2009

Remote Measurements of On-Road Emissions from Heavy-Duty Diesel Vehicles in California; Year 1, 2008

Gary A. Bishop

Nicolas E. Holubowitch

Donald H. Stedman

Remote Measurements of On-Road Emissions from

Heavy-Duty Diesel Vehicles in California; Year 1, 2008

Annual Report prepared under

National Renewable Energy Laboratory Subcontract AEV-8-88609-01

Gary A. Bishop, Nicolas E. Holubowitch, and Donald H. Stedman

Department of Chemistry and Biochemistry

University of Denver

Denver, CO 80208

October 2009

Prepared for:

National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401
Attention: Doug Lawson, Ph.D.

Executive Summary

The University of Denver conducted two five-day remote sensing studies on heavy-duty diesel vehicles (HDDVs) at two sites in the Los Angeles Basin area of California in April of 2008. Two remote sensing instruments were used to measure emissions in a single lane from the elevated plumes of HDDV truck exhausts: RSD 4600 made by ESP and FEAT 3002 equipped with dual UV spectrometers from the University of Denver. These remote sensors measure the ratios of pollutants to carbon dioxide in elevated stack diesel vehicle exhaust. From these ratios, we calculate the mass emissions for each pollutant per mass or volume of fuel. The system from the University of Denver was also configured to determine the speed and acceleration of the vehicle, and was accompanied by a video system to record the license plate of the vehicle. The motivation for the study is implementation of new National new vehicle emission standards and California retrofit and replacement standards for these trucks. The study is the first of a five-year testing program to monitor fleet and emission changes and compliance with the standards.

Five days of field work at each of two sites between April 4 and April 17, 2008 were conducted resulting in 4,065 emission measurements being collected. The sites chosen were Peralta Weigh Station on Hwy 91 in Anaheim near the Weir Canyon Rd exit and a truck exit on Water St. at the Port of Los Angeles in San Pedro. The Peralta Weigh station site was previously used in 1997 to collect measurements and adds a historical perspective to those measurements. The heavy-duty fleet observed at Peralta was about five years newer (2000.4 vs. 1995.6) and was measured at higher operating speeds (~13 mph compared with ~5mph at the Port) than the vehicles in use at the Port location. A database for each site was compiled at Peralta and the Port, respectively, for which the states of Arizona, California, Illinois and Oklahoma provided make and model year information. This database, as well as any previous data our group has obtained for HDDV's can be found at www.feat.biochem.du.edu.

Since 1997 large reductions in CO (38%) and HC (46%) are observed at Peralta while the measured NO emission reductions are smaller at 15%. License plates were not read and matched during the 1997 measurements so we are unable with any certainty to comment on how the fleet change during the past eleven years may have contributed to these reductions. NO_x emissions were observed to be 40% lower at Peralta when compared with the Port location; however the cumulative emission distributions as a fraction of the vehicle fleet are nearly identical. This suggests that driving mode and not age differences between the two locations is the major influence. Since the San Pedro Ports Clean Air Action Plan (CAAP) bans all pre-1989 model year trucks starting in October 2008 we found that at the Port these vehicles account for 9.5% of the measurements and are responsible for 7% of the observed NO_x. At Peralta these vehicles are only 4.1% of the measurements and account for 5.3% of the total NO_x.

At Peralta a small sample (140 trucks) of out of state trucks were plate matched and were compared to California plated trucks. The out of stat trucks were found to be 3.5 model years newer than the California fleet and they were lower in mean emissions for all of the measured species except SO_2. We also observed that gNO_x/kg emission are decreasing

rapidly with newer model year vehicles but have yet to reach the levels that are dictated in the 2010 National requirements. Particulate matter emissions as measured in the infrared and ultraviolet wavelength regions is also decreasing with the newer models. The drop in particulate matter correlated with increases in the NO_2/NO_x ratio. Ammonia emissions were measured, largely to document background levels, and only very low levels were detected.

Sulfur dioxide emission measurements exposed a number of trucks at the Port of Los Angles that were likely using high sulfur fuels in violation of the local regulations. At the time of these measurements retail prices for low sulfur diesel fuel in California were around $4/gal. In Mexico diesel was going for about half this price. The 15 ppm ultra-low sulfur fuel translates to 0.03 g/kg which means the outliers reached [SO_2] levels equivalent to 5000 ppm (10 g/kg) of fuel sulfur.

Emission intercomparisons between the two remote sensing systems for CO, HC and NO produced generally expected results. The CO and HC comparisons are the most difficult on diesels because of the very low levels of emissions seen in diesel exhaust. In general these species depend on a few high emitters to drive the correlation, without which you end of with a large blob of data. At Peralta the CO comparison had some higher emitters and the correlation looks reasonable. At the Port of Los Angels and for HC emissions the levels are consistently low and the correlations are poor. For NO the situation is improved since almost every truck is emitting NO and the range of emissions is large. Both correlations have R^2 greater than 0.82, however the slope of the correlation is approximately 17% below the one to one line. With the ESP instrument reporting the lower NO values. We believe we have traced this to a disagreement between the certified contents of the two calibrations cylinders that were used to calibrate each instrument.

Introduction

The United States Environmental Protection Agency (EPA) has recently mandated stricter emissions standards for on-road heavy-duty diesel vehicles (HDDV's) with the program represented in Table 1 (*1*). The standards are specifically for reduction of particulate matter (PM), non-methane hydrocarbons (NMHC), and oxides of nitrogen (NO_x). However, beginning in 2007 most diesel engine manufacturers opted to meet a Family Emission Limit (FEL) with EPA allowing engine families with FEL's exceeding the applicable standard to obtain emission credits through averaging, trading and/or banking. This will allow some diesel engine manufacturers to meet 2010+ standards with engines that do not meet a rigid 0.2 g/bhp-hr limit subsequent to the 2010 model year.

Table 1. The 2007 EPA Highway Diesel Program.

Species	Standard (g/bhp-hr)	Phase-In by Model Year			
		2007	2008	2009	2010
NO_x	0.2	50%	50%	50%	100%
NMHC	0.14				
PM	0.01	100%	100%	100%	100%

But in California the National EPA Highway Diesel Program is just a part of a number of new regulations that will be implemented over the next decade. The San Pedro Bay Ports Clean Air Action Plan (CAAP) bans all pre-1989 model year trucks starting in October 2008. For all of the remaining trucks it further requires them to meet National 2007 emission standards by 2012. This requirement applies to all trucks, including interstate trucks, which move containers into the South Coast Air Basin and beyond.

The California Air Resources Board (CARB) has implemented a Drayage Truck Regulation that requires by the end of 2009 that all pre-1994 engines be retired or replaced and all 1994 to 2008 engines must meet an 85% PM reduction. By the end of 2013 all drayage trucks must meet 2007 emission standards. This rule applies to all trucks with a gross vehicle weight rating of 33,000 pounds or more that move through port or intermodal rail yard properties for the purposes of loading, unloading or transporting cargo (*2*). In addition, CARB's Statewide Truck and Bus Regulations will phase-in most PM requirements between 2011 and 2014 and will phase in NO_x emission standards between 2013 and 2023 (*3*).

All of these regulations will dramatically alter the composition and emission standards of the current South Coast Air Basin's heavy-duty truck fleet. This despite comprising only 2% of the total on-road population and 4% of the vehicle miles travelled in California's South Coast Air Basin, HDDVs are estimated to account for 40-60% of particulate matter (PM) and oxides of nitrogen (NO_x) emissions in the on-road mobile inventory (*4, 5*).

Before advanced aftertreatment systems, control of NO_x and PM emissions were constrained relative to technologies that trade-off the control of these two pollutants (see

Figure 1). However, advanced control technologies expected to be deployed in the post-2007 timeframe for compliance with the U.S. EPA and CARB heavy-duty engine emission standards will not experience this trade-off. These advanced technologies will include a combination of diesel particulate filter, selective catalytic reduction, and advanced exhaust gas recirculation (EGR) control strategies. In addition, diesel fuel composition can play a role in emissions as well. The compositions are not studied in this research; however, by measuring sulfur dioxide (SO_2) emissions, we can infer the use of illegal high-sulfur fuels. Overall, understanding the expected impacts of future deployment of advanced emission control technologies will facilitate interpretation of data as it is generated throughout the course of this multi-year research project.

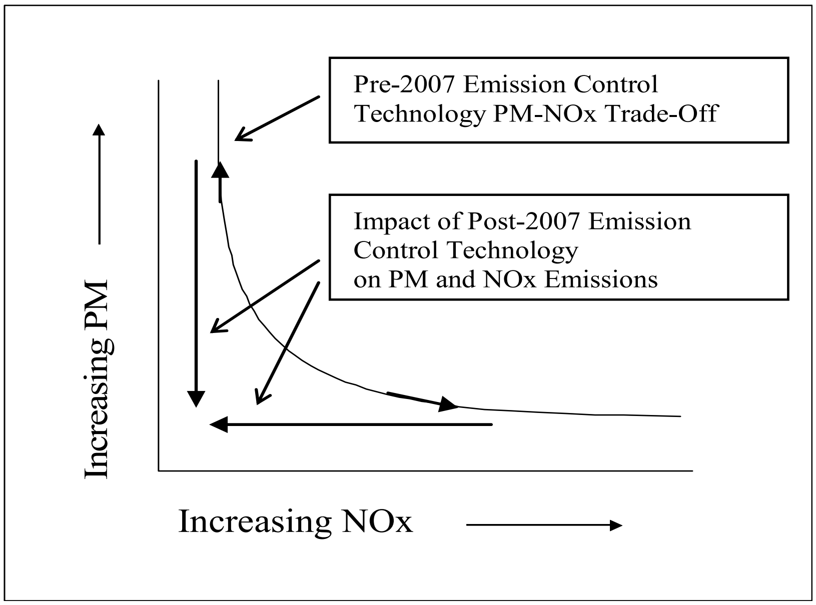

Figure 1. Relative relationship between NO_x and PM emissions in pre-control diesel engines (adapted from Heywood (*7*)). Particulate filters, advanced exhaust gas recirculation techniques and selective catalytic reduction systems change this relationship.

This research report specifically contains data from the first year of this multi-year study, to evaluate the impact on heavy-duty diesel emissions as stricter standards are being introduced into the on-road HDDV fleet. HDDV emissions were measured for two weeks in April 2008 at two locations in California's South Coast Air Basin. CO, HC, NO, NO_2, SO_2, NH_3, and opacity measurements were collected as ratios to their CO_2 reading by the University of Denver equipment. Environmental Systems Products (ESP), the makers of the commercial on-road remote sensor, also had an instrument collecting CO, HC, NO, and UV smoke data collected also as ratios to CO_2. Speed and acceleration data were also collected. The first year of the study serves mostly as a historical baseline for NH_3 emissions since NH_3 is a potential byproduct of future mechanisms to be used in reduction of PM and NO_x emissions.

