CTE / NCDOT

Joint Environmental Research Program

Final Report

Operational Evaluation of Emissions and Fuel Use of B20 Versus Diesel Fueled Dump Trucks

Research Project No. 2004-18
FHWA/NC/2005-07

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September 30, 2005

Technical Report Documentation Page

1. Report No. **FHWA/NC/2005-07**	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle **Operational Evaluation of Emissions and Fuel Use of B20 Versus Diesel Fueled Dump Trucks**		5. Report Date **September 2005** 6. Performing Organization Code
7. Author(s) **H. Christopher Frey, Kangwook Kim**		8. Performing Organization Report No.
9. Performing Organization Name and Address **Center for Transportation and the Environment** **Department of Civil, Construction, and Environmental Engineering** **North Carolina State University** **Raleigh, NC 27695-7908**		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address **U. S. Department of Transportation** **Research and Special Programs Administration** **400 7th Street, SW** **Washington, DC 20590-0001**		13. Type of Report and Period Covered **Final Report** **July 2003 to December 2004** 14. Sponsoring Agency Code **2004-18**

15. Supplementary Notes

Supported by a grant from the U. S. Department of Transportation and the North Carolina Department of Transportation through the Center for Transportation and the Environment, NC State University.

16. Abstract

Diesel vehicles contribute substantially to statewide emissions of NO_x, an ozone precursor, and to particulate matter. NCDOT is conducting a pilot study to demonstrate the use of B20 biodiesel fuel on approximately 1,000 vehicles in selected areas of the state; there are plans to extend the use of B20 fuel to a much larger number of vehicles in all 100 counties in North Carolina. Real-world in-use on-road emissions of selected heavy duty diesel vehicles, including those fueled with B20 biodiesel and petroleum diesel, were measured during normal duty cycles using a portable emissions measurement system (PEMS). Four categories of dump trucks were selected for testing, including: (1) single rear axle with Tier 1 engines; (2) single rear axle with Tier 2 engines; (3) tandems with Tier 1 engines; and (4) tandems with Tier 2 engines. A total of 12 vehicles were tested. Each vehicle was tested for one day on B20 biodiesel and for one day on petroleum diesel, for a total of 24 days of field measurements. The vehicles were operated by drivers assigned by NCDOT. Each test was conducted over the course of an entire workshift, and on average there were 4.5 duty cycles per shift. Each duty cycle is comprised of a uniquely weighted combination of nine operating modes (idle, three levels of acceleration, three levels of cruise, deceleration, and dumping). Average emission rates on a mass per time basis varied substantially among the operating modes. Average fuel use and emissions rates increased 26 to 35 percent when vehicles were loaded versus unloaded. Average fuel use and CO_2 emission rates were approximately the same for the two fuels, but average emission rates of NO, CO, HC, and PM decreased by 10, 11, 22, and 10 percent, respectively, for B20 biodiesel versus petroleum diesel. The average emission rates from the PEMS data were compared with engine dynamometer data. The two data compared reasonably well and appropriately. The role of real world duty cycles, as opposed to arbitrary test cycles, was found to be critical with respect to accurate estimation of emissions, especially for NO. Factors that were responsible for the observed variability in fuel use and emissions include: operating mode, vehicle size, engine type, vehicle weight, and fuel. In some cases, the type of engine clearly had a significant role. In particular, NO and PM emission rates were typically lower for Tier 2 engines than for Tier 1 engines. Recommendations were made regarding operating strategies to reduce emissions, choice of fuel, and the need for future work to collect real world duty cycle data for other vehicle types.

17. Key Word vehicle emissions, biodiesel, petroleum diesel, dump trucks, fuel use, nitrogen oxides, carbon monoxide, hydrocarbons, particulate matter, carbon dioxide, emissions measurement		18. Distribution Statement No restrictions	
19. Security Classif. (of this report) "Unclassified"	20. Security Classif. (of this page) "Unclassified"	21. No. of Pages 374	22. Price

Form DOT F 1700.7 **(8-72)** **Reproduction of completed page authorized**

Acknowledgements

Support was provided by the Center for Transportation and the Environment in cooperation with the U.S. Department of Transportation and North Carolina Department of Transportation through the Institute for Transportation Research and Education, North Carolina State University.

The NCDOT Equipment Inventory and Control Unit, and Division 5 field office, provided valuable assistance regarding study design and access to vehicles for testing. The project team is especially grateful to Bruce Thompson, Drew Harbinson, Jason Holmes, and Derry Schmidt of NCDOT. The project team also expresses gratitude to the NCDOT mechanics and drivers who provided generous assistance during the course of the field work.

The project team is grateful to Clean Air Technologies International, Inc. for their efforts to provide instrumentation and service throughout the duration of the project. In particular, we thank Josh Wilson. We especially thank Michal Vojtisek-Lom for his valuable work throughout the project.

Disclaimer

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EXECUTIVE SUMMARY

NCDOT is proceeding with the use of alternative fueled vehicles (AFVs), including biodiesel-fueled medium duty trucks. A significant number of counties in North Carolina will be designated for non-attainment for both ozone and particulate matter under forthcoming Federal environmental standards. Diesel vehicles contribute substantially to statewide emissions of NO_x, an ozone precursor, and to particulate matter. NCDOT is conducting a pilot study to demonstrate the use of biodiesel (e.g., B20) fuel on approximately 1,000 vehicles in selected areas of the state; there are plans to extend the use of B20 fuel to a much larger number of vehicles in all 100 counties in North Carolina. There is a need for empirical quantification and comparison of emissions, fuel economy, and vehicle operation on both conventional and biodiesel fuels. Furthermore, there is a need for detailed insight into factors influencing both emissions and fuel consumption on a second-by-second basis in order to develop recommendations for improved operation to further reduce emissions and fuel consumption.

Project Objectives

The objectives of this project are to: (1) characterize baseline real-world in-use on-road emissions of selected heavy duty diesel vehicles, including those fueled with B20 biodiesel and petroleum diesel, during normal duty cycles; (2) characterize the episodic nature of emissions and fuel use; (3) identify factors responsible for variability in emissions and fuel use, with specific focus on factors leading to episodes of high emissions and fuel use; and (4) develop recommended strategies for reducing the frequency and duration of high emissions and fuel use episodes, with consideration of operational constraints as well as other possible benefits.

Overview of Products of the Project

The primary product of this work is a database, analysis, and recommendations pertaining to operational practices and their implications for fuel use and emissions. The data are based upon real-world, on-road, in-use measurements of fuel economy and emissions on a second-by-second basis. The results of this work enable NCDOT to quantify changes in real world in-use emissions associated with use of biodiesel instead of conventional diesel fuel. The key conclusions indicate a substantial reduction in emissions (e.g., NO, CO, HC, and PM) when switching from petroleum diesel to soy-based B20 biodiesel. A preliminary analysis of this study provides insight into factors that contribute to variability in emissions during vehicle operating, including differences in emissions at different cruising speeds, as well as comparisons of emissions between idle, acceleration (low medium, high), cruise (low medium, high), deceleration and dumping modes. The modal analysis suggests that it is possible to stratify the data in order to enable comparisons, such as between vehicles. Fuel use and emissions increase approximately 30 percent for loaded versus unloaded vehicles; vehicle weight approximately doubles when loaded.

The analysis in this study addresses key questions such as what factors contribute to episodes of high emissions and high fuel use, and how do emissions differ for different operating modes, fuels, vehicles, and other explanatory variables. The recommendations address what can be done to improve real-world fuel economy and reduce real-world emissions based upon modest changes to vehicle operating practices without sacrificing the duty requirements for the vehicles. A secondary product of this work is information and data that can be used to assess compliance of North Carolina with respect to the NAAQS and conformity. The products of this work should be used by NCDOT and others to develop scientifically rigorous insight regarding factors that contribute to high emissions and fuel use, regarding methods for reducing fuel use and emissions, and in order to more accurately estimate the contribution of heavy duty diesel vehicles to solving energy and environmental policy problems.

Background on Factors Influencing Emissions

Tailpipe emissions are a complex function of many influential variables, including vehicle characteristics, vehicle activity patterns, ambient conditions, fuel properties, and related issues. Examples of related issues include driver behavior, traffic flow, and roadway and route characteristics. These latter issues can influence the vehicle activity pattern. Overall, some of the key factors that influence emissions are found to be fuel properties, vehicle weight, speed and acceleration, and operating modes. In designing a field study for measurement of real-world in-use duty cycles and emissions, consideration was given to obtaining data for different vehicle weight, engine design, load, fuel, and operating mode. These factors are considered when developing the study design and interpreting the results of the data collected in the field.

Methods for Measuring Vehicle Emissions

Several commonly used methods for measuring vehicle emissions have been reviewed, including engine dynamometers, chassis dynamometers, tunnel studies, remote sensing, and on-board measurement. Most of the available data regarding heavy-duty vehicle emissions is typically from engine dynamometer measurements. These data are reported in units of g/bhp-hr, which are not directly relevant to in-use emissions estimation. Furthermore, many engine dynamometer test cycles are based upon steady-state modal tests that are not likely to be representative of real world emissions. There are some transient engine dynamometer tests that may have improved representativeness of real-world operating patterns, but it is not likely that any particular and arbitrary test cycle will be representative of operation of a particular type of vehicle at all times and in all areas of the country. Thus, although relatively less expensive than chassis dynamometer tests, engine dynamometer tests have serious shortcomings for purposes of estimating real world emissions.

Chassis dynamometer tests provide emissions data in units that are more amenable to the development of emission inventories. For example, for on-road vehicles, emissions can be reported in units of grams of pollutant emitted per mile of vehicle travel. This emission factor can be multiplied by estimates or measurements of vehicle miles traveled to arrive at an inventory. However, for vehicles that operate off-road, or that have operating modes that cannot easily be accommodated in the laboratory setting (e.g., dumping of the bed of a dump truck), it may not be possible to obtain data representative of all aspects of a duty cycle. Furthermore, these tests have a non-negligible cost per vehicle and the number of heavy duty dynamometer facilities is limited.

Tunnel studies are limited in their ability to discriminate among specific vehicle types, although it is possible to distinguish between gasoline and diesel vehicles using statistical methods. However, tunnel studies are based upon measurements for a specific link of roadway and thus are not representative of an entire duty cycle. For purposes of this project, there are no tunnels through which the study fleet travels. Thus, this measurement method is not applicable here.

Remote sensing can be used to measure emissions from any vehicle that passes through the infrared and, if available, UV beams that are used to measure pollutant concentrations. For purposes of measuring heavy duty vehicles, remote sensing deployment may need to be adjusted to the appropriate plume height, especially if the trucks discharge emissions above the level of the vehicle's cab. Each measurement is only a snap shot at a particular location, and thus cannot characterize an entire duty cycle. Thus, remote sensing is not applicable here.

On-board emissions measurement systems offer the advantage of being able to capture real world emissions during an entire duty cycle. Thus, for purposes of this project, such systems are preferred. In particular, PEMS, which are more easily installed in multiple vehicles than complex on-board systems, are selected for use in this study.

Literature Review of Emissions Measurements

A review of available engine dynamometer test data for a variety of diesel engines indicates that there is a reduction in the emission rate of PM, CO, and HC and an increase in the emission rate of NO_x. These results are based upon analysis of a database complied by the U.S. EPA. EPA has analyzed the data by general categories of engine types. An overall average among all engine types is that emissions decreased on B20 versus petroleum diesel by 10 percent for PM, 11 percent for CO, and 21 percent for HC, but increased by 2 percent for NO_x. In a new analysis of the EPA data conducted as part of this work, a specific category of engines was analyzed. The typical differences in average emissions for vehicles fueled with soy-based B20 biodiesel versus petroleum diesel were found to be: 1 to 4 percent increase in NO_x; 25 to 33 percent decrease in PM; 11 to 25 percent decrease in CO; and 53 to 83 percent decrease in hydrocarbons. The latter set of comparisons was limited to test cycles for which emissions were measured for each of the two fuels, and thus was confined to transient engine dynamometer FTP tests. Despite the qualitative differences in comparisons between the two fuels depending on what engine categories and test procedures are considered, a general finding appears to be that there is a consistent decrease in emissions of PM, CO, and HC and a consistent small increase in NO_x emissions. However, the test procedures may not be representative of real world activity patterns. As mentioned in Chapter 2, emissions can be influenced substantially by the activity pattern of the vehicle and engine. Therefore, there is a need to further evaluate the differences in emissions for B20 biodiesel versus petroleum diesel under real world conditions.

Portable Emissions Measurement System

The portable emissions measurement system (PEMS) that was used for real world in-use data collection in this project is the OEM-2100 "Montana" system manufactured by Clean Air Technologies International, Inc. The Montana system includes operating software, data acquisition hardware for engine data, gaseous pollutants, and particulate matter, and a Global Position System (GPS).

Design of the Field Data Collection Study

The field study design is based upon clearly stated objectives that are based upon a need for real world in-use data pertaining to multiple types of vehicles, engines, fuels, loads, and operating modes. Four categories of dump trucks were selected for testing, including: (1) single rear axle with Tier 1 engines; (2) single rear axle with Tier 2 engines; (3) tandems with Tier 1 engines; and (4) tandems with Tier 2 engines. The tandems have a significantly higher GVW than the single-axles, and typically have engines with larger displacement, more horsepower, more torque, and more weight. A total of 12 vehicles were included in the measurement program.

This study is unique in that it is based upon operation of vehicles during their normal duty cycles. Thus, the study design must deal with the variation that can occur from day-to-day depending upon the specific routes, loads, and activities of each vehicle. In order to obtain an adequate sample of data, each test was conducted over the course of an entire workshift. Each workshift included, on average, 4.5 duty cycles. Each actual duty cycle is comprised of a uniquely weighted combination of nine operating modes (idle, three levels of acceleration, three levels of cruise, deceleration, and dumping).

A typical duty cycle includes obtaining a load at an origin, delivering the load to a destination, dumping the load, and returning to an origin to obtain a new load. The cycle is repeated. Each vehicle was measured on each day of data collection both with and without a load. The average weight of a typical load was approximately 14.5 tons for the tandems and 7.0 tons for the single rear-axle trucks.

Each of the 12 vehicles was tested for one day on B20 biodiesel and for one day on petroleum diesel, for a total of 24 days of field measurements. The vehicles were operated by drivers assigned by NCDOT. The study relied upon and greatly benefited from the cooperation of professional drivers who conducted their normal work while NCSU collected data. NCDOT does not permanently assign a driver with a specific vehicle. However, NCDOT was able to schedule the same driver and vehicle combination for both fuels for seven of the vehicles, which facilitates comparisons between the two fuels. All of the drivers operated the vehicle in a professional and responsible manner. It is possible that different drivers might have different weighted combinations of operating modes. However, even when a vehicle was operated by one driver for one fuel and a different driver for the other fuel, it is likely that the results can be compared on the basis of individual operating modes.

All of the data collection occurred in Wake County, North Carolina. Data were collected for vehicles operated on B20 biodiesel fuel during more humid (on average) months than when data were collected for petroleum diesel. NO_x emissions in particular may be sensitive to ambient humidity. The implications of the differences in ambient conditions with respect to interpretation of field study results are further considered when analyzing the field study results.

Methods for Data Reduction, Analysis, and Validation

Methods for screening the data collected in the field, and for making corrections or deletions to deal with data problems, were developed and applied. The screening methods are categorized based upon their cause or implications as being related to engine data, gas analyzer data, zeroing procedure, negative emissions values, loss of power, and low concentration. The goal of these screening methods is to create a database that is as free of errors as possible. These errors can involve loss of input data streams, loss of power, data values that are out of range, or data problems associated with operational problems that can occur from time to time (e.g., overheating of a gas analyzer bench). In most cases, the diagnostic checks made during field data collection and during analysis of data from the field identified particularly types of errors only infrequently.

Once a quality assured database has been developed, then methods were applied for analyzing the data. In order to compare emissions between vehicles, loads, and fuels, a set of operating modes was developed that allow any activity pattern to be disaggregated. The modes include idle, three levels of acceleration, three levels of cruise, deceleration, and dumping. Average emissions rates are estimated for each mode based upon binning of second-by-second data. The binning criteria include speed, acceleration, and engine power demand, in various combinations, depending upon the mode. The dumping mode refers to lifting of the rear bed of the truck, which typically occurs during stationary or low speed operation of the truck.

A methodology for partial validation of the Montana system data was developed based upon comparing fuel use estimated by the Montana system with measured fuel use.

