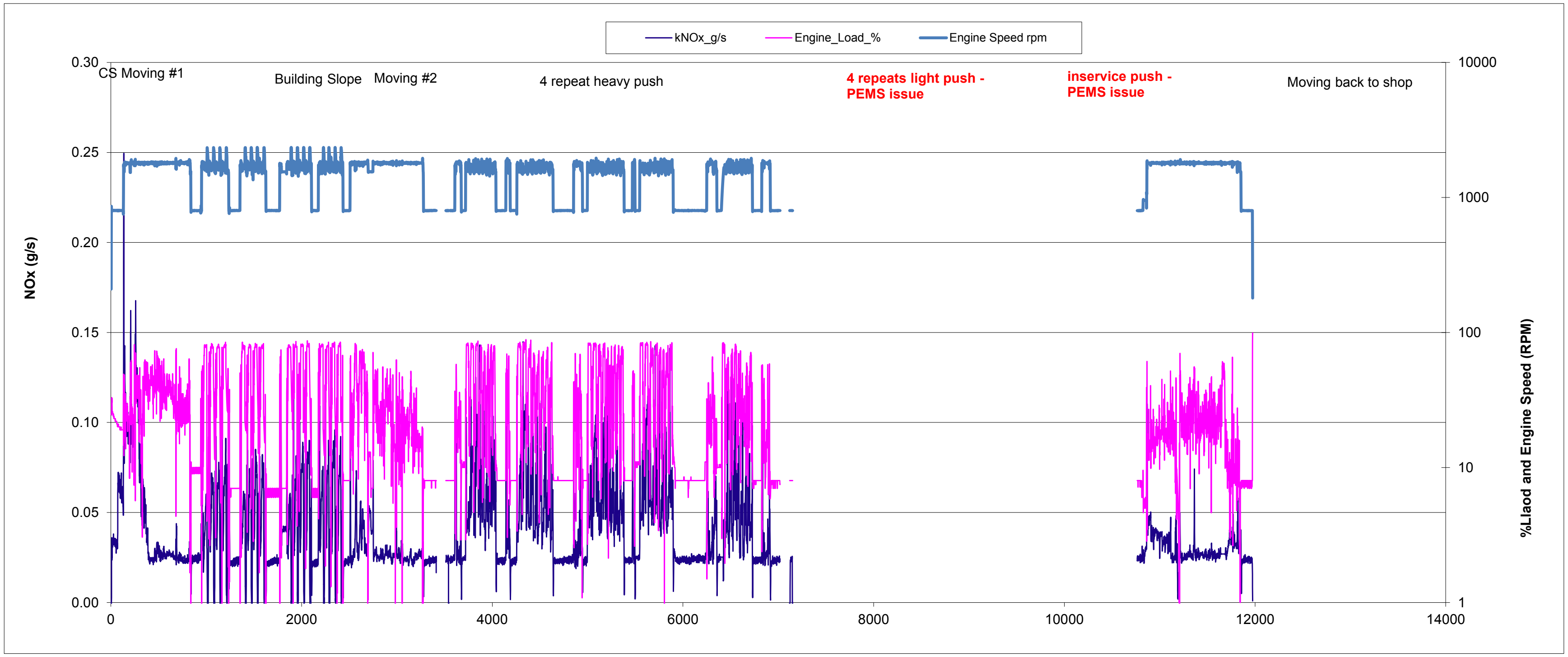

Figure C-25: Modal emissions for 25_D7E_OC 2011 CAT tier 4i bulldozer

26_PC200: 2012.03.01

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.