The study will yield a large database of on-road heavy-duty diesel vehicle emissions for characterization of the fleet. The data collected will allow us to verify the extent to which these new standards are met, to identify trucks not complying with standards, to measure any increase in NH_3 emissions consequent with the new standards, and also to identify trucks that may be using illegal high-sulfur fuel by measurements of exhaust SO_2.

The research was performed under the interest and funding of the South Coast Air Quality Management District (SCAQMD) and the Department of Energy Office of Vehicle Technology through the National Renewable Energy Laboratory (NREL). Control measures to verify the HDDV emissions are typically performed at a special testing facility using a dynamometer. The implementation of remote sensing for this research, however, allows many more trucks to be tested in real-world driving conditions and is significantly cheaper than the dynamometer facility tests.

Experimental

Two remote sensing instruments were set up to measure emissions in a single lane from the elevated plumes of HDDV truck exhausts: RSD 4600 made by ESP and FEAT 3002 equipped with dual UV spectrometers from the University of Denver. The RSD 4600 is a dual beam instrument that consists of a non-dispersive infrared (NDIR) component for detecting CO, CO_2, HC and a dispersive ultraviolet (UV) spectrometer for measuring nitric oxide (NO) and smoke factor at similar wavelengths as those used by the FEAT.

The FEAT 3002 remote sensor used in this study was developed at the University of Denver for measuring the pollutants in motor vehicle exhaust, and has previously been described in the literature (*8 - 10*). The instrument consists of a NDIR component for detecting CO, CO_2, HC, and percent opacity, and two dispersive UV spectrometers for measuring nitric oxide (NO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and ammonia (NH_3). The source and detector units are positioned on opposite sides of the road in a bi-static arrangement. Collinear beams of infrared (IR) and UV light are passed across the roadway into the IR detection unit, and are then focused onto a dichroic beam splitter, which serves to separate the beams into their IR and UV components. The IR light is then passed onto a spinning polygon mirror, which spreads the light across the four infrared detectors: CO, CO_2, HC, and reference (opacity is determined by plotting reference vs. CO_2). The UV light is reflected off the surface of the beam splitter and is focused onto the end of a quartz fiber-optic cable, which transmits the light to dual UV spectrometers. The UV spectrometers are capable of quantifying NO, NO_2, SO_2, and NH_3 by measuring absorbance bands in the regions of 205 - 226 nm, 429 - 446 nm, 200 - 220 nm, and 200 - 215 nm, respectively, in the UV spectrum and comparing them to calibration spectra in the same regions.

The exhaust plume path length and density of the observed plume are highly variable from vehicle to vehicle, and are dependent upon, among other things, the height of the vehicle’s exhaust pipe, wind, and turbulence behind the vehicle. For these reasons, the remote sensor only directly measures ratios of CO, HC, NO, NO_2, NH_3, SO_2 to CO_2. Appendix A gives a list of the criteria for valid/invalid data. These measured ratios can be converted directly into g pollutant per kg of fuel. This conversion is achieved by first converting the pollutant ratio readings to the moles of pollutant per mole of carbon in the exhaust from the following equation:

$$\frac{\text{moles pollutant}}{\text{moles C}} = \frac{\text{pollutant}}{CO + CO_2 + 3HC} = \frac{(\text{pollutant}/CO_2)}{(CO/CO_2) + 1 + 6(HC/CO_2)} = \frac{(Q,2Q',Q'')}{Q+1+6Q'}$$

Next, moles of pollutant are converted to grams by multiplying by molecular weight (e.g., 44 g/mole for HC since propane is measured), and the moles of carbon in the exhaust are converted to kilograms by multiplying (the denominator) by 0.014 kg of fuel per mole of carbon in fuel, assuming the fuel is stoichiometrically CH_2. The HC/CO_2 ratio must use two times the reported HC because the equation depends upon carbon mass balance and the NDIR HC reading is about half a total carbon FID reading (*11*). Grams per kg fuel can be converted to g/bhp-hr by multiplying by a factor of 0.15 based on an average assumption of 470 g CO_2/bhp-hr (*12*).

The FEAT detectors were calibrated as external conditions warranted from certified gas cylinders containing known amounts of the species that were tested. This ensures accurate data by correcting for ambient temperature, instrument drift, etc. with each calibration. Because of the reactivity of NO_2 with NO and SO_2 and NH_3 with CO_2, three separate calibration cylinders are needed: 1) CO, CO_2, propane (HC), NO, SO_2, N_2 balance; 2) NO_2, CO_2, air balance; 3) NH_3, propane, balance N_2.

The FEAT remote sensor is accompanied by a video system to record a freeze-frame image of the license plate of each vehicle measured. The emissions information for the vehicle, as well as a time and date stamp, is also recorded on the video image. The images are stored on videotape, so that license plate information may be incorporated into the emissions database during post-processing. A device to measure the speed and acceleration of vehicles driving past the remote sensor was also used in this study. The system consists of a pair of infrared emitters and detectors (Banner Industries) which generate a pair of infrared beams passing across the road, six feet apart and approximately four feet above the surface. Vehicle speed is calculated from average of two times collected when the front of the tractors cab blocks the first and the second beam and the rear of the cab unblocks each beam. From these two speeds, and the time difference between the two speed measurements, acceleration is calculated, and reported in mph/s. These speed bars are also used to cue the detector to measure each truck plume when the beam is initially blocked. Appendix B defines the database format used for the data set.

This is the first year of the study to characterize HDDV emissions in the Los Angeles area. Measurements were made on five days at each site: Peralta weigh station in Anaheim and at the Port of Los Angeles in San Pedro, CA. The Peralta location was chosen in part because it has a history of previous measurements collected in 1997 that can be used for comparison (*13*). These data more than double the current database of all on-road HDDV emissions of SO_2, NH_3, and NO_2.

At the Peralta Weigh Station, measurements were made Friday, April 4, and from Monday, April 7, to Thursday, April 10 between the hours of 8:00 and 17:00 on the lane reentering Highway 91 eastbound (CA-91 E) after the trucks had been weighed. Measurements were not made on Saturday, April 5 and Sunday, April 6 because the weigh station was closed. This weigh station is just west of the Weir Canyon Road exit (Exit 39). A satellite photo showing the weight station grounds and the approximate location of the scaffolding, motor home and camera is shown in Figure 2. Figure 3 shows a close up picture of the measurement setup. The uphill grade at the measurement location averaged 1.8°. Appendix C lists the hourly temperature and humidity data collected at nearby Fullerton Municipal Airport.

At the Port of Los Angeles, measurements were made on Saturday, April 12, and from Monday, April 14 to Thursday, April 17 between the hours of 8:00 and 17:00 just beyond the exit kiosk where truckers had checked out of the port. Measurements were not made on Sunday, April 13 because the exit was closed. This location is just west of the intersection of West Water Street and South Fries Avenue. A satellite photo of the measurement location is shown in Figure 4 and a close up picture of the setup is shown in Figure 5. The grade at this measurement location is 0°. Appendix C lists the hourly temperature and humidity data collected at nearby Daugherty Field in Long Beach.

The detectors were positioned on clamped wooden boards atop aluminum scaffolding at an elevation of 13’3”, making the photon beam and detector at an elevation of 14’3” (see Figures 3 and 5). The scaffolding was stabilized with three wires arranged in a Y shape. A second set of scaffolding was set up directly across the road on top of which the transfer mirror module (ESP) and IR/UV light source (FEAT) were positioned. The light source for the RSD 4600 is housed with the detector in the instrument and is shone across the road and reflected back. Behind the detector scaffolding was the University of Denver’s mobile lab housing the auxiliary instrumentation (computers, calibration gas cylinders and generator). Speed bar detectors were attached to each scaffolding unit which reported truck speed and acceleration. A video camera was placed down the road from the scaffolding, taking pictures of license plates when triggered by the speed bars.

At the Peralta weigh station, detection took place on the single lane at the end of the station where trucks were reentering the highway. Most trucks were traveling between 10 and 20 mph in an acceleration mode to regain speed for the upcoming highway merger.

The Port of Los Angeles testing site was located at an exit near the intersection of Fries Avenue and Water Street near Wilmington, CA. The exit has three lanes allowing trucks to leave (one reserved for bobtails) and our equipment was set up in Lane #1 where most trucks exited. The location saw significantly less traffic than the Peralta weigh station and trucks were accelerating from a dead stop generally not reaching speeds higher than 5 mph. This was because the ideal set up location for equipment was only about 30 feet down the road from a booth where trucks stopped to check out of the Port.

Results and Discussion

The five days of data collection using the University of Denver FEAT remote sensor at the Peralta weigh station resulted in 3067 license plates that were readable. Plates were not read for the ESP equipment. While California plated trucks constituted the large majority of the trucks measured, there were 518 measurements from trucks registered

Figure 2. A satellite photo of the Peralta weigh station located on the Riverside Freeway (91). The scales are located on the inside lane next to the building in the top center and the outside lane is for unloaded trucks. The measurement location is circled at the upper right with approximate locations of the scaffolding, support vehicle and camera.

Figure 3. Photograph at the Peralta Weigh Station of the setup used to detect exhaust emissions from heavy-duty diesel trucks.

Figure 4. A satellite photo of the Port of Los Angeles Water St. exit. The measurement location is circled in the lower left with approximate locations of the scaffolding, support vehicle and camera.

Figure 5. Photograph at the Port of Los Angeles of the setup used to detect exhaust emissions from heavy-duty diesel trucks.

outside of California. Table 2 details the registration, the total measurements and the number of unique trucks they represent. License plates were matched for California, Arizona, Oklahoma and Illinois trucks. We had desired to match plates from the four largest out of state fleets (they represent almost half of the out of state measurements) but to date have been unable to accomplish this task in Indiana.

Table 2. Distribution of Identifiable Peralta License Plates.

State / Country	Readable Plates	Unique Plates	Matched Unique Plates	Total Measurements
Alabama	2	2	0	0
Arkansas	2	2	0	0
Arizona	40	40	40	40
California	2549	1982	1925	2489
Colorado	5	5	0	0
Florida	7	7	0	0
Georgia	2	2	0	0
Iowa	21	21	0	0
Idaho	4	4	0	0
Illinois	49	49	49	49
Indiana	99	95	0	0
Kansas	3	3	0	0
Louisiana	2	2	0	0
Michigan	11	11	0	0
Minnesota	11	12	0	0
Missouri	13	13	0	0
Montana	8	8	0	0
North Dakota	2	2	0	0
Nebraska	3	3	0	0
New Jersey	6	6	0	0
Nevada	5	5	0	0
New York	3	3	0	0
Ohio	22	22	0	0
Oklahoma	55	54	50	51
Oregon	18	18	0	0
Pennsylvania	2	2	0	0
Tennessee	17	17	0	0
Texas	35	35	0	0
Utah	27	27	0	0
Virginia	1	1	0	0
Vermont	1	1	0	0
Washington	21	21	0	0
Wisconsin	1	1	0	0
Wyoming	1	1	0	0
Canada	25	25	0	0
Totals	3073	2502	2064	2629

Data collected during the five days of measurements using the University of Denver FEAT remote sensor at the Port of LA site resulted in 1462 license plates that were readable. Again the plates were not read for the ESP equipment. There were only 18 out of state plated trucks measured at the port. Table 3 details the registration, the total measurements and the number of unique trucks measured. License plates were matched for the California and Arizona vehicles.