Results of the Field Study

This section provides an overall summary and interpretation of the data collected in the field study.

In general, fuel consumption increased only slightly for B20 biodiesel versus petroleum diesel. As noted earlier, one of the single rear-axle vehicles with a Tier 1 engine towed a trailer, which biases the comparisons for this group. When this one vehicle, number 4743, is excluded, the average change in fuel consumption for this vehicle group is approximately as expected. The results for the other vehicle groups are approximately insignificant. Overall, the results imply a slight increase in fuel consumption, as expected. Similarly, when vehicle 4743 is excluded from the comparison, the results imply an insignificant change in CO_2 emission rates.

In general, the emissions rate of NO, HC, CO, and PM decreased for three out of four vehicle groups, and for one group there was approximately no significant change. The emissions rate of all four of these pollutants decreased significantly for the single rear-axle trucks.

The average NO emissions rate decreased significantly for the single rear-axle trucks, including both Tier 1 and Tier 2 engines. The average NO emissions rate decreased slightly for the tandems with Tier 1 engines and increased slightly for the tandems with Tier 2 engines. However, the latter is not likely to be statistically significant. Therefore, the results imply that NO emissions rate either had no significant change or decreased, depending on the vehicle group. It appears to be the case that the Tier 2 engines had a smaller change in NO emissions rate, on average, than did the Tier 1 engines.

The HC emission rates decreased more for the Tier 1 engines than for the Tier 2 engines, on average. For the tandems with Tier 2 engines, the average change in HC emissions rate was insignificant.

Table ES-1. Average Percentage Change in Average Fuel Consumption and Emission Rates for all Four Vehicle Types for B20 Biodiesel versus Petroleum Diesel, for Unloaded and Loaded Vehicles.

	Unloaded	Loaded	Average
Fuel Use	5.6 (1.1) [a]	7.1 (3.0) [a]	6.3 (2.1) [a]
NO	-13 (-8.9) [b]	-14 (-11) [b]	-14 (-10) [b]
HC	-21	-23	-22
CO	-11	-12	-11
CO_2	3.6 (-1.0) [a]	4.4 (0.5) [a]	4.0 (-0.5) [a]
PM	-7.3	-14	-10

[a] Average change when one vehicle, that towed a trailer, was excluded from the comparison.

[b] Applied the NO_x humidity correction factor for diesel engines based on 40 CFR Chapter I Section 86.1342-90 (2003).

For CO emission rates, there is not a clear pattern regarding the change when comparing the two fuels for the different vehicle groups. The greatest percentage decrease was for the smaller trucks with the older engines. The average decrease for the newer vehicles was approximately the same for both the single rear-axle and tandems. The average change in CO emission rate for the older tandems was insignificant.

For PM, there were insignificant to modest reductions in average emissions rates, with the largest decreases occurring for the single rear axle vehicles.

Table ES-1 summarizes the change in average fuel consumption and emission rates when averaged over all four vehicle groups. The average changes in fuel consumption and CO_2 emissions rates imply a slight increase in both. A slight increase is expected, because of differences in the fuel properties, as previously discussed.

The average decrease in NO emissions rate is 10 percent. Data reported elsewhere imply, on average, that NO_x emissions rate increase by approximately 2 percent for B20 biodiesel versus petroleum diesel.

There are at least three possible reasons for the observed decrease in NO emissions rate and why this appears to be different from previously reported comparisons. One is that the distribution of time in different operating modes is different for the real world duty cycles versus the laboratory dynamometer cycles. The data obtained in this study imply that the ratio of NO emissions rate on B20 biodiesel to petroleum diesel depend on the operating mode. For example, low cruise tends to produce higher NO emissions rate on B20 biodiesel than does the high acceleration mode, whereas high acceleration, on average, had a lower NO emissions rate for B20 biodiesel versus petroleum diesel for all four vehicle groups. Thus, driving cycles that have more emphasis on modal activity similar to low cruise might imply higher NO on B20 biodiesel, whereas those with less emphasis on this type of activity might imply lower NO emissions rate. The duty cycles of this work were measured in the field and thus are representative of real world in-use activity patterns.

Measurements were made of NO but not of total NO_x. It could be the case that the ratio of NO_2 to NO varies either by operating mode, for different fuels, or for combinations of both. The PEMS used in this project does not have a capability to measure NO_2 or total NO_x. However, it could be possible to obtain supplemental equipment to make measurements of NO and total NO_x for comparison with the PEMS measurements. Data in the literature imply that engine-out emissions rate of NO_x typically are comprised of only 5 to 8 percent, on average, of NO_2, with the majority of the NO_x in the form of NO_2. However, there are little data available at this time to characterize the ratio of NO_2 to NO_x as a function of operating mode.

A third consideration is that others have reported that NO_x emissions rate tend to decrease for B20 biodiesel versus petroleum diesel if the biodiesel conforms to the applicable ASTM standard. However, if the glycerin content of biodiesel exceeds the standard, apparently NO_x emissions rate may increase. The observation in this study of a reduction in average NO emission rates could imply that the biodiesel fuel used here has low glycerin content; otherwise, an increase in NO emission rate would be expected.

The observed decrease in NO emission rates was slightly higher for loaded vehicles than for unloaded vehicles, suggesting that vehicle weight influences the emission rates differently for the two fuels.

The average HC emission rate was decreased by 22 percent for B20 biodiesel versus petroleum diesel. This average change is comparable to the 21 percent decrease reported in reported in Table 4-9 based upon analysis of dynamometer data compiled by EPA. HC emission rates appeared to consistently decrease for all operating modes for those vehicle groups in which a significant overall average decrease occurred. These groups include single rear-axle vehicles with Tier 1 engines and tandem vehicles with Tier 1 engines. This implies that the change in HC emission rates would be less sensitive to the duty cycle than appears to be the case for NO. In general, HC emission rates are less variable than those of other pollutants, which also implies that the emissions rates are more consistent across operating modes for a given fuel.

The average CO emission rate decreased by 11 percent, which is the same relative change estimated based upon data compiled by EPA as shown in Table 4-9. There appears to be significant variability across vehicles and operating modes regarding the percentage change in average emissions rate on an operating mode- and vehicle-specific basis. However, it is typically the case that the percentage decrease in average emissions rates for many of the modes significantly outweighs more modest increases, if any, that occur for some of the modes. For example, on average across all vehicle groups, the idling, medium acceleration, low cruise, medium cruise, and deceleration modes have decreases in emissions rate, whereas other modes have approximately the same average emissions rate on both fuels. The difference in CO emissions rate between the two fuels is not as sensitive to the proportion of different operating modes in a duty cycle as is the case for NO.

The average change in PM emission rate was a decrease of 10 percent, which is comparable to the estimate based upon dynamometer data that is shown in Table 4-9. When averaged over the four vehicle groups, PM emissions rates were lower for B20 biodiesel versus petroleum diesel for the idle, low cruise, medium cruise, high cruise, and deceleration modes for both unloaded and loaded vehicles, and for the dumping mode for loaded vehicles. PM emissions rate tended to be higher on B20 biodiesel for the acceleration modes. Thus, the overall average change in PM emissions rate could have some sensitivity to the proportion of the operating modes in a given duty cycle. However, it is clear from these data that the average decrease in the overall PM emission rate is based upon representative duty cycles for these types of vehicles.

In general, the tandems have higher mass per time fuel consumption and CO_2 emission rates than the single rear axle-vehicles, as expected. The average mass per time emission rates of HC and PM are also higher for tandems than for single rear-axle trucks. For NO, the average mass emission rates are higher for the tandems with Tier 1 engines compared to the single rear-axle vehicles with Tier 1 engines, but the average emission rates are approximately similar for both single rear-axle and tandem trucks with Tier 2 engines. For CO, the emission rates of the tandems are lower than for single rear axle for the Tier 1 engines, but higher for the Tier 2 engines.

The Tier 2 engines typically have approximately the same or lower average emission rates compared to Tier 1 engines, for a given size of vehicle, for NO and PM regardless of vehicle load or fuel type.

Comparison of Data from the Field Study to Published Engine Dynamometer Data

For petroleum diesel, the comparison of PEMS and dynamometer data suggests general agreement for CO and HC, higher NO emissions, and lower PM emissions. The higher NO emissions might be attributable to differences in duty cycles. The lower PM emissions might be attributable to the effectiveness of Tier 2 engines in reducing emission rates relative to older engines.

For B20 biodiesel, the comparison of PEMS and dynamometer data suggest that the Tier 2 engines have lower PM emission rates than the older engines in the dynamometer data base, as expected, that NO emissions tend to be higher for the real world duty cycles than for the FTP test, and that the CO and HC emissions have approximately agreement regarding the ranges of values between the two data sets.

Thus, the comparison of PEMS data to dynamometer data provides some confidence that the PEMS data are reasonable with respect to absolute emission values. For example, despite the fact that the HC measurement is based on NDIR, and thus might be biased low, the HC emission rates obtained from the PEMS data are typically as large or larger than those from the dynamometer data. The PEMS measurements for NO are based upon NO only, whereas the dynamometer measurements are based upon both NO and NO_2. However, the fact that the PEMS estimates of NO emissions (reported on an equivalent mass basis in terms of NO_2) are at least as large, and typically larger, than for the dynamometer data, suggests that the vast majority of NO_x emissions are in the form of NO. However, this assumption could be verified based on additional measurements.

Diesel engines are typically considered a significant emission source of PM and NO_x, and emissions of CO and HC are generally lower than for other mobile sources, such as those fueled with gasoline. There was approximately qualitative agreement in the emission rates for CO and HC when comparing the PEMS and dynamometer data. Overall, the PEMS data compare reasonably well and appropriately to the engine dynamometer data.

Overall Conclusions and Recommendations

The main results of the field study measurements are the following:

- There is substantial variability in fuel use and emission rates by operating mode regardless of whether these are analyzed in terms of mass per time, mass per mile driven, or mass per gallon of fuel consumed. The mass per time approach was the most useful for this work because it enabled evaluation of the contribution of each second of operation in a given mode to the total fuel use and total emissions. However, for purposes of developing emission inventories in the future, NCDOT may find that the mass per gallon of fuel consumed emission factors are more useful in that the total amount of fuel consumed is easier to measure and document than the amount of time spent or the distance driven.
- There are extensive data from this study regarding the distribution of operating modes for a typical duty cycle with respect to time, distance, fuel consumption, and emissions. These data can be used to improve emissions inventories in combination with the modal emission factors by more appropriately weighting the modal emission rates.
- The baseline real-world in-use emissions of a selected set of diesel trucks were

characterized based upon PEMS measurements during normal duty cycles. These data were partially validated with respect to fuel consumption and were compared with engine dynamometer data. These consistency checks provide some degree of confidence regarding the reasonableness of the PEMS data.

- The episodic nature of fuel use and emission rates was confirmed based upon comparison of the average emission rates for different operating modes. For example, on a mass per time basis, there was typically a factor of 4 to 20 when comparing the mode with the highest rate to the mode with the lowest rate. In many cases, the high acceleration mode had the highest mass per time rate and the idle mode had the lowest mass per time rate, but there are some exceptions depending on the pollutant.

- Factors that were responsible for the observed variability in fuel use and emissions include: operating mode, vehicle size, engine type, vehicle weight, and fuel. The role of operating mode is summarized above. Vehicle size and weight clearly influenced fuel use and emissions. Fuel use and CO_2 emissions increase with vehicle size and weight. The emissions of other pollutants typically, but not always, increased by size and weight.

- In some cases, the type of engine clearly had a significant role. In particular, NO and PM emission rates were typically lower for Tier 2 engines than for Tier 1 engines.

- Vehicle load leads to an increase in fuel use and emissions for a given vehicle on an individual basis or for groups of vehicles on an average basis. For the smaller single rear-axle vehicles, there was approximately a 26 percent increase in fuel use and emissions associated with an averaging doubling of vehicle weight. For the larger tandems, the vehicle weight with a load increases by approximately 140 percent and produces an increase in average fuel use and emission rates of 30 to 35 percent.

- The emission rates on B20 biodiesel were typically lower than those for petroleum diesel for NO, CO, HC, and PM. The finding for NO is somewhat different than that based upon engine dynamometer data reported by EPA, but an analysis of average emission rates by operating mode suggests that the average NO emission rate for a duty cycle is sensitive to the proportional contribution of each mode to the total. Therefore, a finding is that whether NO emissions appear to increase or decrease when comparing the fuels depends, at least on part, on what duty cycles are used for making the comparison.

- For CO, HC, and PM, the average percentage change in emission rates from the field study was comparable to that estimated based upon data reported by EPA.

Based upon the results of the study, the following recommendations are made:

- The emissions of greatest concern from diesel trucks are NO_x and PM, particularly because this type of emission source tends to have a higher emission rate for these pollutants than other sources and because these two pollutants contribute significantly to ambient air qualities that are governed by the National Ambient Air Quality Standards (NAAQS). Therefore, it is recommended that owners and operators of fleets of these types of emission sources characterize the emission rates and the emission inventories for their fleets, using real-world representative data where possible.

- It is clear from the comparison of PEMS data to dynamometer data that, while there is some consistency or comparability, the former can lead to estimates of emissions that are higher than those obtained from the latter at least in part because real world duty cycles are more challenging than the test cycles used for dynamometer testing, and because the former are based upon testing of the entire vehicle and not just the engine. Thus, the collection and interpretation of real-world in-use data for duty cycles, as well as for emissions, is recommended for other significant categories of vehicles aside from single rear-axle and tandem dump trucks.

- Similarly, the difference in results when comparing B20 biodiesel versus petroleum imply that different results can be obtained depending in part on the duty or test cycle, further emphasizing the need for characterization and use of realistic duty cycles when making estimates and comparisons of emissions.
- The findings that average emission rates were reduced when vehicles were fueled with B20 biodiesel versus petroleum diesel suggests that there is a benefit to the use of biodiesel fuel in terms of emissions that occur within the airsheds where the vehicles operate. Thus, the substitution of B20 biodiesel for petroleum diesel should be evaluated as an option for reducing tailpipe emissions especially in airsheds where attainment of the NAAQS for NO_2 and PM may be of concern.
- Other factors that influence vehicle emissions, such as vehicle load and operating mode, provide insight into situations that can produce high emissions. For example, the highest emission rates would be expected to occur for a vehicle that is in medium or high acceleration and carrying a load. To the extent that the vehicle duty cycle could be modified to accommodate extenuating circumstances, such as to manage or reduce emissions on a day that might be subject to an exceedence of the NAAQS for NO_2 or PM, an effort could be made to moderate acceleration rates in order to reduce the total emissions for a duty cycle. However, on a day when it is unlikely that an exceedence of the NAAQS might occur, such measures would be unnecessary.
- Although the trucks tested in this study spent a significant amount of time idling, the total fuel use and emissions associated with idling was a small fraction of the total fuel use and emissions for the entire duty cycle. Nonetheless, on a mass per gallon of fuel consumed basis, the emission rate during idling can be relatively large. Therefore, consideration could be given to reducing fuel use and emissions by reducing the amount of time spent idling. For example, if it can be predicted that the truck will sit idle for an extended period of time, then guidelines could be developed regarding when and for how long to shut down the engine.

Overall, all of the key project objectives are satisfied based upon the findings and recommendations of this study.

Any study has some limitations that could motivate future work to expand the scope of the analysis or to apply improved methods. A few limitations of this study imply recommendations for future work:

- This study did not address the life cycle emissions associated with production and distribution of either B20 biodiesel or petroleum diesel. Thus, although the tailpipe emissions at the location of end-use of the fuel may be lower for B20 biodiesel, this study does not establish whether the life cycle emissions are lower or the geographic and temperal scales of emissions associated with fuel production and distribution.

- This study was based upon measurement of NO. In future work, it would be appropriate to measure the ratio of NO to total NO_x to verify whether the findings here for NO are fully applicable to total NO_x. This could be done either by adding instrumentation during field measurements to measure total NO_x or NO_2, or by using the PEMS simultaneously with a dynamometer in order to compare both measurement systems.
- The overall vehicle sample size of 12 is relatively small compared to the in-use fleet. Furthermore, the sample size of only two Tier 2 tandem and two Tier 2 single rear-axle vehicles, including among the 12 vehicles tested, is small. Thus, it is appropriate to consider expanding data collection to a larger number of vehicles.
- This study did not consider occupational exposures to emissions, especially during idling. The benefits of shortening or avoiding long periods of idling with respect to human occupational exposures may be of importance, in addition to the relatively small benefits of reductions in total fuel use and total emissions. The effect of reducing idling emission on human exposures could be evaluated in future work.