Table C-27: 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

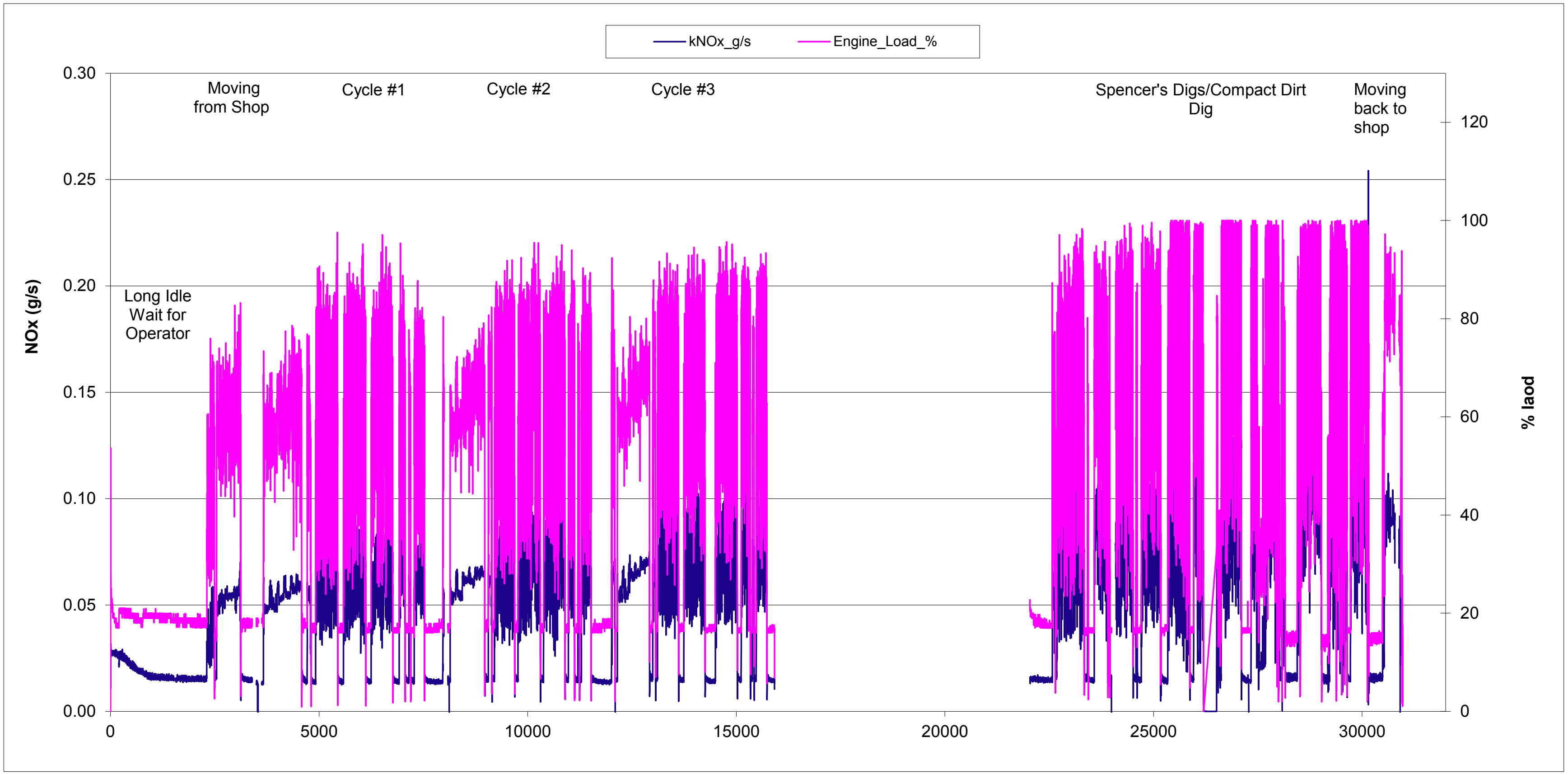

Figure C-26: Modal emissions for 26_PC200 2007 Komatsu tier 3 excavator

27_HB215: 2013.02.28

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.