Table 3. Distribution of Identifiable Port of Los Angeles License Plates.

State	Readable Plates	Unique Plates	Unique Matched Plates	Total Measurements
Arizona	7	7	7	7
California	1444	817	808	1429
Colorado	6	6	0	0
Indiana	2	2	0	0
Oregon	1	1	0	0
Texas	1	1	0	0
Utah	1	1	0	0
Totals	1462	835	815	1436

Table 4 provides a data summary of the previous and current measurements that have been collected at the two measurement sites. Since 1997 large reductions in CO (38%) and HC (46%) are observed while the measured NO emission reductions are smaller at 15%. License plates were not read and matched during the 1997 measurements so we are unable with any certainty to comment on how the fleet changes during the past eleven years may have contributed to these reductions. The cumulative NO emission distribution has become slightly more skewed since 1997 (see Figure 6) and reflects the observed decreases in NO.

Table 5 provides a data summary comparison of the California plated trucks against the matched out of state trucks measured at the Peralta weigh station and compares their age and emission measurements. To simplify this comparison we required a valid measurement for each species so that the numbers of vehicles are consistent across all of the columns. The small sample of out of state trucks are almost 3.5 chassis model years newer with all but the mean gSO_2/kg emissions being lower and that difference is not statistically significant.

Fleet composition and driving mode are noticeably different between the two sites sampled in 2008. The Port of Los Angeles locations fleet is almost five years older and the measurements observe what is often referred to as creep mode. This is a high load, low speed acceleration as the trucks move away from the check out gate. Figure 7 shows the fleet fractions (calculated by dividing the number of HDDV in each model year by the total number of HDDV vehicles in the database for that location) as a function of model year for Peralta and the Port. The 1989 model year category combines all 1989 and older model years. At the Port these vehicles are 9.5% of the measurements and are responsible for 7% of the observed NO_x. At Peralta these vehicles are only 4.1% of the

Table 4. Peralta Weigh Station and Port of Los Angeles FEAT Data Summary.

Location Study Year	Peralta 1997	Peralta 2008	Port of LA 2008
Mean CO/CO_2 (g/kg of fuel)	0.008 (16.1)	0.005 (10.0)	0.006 (12.7)
Median gCO/kg	9.3	6.7	10.6
Mean HC/CO_2 (g/kg of fuel)	0.0008 (5.0)	0.0004 (2.7)	0.0009 (5.3)
Median gHC/kg	3.7	2.1	4.2
Mean NO/CO_2 (g/kg of fuel)	0.009 (19.2)	0.008 (16.4)	0.013 (27.1)
Median gNO/kg	18.0	15.2	24.8
Mean SO_2/CO_2 (g/kg of fuel)	NA	0.00006 (0.26)	0.00004 (0.18)
Median gSO_2/kg	NA	0.22	0.16
Mean NH_3/CO_2 (g/kg of fuel)	NA	0.00003 (0.03)	0.00001 (0.02)
Median gNH_3/kg	NA	0.02	0.02
Mean NO_2/CO_2 (g/kg of fuel)	NA	0.0006 (2.1)	0.001 (3.9)
Median gNO_2/kg	NA	1.6	3.4
Mean gNO_x/kg	NA	27.3	45.4
Median gNO_x/kg	NA	25.2	41.7
Mean Model Year	NA	2000.4	1995.6
Mean Speed (mph)	NA	13.4	<5
Mean Acceleration (mph/s)	NA	1.1	NA
Mean VSP (kw/tonne)	NA		
Slope (degrees)	1.8°	1.8°	0°

measurements and account for 5.3% of the total NO_x. These vehicles have been targeted for removal as part of the San Pedro Bay Ports Clean Air Action Plan as of October 2008.

Figure 8 plots mean gNO_x/kg emissions versus model year and show a downward trend with newer trucks at both sites. The data from the Port are noisier due to fewer measurements though the mean gNO_x/kg emissions are statistically higher than at Peralta. Uncertainty bars represent standard errors of the mean calculated using the daily emission values at each site. Figure 9 plots the cumulative fraction of NO_x emissions against the fraction of the fleet. This plot shows that the NO_x emissions distribution is nearly identical between the two sites despite the fact that the NO_x emissions at the Port are 40% higher. This suggests that driving mode is likely the major influence in the increased NO_x emissions observed with the trucks operating at the Port sampling site.

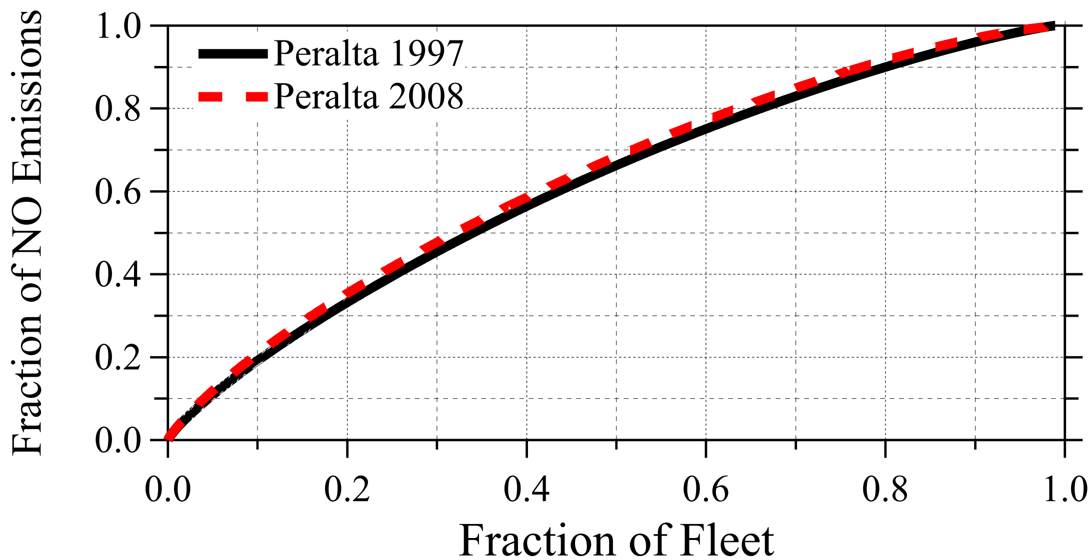

Figure 6. Cumlative NO emissions plotted versus the fraction of the truck fleet for the 1997 and 2008 Peralta weigh station measurements. Slight increases at 10% of the fleet and 50% of the fleet indicated a slight increase in the skewedness of the emission distribution as emissions have decreased during the last eleven years.

Table 5. Peralta emission summary comparison for California and out-of-state plated trucks.

State	Trucks	Mean gCO/kg	Mean gHC/kg	Mean gNO/kg	Mean gNO_2/kg	Mean gNO_x/kg	Mean gSO_2/kg	Mean gNH_3/kg	Mean Model Year
CA	2487	10.0	2.8	16.6	2.1	27.6	0.3	0.03	2000.2
Other	140	9.2	2.0	13.2	1.6	21.8	0.3	0.02	2003.7
Δ		8.7%	40%	25.8%	31.3%	26.6%	0%	33%	-3.5

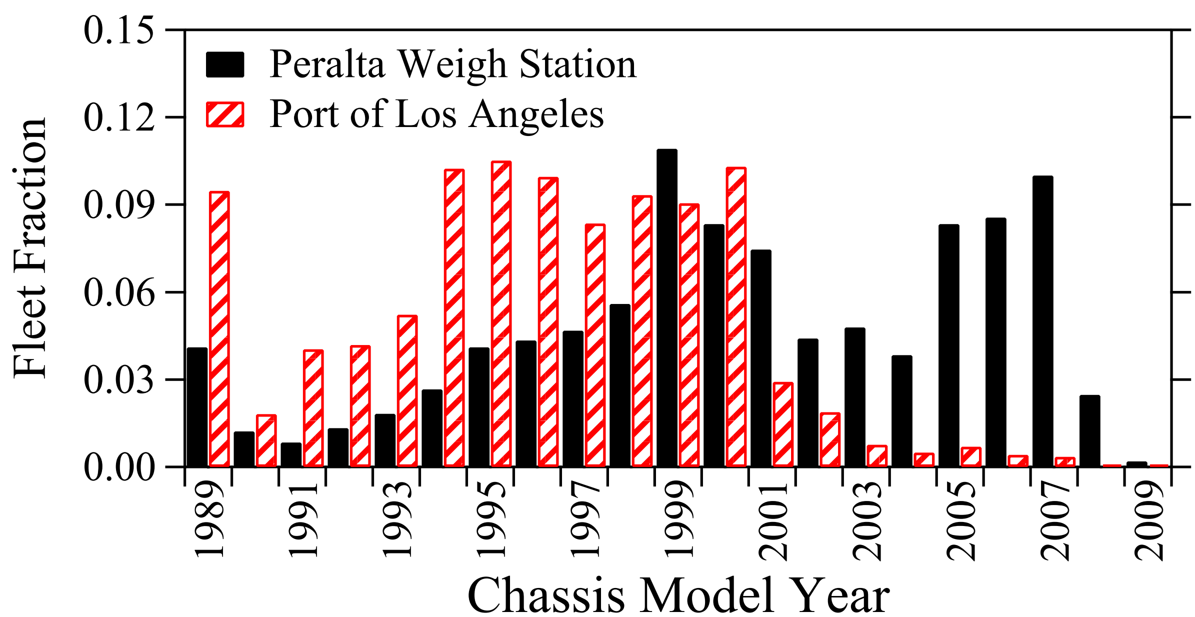

Figure 7. Fleet fractions versus model year for the Peralta weigh station and the Port of Los Angeles. The 1989 model year grouping combines all 1989 and older model year vehicles into the last category.