1.0 INTRODUCTION

The purpose of this project is to provide real world assessment of the emissions and fuel use of heavy duty diesel vehicles operated by NCDOT. There are many needs for this information, each with different implications. Four critical needs are briefly summarized here.

An understanding of the episodic nature of emissions and fuel use, which has been demonstrated in recent data collection and modeling efforts, is the foundation for the development of scientifically-sound operational strategies aimed at pollution prevention and energy resource conservation. Moreover, there may be opportunities to reduce emissions and energy use without significant compromise with respect to duty cycles.

Heavy duty diesel equipment contributes substantially to statewide emissions of nitrogen oxides (NO_x) and particulate matter, including particulate matter less than 2.5 microns in aerodynamic diameter. The latter is refered to as "$PM_{2.5}$." NO_x is a key precursor to the formation of tropospheric ozone. Under new National Ambient Air Quality Standards (NAAQS) for ozone, three major areas of North Carolina are in non-attainment for both pollutants. These areas include Charlotte, the Triad (Greensboro, Winston-Salem, High Point), and the Triangle (Raleigh, Durham, and Chapel Hill). In total, 32 counties are included in nonattainment areas for ozone. Eight counties, or portions thereof, have been recommended by EPA for nonattainment designation under the $PM_{2.5}$ standard. The economic consequences of non-attainment status are significant. This project will enable the NCDOT to assess its role in these areas and in this problem

A third motivation for this work is to develop a rigorous baseline for estimation of emissions from heavy duty diesel vehicles under conditions typical of North Carolina.

A fourth motivation is to establish a baseline for comparison of alternative fuels and vehicle technologies, whether included in this project or in future work. For example, by establishing a statistically sound baseline regarding emissions from the current fleet of diesel vehicles, it is later possible to determine whether a new fuel additive or a change in lubricating oil (as examples) lead to significant reductions in emissions and/or fuel use and under what conditions of engine load, ambient temperature, road grade, and so on that such changes are observable.

This chapter provides background regarding the need for this study, a definition of the problem addressed by this work, and the key project objectives.

1.1 Background

In compliance with the Energy Policy Act of 1992, NCDOT is proceeding with the use of alternative fueled vehicles (AFVs), including biodiesel-fueled medium duty trucks. Biodiesel (e.g., B20) fuel may offer benefits of lower emissions than conventional diesel fuel for at least some pollutants. However, there is some concern that biodiesel fuel usage may lead to higher NO_x emissions than with petroleum-based diesel fuels. Thus, there is a need to quantify the real-world emissions for biodiesel fueled vehicles to confirm whether a problem actually exists. Furthermore, because real world emissions are episodic in nature, it is important to have a thorough understanding of factors that lead to episodes of high emissions, as well as high fuel consumption. Such information will be used to recommend specific operational strategies for reducing emissions and fuel use. Based upon previous work at NCSU and elsewhere using portable on-board emissions and fuel use measurement instruments, a consistent finding is that how a vehicle is driven, and not necessarily how many miles it is driven, plays a critical role with respect to emissions and fuel use. Thus, there are opportunities to reduce emissions and fuel use without reducing miles traveled or without interfering significantly with typical duty cycles.

A significant number of counties in North Carolina will be designated for non-attainment for both ozone and particulate matter under Federal NAAQS standards. Diesel vehicles contribute substantially to statewide emissions of NO_x, an ozone precursor, and to particulate matter. In order to enable NCDOT to quantify and claim appropriate credit/benefit for changes in real world in-use emissions and fuel use associated with use of biodiesel instead of conventional diesel fuel, and with implementation of strategies developed in this project, there is a need to quantitatively evaluate the environmental sustainability benefits of AFVs, with specific focus on biodiesel fuels. Specifically, there is a need for empirical quantification of second-by-second real world in-use emissions, fuel economy, and vehicle operation on biodiesel fuels. Furthermore, there is a need for detailed insight into factors influencing both emissions and fuel consumption on a second-by-second basis in order to develop recommendations for improved operation to further reduce emissions and/or fuel consumption. These benefits accrue in both short and long term.

One of the most important air pollution regulations that affect mobile sources is the “conformity” rule. Conformity is a determination made by Metropolitan Planning Organizations (MPOs) and Departments of Transportation (DOT) that transportation plans, programs, and projects in non-attainment areas are in compliance with the standards contained in State Implementation Plans (SIPs) (i.e., plans that codify a state’s CAAA compliance actions) (FHWA, 1992). To demonstrate conformity, a transportation plan or project must improve air quality with respect to one or more of the following: (1) the motor vehicle emission budget in the SIP; (2) emissions that would be realized if the proposed plan or program is not implemented; and/or (3) emissions levels in 1990 (TRB, 1995). Conformity requirements have made air quality a key consideration in transportation planning (Sargeant, 1994).

The Congestion Management and Air Quality Improvement (CMAQ) program is another important piece of legislation that integrates air quality and transportation. The CMAQ program was introduced under the Intermodal Surface Transportation Efficiency Act (ISTEA) in 1991 and continued later under the Transportation Efficiency Act for the 21st Century (TEA-21) in 1998. Only non-attainment and maintenance areas are eligible for CMAQ funding. The first priority for CMAQ funding is programs and projects in the SIP. Regardless of whether a project is in the SIP, the project must be in a state’s Transportation Improvement Plan (TIP) to be eligible for CMAQ funding. Various project types are allowed for CMAQ funding, such as transit projects, pedestrian/bicycle projects, traffic signal coordination projects, travel demand management programs, and emissions inspection and maintenance (I/M) programs

The development of representative in-use empirical data regarding emissions from biodiesel fueled vehicles will support the development of emission inventories, air quality management strategies under the new Federal ozone and PM standards, CMAQ compliance, EPACT compliance, and selection of alternative fuels and AFV programs. This information will be useful as a guide for continued implementation of AFV programs.

There is a price premium for B20 fuel compared to conventional diesel fuel. At this time

NCDOT is conducting a pilot study to demonstrate the use of B20 fuel on approximately 1,000 vehicles in selected areas of the state. There are plans to extend the use of B20 fuel to a much larger number of vehicles in all 100 counties in North Carolina. Therefore, it is important to be able to quantify the benefits of using the more expensive B20 fuel so that these benefits can be explained to constituencies within the agency.

NCDOT has a state-owned fleet of approximately 12,000 vehicles and equipment that include dump trucks, motor graders, front end loaders, backhoes, and others. Of this fleet, dump trucks constitute a substantial portion both with respect to the total number of vehicles as well as with respect to fuel consumption. Dump trucks are used for a variety of tasks, including transport of sand, gravel, aggregate, and other materials, as well as for use as spreaders and snow plows. Thus, this project focuses on dump trucks. There are several types of dump trucks. The key ones in the NCDOT fleet include single rear-axle and double rear axle vehicles. Single rear-axle vehicles that have two front wheels on one axle, and dual wheels on the rear axle (for a total of four wheels on the rear axle). These are sometimes referred to as "single axle" trucks. The double rear axle trucks are referred to as "tandems." The tandems have a pair of wheels on the front axles, and four wheels on each of the two rear axles, for a total of ten wheels. The NCDOT fleet contains vehicles built at different periods in time, including those with engines subject to the Federal Tier 1 emission regulations (from approximately 1996 to 2003) and new vehicles subject to the Federal Tier 2 emission regulations (e.g., 2004 model year). Both types of vehicles are included in this study.

1.2 Problem Definition

The key problems to be addressed by this work are the following: (1) what are the baseline real-world in-use emissions and fuel use during actual operation of the vehicle under typical duty cycles?; (2) what factors contribute the most to episodes of high emissions and/or fuel use?; (3) what operational strategies can be demonstrated and verified with respect to reductions in episodes of high emissions and fuel use?; and (4) what is the feasibility of such strategies?

1.3 Project Objectives

The objectives of this project are to: (1) characterize baseline real-world in-use on-road emissions of selected heavy duty diesel vehicles, including those fueled with B20, during normal duty cycles; (2) characterize the episodic nature of emissions and fuel use; (3) identify factors responsible for variability in emissions and fuel use, with specific focus on factors leading to episodes of high emissions and fuel use; and (4) develop recommended strategies for reducing the frequency and duration of high emissions and fuel use episodes, with consideration of operational constraints as well as other possible benefits.

1.4 Organization of This Report

This report is organized into chapters that cover major topics relevant to the problem definition and study objectives. A brief summary of the chapters is given here:

- Chapter 2 provides an overview of factors that affect emissions and fuel consumption rates for diesel vehicles, based upon information reported in the literature. This information provides a scientific and technical basis for prioritizing what type of data should be collected in the field study that is the key component of this work.
- Chapter 3 provides an overview of commonly used and accepted methods for measuring vehicle emissions. Many of the data that are available in the literature have been measured using laboratory based methods, such as engine dynamometers or chassis dynamometers, or using either tunnel studies or infrared remote sensing. The latter two provide real world, in-use data but are limited to conditions encountered at specific locations. In contrast, the measurement method used in this study involves portable on-board instrumentation, which enables measurement of real world, in-use emissions for an actual duty cycle at any location and under any conditions encountered by the vehicle.
- Chapter 4 provides a summary of existing data upon which others have compared emissions of vehicles fueled with B20 biodiesel versus those fueled with petroleum diesel. These data are primarily based upon engine dynamometer or chassis dynamometer data, and thus are not likely to be representative of real world operation. However, these data are potentially used as a basis for benchmark comparison with the data collected in this study.
- Chapter 5 provides details regarding the instrumentation used in this study, which is the OEM-2100 "Montana" system manufactured by Clean Air Technologies International, Inc.
- Chapter 6 provides an overview of the key factors that must be considered in designing a field data collection study to measure real world, in-use emissions and fuel consumption, and summarizes the key components of the study design for this project.
- Chapter 7 discusses the methods used to review and screen data collected in the field study and, where appropriate, to correct or discard data if problems were encountered. Furthermore, methods for estimating emission rates and fuel consumption for different "modes" are described. A "mode" is a specific type of activity performed by the vehicle. The modes include idle, various magnitudes of accelerations, various levels of cruising (depending upon different speed ranges), deceleration, and dumping. Disaggregating a total activity cycle into modes facilitates comparisons between vehicles and fuels for similar operating conditions.
- Chapter 8 provides a summary of the data collected in this project. The data are presented with respect to vehicle type (single rear axle or tandem dump truck), engine type (Tier 1 or Tier 2), vehicle load (unloaded or loaded), fuel type (B20 biodiesel or petroleum diesel), and operating mode (idle, low acceleration, medium acceleration, high acceleration, low cruise, medium cruise, high cruise, deceleration, and dumping). Data are reported for emissions and fuel consumption on a mass per time basis. Emissions that are characterized include nitric oxide (NO), carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbons (HC), and particulate matter (PM). Chapter 8 focuses on a summary of the data collected for a total of 12 vehicles, each of which was tested for one day with each of the two fuels. Additional data regarding each individual daily test is provided in the Appendix. Furthermore, the Appendix also includes emission rates and

fuel consumption on a per mile of vehicle travel basis, and emission rates on a per gallon of fuel consumed basis.

- Chapter 9 focuses on comparison of the data collected from the field study in this work to the data reported in the literature that were summarized in Chapter 4. The purpose of this chapter is to assess key similarities and differences in the findings of this project versus what has been reported in the literature.
- Chapter 10 provides the key findings and recommendations of this work.
- Supporting Appendices provide additional detail regarding the data collected in the field study of this project, as described above.

2.0 IDENTIFICATION OF FACTORS AFFECTING EMISSIONS AND FUEL CONSUMPTION OF PETROLEUM DIESEL AND BIODIESEL FUELED VEHICLES

The purpose of this chapter is to identify the key factors associated with the magnitude and variation in emission rates and fuel consumption for diesel vehicles. These factors include vehicle characteristics, vehicle activity patterns, ambient conditions, fuel properties, and several related issues. Examples of the latter include driver behavior, traffic flow (for activity that occurs on the roadway network), and roadway and route characteristics. The information provided here is based upon the existing literature, and provides background and context for the new data that was collected in this project and that is described in later chapters. Furthermore, an understanding of the key factors associated with emissions and fuel use provides a scientific and technical basis regarding what issues should be considered in designing a field study as well as regarding what data should be collected in such a study.

2.1 Vehicle Characteristics

This section briefly reviews two of the most important vehicle characteristics that affect fuel use and emissions, which include engine design and vehicle weight.

2.1.1 Engine Design

Engines are developed under different exhaust emission certification requirements, and thus are designed to comply with the standards in effect at they time that they were manufactured. As these standards have changed, the emissions of new engines have also changed. The in-use fleet is comprised of contributions from various model years, and thus there is variability in emission rates among in-use vehicles. Thus, engine design has a substantial impact on fuel use and emissions. For example, engines that are designed to operate with gasoline fuel are spark ignited, and tend to operate at relatively lower peak pressures and temperatures than those designed to operate with diesel fuel. The latter are compression ignited. The higher peak pressures reached by diesel engines tend to make them more fuel efficient, but are also conducive to formation of larger quantities of nitrogen oxides (NO_x) during combustion (e.g., Flagan and Seinfeld, 1998). Furthermore, whereas gasoline engines operate with approximately the stoichiometric (theoretical minimum for complete combustion) ratio of air to fuel, diesel engines operate with "excess" air. Thus, there is a substantial amount of oxygen present during combustion of fuel in the power stroke, and there is a larger proportion of oxygen in the exhaust of a diesel engine than a gasoline engine. The increased amount of oxygen is partly responsible for the higher NO_x emissions of diesel versus gasoline engines. However, the increased oxygen levels also tend to lead to lower emissions of products of incomplete combustion, such as CO and HC, compared to gasoline engines.

The trade-off between improved engine efficiency and NO_x emissions, as well as between higher NO_x emissions and lower emissions of CO and HC, is a typical one for many emission sources. Another characteristic of diesel engines is that they emit larger quantities of particulate matter than do gasoline engines. There is variability in fuel use and emissions for specific diesel engines, depending on the manufacturer and engine model. For example, the specifics of the time and temperature history of the fuel and air, and exhaust products, during the combustion process depend on the design of the combustion chamber and fuel injection system, among other factors (Haddad and Watson, 1984).

The performance of diesel engines is often enhanced by the use of a turbocharger. However, transient events during engine operation can produce higher than normal emission rates on an episodic basis. In particular, “turbocharger lag” is an effect that causes turbocharged diesel engines to emit excess CO and PM emissions. Turbocharger lag happens during large accelerations or other rapid changes in engine load. This hesitation results in a temporary lack of adequate air to the intake manifold, which in turn leads to a lower air-to-fuel ratio. As the air-to-fuel ratio decreases, then products of incomplete combustion (such as CO and PM) tend to occur at a higher rate. Thus, one strategy for preventing emissions from turbo-charged diesel engines is to attempt to reduce or minimize the turbo-charger lag effect (Haddad and Watson, 1984).

Table 2-1 shows EPA Tier 1 through Tier 3 Highway Heavy Duty Diesel Engine Emission Standards. Heavy-duty vehicles are defined as vehicles of GVWR (gross vehicle weight rating) of greater than 8,500 lbs. GVWR is the maximum recommended weight for a vehicle, including the weight of the vehicle itself, fuel and all cargo. Under the 1994 and later standards, sulfur content in the certification fuel (No.2 diesel) has been limited to 500 ppm by weight.

The different Tiers of standards have been announced in advance to allow engine manufacturers time to modify designs and introduce new engines to the market. Tier 1 and Tier 2 engines are currently available. Manufacturers of heavy duty diesel Tier 2 engines have the flexibility to certify their engines to one of the two options, which are shown in Table 2-1. Tier 3 engines are required starting in 2007. On December 21, 2000 the EPA signed emission standards for model year 2007 and later heavy-duty highway engines. The Tier 3 PM emission standard will take effect in the 2007 heavy-duty engine model year. The Tier 3 NO_x and non-methane hydrocarbon (NMHC) standards will be phased in for diesel engines between 2007 and 2010. The phase-in will be on a percent basis: 50 percent of heavy-duty engines sold need to achieve NO_x emissions of 0.20 g/bhp-hr and NMHC emissions of 0.14 g/bhp-hr from 2007 to 2009 and 100 percent need to achieve these standards in 2010.