Table C-28: 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

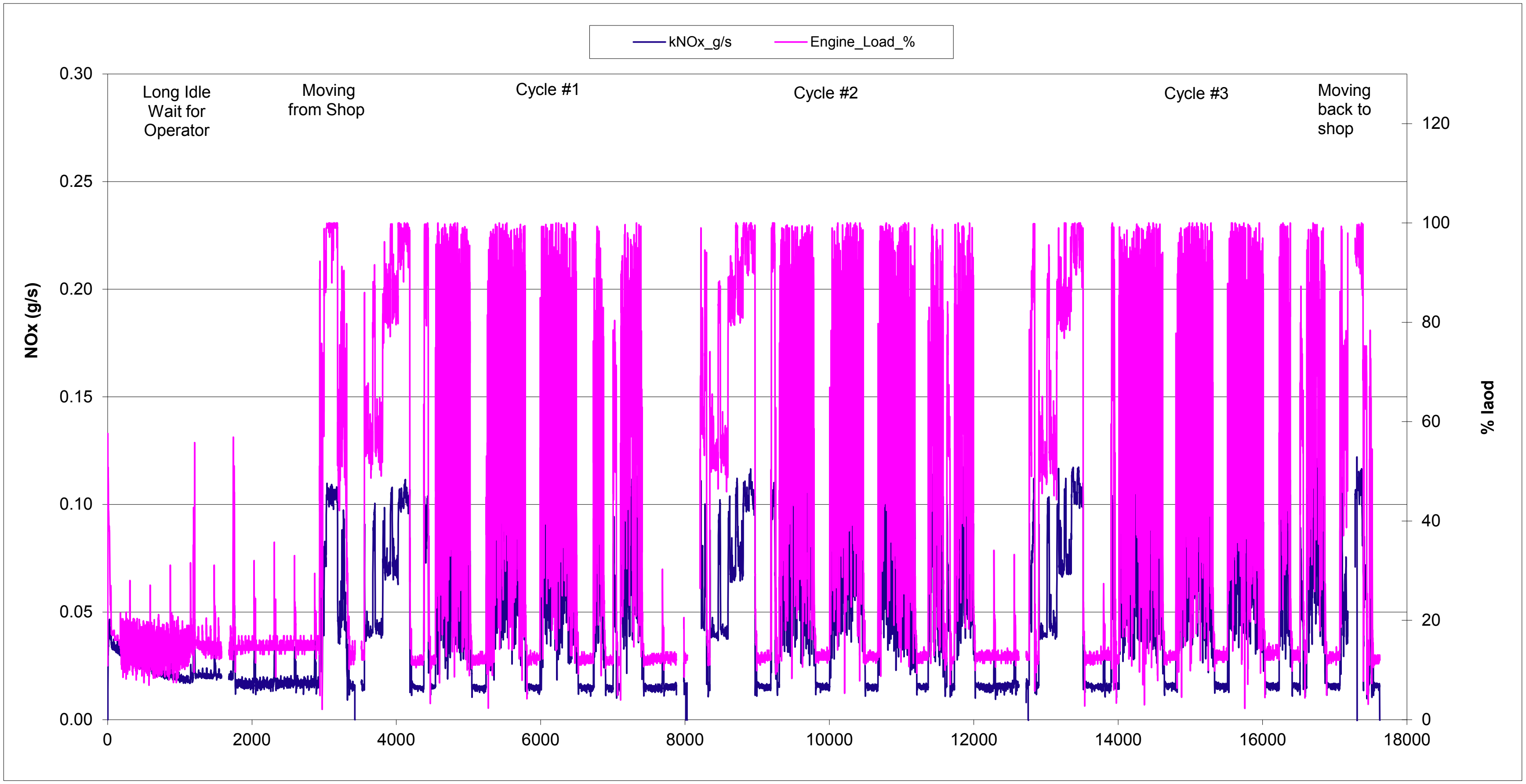

Figure C-27: Modal emissions for 27_HB215 2011 Komatsu tier 3 excavator