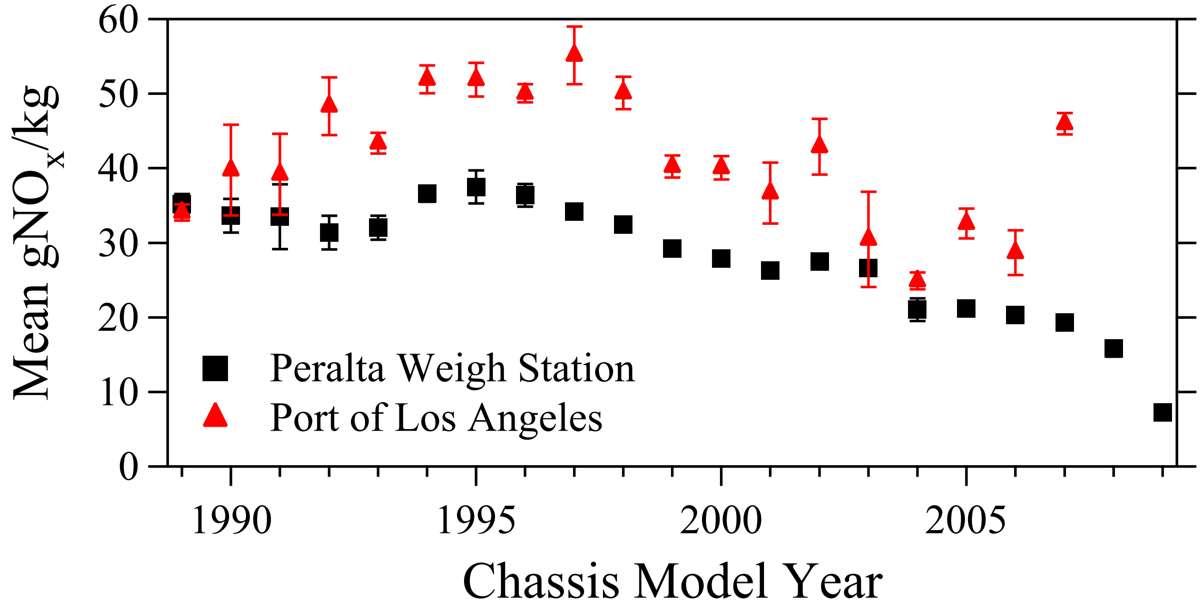

Figure 8. Comparison of NO_x emissions between the two sites. Emissions are higher at the Port, possibly due to the lower speed driving mode observed. Uncertainty bars represent standard errors of the means. There were only five 2007 trucks measured at the port.

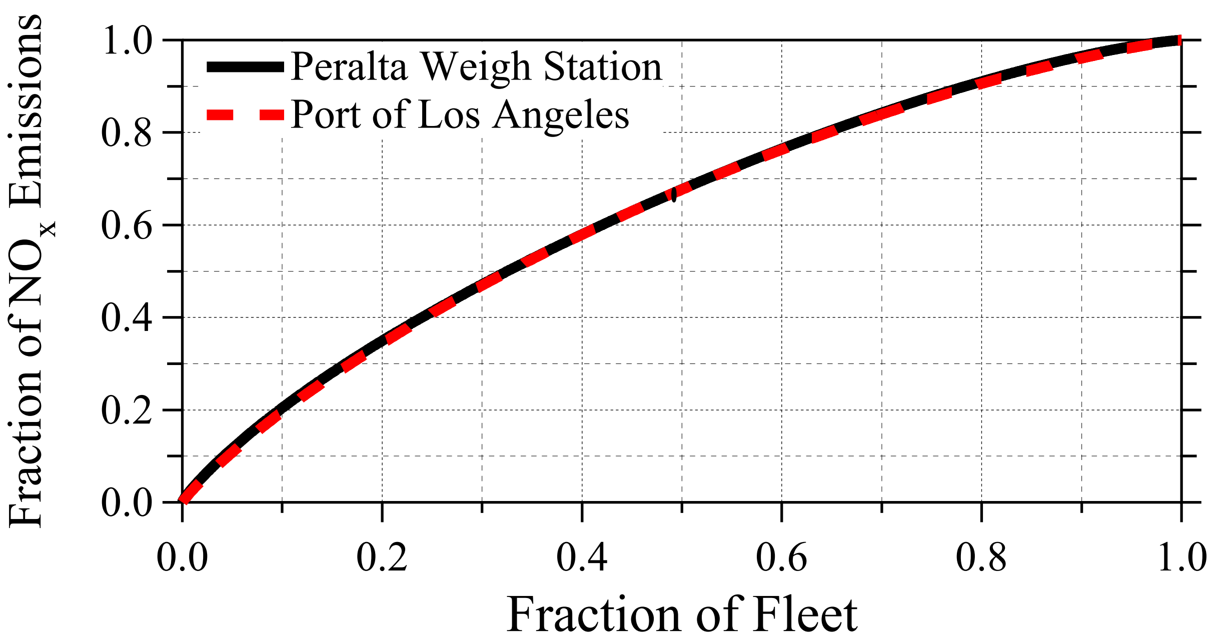

Figure 9. Cumlative NO_x emissions plotted versus the fraction of the truck fleet for the 2008 Peralta weigh station and Port of Los Angeles measurements. The nearly identical lines indicate similar shapes of the two emission distributions.

A comparison with the only previously published on-road HDDV measurements (N=1532) obtained by Burgard et. al. in 2005 in Golden and Dumont, CO shows that NO_x levels of trucks measured at Peralta and the Port are lower for the same model years (see Figure 10) despite the California vehicles being 3 years older for the same model year(*14*). Dumont and Peralta are both Interstate weigh stations with similar road grades and driving modes. The driving mode at Golden is a low speed cruise mode that falls somewhere between Peralta and the Port driving modes. This may potentially be explained by the lower altitudes, lower sulfur levels of diesel fuel several years later or better maintenance of trucks in California. Also, these data are representative of a continuation of the downward trend of NO_x emissions, however, if the current trend were to continue it would not drop to the 0.2 g/bhp-hr NO_x (translates to approximately 1.3g/kg, see earlier discussion) standard mandated by the EPA for full compliance by 2010 without drastic changes in the NO_x reduction methods. The low MY 2009 data point represents only five measurements of four different trucks which were returned from plate matching as 2009 model year tractors. These limited data may represent the onset of a steep downward trend of new vehicles towards the EPA standard.

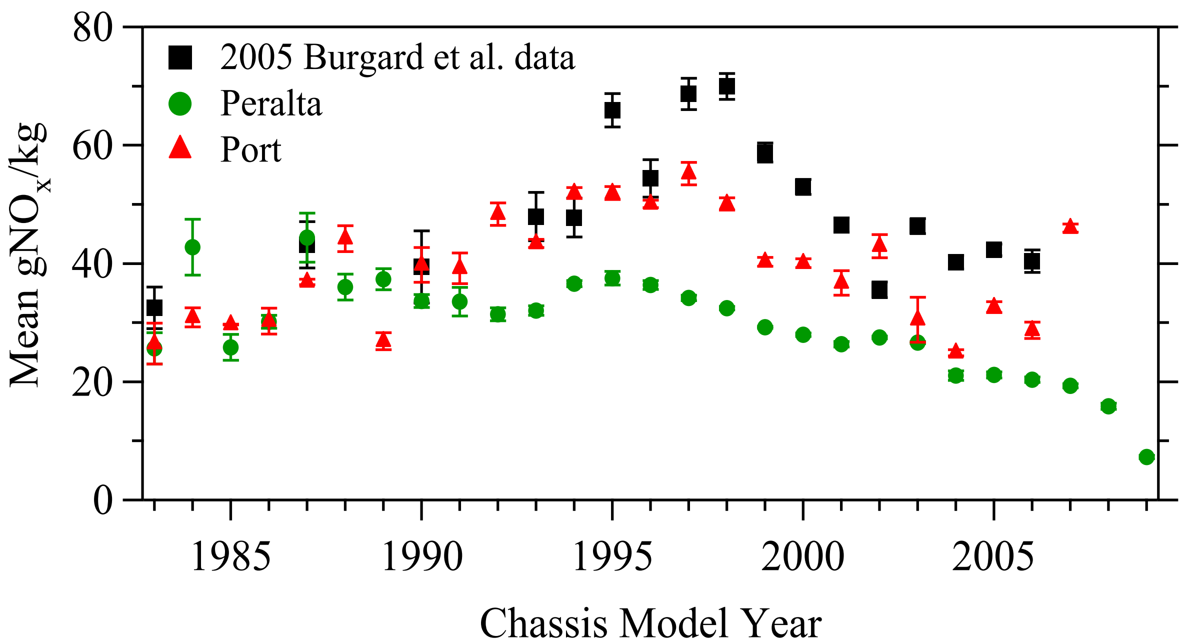

Figure 10. Comparison of NO_x data from Burgard (*11*) for 1532 diesel exhaust measurements in Dumont, CO and Golden, CO against the data collected at the two sites from this study. Uncertainty bars represent standard errors of the means and the ages of the Colorado vehicles are 3 years younger for the same model years.

The National and California emission regulations that have targeted major reduction in particulate emissions have forced the introduction of diesel particulate filters (DPF). Since these filters physically trap the particles they require a mechanism to oxidize the trapped particles to keep the filter from plugging. One approach used to date has been to install an oxidation catalyst upstream of the filter and use it to convert engine out NO emissions to NO_2. NO_2 is then capable of oxidizing the trapped particles to regenerate the filter and is able to accomplish this at lower temperatures than is possible with other molecules. However, if the production of NO_2 is not controlled well it can lead to an increase in tailpipe emissions of NO_2, an important precursor molecule in urban ozone formation chemistry (*15*).

European experiences with DPF's have shown a correlation with increases in urban NO_2 emission (*16*). California has codified this concerned by passing several rules that limit any increases in NO_2 emissions from the uncontrolled engine baseline emissions for retrofit DPF devices (*17*). Nationally new vehicle manufactures are only constrained with a total NO_x standard that does not differentiate between NO and NO_2 emissions. Traditionally diesel exhaust NO_2 has comprised less than 10% of the tailpipe NO_x emissions, however we would expect this ratio to increase in the new and retrofitted trucks. Figure 11 presents, for the first time in the USA, on-road data for NO_2/NO_x of HDDV emissions by model year. Nearly the entire fleet of the newest trucks (model year 2008 and 2009), from which there are only 59 records (only 5 from MY 2009) at Peralta, have been fitted with one of these PM-reducing devices in accordance with the new EPA standards. The result is an observed increase in the NO_2/NO_x ratio in line with the expectation of increased emissions of NO_2.