Table 2-1. EPA Tier 1 through Tier 3 Heavy Duty Diesel Engine Emission Standards, g/bhp-hr basis

Tier	Model Year		HC	CO	NO_x	PM	NMHC[a] + NO_x	NMHC[a]
Tier1	1988-1989		1.3	15.5	10.7	0.60	-	-
	1990		1.3	15.5	6	0.60	-	-
	1991		1.3	15.5	5	0.25	-	-
	1994-1997		1.3	15.5	5	0.10	-	-
	1998-2003		1.3	15.5	4	0.10	-	-
Tier2[b]	2004 -2006	Option 1	1.3	15.5	2	0.10	2.4	N/A
		Option 2	1.3	15.5	2	0.10	2.5	0.50
Tier3	2007-2010		1.3	15.5	0.20	0.01	-	0.14

[a] non methane hydrocarbon: These are hydrocarbons such as ethylene, butane, hexane, propane. Typically, large quantities of NMHCs are emitted from vegetation, the vast majority as isoprene, C_5H_8.

[b] Manufacturers of heavy duty diesel Tier 2 engines can choose either Option 1 or 2 options.

Source : Yanowitz, McCormick, and Graboski (2000); Sheehan *et al*. (1998)

2.1.2 Vehicle Load and Weight

This section summarizes the findings of published studies regarding the effect of vehicle load and vehicle weight on emissions and fuel use. Heavier loads for given vehicles typically result in increased fuel consumption and, thus, decreased fuel economy (EPA, 2002).

In response to lingering concerns about dynamometer data, the U.S. EPA has constructed an on-road test facility to characterize the real world emissions of heavy duty diesel trucks. Data are collected by a computerized data acquisition system (DAS) and continuous emissions monitoring (CEM) system analyzers installed in the trailer of a tractor-trailer truck (Brown *et al.*, 2002). One objective of this research was to identify the magnitude of emissions increase associated with increase of vehicle load. Particular attention was paid to NO_x and PM emissions because heavy duty diesel vehicles are large contributors of these pollutants, but they are relatively smaller sources of CO and HC. Increases in gross vehicle weight from 52,000 *lb* to 80,000 *lb* resulted in approximately 40 percent or greater increases in NO_x grams per mile emissions during the accelerations and high cruise operations.

In addition to the EPA study, a variety of testing has been conducted to determine the effect of weight variations on heavy-duty vehicle emissions. Durbin *et al.* (2000) tested diesel vehicles to determine the effect of vehicle weight on emissions. PM and NO_x emissions were increased with increasing vehicle weight. The trends in HC and CO emissions were not consistent over the tests. Keller and Fulper (2000) also found that vehicle weight increases resulted in increased NO_x and PM. Only slight changes in HC and CO were observed as vehicle weight increased. The level of emissions varied considerably between vehicles. McCormick *et al.* (1998) examined the effect of changes in payload on PM, NO_x, and CO emissions from eight heavy duty dump trucks. NO_x and PM increases were observed as vehicle load increased.

2.2 Vehicle Activity

Vehicle activity refers to the sequence of events that occur during a duty cycle, which can include vehicle movement, as well as various activities that might occur while the vehicle is stationary. For example, vehicle activity includes over-the-road driving, as well as idling and other effects on engine load.

Engine load will affect emissions and fuel economy for heavy duty diesel trucks. For example, changes to the load on a diesel engine affect the engine torque that in turn affects the emissions and fuel use (Brodrick *et al.*, 2002). The use of accessories, such as air conditioners or lift equipment (e.g., for unloading a dump truck by raising the rear bed), as well as changes in load during over-the-road driving, affects emissions and fuel use.

Several of the key factors that can be used to quantify vehicle activity include vehicle speed, acceleration, and operating mode (e.g., Frey *et al.*, 2002b). Each of these is briefly discussed in the following sections.

2.2.1 Speed

Vehicle speed is a potentially useful measure of activity for vehicles that operate over-the-road. In an analysis of second-by-second data regarding in-use emissions of a small fleet of diesel transit buses, Frey *et al.* (2002b) found that speed was a statistically significant explanatory variable for NO_x, CO, HC, and CO_2 emissions.

There are some exceptions to the association between speed and emissions. For example, speed was not statistically significant with respect to NO_x emissions when the vehicle operated under "high accelerations," possibly because the engine was at or near maximum power demand. In such cases, the engine operates at approximately a steady-state condition and the NO_x emission rate might not vary even though speed is changing during the hard accelerations. For some operating modes, speed was not statistically significant with respect to HC emissions. The latter result is because HC emissions are primarily dependent upon the air-to-fuel ratio, which has a weak dependence on second-by-second speed and may depend more on all of the factors that contribute to overall engine power demand.

Because most of the carbon in the fuel is emitted as CO_2, CO_2 emissions may serve as a surrogate for fuel consumption. Therefore, there is a relationship between speed and fuel use.

Although a statistically significant relationship was found between emissions of some pollutants and second-by-second vehicle speed, speed alone explains only a small portion of the observed variation in emissions. Thus, speed alone is not expected to be an adequate basis for attempting to discriminate among different levels of emissions or fuel use.

2.2.2 Acceleration

Acceleration is a change in speed and is typically inferred on a second-by-second basis, such as in the study by Frey *et al*. (2002b) that evaluated the relationship between emissions and activity data for selected diesel transit buses. In that study, a statistically significant association was found between emissions of NO_x, CO, HC, and CO_2 with respect to acceleration for at least some operating conditions. Thus, acceleration is a potentially useful explanatory variable for both emissions and fuel use. Also, Kean *et al*. (2003) noted that fuel consumption and emissions might be more sensitive to the level of vehicle acceleration than to the vehicle speed. However, by itself, acceleration does not explain much of the total variation in emissions.

2.2.3 Operating Modes

As noted in previous sections, there does not appear to be any single explanatory variable, such as speed or acceleration, that provides an adequately complete basis for estimating the measured variability in emissions and fuel use for diesel vehicles. Frey *et al.* (2002b) evaluated many candidate explanatory variables, including engine size, ambient temperature and humidity, speed, acceleration, and road grade. Individually, none of these explain a substantial portion of the variation in emissions. However, an alternative approach to evaluating the variation in emissions is to classify second-by-second measurements into categories that represent different operating modes. For each operating mode, an average emission rate is estimated based upon measured data. The operating modes can be weighted to represent a real-world duty cycle.

An operating mode can be defined in a variety of ways. Using the example of a select fleet of diesel transit buses, Frey *et al.* (2002b) developed a simple set of four operating modes: (1) idle; (2) acceleration; (3) deceleration; and (4) cruise. Idle is defined as zero speed and zero acceleration. Acceleration was defined as vehicle movement during which the increase in speed exceeded a minimum criterion for acceleration. Deceleration was defined as vehicle movement during which the magnitude of the decrease in speed exceeded a minimum criterion. Cruise was defined as all vehicle activity not otherwise categorized, and typically represented driving at approximately constant speed. Thus, the modes are based upon various combinations of speed and acceleration.

The usefulness of these modal definitions was evaluated by comparing the mean emission rates among the different modes. The average emissions during the acceleration mode were significantly higher than for any other driving mode for all of the pollutants, except for HC. Conversely, the average emission rate during idling was the lowest of the four modes for all four pollutants. The ratio of the mean acceleration to the idle emissions was approximately a factor of five to ten for NO_x, CO, and CO_2, but only about a factor of 2 to 3 for HC. Idle and deceleration emissions were approximately the same for NO_x, CO, and CO_2. The amount of variability that can be captured by comparing operating modes is large compared to the amount of variability that can be explained by any individual variable. Frey *et al.* (2002b) explored additional refinements to the driving mode definitions, such as by splitting the acceleration mode into two modes, one for "low" acceleration and one for "high" acceleration. The average emissions were found to differ significantly between these two acceleration modes.

The results from Frey *et al.* (2002b) imply that the definition of a suitable set of operating modes for a particular vehicle type or duty cycle can be useful as a method for explaining and estimating variability in emissions and fuel use within a duty cycle.

2.3 Ambient Conditions

The purpose of this section is to discuss the relationship between ambient conditions versus the emissions and fuel use of diesel vehicles.

2.3.1 Temperature

The emissions of various pollutants may have some relationship with ambient temperature. For example, to the extent that a change in ambient temperature might lead to a change in the peak temperatures reached in the engine cylinders during combustion, there could be an effect on NO_x emissions. In particular, NO_x emissions tend to increase as peak combustion temperatures increases (e.g., Flagan and Seinfeld, 1998).

However, the relationship between ambient air temperature and peak combustion temperatures during combustion is not well-characterized. For example, as noted in Chapter 6, measurements conducted in this work occurred under different ambient temperatures; however, the intake air temperature as reported by the vehicle electronic control unit remained approximately constant. This implies that the temperature of the air entering the combustion chamber was approximately constant, even though ambient temperature varied. This might have occurred because of preheating of the air as it entered the air intake passages but prior to entering the cylinder. To the extent that intake air reaches an approximately constant temperature prior to entry into the cylinder, then peak combustion temperatures would not be affected significantly by changes in ambient temperatures. Hence, NO_x emissions might have little sensitivity to ambient temperature.

2.3.2 Humidity

Humidity is an environmental parameter that can have an effect on NO_x emissions for diesel engines (SwRI, 2003). Ambient humidity may affect the peak combustion temperature, which would affect NO_x formation. In particular, as humidity goes up, NO_x emissions are expected to decrease. According to SwRI (2003), humidity has some effect on NO_x emissions for heavy duty engines. However, Hearne (2004) reports that there are no conclusive trends for NO_x between humidity and emissions.

The US EPA has developed a correction factor for NO_x with respect to the humidity of inlet air for diesel engine (EPA, Part II, 40 CFR 85, 86, 90 *et al*., 2004; Chapter1, 40 CFR 86.1342-90, 2003):

$$K_H = \frac{1}{1 - 0.0182 \,(H - 10.71)} \qquad (2\text{-}1)$$

Where,
K_H = Humidity Correction factor on NO_x formation for diesel engines
H = Absolute Humidity (g/kg); H_A: 10.71 g/kg if relative humidity is 54.5 percent.

Because the absolute humidity is a function of temperature, the humidity correction needs to be calculated simultaneously with ambient temperature. Ambient temperatures varied from approximately 14 °C to 32 °C during the course of the field measurement study results that are reported in Table 6-5 of Chapter 6. As an example to illustrate the possible range of variation in NO_x emissions that might be attributable to humidity, the humidity correction factor for NO_x emissions after converting relative humidity to absolute humidity are shown Table 2-2.

Table 2-2. Variation of Humidity Factors based on the Ambient Conditions from the Field Study

Vehicle Type		Minimum	Maximum
Tier 1	Tandem	0.92	1.15
	Single Axle	0.87	1.02
Tier 2	Tandem	0.93	1.11
	Single Axle	0.93	1.06

Based upon the temperatures and humidities observed during data collection, as reported in Table 6-5, a bounding analysis was performed to determine the extent to which differences in temperature and humidity might affect comparisons of NO_x emissions. For all of the vehicles, the humidity correction factor ranges from as low as 0.87 to as high as 1.15, or a range of approximately ±15 percent. Although the reliability of this correction factor is not known, the implications of differences in humidity should be considered when interpreting comparisons of NO_x emissions. The results after applying these NO_x correction factors are incorporated in the Appendix in Tables A-59 to A-70.

2.4 Fuel Properties

The emissions and fuel use of a diesel vehicle are influenced by fuel properties. In particular, a key motivation of this study is to evaluate the effect of a change from petroleum diesel to B20 biodiesel fuel for a selected group of diesel vehicles. Previous studies have a reported a decrease in emissions of CO, HC, and PM, and a slight increase in NO_x, when this switch is made (EPA, 2002).

For diesel fuels, there are a number of parameters that are used to measure chemical and physical properties. Previous work, typically involving comparison of different fuel formulations, has provided insight that at least some of these properties have associations with emissions of specific pollutants. For example, EPA (2002) reports that fuel density, cetane number, distillation range, aromatics content, and lower heating value (LHV) have individual or combined effects on one or more of each of the following pollutants: PM, NO_x, HC, CO, and CO_2. Other properties are often used to distinguish or compare different fuels with respect to fuel economy or fuel handling issues. For example, the energy density of the fuel will have an affect on the apparent fuel economy (e.g., gallons of fuel used per duty cycle). Physical, chemical, and perhaps even biological properties of the fuel will influence issues such as handling and befouling. Handling issues include the ability of fuel to flow during cold versus warm weather. Biofouling refers to the growth of organisms in the fuel during storage, and this can be a problem for biodiesel fuels (Encinar *et al*., 2002).

The following subsections describe fuel properties that have been identified elsewhere that are relevant to variation in emissions, fuel use, or fuel handling.

- ***Density (r)***

The density (*r*) of petroleum products is the mass of fuel per volume, sometimes expressed in units of grams per milliliter (g/*ml*). However, often the density is described by a closely related measure, which is the specific gravity. The specific gravity is defined as the ratio of the density of the fuel to the density of water, at 60°F.

According to Durbin and Norbeck (2002), a 3.5 percent increase in fuel density leads to a 3 to 4 percent increase in NO_x emissions. An increase in fuel density could mean that more fuel is injected into the cylinder, if a constant volume of fuel is injected. More mass of fuel can translate into a higher heat release rate, if the energy content of the fuel increases with density. A higher heat release rate would lead to higher peak combustion temperatures, which in turn would tend to increase NO_x emissions.

- ***Cetane Number***

The cetane number is the standard measure of fuel ignition characteristics when injected into a diesel engine. It relates to the delay between when fuel is injected into the cylinder and when ignition occurs. The method for determining cetane number is ASTM test D-613 (EPA, 2001). In compression ignition diesel engines, the cetane number is the measure of ignition promotion and an indicator of the combustion smoothness (Graboski *et al.*, 2003). Higher cetane number indicates shorter times between injection of the fuel and its ignition. Good ignition from a high cetane number assists in easy starting, starting at low temperature, low ignition pressures, and smooth operation with lower knocking characteristics.

Many claim that cetane number is difficult to measure precisely. Furthermore, cetane number has been criticized in recent years as not being useful for characterizing auto-ignition conditions in modern turbocharged engines, particularly with alternative fuels (Stolter and Human, 1995).

According to McCormick (1997), PM decreases when cetane number increases, while NO_x slightly increases. In their study, an approximate 15 to 20 percent reduction of PM and a 1 to 2 percent increase of NO_x was observed when cetane number was increased by 8 to 9 percent.

- ***Cetane Index***

The cetane index is a calculated quantity that is intended to estimate the cetane number. However, it generally does not provide an accurate indication of cetane number if the fuel contains cetane-improving additives or for non-petroleum-based alternative fuels (McCormick *et al.*, 2001; Morris *et al.* 2003).

- ***Distillation Range***

Distillation range refers to the range of boiling points of different liquid fractions of the fuel, which are observed when separating the fuel into its components (Sheehan *et.al*, 1998). The distillation range is generally expressed in terms of the temperatures at which 10 percent (T10), 50 percent (T50), and 90 percent (T90) of the fuel will be evaporated. The highest temperature recorded during distillation is called the end point. However, because a fuel's end point is difficult to measure with good repeatability, 90 percent distillation point of fuel is commonly used. Lowering end point is expected to reduce PM (Kleinschek *et al.*, 1997).

- ***Aromatic Content***

Aromatic content is characterized by the presence of the benzene family in hydrocarbon compounds in the fuel. Aromatic compounds include heavier compounds such as toluene, xylene, and naphthalene. Limiting the amount of these aromatic compounds has the effect of reducing carbonaceous soot formation in burning (EPA, 2001; 2002). However, there are no reported significant effects on other emissions.

- ***Lower Heating Value (LHV)***

The heating value of a fuel is the enthalpy of reaction for combustion of the fuel. Thus, the heating value is the amount of energy released when the fuel is completely burned in a steady-flow process. The magnitude of the heating value depends on the fate of H_2O in the combustion products. In most real systems, the H_2O leaves the engine or combustor in the vapor phase. For this situation, the Lower Heating Value (LHV) is used. However, in principle, one could condense the water vapor and recover the latent heat of vaporization associated with this phase change. If this could be done, then the total heating value would be the sum of the LHV and the latent heat of condensation, which is referred to as the Higher Heating Value (HHV). Typically, the LHV is used to describe the heating value of diesel fuel. The HHV is often used in some industries, such as coal power generation. Thus, both types of heating values will be encountered in practice and there heating values might impact fuel economy and emissions (Kleinschek *et al.*, 1997; Schumacher *et al.*, 1997). No significant energy and emission impacts are identified; however, the heating value per mass or volume of a fuel is related to the fuel economy. When comparing fuels with different heating values and densities, there can be an apparent difference in fuel economy (e.g., miles of vehicle travel per gallon of fuel consumed) but not necessarily a difference in energy efficiency.