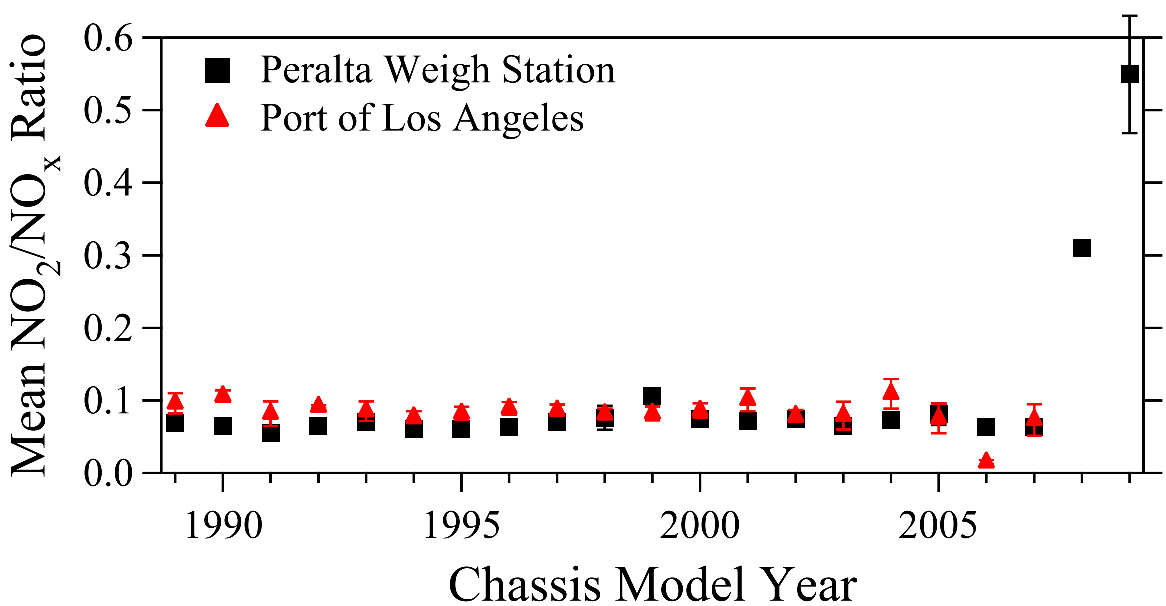

Figure 11. Ratio of NO_2/NO_x vs. model year for HDDV's at each site. New technologies implemented to meet new EPA standards yield higher proportions of NO_2 in MY 2008 and 2009 trucks. Uncertainties are standard errors of the mean and the 1989 model year contains 1989 and older model years.

As the diesel particulate filters are being phased into the fleet we would expect to observe large reductions in particulate emissions. Figure 12 graphs the particulate emissions recorded by the two remote sensing systems at Peralta (the Port data is lacking any vehicles new enough to be equipped with DPF filters). The FEAT system measures

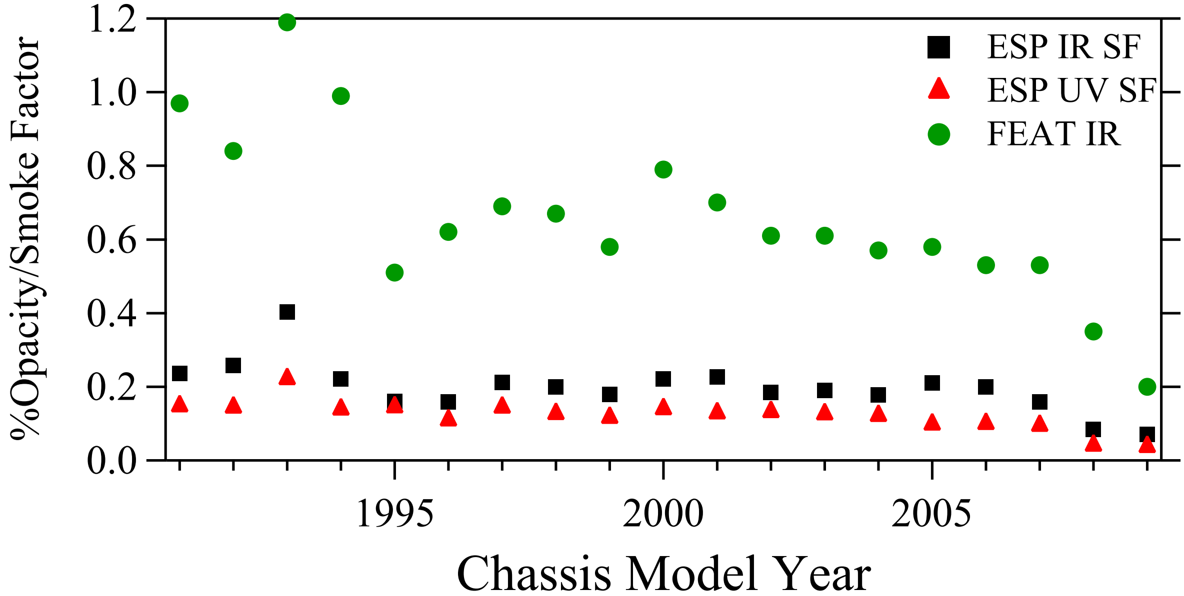

Figure 12. Peralta smoke measurements as a function of model year for the two remote sensing systems. The FEAT reports a %Opacity from the infrared and the ESP system reports a smoke factor from the infrared and the ultraviolet.

%opacity in the infrared while the RSD 4600 reports a smoke factor value in both the infrared and the ultraviolet. A UV smoke factor for 0.1 is equivalent to 1 gram of Soot per kilogram of fuel. As seen in Figure 12 large reductions are observed with both systems beginning with the 2008 model chassis's. Figure 13 shows the cumulative smoke emission distributions for the three metrics and indicates that the overall emissions distribution for smoke at Peralta is not heavily skewed towards high emitters.

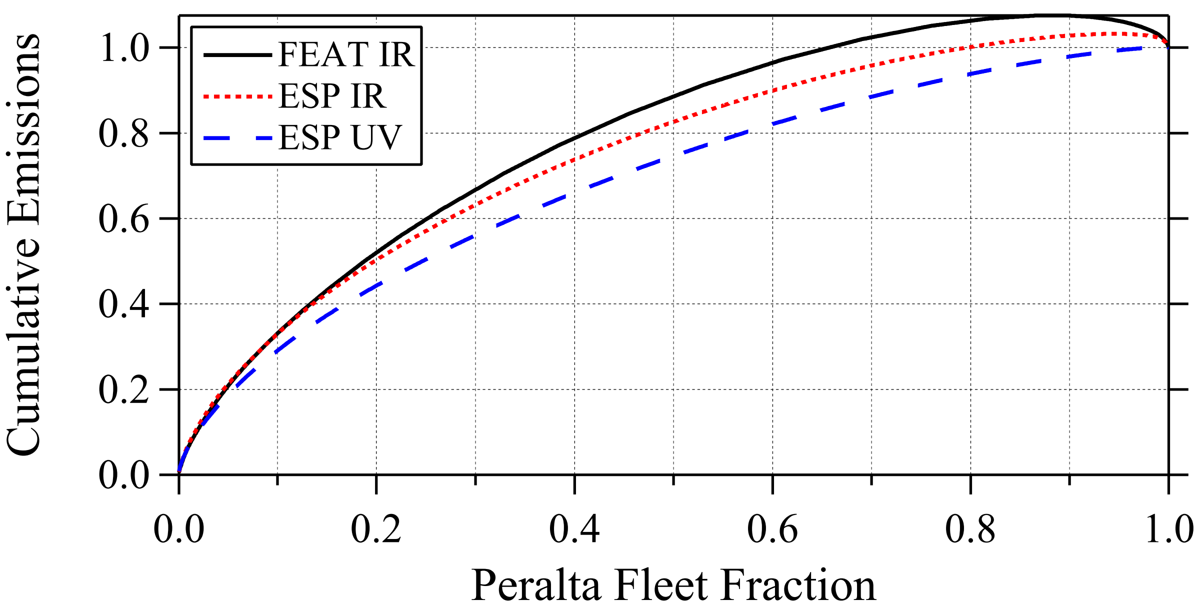

Figure 13. Matched emission data sets from Peralta for the FEAT and ESP 4600 plotting the cumulative total emission for the infrared and ultraviolet smoke measurements. The fact that 10% of the fleet accounts for approximately 30% of the smoke emissions indicates that the distributions are only slightly skewed.

Another goal of the research was to quantify ammonia emissions over the five-year period. Ammonia is a potential byproduct of methods to be implemented to reduce NO_x and PM emissions in diesel trucks in order to meet the EPA standards. Since the standards are not yet in full effect, and NO_x emissions are clearly still above the 0.2 g/bhp-hr mark, there should be a very small contribution to total ammonia emissions by HDDV's. In a recent study on light-duty vehicles, Peddle found that the mean ammonia emitted by California cars is 0.49 g/kg (*18*). These emissions come about as a by-product of NO reduction by three-way catalysts in the light-duty vehicles which have no HDDV equivalent. With the forthcoming NO_x reductions in diesel trucks, ammonia may be seen in higher concentrations over the next five years and the ammonia data presented in Figure 14 show the current averages by model year. The small ammonia emission levels mostly fall within the uncertainty bounds between the two sites. The total average for these emissions is a negligible 0.03 g/kg; significantly lower than that (0.49 g/kg) of light-duty vehicles which are currently responsible for the bulk of ammonia emissions.

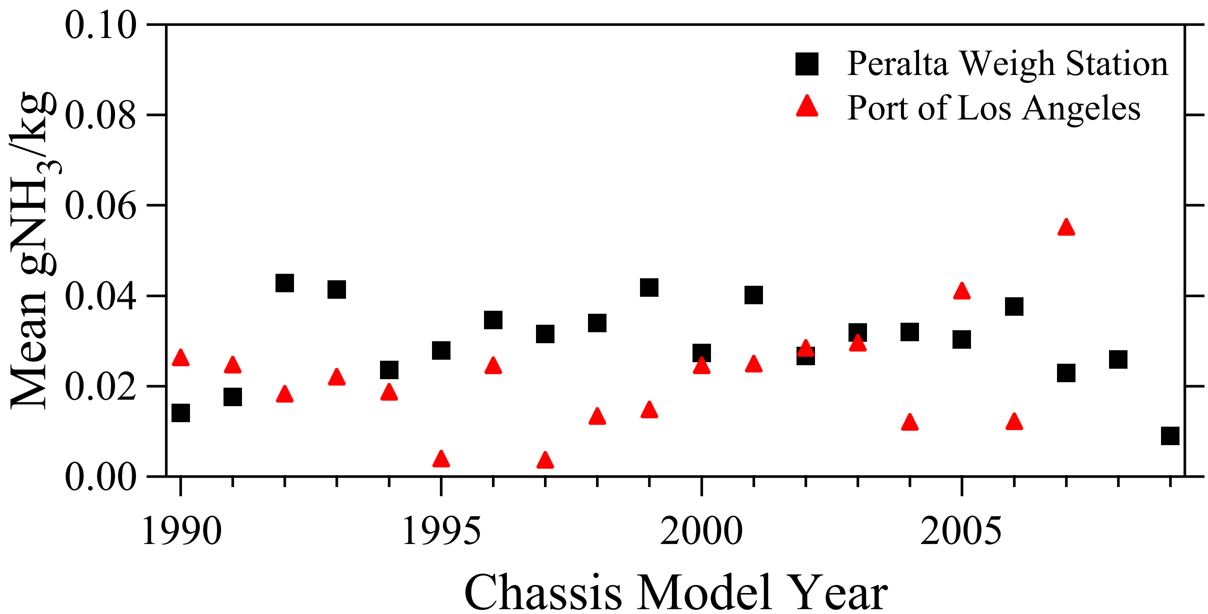

Figure 14. Mean ammonia emissions vs model year for the Peralta and Port of Los Angeles sites. The overall average of 0.03 g/kg is well below the light duty contributions of this molecule.

A brief study of SO_2 emissions shows that the average for HDDV's is 0.22 g/kg, considerably less than the results from a study by Burgard et al. reporting 0.85 g/kg and 0.83 g/kg for diesel vehicles at Dumont and Golden, CO sites, respectively (*14*). This is almost certainly due to the increased prevalence of 15 ppm ultra-low sulfur diesel fuel as required by law in North America in September, 2006 (*19*). Emissions as a function of model year are plotted in Figure 15. The large variability observed with the Port measurement is in large part due to a few trucks with extremely high SO_2 (>7 g/kg) emissions. Figure 16 is a scatter plot of all of the valid measurements from both locations. In this format it is easy to spot the outliers and the enlarged triangles signify repeat measurements on the same truck. One of these trucks was measured four different

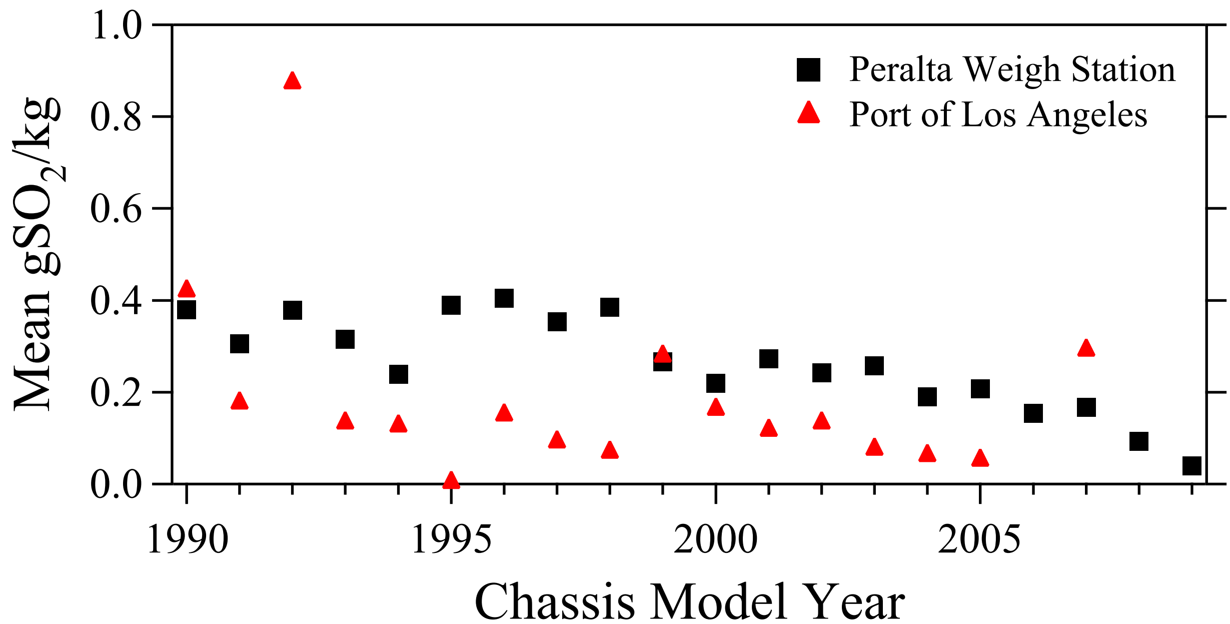

Figure 15. Average SO_2 data by model year for all trucks measured. Four separate measurements of one high SO_2-emitting truck account for the large variability of model year 1992 measurements.

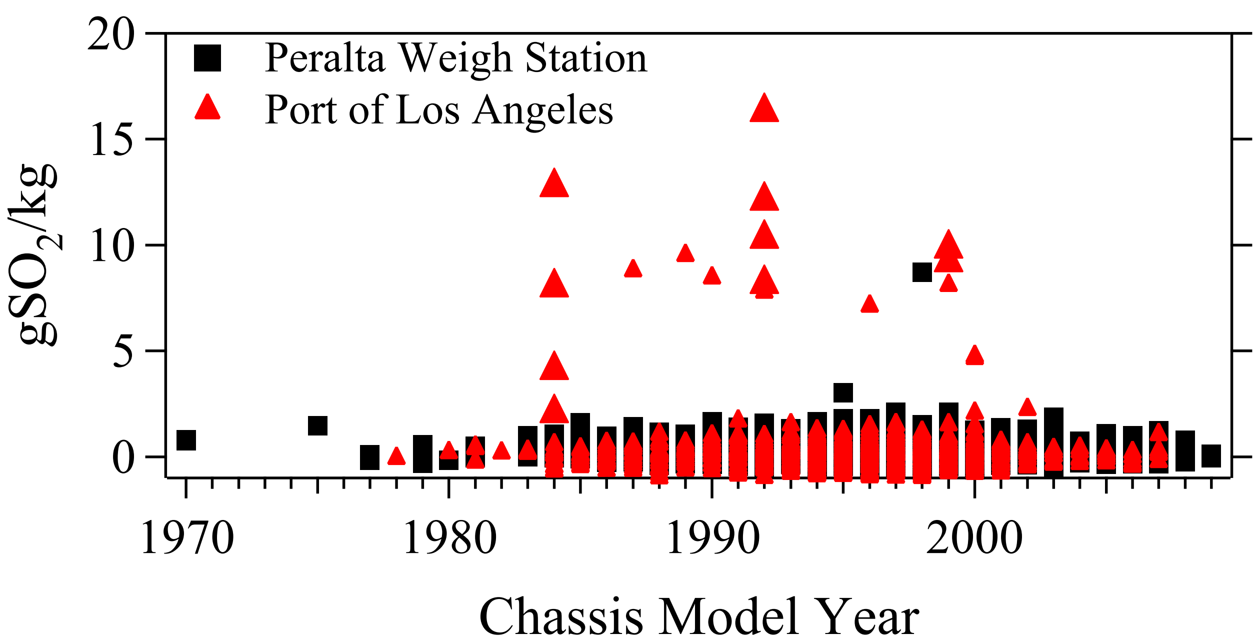

Figure 16. Individual SO_2 emissions by model year. The scatter plot shows several outliers believed to be violating sulfur diesel fuel standards. The large triangles show repeat measurements on the same truck. There was only one instance of an extremely high emitter at the Peralta weigh station despite the fact that more than double the numbers of trucks were measured.

times on two different days with >7 g/kg SO_2 levels. This truck alone accounts for the large variability in model year 1992 SO_2 emissions. These trucks likely are using some form of high-sulfur fuel either obtained locally (marine or off-road) or from Mexico. At the time of these measurements retail prices for low sulfur diesel fuel in California were around $4/gal. In Mexico diesel was going for about half this price. The 15 ppm ultra-low sulfur fuel translates to 0.03 g/kg which means the outliers reached [SO_2] levels equivalent to 5000 ppm (10 g/kg) of fuel sulfur (*14*). Burgard's study noted approximately 20 high-sulfur emitters out of 1532 readings, although none greater than 5 g/kg. Appropriate authorities may be interested in using the Port of L.A. data to identify owners of these gross-SO_2 emitting trucks to take fuel samples for potential legal action against them.

Using only the California plated trucks we undertook a task of matching emission measurements on trucks captured by both remote sensing devices. Each day's database was compared, using the recorded pictures, to determine the time differences between the two data sets. After determining this difference it was possible to time align the two measurement sets to within ± 1 seconds for the entire days data. The readings were then manually matched with each other and any questionable matches were resolved using the video images.

Figures 17 and 18 graphically compare the two time-aligned databases for CO, HC and NO with the line plotted being a least squares best fit through the data points. The equation included provides the slope and intercept for the least squares line. At Peralta there are 1851 matched measurements and at the LA Port there are 965 matched measurements. The data collected at the Port have noticeably more noise that the measurements collected at Peralta and this is likely a consequence of the low speed driving mode observed at the Port. In addition you will notice that there are a number of negative readings reported by the FEAT while the ESP equipment has few if any negative readings. This is a result of the two different ways that the remote sensors calculate the emission ratios. The FEAT determines the emission ratios from a least squares line fit through the correlated emissions plume data. Fits close to zero will always have positive and negative results. The ESP equipment on the other hand uses an integral method where each species plume data is summed and then the ratios are calculated from these sums. This method rarely produces negative results.

Generally only the NO measurements have enough spread to lend themselves to being compared. While the noise is greater for the NO data collected at the Port both data sets have a similar slope with the ESP instrument consistently reporting lower NO emissions when compared with the FEAT measurements. Keep in mind that we did not try to collocate the two remote sensing beams and as such some disagreement because of differences in driving mode will be unavoidable. However, the systematic underreporting of NO by the ESP equipment appears to be much larger than one would expect a driving mode difference to produce.

While there are major operational differences between FEAT and the RSD 4600 they both basically operate as comparators that compare the ratios of a standard gas cylinder