- ***Viscosity***

Viscosity is a measure of the resistance of a fuel to shear or flow, and is a measure of the fuel's adhesive/cohesive or frictional properties. Viscosity affects the atomization of the fuel injected into the engine combustion chamber (Yanowitz *et al.*, 1999). A high viscosity fuel will produce a larger droplet of fuel that may not burn well in an engine. A smaller droplet may produce more complete combustion (Graboski *et.al*, 2003). Better combustion typically translates into lower emissions of products of incomplete combustion, such as CO, HC, and PM. Although B100 blend stock has a higher viscosity than petroleum diesel, B20 biodiesel has a viscosity that is much closer to that of petroleum diesel. Thus, it is not expected that the relatively small difference in viscosity between these latter two fuels would significantly account for differences in emissions. In fact, the observed decreases in average CO, HC, and PM emissions for B20 versus petroleum diesel suggest that any effects of the slightly higher viscosity of B20 with respect to atomization are outweighed by other factors.

- ***Iodine Number***

Iodine number is based upon a standard natural oil assay to measure the degree of unsaturation, which is the number of double bonds present in vegetable oils and fats (McCormick *et al.*, 2001). Iodine number is inversely correlated with cetane number (EPA, 2001). Thus, if iodine number increases, PM emissions tend to increase and NO_x tends to decrease.

- ***Other Fuel Properties***

Some other fuel properties that are often reported for diesel fuels include flash point, initial boiling point (IBP), cloud point, and pour point. These properties are typically associated with handling characteristics of the fuel.

Flash point is a measure of the temperature to which a fuel must be heated such that a mixture of the vapor and air above the fuel can be ignited (Kleinschek *et al.*, 1997). The flash point of neat biodiesel is typically greater than 207 °F (Sheehan *et.al*, 1998). The U.S. Department of Transportation considers a material with a flash point of 207°F or higher to be non-hazardous (Ullman, 1989). IBP is the temperature at which the first vapor appears when heating the fuel (Kleinschek *et al.*, 1997). Cloud point is the temperature at which the first wax crystals appear as the fuel is cooled (Sheehan *et al.*, 1998). Pour point is the temperature at which the fuel is no longer pumpable as the fuel is cooled (Durbin *et al.*, 2000)

Fuels that have higher flash, IBP, cloud, and pour points can be more difficult to handle. For example, biofuels can produce more handling problems in cold temperatures because of greater difficulting in pouring the fuel and because of the formation of wax crystals (Duffield *et al.*, 1998). However, there is not a direct reported association between these properties and either emissions or fuel economy.

- ***Summary of Fuel Properties for Petroleum Diesel, Biodiesel, and Blend Stock***

Table 2-3 summarizes the fuel properties of three fuels; LHV, specific gravity, cetane number, weight percent of carbon, hydrogen, and oxygen, cloud point, flash point, IBP, pour point, distillation point (T90), aromatic content, and viscosity.

When comparing soy-based B100 blend stock with No. 2 petroleum diesel, the blend stock has a smaller heating value, larger density, larger cetane number, less carbon, less hydrogen, more oxygen, and higher values for the cloud point, flash point, initial boiling point, and distillation point. The blend stock has a lower aromatics content, and a higher viscosity.

The relatively large differences between No. 2 petroleum diesel and the B100 blend stock are reduced significantly when both are mixed to create a B20 biodiesel blend. For example, the cloud point of B20 fuel is much closer to that of petroleum diesel than the B100 blend stock. Thus, the blend has many of the advantages of each of its components. For example, the fuel handling issues with B20 are not quite as potentially problematic as for B100. Furthermore, B20 is partially oxygenated, which is expected to lead to lower emissions of products of incomplete combustion when compared with petroleum diesel.

Table 2-3. Summary of Properties for Typical No. 2 Petroleum Diesel, Soy-Based B20 Biodiesel, and Soy-Based B100 Blend Stock

Property	No. 2 Petroleum Diesel	B20	B100
LHV (*BTU/lb*)	18,730	18,100	15,800
Specific Gravity(*kg/l*) @60°F)	0.84	0.85	0.89
Cetane No.	44	46	54
Carbon, wt%	86.4	84.5	76.9
Hydrogen, wt%	13.6	13.3	12.1
Oxygen, wt%	0.00	2.20	11.0
Cloud point (°F)	18	20	40
Flash point (°F)	150	180	260
IBP(°F)	352	373	573
Pour point (°F)	-4	9	34
Distillation Point (T90 °F)	603	640	666
Aromatics, vol%	30	24	0
Viscosity@40°C (mm^2/s)	2.6	2.9	4.1

Source : McCormick *et al*. (2001); Yanowitz, Graboski, Ryan, Alleman, and McCormick (1999); EPA (2001); EPA(2002)

The next sections discuss the chemical composition of petroleum diesel effects on fuel properties and the effect of blending on biodiesel fuel properties. They summarize the advantages and disadvantages from the published studies regarding the use of biodiesel instead of petroleum diesel fuel.

2.4.1 Petroleum Diesel

Petroleum diesel fuel is a complex mixture of many different hydrocarbons with carbon numbers in the range of C9 to C28 and with a distillation range of 350 to 640 °F. The hydrocarbon composition influences many of the fuel's properties, including ignition quality, heating value, volatility, and oxidation stability (Flagan and Seinfeld, 1998).

Three types of diesel fuel are commonly used in the United States: No. 1 diesel, No. 2 diesel (which is described in Table 2-3), and No. 4 diesel. No.1 diesel and No. 2 diesel are used for highway vehicles and industrial application. No. 4 diesel is a lower quality blend of distillates, compared to No. 1 and No. 2 diesel, which is used for low speed engines or non-automotive applications (Singer *et al.*, 1996; Flagan and Seinfeld, 1998).

2.4.2 Biodiesel

Biodiesel is a naturally oxygenated and possibly cleaner burning diesel replacement fuel made from natural, renewable sources such as new and used vegetable oils or animal fats. It can be used directly in diesel engines without major modifications to the engines and vehicles (EPA, 2002). Biodiesel can be blended with petroleum diesel fuel at any ratio. A common blend rate is 20 percent renewable source and 80 percent petroleum diesel. Biodiesel is registered as a fuel and fuel additive with the U.S. EPA (Bockey, 2004; Coltrain, 2002).

However, use of biodiesel fuel can lead to clogging of a fuel filter. Biodiesel fuel has a strong solvent action, and thus can dissolve residues in the fuel tank and fuel line. These dissolved residues can cause clogging of the fuel filter (Tyson, 2001). Thus, a typical need is to replace or enlarge fuel filters when switching for petroleum diesel to biodiesel.

2.4.2.1 Blend Stocks (B100)

Pure biodiesel blend stock is referred to as B100 or as “neat” biodiesel. B100 has been classified as an alternative fuel by the U.S Department of Energy, and meets California Air Resources Board (CARB) clean diesel standards (Morris *et al.* 2003)

Biodiesel blend stocks contain a variety of fatty acid methyl esters with carbon chains. The carbon number ranges approximately from C12 to C22 (Faupel and Kurki, 2002). Blend stocks degrade about 4 times faster than petroleum diesel (Coltrain, 2002). Because of the high molecular weight esters, it elevates the boiling point up to 573 °F (Mushrush *et al.*, 2000).

B100 is sensitive to cold weather and may require special antifreezing precautions (Morris *et al.*, 2003). B100 acts like a detergent additive, loosening and dissolving sediments in storage tanks. Because biodiesel is a solvent, B100 may cause rubber and other components to fail in older vehicles (McCormick *et al*, 2001).

2.4.2.2 Biodiesel Fuel (B20)

B20 can be used in any diesel vehicle without major modifications (Duffield *et al.*, 1998), but a typical required change is to replace or enlarge the fuel filter. B20 is often used because it has some of the advantages of petroleum diesel, such as with respect to handling, and some of the emissions of the blend stock, such as with respect to lower emissions of some pollutants. For example, B20 has a higher energy content compared to B100, and a higher cetane number and lower aromatic content compared to petroleum diesel. Based upon engine dynamometer testing, it appears that B20 is associated with lower emissions of HC, CO, and PM compared to petroleum diesel (Bockey, 2004).

Disadvantage of this fuel is presence of the sodium- and potassium- containing ash. These ashes are made from contamination from catalysts used in trans-esterification. Trans-esterification refers to the process of exchanging the alkoxy (alkyl with oxygen) group of an ester by another alcohol. Algae growth might be also a problem the long-term storage (Sheehan *et al.*, 1998).

2.4.3 Effects of Fuel Properties on Emissions

The characteristics of B20 fuel, in comparison to No. 2 petroleum diesel, are considered with respect to expected or observed changes in emissions of key pollutants, based upon information reported in the literature.

2.4.3.1 Particulate Matter (*PM*)

Diesel vehicles emit significant quantities of PM. Reducing PM emissions from diesel vehicles tends to be of highest priority because these PM emissions are likely to cause cancer (Morris *et al.*, 2003). Typically, oxygenation of fuel, cetane number, distillation range, and aromatic content can affect PM emissions at tail-pipe.

PM reduction is related to the amount of oxygen in the fuel. Substantial reduction in PM emissions can be obtained through the addition of oxygenates to diesel fuel (Yanowitz *et al.*, 2000). B20 has approximately 2.20 weight percent oxygen, compared to no oxygen in petroleum diesel. According to Akasaka *et al.*(1997) and McCormick *et al.*(2001), PM reduction using B20 instead of petroleum diesel is between 0 to 16 percent during turbocharged engine operation.

However, PM reduction is affected by factors other than oxygen content because PM concentration can be increased due to a decrease in cetane number and increase in aromatic compounds and distillation end point. Decreased cetane number and increased aromatic content along with higher end point are correlated with higher PM. Cetane number helps improve combustion quality. Poorer combustion quality makes PM emissions increase. Also, aromatics have a great tendency to form carbonaceous soot in burning and end point temperatures might minimize deposits in combustion chamber. Thus, B20 and B100, which have high cetane number, but lower end point without any aromatics, can actually reduce PM emissions (Akasaka *et al.*, 1997; McCormick *et al.*, 1997; 2001).

2.4.3.2 Nitrogen Oxides (*NO_x*)

The blending effect for the NO_x emissions is complicated and NO_x emissions do not appear to be simply related to the blend percentage as characterized by the oxygen level (Graboski *et al.*, 2003). Provisionally, one could estimate NO_x emissions by a linear combination of petroleum fuel and neat biodiesel. For 20 percent blends such an estimate would seem to be conservative.

Reported NO_x emissions from biodiesel are slightly higher than those from petroleum diesel fuel

(EPA, 2002). The higher NO_x emissions are theorized to come from the higher density of fuel (Durbin and Norbeck, 2002). Linear increases in NO_x emissions occur when the concentration of biodiesel in the fuel increased (McCormick *et al.*, 2001). Durbin and Norbeck (2002) reported that an increase in fuel density of 3.5 percent is associated with an increase in NO_x emissions of 3 to 4 percent. Based on EPA (2003) study of cetane effects on NO_x emissions, cetane number also tends to have a role in slight increase of nitrogen oxides emission effects for heavy duty diesel engines.

2.4.3.3 Hydrocarbons (*HC*)

HC emissions can be either unburned or partially burned fuel molecules (Flagen and Seinfeld, 1998). HC emissions are typically from incomplete combustion. According to EPA (2001), a 19 to 32 percent decrease of HC emissions can be expected after switching from petroleum diesel to B20 fuel. This might be in part because of the higher oxygen content of B20, which tends to promote more complete combustion.

2.4.3.4 Carbon Monoxide (*CO*)

CO is a result of incomplete combustion and is formed mostly when fuels containing carbon are burned where there is too little oxygen. As described in Section 2.1.1, CO emissions from diesel engines are generally low since diesel engines operate fuel lean. However, oxygenated fuels such as biodiesel can further reduce CO emissions because of the oxygen content in the fuel itself, which further promote complete combustion (Durbin and Norbeck, 2002). For example, Wang *et al.* (2000) found that there is a 12 percent reduction in CO emissions when using B35, which is 35 percent of biomass and 65 percent of petroleum diesel, instead of petroleum diesel.

2.4.3.5 Carbon Dioxide (CO_2)

Biodiesel provides a reduction in net CO_2 emissions (Sheehan *et al.*, 1998). Although the amount of CO_2 emitted from the exhaust pipe is slightly higher than for petroleum diesel fuel, a significant portion of the carbon in B20 is based upon biomass from soybeans, which in turn is based upon CO_2 taken up by the soybean plant from the ambient air. The net CO_2 emissions from the soy-based blend stock component of the fuel are approximately zero (McCormick *et.al*, 2001; Graboski *et al.*, 2003). In contrast, the CO_2 emitted from the petroleum portion of the fuel results in a net increase in CO_2 flux to the atmosphere. However, when compared to petroleum diesel, the portion of carbon in the fuel that is non-renewable is smaller.

The total CO_2 emissions on a per energy basis depend on the weight percent of carbon in the fuel, the combustion efficiency, and the heating vale of the fuel (Sheehan *et al.*, 1998).

2.4.4 Fuel Economy

Fuel consumption is proportional to the volumetric energy density of the fuel, which in turn depends on the heating value and the density of the fuel (Monahan and Friedman, 2004). Fuel economy is related to the volume-based heating value of the fuel (Muster *et al.*, 2000). Tsolakis *et al.* (2003) estimated that fuel economy will decrease when comparing biodiesel with petroleum diesel.

For petroleum diesel and biodiesel fuels, the heating value on a BTU per gallon of fuel basis was calculated from the lower heating value and the fuel density that are reported in Table 2-3. The results are shown in Figure 2-1. B20 biodiesel has a 2.21 percent lower volume-based heating value than does petroleum diesel. This implies that a reduction in fuel economy of approximately two percent is expected when switching from petroleum diesel to B20 biodiesel fuel.

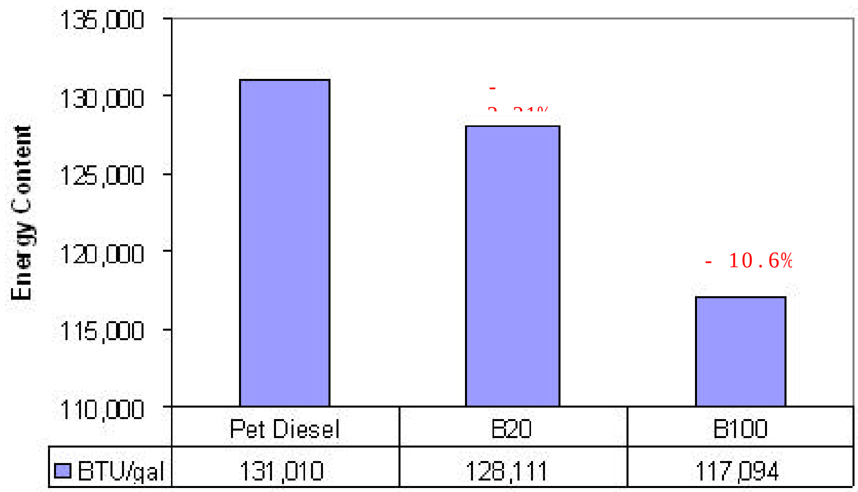


Figure 2-1. Average energy content of conventional diesel and soy-based blend stocks per gallon of fuel

2.4.5 Power Loss

This section focuses on evaluating the possibility of power loss when switching from petroleum diesel to a biodiesel fuel. According to Wayne *et al.* (2004), the peak engine horsepower is related to the heating value of the fuel. A fuel with a smaller volume-based heating value might affect engine operation if there is a volumetric fuel flow limitation, such as that less chemical energy is delivered to the engine under peak load conditions. In turn, the reduction in the chemical energy available to the engine under peak flow conditions would lead to less peak horsepower. This amount of difference is typically referred to as "power loss."