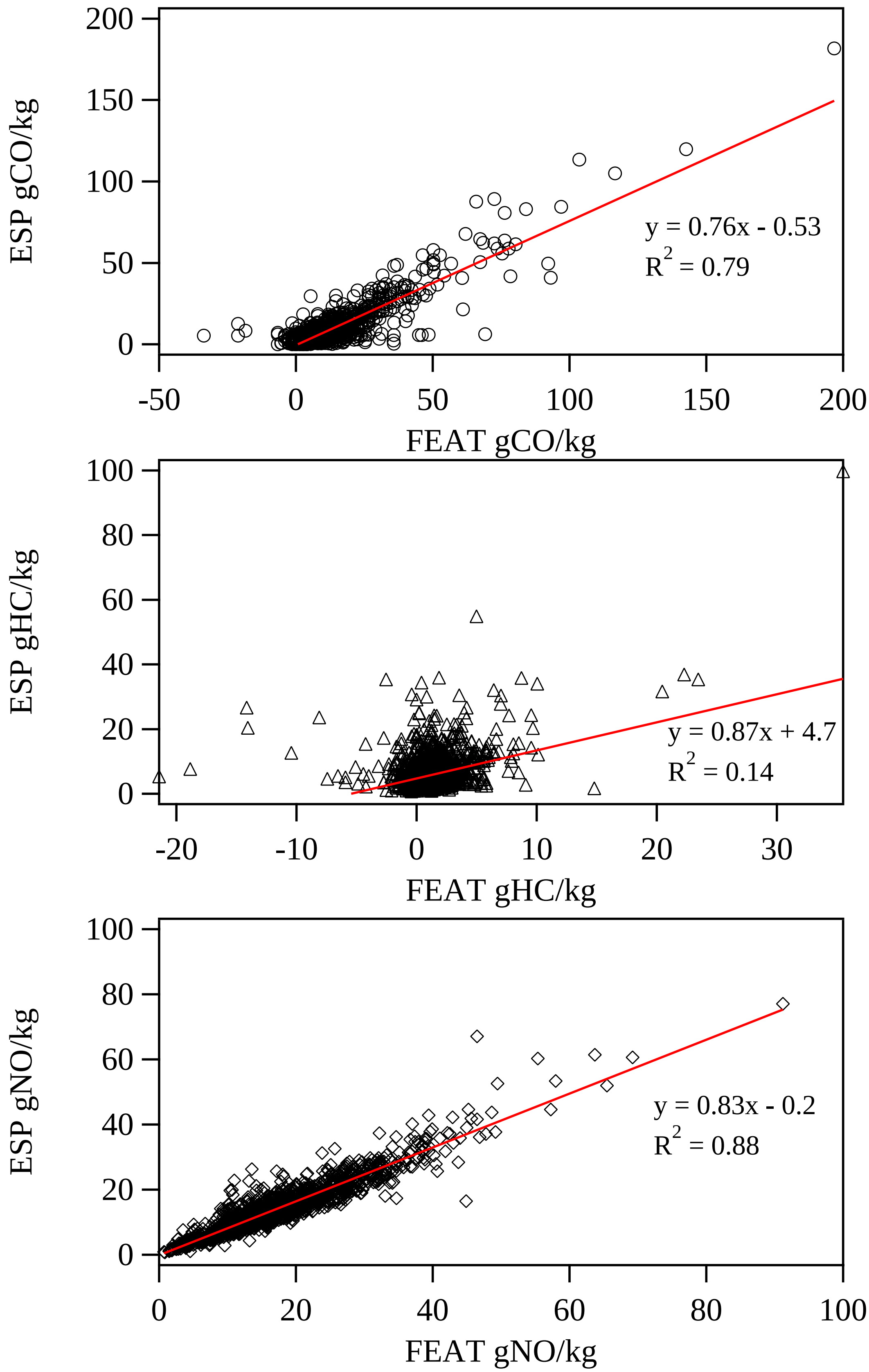

Figure 17. 1851 time aligned emission measurements for CO, HC and NO collected at the Peralta weigh station by the two remote sensing systems. A least squares best fit line is plotted for each and the equation for that line is included.

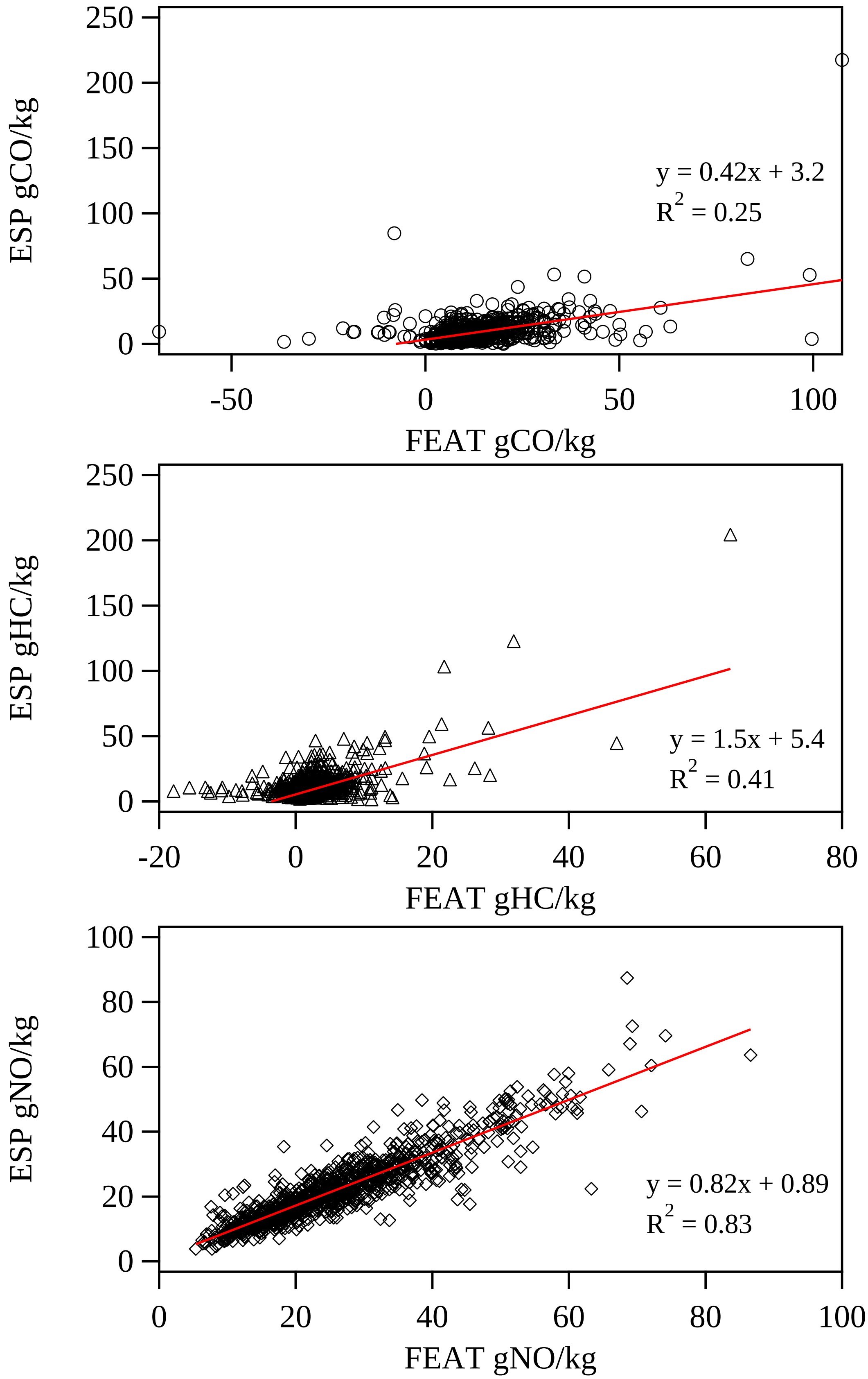

Figure 18. 965 time aligned emission measurements for CO, HC and NO collected at the LA Port by the two remote sensing systems. A least squares best fit line is plotted for each and the equation for that line is included.

with the ratios measured from the passing trucks. Since the systematic difference between the two instruments was observed in the field at Peralta it was decided to compare the two calibration cylinders at the LA Port. It was a simple matter to use ESP's bottle on the FEAT instrument and using the Port setup we first used the FEAT to measure its calibration bottle and then we repeated measurements on the ESP bottle. Both cylinders were products of Scott Specialty Gases and Table 6 details those measurements.

Table 6. Results of using the FEAT remote sensor to compare calibration cylinders

	FEAT Cylinder			ESP Cylinder		
	CO/CO_2	HC/CO_2	NO/CO_2	CO/CO_2	HC/CO_2	NO/CO_2
	1.36	0.130	0.046	0.569	0.01514	0.02
	1.40	0.132	0.053	0.524	0.014	0.019
	1.47	0.137	0.05	0.519	0.0137	0.019
	1.33	0.124	0.049	0.515	0.0137	0.02
	1.37	0.129	0.05	0.510	0.0138	0.02
				0.524	0.0132	0.02
Mean	1.386	0.1304	0.0496	0.527	0.0139	0.0197
Bottle Ratio	1	0.0996	0.0499	0.336	0.01	0.0168
Cal Factor	1.39	1.31	0.99	1.57	1.39	1.17
Percent Difference				+13.1	+6.3	+17.8

The procedure was to simply puff each bottle into the FEAT's light path and record the ratio that it measured. Then average each set of readings and ratio that to the reported ratios in the calibration cylinders producing a calibration factor that would normally be used to compare that bottle to the exhaust measurements being made from the trucks. Ideally each cylinder would produce approximately the same calibration factors. The fact that the ESP cylinder calibrations are all larger relative the FEAT bottle indicates that the two certified cylinders do not agree on their contents and that FEAT would underreport each ratio if the ESP bottle was used for calibration. From this comparison it is impossible to say which bottle is off but the disagreement between the two bottles NO/CO_2 ratios possibly explains the observed differences between the comparisons of truck emissions with the two remote sensors.

Acknowledgements

The successful outcome of this project would not be possible without the financial support of the National Renewable Energy Laboratory under sub contract number AEV-8-88609-01 and the South Coast Air Quality Management District under contract number 08230. Additionally we want to acknowledge the assistance of Sgt. Rod Strate, Officers Ron Jordon and Josh Sarinas of the California Highway Patrol and Joseph J. Francis III and Paul Richey of TraPac. Comments from the various reviewers of this report were also invaluable.

References

1. USEPA Highway Diesel Progress Review, 2002, http://www.epa.gov/oms/highway-diesel/compliance/420r02016.pdf.
2. California Code of Regulations, Title 13, Section 2027, 2008.
3. California Code of Regulations, Title 13, Section 2025, 2008.
4. 2006 Estimated Annual Average Emissions: Statewide. http://www.arb.ca.gov/ei/emissiondata.htm, California Air Resources Board, 2007.
5. Harley, R.A.; Marr, L.C.; Lehner, J.K.; Giddings, S.N. *Environ. Sci. Technol.*, **2005**, *39*, 5356-5362.
6. McCormick, R. L.; Ross, J. D.; Graboski, M. S. *Environ. Sci. Tech.*, **1997**, *31*, 1144-1150.
7. Heywood, J. B. Internal Combustion Engine Fundamentals, McGraw-Hill Publishing: New York, p. 866, 1988.
8. Bishop, G.A.; Stedman, D.H. *Acc. Chem. Res.* **1996**, *29*, 489.
9. Popp, P.J.; Bishop, G.A.; Stedman, D.H. *J. Air & Waste Manage. Assoc*. **1999**, *49*, 1463.
10. Burgard, D.A.; Dalton, T.R.; Bishop, G.A.; Starkey, J.R.; Stedman, D.H. *Rev. Sci. Instrum.* **2006**, *77*, 014101.
11. Singer, B.C.; Harley, R.A.; Littlejohn, D.; Ho, J.; Vo, T. *Environ. Sci. Technol.* **1998**, *32*, 3241.
12. Broering, L. C. *Diesel Engine Emissions Reduction History and Future Prospects*, Cummins Engine Company, Presentation at the National Conference of State Legislatures, 1997.
13. Bishop, G.A.; Morris, J.A.; Stedman, D.H.; Cohen, L.H.; Countess, R.J; Countess, S.J.; Maly, P.; Scherer, S. *Environmental Science & Technology*, **2001**, *35*, 1574-1578.
14. Burgard, D. A.; Stedman, D. S.; Bishop, G. A. *Environmental Science & Technology*, **2006**, *40*, 7018-7022.
15. Stedman, D.H. *Environ. Chem.*, **2004**, *1*, 65-66.
16. Lemaire, J. *Österreichische Ingenieur und Architekten-Zeitschrift*, **2007**, *152*, 1-12, http://www.feat.biochem.du.edu/library/Lemaire_2007.pdf.
17. California Code of Regulations, Title 13, Section 2702(f) and 2706(a), 2003.
18. Peddle, A. M. M. Sc. Thesis, University of Denver, Denver, CO 2008.
19. USEPA 2007 Highway Rule, http://www.epa.gov/otaq/highway-diesel/index.htm.

APPENDIX A: FEAT criteria to render a reading “invalid”.

Invalid :

1) insufficient plume to rear of vehicle relative to cleanest air observed in front or in the rear; at least five, 10ms >160ppmm CO_2 or >400 ppmm CO. (0.2 %CO_2 or 0.5% CO in an 8 cm cell. This is equivalent to the units used for CO_2 max.). For HDDV’s this often occurs when the vehicle shifts gears at the sampling beam.

2) excessive error on CO/CO_2 slope, equivalent to $\pm$20% for CO/CO_2 > 0.069, 0.0134 CO/CO_2 for CO/CO_2 < 0.069.

3) reported CO/CO_2 , < -0.063 or > 5. All gases invalid in these cases.

4) excessive error on HC/CO_2 slope, equivalent to $\pm$20% for HC/CO_2 > 0.0166 propane, 0.0033 propane for HC/CO_2 < 0.0166.

5) reported HC/CO_2 < -0.0066 propane or > 0.266. HC/CO_2 is invalid.

6) excessive error on NO/CO_2 slope, equivalent to $\pm$20% for NO/CO_2 > 0.001, 0.002 for NO/CO_2 < 0.001.

7) reported NO/CO_2 < -0.00465 or > 0.0465. NO/CO_2 is invalid.

8) excessive error on SO_2/CO_2 slope, ± 0.0134 SO_2/CO_2.

9) reported SO_2/CO_2 , < -0.00053 or > 0.0465. SO_2/CO_2 is invalid.

10) excessive error on NH_3/CO_2 slope, ± 0.00033 NH_3/CO_2.

11) reported NH_3/CO_2 < -0.00053 or > 0.0465. NH_3/CO_2 is invalid.

12) excessive error on NO_2/CO_2 slope, equivalent to $\pm$20% for NO_2/CO_2 > 0.00133, 0.000265 for NO_2/CO_2 < 0.00133.

13) reported NO_2/CO_2 < -0.0033 or > 0.0465. NO_2/CO_2 is invalid.

Speed/Acceleration valid only if at least two blocks and two unblocks in the time buffer and all blocks occur before all unblocks on each sensor and the number of blocks and unblocks is equal on each sensor and 100mph>speed>5mph and 14mph/s>accel>-13mph/s and there are no restarts, or there is one restart and exactly two blocks and unblocks in the time buffer.

APPENDIX B: Explanation of the Peralt08.dbf and LAPort08.dbf databases.

The Peralt08.dbf and LAPort08.dbf are Microsoft FoxPro database files, and can be opened by any version of MS FoxPro. These files can be read by a number of other database management and spreadsheet programs as well, and is available from www.feat.biochem.du.edu. The grams of pollutant/kilogram of fuel consumed are calculated assuming the fuel has 860 grams of carbon per kilogram of fuel. The following is an explanation of the data fields found in this database:

License	Vehicle license plate.
State	State license plate issued by.
Date	Date of measurement, in standard format.
Time	Time of measurement, in standard format.
Co_co2	Measured Carbon monoxide / Carbon dioxide ratio
Co_err	Standard error of the CO/CO_2 measurement.
Hc_co2	Measured Hydrocarbon / Carbon dioxide ratio (propane equivalents).
Hc_err	Standard error of the HC/CO_2 measurement.
No_no2	Measured Nitric oxide / Carbon dioxide ratio.
No_err	Standard error of the NO/CO_2 measurement.
So2_co2	Measured Sulfur dioxide / Carbon dioxide ratio.
So2_err	Standard error of the SO_2/CO_2 measurement.
Nh3_co2	Measured Ammonia / Carbon dioxide ratio.
Nh3_err	Standard error of the NH_3/CO_2 measurement.
No2_co2	Measured Nitrogen dioxide / Carbon dioxide ratio.
No2_err	Standard error of the NO_2/CO_2 measurement.
Opacity	IR Opacity measurement, in percent.
Opac_err	Standard error of the opacity measurement.
Restart	Number of times data collection is interrupted and restarted by a close-following vehicle, or the rear wheels of tractor trailer.
Hc_flag	Indicates a valid hydrocarbon measurement by a “V”, invalid by an “X”.
No_flag	Indicates a valid nitric oxide measurement by a “V”, invalid by an “X”.
So2_flag	Indicates a valid sulfur dioxide measurement by a “V”, Invalid by an “X”.
Nh3_flag	Indicates a valid ammonia measurement by a “V”, Invalid by an “X”.
No2_flag	Indicates a valid Nitrogen dioxide measurement by a “V”, Invalid by an “X”.
Opac_flag	Indicates a valid opacity measurement by a “V”, invalid by an “X”.

Max_co2	Reports the highest absolute concentration of carbon dioxide measured by the remote sensor over an 8 cm path; indicates plume strength.
Speed_flag	Indicates a valid speed measurement by a "V", an invalid by an "X", and slow speed (excluded from the data analysis) by an "S".
Speed	Measured speed of the vehicle, in mph.
Accel	Measured acceleration of the vehicle, in mph/s.
Ref_factor	Reference factor.
CO2_factor	CO2 factor.
Tag_name	File name for the digital picture of the vehicle.
Exp_Date	Date that current vehicle registration expires.
Year	Model year of the vehicles chassis.
Make	Manufacturer of the vehicle.
Vin	Vehicle identification number.
County	County code where vehicle resides.
CO_gkg	Grams of CO per kilogram of fuel consumed.
HC_gkg	Grams of HC per kilogram of fuel consumed.
NO_gkg	Grams of NO per kilogram of fuel consumed.
SO2_gkg	Grams of SO_2 per kilogram of fuel consumed.
NH3_gkg	Grams of NH_3 per kilogram of fuel consumed.
NO2_gkg	Grams of NO_2 per kilogram of fuel consumed.

APPENDIX C: Temperature and Humidity Data.

Data collected at Fullerton Municipal Airport

Peralta 2008 Temperature and Humidity Data										
Time	4/4 °F	4/4 %RH	4/7 °F	4/7 %RH	4/8 °F	4/8 %RH	4/9 °F	4/9 %RH	4/10 °F	4/10 %RH
5:53	57	78	54	80	56	78	52	74	49	74
6:53	56	80	57	75	58	72	55	69	54	62
7:53	59	72	60	65	60	67	59	58	59	50
8:53	64	63	62	56	63	52	60	52	63	43
9:53	65	59	65	49	64	50	63	43	66	40
10:53	71	49	67	44	65	50	65	36	71	30
11:53	72	50	69	44	64	52	66	37	75	25
12:53	69	55	68	45	65	50	67	32	77	29
13:53	70	53	67	49	64	52	67	30	77	32
14:53	71	51	66	52	63	54	66	32	78	34
15:53	70	53	66	52	64	50	66	32	78	23
16:53	68	55	64	56	62	54	64	48	74	33

Data collected at Daugherty Field in Long Beach

Port of LA 2008 Temperature and Humidity Data										
Time	4/12 °F	4/12 %RH	4/14 °F	4/14 %RH	4/15 °F	4/15 %RH	4/16 °F	4/16 %RH	4/17 °F	4/17 %RH
5:53	60	34	58	72	57	69	54	77	52	74
6:53	65	30	63	63	57	69	56	75	57	64
7:53	75	18	65	61	58	67	59	62	62	56
8:53	82	12	67	55	60	62	59	60	68	41
9:53	88	6	67	55	60	65	61	58	75	26
10:53	91	6	74	36	62	60	63	54	75	25
11:53	92	5	78	26	63	58	64	52	80	12
12:53	93	4	77	26	67	51	66	49	81	8
13:53	95	5	78	27	65	54	69	44	80	9
14:53	95	5	78	34	67	49	68	42	80	8
15:53	90	7	73	37	65	49	66	36	80	24
16:53	85	8	71	38	62	48	65	45	75	24

APPENDIX D: Field Calibration Record.

Peralta 2008 Calibration Factors							
Date	Time	CO	HC	NO	SO_2	NH_3	NO_2
4/4	9:30	2.29	2.18	1.23	1.28	0.83	1.13
4/4	11:45	1.79	1.69	1.18	0.99	0.97	0.76
4/7	8:30	1.91	1.79	1.62	1.61	0.88	0.88
4/7	10:30	1.81	1.71	1.44	1.56	0.91	0.93
4/7	12:00	1.77	1.67	1.38	1.55	0.91	0.87
4/8	7:30	1.85	1.80	1.6	1.66	0.97	1.25
4/8	10:00	1.76	1.65	1.33	1.38	0.91	1.34
4/8	12:15	1.66	1.56	1.25	1.28	0.91	1.2
4/9	7:30	2.29	2.24	1.94	2.41	0.95	1.65
4/9	9:00	1.9	1.8	1.21	1.5	0.82	1.49
4/9	11:15	1.81	1.72	1.12	1.41	0.88	1.22
4/9	14:00	1.67	1.65	1.4	1.86	1.03	1.25
4/10	7:45	2.28	2.18	1.69	2.11	1	1.68
4/10	9:30	2.01	1.94	1.33	1.69	1.01	1.5
4/10	11:15	1.73	1.63	1.28	1.61	0.95	1.12

Port of LA 2008 Calibration Factors							
Date	Time	CO	HC	NO	SO_2	NH_3	NO_2
4/12	9:15	1.58	1.46	1.28	1.41	0.9	0.79
4/12	12:00	1.23	1.12	1.0	1.0	0.91	0.62
4/14	8:10	1.71	1.6	1.3	1.47	0.91	1.13
4/14	12:00	1.28	1.16	1.0	1.19	0.92	0.73
4/15	8:10	1.57	1.46	1.28	1.43	0.79	1.09
4/15	12:20	1.45	1.38	1.28	1.45	0.89	0.84
4/16	8:00	1.53	1.45	1.26	1.42	0.86	1.21
4/16	12:30	1.46	1.39	1.22	1.32	0.86	0.94
4/17	8:30	1.97	1.87	1.71	1.77	0.83	1.34
4/17	10:20	1.71	1.6	1.4	1.47	0.77	1.19
4/17	14:00	1.31	1.21	1.03	1.05	0.82	0.81