According to Tsolakis *et al.(*2003), there is a small amount of power loss using B100 instead of petroleum diesel. According to EPA (2002), the use of B20 biodiesel instead of B100 blend stock is expected to reduce the power loss problem.

There are few studies that have quantified power loss for biodiesel fuels. A study by Dorado *et al.*(2003) involved testing of B100 blend stock on 6 different engine setting that had previously used petroleum diesel. Initially, a loss in maximum power of 5 to 7 percent was observed. However, after 50 hours of engine operation, the power loss was found to decrease to less than 2 percent. A clear explanation was not available as to why power loss changed with time. A possibility is that the solvent properties of B100 blend stock might clean out fuel lines and fuel injectors, such that after an initial period of introduction of the new fuel, a slight increase in fuel delivery rate might be achieved. However, an actual mechanism for the change in power loss has not yet been confirmed.

2.5 Related Issues

In this section, other variables that can influence vehicle emissions and fuel consumption, and that are not discussed in previous sections, are briefly considered.

2.5.1 Driver Behavior

Driving behavior may affect the emissions of heavy duty diesel vehicles (Clark *et al.*, 2002). Drivers may undergo different periods of attentiveness during long periods of repetitive activity (Gordon and Deborah, 1991). Although a professional driver must respond to the task at hand, and conduct a duty cycle that meets the needs of the task, there can be some variation in the specifics of how the duty cycle is performed. For example, drivers might be more or less aggressive in terms of accelerations and might choose different cruising speeds if traffic conditions allow. Different driving behaviors might affect engine power demand and lead to differences in emissions.

2.5.2 Traffic Flow

Traffic flow can have an influence on fuel consumption and emissions. Smooth traffic flows correspond to lower accelerations and driving dynamics (Charroborty *et al.*, 2004). For example, cross roads, traffic lights and traffic jams can lead to more frequent stops and accelerations, which might lead to variation in emissions (e.g., Mierlo *et al.*, 2004).

2.5.3 Roadway and Route Characteristics

Roadway and route characteristics can have an effect on vehicle emissions and fuel consumption at specific location of corridors or at work places (Mierlo *et al.*, 2004; Charroborty *et al.*, 2004). Heavy duty diesel vehicles can travel on local roads, highways, and off-road. Off-road work may involve significant time periods of idling. On-road driving will be influenced by traffic conditions as well as speed limits and design speeds of roadways, and roadway geometries (e.g., curves) that might necessitate changes in speed. Some factors that may influence emissions include road type, road design and proximity to a traffic signal (Charroborty *et al.*, 2004).

2.6 Conclusion

Tailpipe emissions are a complex function of many influential variables, including vehicle characteristics, vehicle activity patterns, ambient conditions, fuel properties, and related issues. Examples of related issues include driver behavior, traffic flow, and roadway and route characteristics. These latter issues can influence the vehicle activity pattern. Overall, some of the key factors that influence emissions are found to be fuel properties, vehicle weight, speed and acceleration, and operating modes. Based upon the insights from information reviewed in this chapter, a recommendation is that vehicles measured in this study be categorized based upon their weight, engine design, load, fuel, and operating mode. These factors are considered in later chapters when developing the study design and interpreting the results of the data collected in the field.

3.0 METHODS FOR MEASUREMENT OF VEHICLE EMISSIONS AND FUEL USE

This chapter provides an overview of methods for measuring vehicle emissions, with a focus on heavy duty diesel vehicles. Measurements of emissions from heavy duty diesel vehicles have typically been made using the following methods:

- Engine dynamometer tests
- Chassis dynamometer tests
- Tunnel studies
- Remote sensing
- On-board instrumentation

Each of these is briefly described in the sections that follow.

3.1 Engine Dynamometer

Engine dynamometer tests involve testing an engine apart from any vehicles in which it is used. There are a variety of test cycles used for these types of measurements, and they generally are categorized as either steady state or transient tests. Steady state tests involve running the engine under constant conditions, such as constant engine RPM and load. Many of the steady state tests involve more than one "mode," where each mode has constant conditions. In contrast, transient tests involve some degree of continuous variation of operating conditions as part of the test schedule. The latter may be more representative of real world conditions.

The next section provides an overview of engine dynamometer testing, followed by sections on steady-state modal tests and transient tests, respectively.

3.1.1 Overview of Engine Dynamometer

An engine dynamometer is a device which measures mechanical power of engine. To test an engine's capability, the dynamometer puts a load on an engine. The dynamometer is typically used for engine research, development, and engine performance tuning or to troubleshoot problems such as low horsepower, insufficient torque, and leaks. A dynamometer attaches directly to the engine shaft and places a specified load on the engine. The use of an engine dynamometer requires removing the engine from the vehicle (Artelt *et al.*, 1999; Oh and Cavendish, 1985).

The emissions measurements obtained from engine dynamometers are typically reported in units of grams of pollutant emitted per brake horsepower-hour of engine output (g/bhp-hr). Thus, engine dynamometers do not produce data in units that are directly relevant to real world activity patterns, such as grams per mile of vehicle travel. In order to estimate total emissions using this type of emission factor, one needs to know the engine capacity (hp), the load (percentage of maximum capacity) and the number of hours of operation. This approach is used in EPA's NONROAD model (EPA, 2002), but is often criticized for requiring data that are not readily available.

The engine dynamometer usually measures power at the flywheel of the engine for highest accuracy: in this case, no transmission or driveline losses influence the results. It is possible to have very good control over all test parameters and test conditions for repeatability. An engine dynamometer needs to have a cooling system to control the engine temperature in the interest of accuracy and reliability. Also, it is important to maintain the maximum tested engine RPM within safe levels (Oh and Cavendish, 1985).

3.1.2 Steady-State Test

Steady state engine dynamometer test cycles typically involve operating the engine at one or more settings of constant load and engine speed (revolutions per minute – RPM). Each setting is referred to as a mode. For each mode, the engine is typically operated for a sufficient amount of time to produce approximately stabilized emission rates with respect to time. When two or more modes are included in the test cycle, the emissions measurements from each mode are typically combined using a weighted averaging scheme. The specific definitions of each mode, and the weighting scheme used to combine modes, differ from one test cycle to another (Artelt *et al*, 1999).

Some steady test cycle are defined in the Code of Federal Regulations (40CFR336) for the US. For example, the EPA 13 mode test typically consists of 13 sequential steady state operating modes with 4.5 to 6 minutes of measurements in each mode. The engine RPM during each mode must be within ±50 rpm of the engine speed specified in the test procedure. The actual torque must be within ± 2 percent of the maximum torque at the test speed. This steady-state test cycle is categorized by 3 sections: idle (zero speed), intermediate speed, and rated speed. The intermediate speed can be defined as a peak torque speed and the rated speed is defined as a maximum measured, full power speed. The loads correspond to 2, 25, 50, 75, and 100 percent of maximum available torque at a given test speed (EPA 2001; Oh and Cavendish, 1985).

Internationally, many different steady state test cycles have been used. Some of the more commonly used ones, including the R49, JAP13, and AVL 8 mode test cycles are briefly described. These three test cycles, as well as the EPA 13 mode cycle, are summarized in Table 3-1.

- **R49 cycle**. The R49 cycle is a European 13-mode steady-state test cycle for heavy-duty diesel engines. This test cycle is similar to the EPA 13 mode cycle, as both cycles have the same operating conditions, but they differ with respect to weighting factors. For example, R49 has smaller weighting factors for high engine loads and a slightly larger weighting factor for the idle mode (EPA, 2001).

- **AVL 8 mode**. The AVL 8 Mode test is an 8 mode steady state engine test procedure. This test cycle was initially designed for simulating the US FTP (Federal Test Procedure) transient engine dynamometer test cycle for heavy duty diesel engines. Thus, NO_x and HC exhaust emissions of this steady state test cycle typically produce similar trends compared to the US FTP test cycle (EPA, 2001).

- **Japanese 13 mode** (JAP13). The Japanese 13 Mode test cycle is a steady-state engine test cycle for heavy-duty engines in Japan (EPA, 2001). This test cycle operates at low weighting factor compared to AVL8. Approximately, 80 to 95 percent of weighting factors are in the range of 0.032 to 0.142.

Table 3-1. Characteristics of Engine Dynamometer Test Cycles.

Mode No.	Engine RPM Speed(% of nomal[a])				Loading Factor (%)				Weighting Factors[b]			
	R49	EPA13	JAF13	AVL8	R49	EPA13	JAF13	AVL8	R49	EPA13	JAP13	AVL8
1	idle	idle	idle	0	-	-	-	0	0.08	0.07	0.21	35
2	max torque speed	max torque speed	40	11	10	10	20	25	0.08	0.08	0.037	6.34
3			40	21	25	25	40	63	0.08	0.08	0.027	2.91
4			idle	32	50	50	-	84	0.08	0.08	0.21	3.34
5			60	100	75	75	20	18	0.08	0.08	0.029	8.4
6			60	95	100	100	40	40	0.25	0.08	0.064	10.45
7	idle	idle	80	95	-	-	40	69	0.08	0.07	0.041	10.21
8	rated power speed	rated power speed	80	89	100	100	60	95	0.1	0.08	0.032	7.34
9			60		75	75	60		0.02	0.08	0.077	
10			60		50	50	80		0.02	0.08	0.055	
11			60		25	25	95		0.02	0.08	0.049	
12			80		10	10	80		0.02	0.08	0.037	
13	idle	idle	60		-	-	5		0.08	0.07	0.142	

[a]: Normalized speed: 0% = low idle, 100% = rated speed
[b]: Relative weight factors, not normalized (they do not add to 100%)

Source: EPA (2001)

3.1.3 Transient Test

Transient engine dynamometer test cycles involve dynamic variation in engine operating conditions on a continuous basis during the course of a test. Although transient tests can include portions during which engine operation may reach a steady-state, they also include portions during which engine speed, engine load, or both are varied in order to reproduce an observed real-world engine duty cycle. For example, a transient test can account for real world operations such as idling, acceleration, and deceleration. One of the most commonly used transient engine dynamometer test cycles is the heavy-duty engine Federal Test Procedure (FTP).

The heavy-duty engine FTP is commonly referred to as the Transient test cycle. This cycle is used for certification emissions testing of diesel engines in the US. The FTP transient test is based on the UDDS (Urban Dynamometer Driving Schedule) chassis dynamometer driving cycle (EPA, 2001). FTP test cycle consists of four phases: New York Non Freeway (NYNF) phase for light urban traffic with frequent stops and starts; Los Angeles Non Freeway (LANF) phase for heavy urban traffic with several stops and starts; Los Angeles Freeway (LAFY) phase simulating a crowded highway in LA; and repetition of the first NYNF phase. This 4-phase cycle is typically carried out twice. There is a 20 minute period of idle between the first and second test. The second test is intended to represent a hot-start, which is a start after the engine is warmed-up. The equivalent average speed is about 19 mph and the equivalent travel distance is approximately 5.7 miles for 18 minutes. The average load factor of the heavy-duty FTP cycle is about 20 to 25 percent of the maximum engine horsepower available at a given speed. The FTP transient cycle run with a hot start only is referred to as FTP (hot) (EPA, 2001&2002; DNC, 2005).

3.2 Chassis Dynamometer

A chassis dynamometer test involves the entire vehicle. The drive wheels of the vehicle are placed upon rollers, and the vehicle is tied down so that it remains stationary during the test. The vehicle is operated according to a predetermined speed profile by a driver who follows a computer screen that displays the current required speed. The driver operates the vehicle to closely match the required speed (Nine *et al.*, 1999).

Chassis dynamometer test cycles are typically transient cycles (Yanowitz and McCormick 2000). Therefore, the driver must anticipate and comply with changes in the required speed within a specified tolerance. For on-road vehicles, the speed profile represents driving speed in miles per hour (Wang *et al.*, 1997; Wang *et al.*, 1999). The load applied to the vehicle via the rollers can be controlled by the laboratory operator.

Chassis dynamometer tests are more commonly used for light duty than for heavy duty vehicles (Wang *et al.*, 1999). As the size of the vehicle increases, so does the cost of the facility. Thus, there are fewer heavy duty chassis dynamometer facilities than there are light duty chassis dynamometer facilities.

An advantage of a chassis dynamometer test over that of an engine dynamometer is that is possible to more directly reproduce an on-road duty cycle and to obtain emissions measurements in units that might be more useful for emission inventory purposes, such as grams of pollutant emitted per mile of vehicle travel (Yanowitz and McCormick 2000; Nine *et al.*, 1999). Furthermore, the effect of the entire drive train is accounted for, whereas in an engine dynamometer test often the engine is directly coupled to the dynamometer, without a transmission or lengthy drive shaft. A disadvantage of a chassis dynamometer test is that it is relatively expensive.

There are numerous chassis dynamometer test cycles. Some of the more common ones are briefly described here (DNC, 2005) and are summarized in Table 3-2.

- **Braunshweig City cycle.** The Braunschweig City cycle was developed at the Technical University of Braunschweig. It is a transient chassis dynamometer test cycle simulating urban bus driving with frequent stops in Braunschweig City and has been one of very few heavy-duty transient cycles in Europe.

- **Business-Arterial-Commuter (BAC)**. The BAC cycle was developed to measure the fuel economy of heavy duty diesel vehicles. It represents driving conditions on arterial roads and has a long test period (47 minutes).

- **Central Business District Cycle (CBD)**. The CBD cycle is the activity pattern of a delivery vehicle in downtown traffic. It is composed of 14 repetitive sub-cycles. Each sub-cycle includes idle, acceleration, cruise, and deceleration modes (Hendricks and O'Keefe, 2002).

- **City-Suburban Heavy Vehicle Cycle (CSHVC)**. The CSHVC cycle is a chassis dynamometer test cycle for heavy duty diesel vehicles developed by the West Virginia University (Hendricks and O'Keefe, 2002). This test cycle was made for representing emissions from city and suburban areas.

- **Manhattan Bus Cycle.** The Manhattan Bus Cycle is a chassis dynamometer test for urban buses. It was based on the driving patterns of urban transit buses in Manhattan, New York City. The cycle is characterized by frequent stops and low average speed.

- **New York Bus Cycle (NYBus)**. NYBus is a chassis dynamometer test for urban buses. It represents driving patterns of New York transit buses. It is a short cycle characterized by frequent stops, fast average acceleration, and low speed. This cycle has similar pattern to Manhattan, but this cycle is more generalized cycle that is intended to be applicable to all urban areas in New York City, not just the borough of Manhattan.

- **New York Composite cycle (NYComp)**. NYComp is a chassis dynamometer test cycle for heavy duty vehicles. It represents driving patterns in New York City and has slightly higher average speed and fewer stops compared to the Manhattan Bus Cycle (Hendricks and O'Keefe, 2002).

- **Urban Dynamometer Driving Schedule (UDDS)**. The Urban Dynamometer Driving Schedule (UDDS) is a basis for the EPA FTP engine dynamometer transient test (EPA, 2002). This chassis test is characterized by high speed, representing a real world highway scenario.

- **WVU 5-Peak cycle**. West Virginia University (WVU) developed this cycle in 1994 for heavy duty diesel dump trucks. The cycle is comprised of five components, each of which has four modes: idle, acceleration, cruise, and deceleration. The five components differ with respect to their maximum cruising speed, which ranges from 25 to 40 mph (Yanowitz *et al.*, 2000).

Among these common test cycles, the UDDS is the most relevant, based on similarity to driving conditions of our study. The key similarity is the inclusion of some highway driving, which is not included in many of the other test cycles.

Table 3-2. Characteristics of Chassis dynamometer test cycles.

CYCLE	Duration (*sec*)	Distance (*mile*)	Avg. Speed (*mph*)	Max. Speed (*mph*)	Average Acceleration (*ft/s*^{2})	Maximum Acceleration (*ft/s*^{2})	Number of Stops
Braunshweig City cycle	1,740	6.88	14.3	36.4	-	-	29
BAC	2,830	14.0	18.0	55.0	-	-	23
CBD	560	2.00	12.6	20.0	2.94	5.91	14
CSHVC	1,700	6.68	14.2	43.8	-	-	14
Manhattan Bus cycle	1,089	-	6.80	25.4	-	-	20
NYBus	600	0.620	3.70	30.8	3.86	9.14	11
NYComp	-	2.52	8.85	36.0	1.58	17.9	16
UDDS	1,060	5.55	18.9	58.0	-	-	11
WVU 5-peak cycle	900	5.00	-	-	-	-	5

On line source : http://www.dieselnet.com/standards/cycles/

3.3 Tunnel Study

Tunnel studies typically involve measuring the total flux of pollutants from vehicles passing through a tunnel and correlating the pollutant flux to traffic flow (Jamriska *et al.*, 2004). Using statistical analysis, it may be possible to apportion the emissions among major categories of vehicles (e.g., gasoline versus diesel, or light duty versus heavy duty). An advantage of a tunnel study is that it can capture a cross-section of the on-road vehicle fleet and represents real world operation at the location of the tunnel. A disadvantage is that it is difficult to apportion emissions to specific vehicle classes (i.e. subcategories within diesel fueled-vehicles) and the traffic conditions of the tunnel may not be representative of conditions elsewhere. Emissions can be estimated on a fuel consumed basis if a carbon balance can be assumed, or on an average per mile basis. Flux measurements are similar conceptually to tunnel studies, but involve measurement of flux of pollution surrounding a roadway (Jamriska *et al.*, 2004, Stemmler *et al.*, 2004)

3.4 Remote Sensing

Remote sensing devices uses infrared (IR) and, in some cases, ultraviolet (UV) spectroscopy to measure the concentrations of pollutants in exhaust emissions as the vehicle passes a sensor on the roadway. Some applications of RSD include: monitoring of emissions to evaluate the overall effectiveness of inspection and maintenance programs; identification of high emitting vehicles for inspection or enforcement purposes; and development of emission factors (Stephens and Cadle, 1991). The major advantage of remote sensing is that it is possible to measure a large number of on-road vehicles (e.g., thousands per day). The major disadvantages of remote sensing are that it only gives an instantaneous estimate of emissions at a specific location, and cannot be used across multiple lanes of heavy traffic. Furthermore, remote sensing is more or less a fair weather technology (Frey and Eichenberger, 1997; Rouphail *et al.*, 2000). Thus, remote sensing produces only an instantaneous snapshot of vehicle emissions under limited conditions, and does not provide insight regarding how emissions vary at different points of a trip by any one vehicle.

Additional assumptions are required to convert fuel-based emissions to distance- or time-based estimates. For purposes of area-wide emissions estimation, a fuel-based approach may be adequate, but for meso-scale or micro-scale emissions inventories, it is not clear that a fuel-based approach is appropriate (Cadle and Stephens, 1994).

3.5 On-Board Measurements

On-board emissions measurement is widely recognized as a desirable approach for measuring emissions from vehicles, since data are collected under real-world conditions in the driving environment (Cicero-Fernandez and Long, 1997; Gierczak *et al.*, 1994; Tong *et al.*, 2000). Compared to dynamometer-based measurement methods, the advantage of on-board measurement is that it is possible to obtain real-world in-use data that is representative of actual operation and emissions. Compared to tunnel studies and remote sensing, it is possible to obtain data at any location driven by the vehicle.

On-board measurements can be made with large, complex, and expensive instrumentation or with smaller, less expensive, and more portable systems. The former systems typically involve a permanent installation in a vehicle or trailer, and take considerable room and add perhaps substantial weight to the vehicle or a significant trailer towing load. The advantage of more complex systems is that they use the most advanced instrumentation that can survive the motions of on-road travel, and thus would tend to be of the same precision and accuracy as laboratory grade instruments used in some dynamometer facilities. The disadvantage is the higher cost and the lack of flexibility to easily install with many different types of vehicles.

On-board measurement systems have had limited applicability because of high cost. However, in the last few years, efforts have been underway to develop lower-cost instruments capable of measuring both vehicle activity and emissions (e.g., Scarbro, 2000; Vojtisek-Lom and Cobb, 1997). These systems are known as portable emissions measurement systems (PEMS).

Hence, we briefly describe two categories of on-board systems: complex on-board measurement systems and PEMS.

3.5.1 Complex On-Board Measurements System

Complex on-board measurement systems have been developed that are capable of measuring real-time mass emissions of air pollutants (NO_x, HC, CO, and PM), fuel consumption, and engine output simultaneously. These systems are elaborate, expensive, and time and resource intensive with respect to data collection for a large number of vehicles, in comparison to PEMS (Kihara and Tsukamoto, 2001).

In the U.S., there are two examples of complex on-board emissions measurement systems that are relevant to over-the-road diesel trucks. Both involve installation of instrumentation in a 53 foot trailer that can be towed in a tractor-trailer configuration. One system is owned by the U.S. Environmental Protection Agency and the other by the University of California at Riverside (UCR) (Brown *et al*., 2002; UC-CERT, 2002). Some of the details of the EPA system are briefly summarized to illustrate the size and complexity of these types of systems.

The EPA facility can be used for a variety of road conditions, operating modes, and loaded vehicle weights. The facility can simulate the combination of operating conditions that an in-use truck would encounter. These conditions include increments and extremes of load, grade, and speed. Load can be varied by the operator using large weights in 1.5 ton increments. Grade and speed limits are a function of roadway characteristics and thus are influenced by route selection. The trailer is equipped with an air suspension system to minimize shock and vibration for sensitive electronic equipment, including a computerized Data Acquisition System (DAS), and continuous emissions monitoring system (CEMS) analyzers. The CEMS measure O_2, CO_2, CO, and total hydrocarbons (THCs) sampled directly from the exhaust. The CEMS also incorporates a sample conditioning and delivery subsystem that maintains the sample at 191 ± 6 °C. Each analyzer, with the exception of the THC instrument, receives its sample through a valve that selects between sample and calibration gas (Brown *et al.*, 2002).

This type of facility generally takes a great deal of energy to operate (UC-CERT, 2002). For example, the EPA facility uses a 10.5 kW diesel generator mounted to the underside of the trailer. This electric power is used for all of the various pumps, heaters, and electronics (Brown *et al.*, 2002).

3.5.2 Portable On-Board Emissions Measurement Systems (*PEMS*)

Portable On-board Emissions Measurement Systems (PEMS) are relatively simple and inexpensive. These system are designed for measuring in-use emissions during real-world on-road operation under any ambient conditions, traffic conditions, and operational/duty cycles. Initially, PEMS have had the capability to measure HC, NO, CO, and CO_2 emissions using repair grade gas analyzers (Kihara and Tsukamoto, 2001). More recently, PM measurement capabilities have been added to some PEMS systems (CATI, 2003).

The key advantage of a PEMS over a more complex on-board measurement system is that it can be installed more easily in a wide variety of vehicles. Thus, it is possible to collect on-board, in-use, and real-world emissions data during actual duty cycles. Whereas the complex systems can weight hundreds or thousands of pounds, the portable systems might typically weight 30 to 100 pounds, and can typically be installed in about an hour or less. The connections of the portable system to the vehicle are typically reversible, and no modifications are necessary in many cases. There is some trade-off in that the PEMS measurement methods may not be as accurate or precise as those of the more complex and expensive equipment used in more permanent on-board installations, such as the large tractor trailers at EPA or UCR. However, PEMS have been compared with dynamometer measurements on the same test cycles and have been found to have adequate accuracy and precision (Vojtisek-Lom *et al.*, 2002). Furthermore, PEMS are useful for making relative comparisons of emissions under real world conditions.

A PEMS system is used as the basis for data collection in this project and is described in more detail in Chapter 5.

3.6 Conclusion

In this chapter, several commonly used methods for measuring vehicle emissions have been reviewed, including engine dynamometers, chassis dynamometers, tunnel studies, remote sensing, and on-board measurement.

Most of the available data regarding heavy-duty vehicle emissions is typically from engine dynamometer measurements. These data are reported in units of g/bhp-hr, which are not directly relevant to in-use emissions estimation. Furthermore, many engine dynamometer test cycles are based upon steady-state modal tests that are not likely to be representative of real world emissions. There are some transient engine dynamometer tests that may have improved representativeness of real-world operating patterns, but it is not likely that any particular and arbitrary test cycle will be representative of operation of a particular type of vehicle at all times and in all areas of the country. Thus, although relatively less expensive than chassis dynamometer tests, engine dynamometer tests have serious shortcomings for purposes of estimating real world emissions.

Chassis dynamometer tests provide emissions data in units that are more amenable to the development of emission inventories. For example, for on-road vehicles, emissions can be reported in units of grams of pollutant emitted per mile of vehicle travel. This emission factor can be multiplied by estimates or measurements of vehicle miles traveled to arrive at an inventory. However, for vehicles that operate off-road, or that have operating modes that cannot easily be accommodated in the laboratory setting (e.g., dumping of the bed of a dump truck), it may not be possible to obtain data representative of all aspects of a duty cycle. Furthermore, these tests have a non-negligible cost per vehicle and the number of heavy duty dynamometer facilities is limited.

Tunnel studies are limited in their ability to discriminate among specific vehicle types, although it is possible to distinguish between gasoline and diesel vehicles using statistical methods. However, tunnel studies are based upon measurements for a specific link of roadway and thus are not representative of an entire duty cycle. For purposes of this project, there are no tunnels through which the study fleet travels. Thus, this measurement method is not applicable here.

Remote sensing can be used to measure emissions from any vehicle that passes through the infrared and, if available, UV beams that are used to measure pollutant concentrations. For purposes of measuring heavy duty vehicles, remote sensing deployment may need to be adjusted to the appropriate plume height, especially if the trucks discharge emissions above the level of the vehicle’s cab. Each measurement is only a snap shot at a particular location, and thus cannot characterize an entire duty cycle. Thus, remote sensing is not applicable here.

On-board emissions measurement systems offer the advantage of being able to capture real world emissions during an entire duty cycle. Thus, for purposes of this project, such systems are preferred. In particular, PEMS, which are more easily installed in multiple vehicles than complex on-board systems, are selected for use in this study.

4.0 IDENTIFICATION AND EVALUATION OF EXISTING DATA REGARDING COMPARISON OF EMISSIONS FOR PETROLEUM DIESEL VERSUS BIODIESEL

4.1 Introduction

The purpose of this chapter is to identify and evaluate data that provide insight regarding how emissions of heavy duty diesel vehicles compare when operated on soy-based B20 biodiesel in comparison to petroleum diesel. Chapter 2 provides an overview of factors that affect vehicle emissions, including fuel properties. To date, data available to compare emissions based upon the two fuels is based on dynamometer tests. As discussed in Chapter 3, these tests have limitations with respect to representativeness of real world duty cycles. However, the available data are analyzed in this chapter to serve as a benchmark for later comparison with the PEMS data collected in this study.

The U.S. Environmental Protection Agency (EPA) has compiled a database of heavy duty vehicle emissions based on the fuels of interest (EPA, 2001&2002). These data are summarized later in this chapter. Based upon the database compiled by EPA, it is possible to estimate the average change in emissions that has been observed based upon engine dynamometer testing. However, the EPA database contains a wide variety of engine sizes. Thus, in this chapter, in addition to considering the overall average comparisons implied by the EPA database, a comparison is made based upon a range of engine sizes that is more comparable to that of the vehicles tested in this work.

The methodology used here is to stratify the EPA database and focus on vehicles that are approximately similar to the test fleet that is the focus of this work, at least with respect to engine size. For the selected data, statistical summaries were prepared of emissions for each fuel. The mean emissions for each fuel were compared for each pollutant and a test of statistical significance was performed to determine if any differences in emissions are statistically significant. Comparisons were made for petroleum diesel, B20 biodiesel, and B100 blend stock. By comparing these three fuels, some insight is provided regarding how different proportions of the biodiesel blend stock affect average emission rates.

EPA identified 70 studies that they included in an emissions database. The studies from which the data were obtained are summarized in Table 4-1. In the compiled dataset, there were many cases in which the same fuel was tested on the same engine multiple times. All repeated measurements for a given engine and fuel combination were entered into the database. All of the collected data are based upon engine dynamometer testing using transient and steady state test cycles.

For the purposes of our analysis, data were selected for 4-stroke engines, ranging from 150 to 450 horsepower, and with rated engine speeds of 1,600 to 3,000 RPM, which are shown Table 4-2. A total of 28 of these types of engines, out of 70 in the database, were identified that were tested on petroleum diesel, soy-based B20, or B100. In some cases, although multiple tests were done on an engine, only the average emission rate and the number of tests were reported. In such cases, the average values were entered into the database the same number of times as the number of repeated tests on which the average was based.

Table 4-2 presents the characteristics of the 28 selected engines including model year, engine displacement, number of cylinders, rated power, rated engine speed, peak torque, and peak speed.

Table 4-1. Sources of Information for the U.S. Environmental Protection Agency's Database of Heavy Duty Vehicle Emissions (EPA 2001&2002).

Description	Authors	No. of Observations	No. of Engines
SAE 942053	K. Mitchell, D.E. Steere, J.A. Taylor, B. Manicom, *et al.*	48	2
VE-1, PHASE II	Ullman, T. L., Robert L. Mason, Daniel A. Montalvo	36	1
SAE 961973	Geiman, R. A., Patrick B. Cullen, Peter R. Chant, *et al.*	23	1
SAE 970758	Tamanouchi, M., Hiroki Morihisa, Shigehisa Yamada, *et al.*	16	2
SAE 910735	Ullman, T. L., David M. Human	20	2
VE-1,PHASEI CAPE32-80	Terry L. Ullman	28	1
SAE 980530	Tamanouchi, M., H. Morihisa, H. Araki, S. Yamada	42	3
SAE 910736	Terry L. Ullman, David M. Human	52	2
SAE 940669	Cynthia A. Chaffin and Terry L. Ullman	24	1
SAE 942019	Nandi, M.K., David C. Jacobs, Frank J. Liotta, Jr., H.S. Kesling, Jr.	6	1
McCormick 2001	McCormick, R., Ross, J. D., and Graboski, M. S.	**-**	**-**
SAE 932733	C. Bertoli, N. Del Giacomo, B. Iorio, and M.V. Prati	**-**	**-**
ACEA REPORT	G. Kleinschek, K. Richter, A. Roj, M. Signer, H.J. Stein	21	1
EPEFE	M. Signer, P.Heinze, R. Mercogliano, H.J. Stein	275	5
SAE 972894	W.W. Lange, J.A. Cooke, P. Gadd, H.J. Zurner, H. Schlogl, K. Richter	16	1
HDEWG PHASE II EPA68-C-98-169	Andrew C. Matheaus, Thomas W. Ryan III, Robert Mason, Gary Neely, Rafal Sobotowski	81	4
A1-A6	Yanowitz, J., Graboski, M., Ryan, L., Alleman, T., and McCormick, R.	-	-

Table 4-2. Characteristics of 28 Selected Heavy Duty Diesel Engines (4 Stroke only).

Engine Company	Engine Series	Model Year	Engine Displacement	Cylinder	Rated Power[b]	Rated Speed[c]	Peak Torque[d]	Peak Speed[e]
		(year)	(*l*)	number	(hp)	(rpm)	(ft-lb)	(rpm)
Caterpillar	CAT 3176	2004	10.3	6	350	1,800	1,350	1,200
	CAT 3208	1979	10.4	8	157	2,800	655	1,400
	CAT 3406B	1988	14.6	6	350	1,800	1,003	1,260
	CAT 3406E	1995	14.6	6	435	1,800	1,650	1,200
Cummins	B5.9	1993	5.9	6	175	2,500	420	1,600
	B5.9	1994	5.9	6	231	2,300	605	1,500
	L-10	1990	10.0	6	260	2,100	-	-
	N14	1994	14.0	6	460	1,800	1,650	1,100
	N14	1995	14.0	6	460	1,700	1,650	1,200
Detroit	SERIES 50	1995	8.5	4	275	2,100	-	1,200
	SERIES 50	1996	8.5	4	315	2,100	1,150	1,200
	SERIES 60	1991	11.1	6	330	1,800	1,270	1,200
	SERIES 60	1991	12.7	6	370	1,800	1,450	1,200
	SERIES 60	1993	11.1	6	330	1,800	1,302	1,218
	SERIES 60	1994	11.1	6	320	1,800	1,250	1,200
EPEFE[a]	-	1996	6.2	6	168	2,500	465	1,500
	-	1996	6.9	6	217	2,400	605	1,400
	-	1996	8.65	6	298	2,300	848	1,700
	-	1996	11.0	6	335	1,900	1,180	1,100
Hino	HO6C	1991	6.5	6	236	2,700	506	1,600
	HO7D	1991	7.4	6	192	2,900	369	1,700
Iveco	8460.41	1996	9.5	6	275	2,100	1,239	1,400
Mercedes -Benz	OM366LA	1991	6.0	6	237	2,600	553	1,500
Navistar	DTA 466	1991	7.6	6	230	2,400	610	1,600
	DTA 466	1994	7.6	6	199	2,400	670	1,600
	T444E	1994	7.3	8	185	2,550	600	1,510
Nissan	FE6A	1989	6.9	6	158	3,000	304	1,800
	FE6T	1991	6.9	6	197	2,800	434	1,400

[a] EPEFE (European Programs on Emissions, Fuels, and Engine Technologies) : used 4 types of heavy duty diesel engines, but engine company name and engine series are not available

[b] Rated power is the power output of an engine as horsepower (hp) or kilowatt (Toboldt *et al*., 2000; Haddad and Watson, 1984).

[c] Rated speed refers to the RPM (Revolutions Per Minute) or the rotations of the engine shaft (Toboldt *et al*., 2000; Haddad and Watson, 1984).

[d] Peak torque is the maximal value of the MAP curve. The peak torque is usually selected as a design parameter for load acceleration and braking (Toboldt *et al*., 2000; Haddad and Watson, 1984).

[e] Engine peak speed is determined when the transmission initiates upshifts and downshifts. This should be set according to the engine's speed where the maximum peak torque is developed (Toboldt *et al*., 2000; Haddad and Watson, 1984).

Source : References are described in Table 4-1.

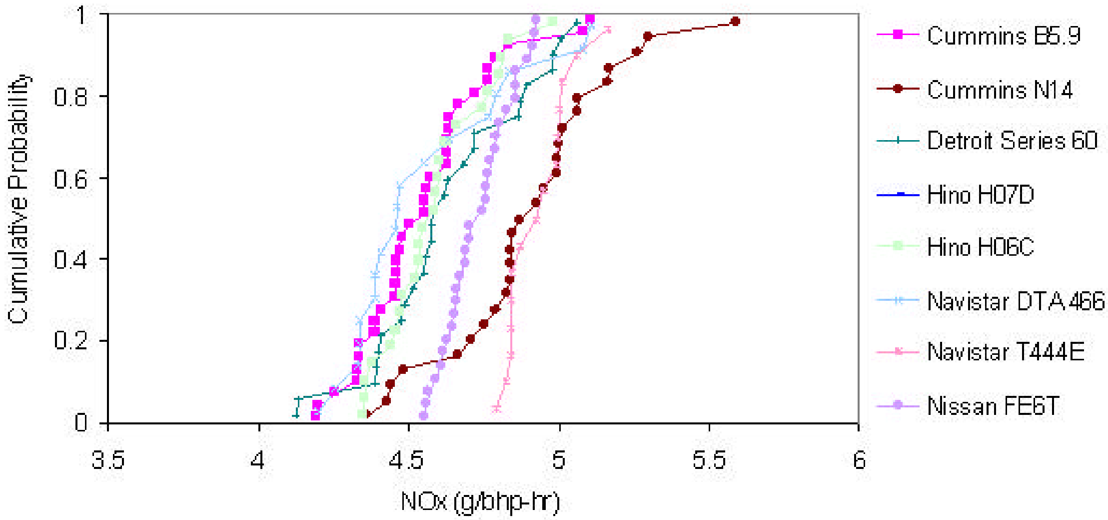


Figure 4-1. Intra-Engine Variability in NO_x emissions for petroleum diesel fueled vehicles in FTP transient engine dynamometer test cycle.
Source : References are described in Table 4-1.

Because there are repeated measurements for the engines tested as reported in the EPA database and in the primary references listed in Table 4-1, a question is whether there is significant variability among the repeated measurements for a given engine, and how the intra-engine variability compares to variation in emissions between engines. An example, Figure 4-1 compares the intra-engine variability in emissions for seven engines. For each engine, there are 15 to 32 individual measurements. For six of the seven engines, all of the emission measurements are enclosed by a range of 4.1 to 5.2 g/bhp-hr. Furthermore, there is substantial overlap between the distributions among most of these engines. For example, the four engines with the lowest median emission rates have approximately similar distributions. The three engines with the highest median emissions have distributions for which 90 percent or more of the reported values overlap with those of the lower median emissions engines. The inter-engine variability in median emissions is from approximately 4.4 to 4.9 g/bhp-hr, which is comparable to the typical range of intra-engine variability in emissions. Because the intra-engine variability and inter-engine variability are approximately similar, all of the individual measurements were combined into one database for purposes of further analysis and comparison of emissions for each of the fuels.

Table 4-3. Summary of Available Engine Dynamometer Test Cycle Data for Heavy Duty Diesel Engines Fueled with Petroleum Diesel.

Engine Company	Engine Series	Model Year	JAP13	R 49	FTP	FTP(hot)
Caterpillar	CAT 3176	2004			X	X
	CAT 3208	1979			X	X
	CAT 3406B	1988		X		X
	CAT 3406E	1995				X
Cummins	B5.9	1993				X
	B5.9	1994	X		X	X
	L-10	1990			X	X
	N14	1994			X	X
	N14	1995				X
Detroit	SERIES 50	1996		X		X
	SERIES 60	1991			X	X
	SERIES 60	1991		X		X
	SERIES 60	1993				X
	SERIES 60	1994	X		X	
Hino	HO6C	1991	X		X	
	HO7D	1991	X		X	
Iveco	8460.41	1996		X		
EPEFE[a]	6.2	1996		X		
	6.9	1996		X		
	8.65	1996		X		
	10.96	1996		X		
Mercedez-Benz	OM366LA	1991		X		X
Navistar	DTA 466	1991			X	X
	DTA 466	1994			X	
	T444E	1994			X	X
Nissan	FE6A	1989	X		X	
	FE6T	1991	X		X	

[a] European Programs on Emissions, Fuels, and Engine Technologies (EPEFE) used 4 types of heavy duty diesel engines, but engine company name and engine series are not available.
Source : References are described in Table 4-1.

4.2 Engine Dynamometer Emission Results for Petroleum Diesel

Of the 28 engines identified in Table 4-2, emissions data based upon use of petroleum diesel fuel are available for 27 as listed in Table 4-3. Each engine was typically tested on at least one and as many as three test cycles, including JAP13, R49, FTP and FTP (hot). Table 4-3 summarizes the test cycles for which data were collected for each of the identified engines operated on petroleum diesel.

The inter-engine variability in emissions as measured during each of the four test cycles is summarized using cumulative distribution functions (CDFs), as shown in Figures 4-2 through 4-5 for PM, CO, NO_x, and HC emissions, respectively.

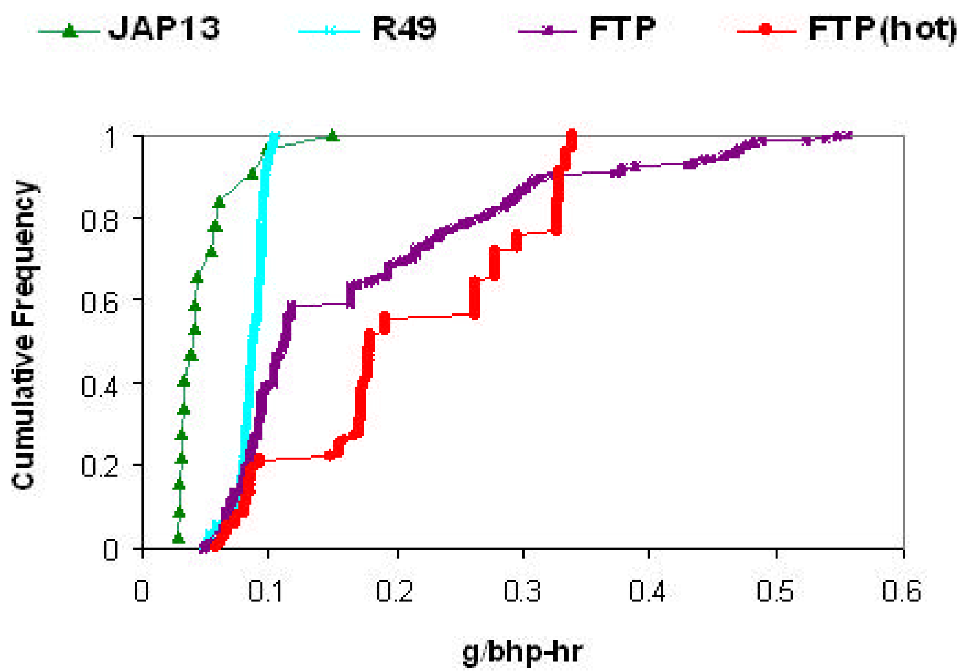


Figure 4-2. Inter-vehicle Variability in PM emissions (g/bhp-hr) for Petroleum Diesel-Fueled Vehicles in Two Steady-State (JAP13, and R49) and Two Transient Engine Dynamometer Test Cycles (FTP, and FTP(hot)).

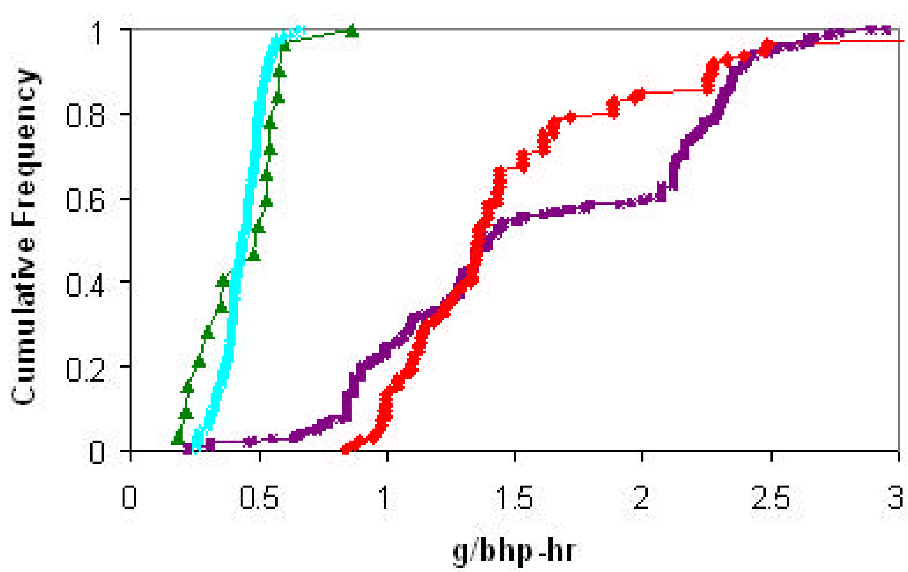


Figure 4-3. Inter-vehicle Variability in CO emissions (g/bhp-hr) for Petroleum Diesel-Fueled

Vehicles in Two Steady-State (JAP13, and R49) and Two Transient Engine Dynamometer Test Cycles (FTP, FTP(hot)).

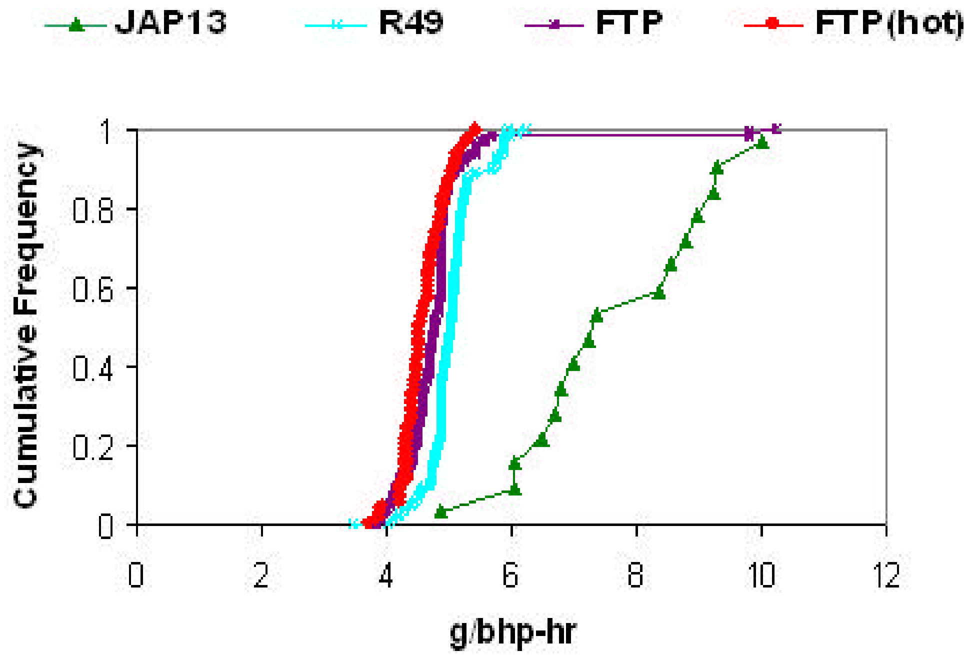


Figure 4-4. Inter-vehicle Variability in NO_x emissions (g/bhp-hr) for Petroleum Diesel-Fueled Vehicles in Two Steady-State (JAP13, and R49) and Two Transient Engine Dynamometer Test Cycles (FTP, FTP(hot)).

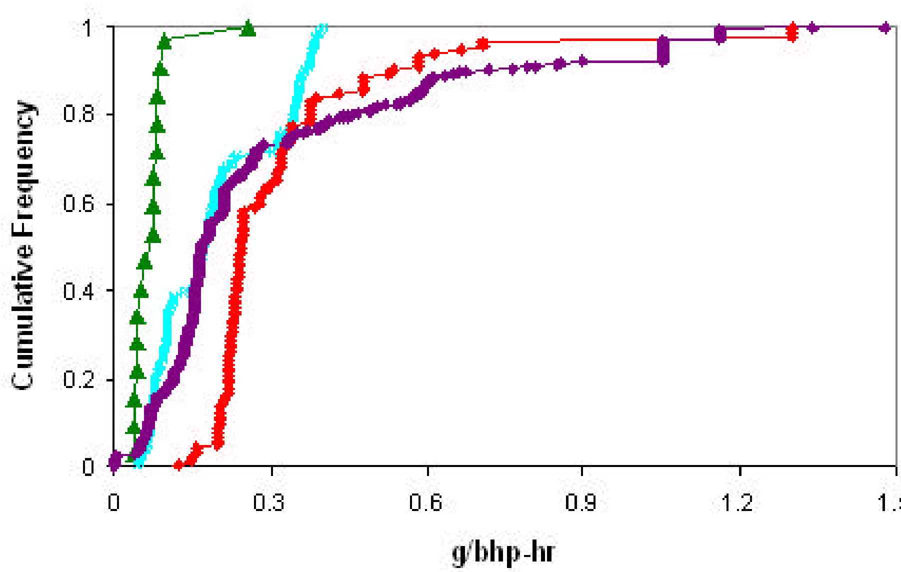


Figure 4-5. Inter-vehicle Variability in HC emissions (g/bhp-hr) for Petroleum Diesel-Fueled Vehicles in Two Steady-State (JAP13, and R49) and Two Transient Engine Dynamometer Test Cycles (FTP, FTP(hot)).

Source : References are described in Table 4-1.

For PM, the emissions measurements range from approximately 0.03 to 0.57 g/bhp-hr. However, the range of emissions for the two steady-state test cycles, JAP13 and R49, is much narrower than that for the two transient test cycles, FTP and the hot-start FTP. In particular, the R49 cycle produces very similar results for all of the tested engines, with emissions ranging only from approximately 0.05 to 0.10 g/bhp-hr. It appears that the transient test cycles lead to not only larger variability in emissions, but also larger average emission rates, than the steady-state test cycles. The two FTP-based tests have substantial overlap with respect to variability in emissions.

In Figure 4-3, the inter-test variability in CO emissions for the two steady-state cycles is much less than that for the two transient cycles, and the latter have significantly higher emission rates.

For NO_x and hydrocarbon, there is more overlap among the steady-state and transient test cycle measurements. For NO_x, the two transient cycles and the R49 test have very similar distributions for inter-test variability, with the exception of two large emission rates measured during FTP tests. However, the JAP13 cycle produced significantly larger emission rates. For HC, the two transient cycles have similar distributions, with values as high as 1.2 g/bhp-hr, whereas the two steady-state modal tests have emissions of typically less than 0.4 g/bhp-hr.

With the exception of NO_x emissions, the two transient cycles typically produced the widest range of variability and the highest median emissions compared to the other cycles.

For petroleum diesel for engine dynamometer test, no data are available for CO_2 emission.

Table 4-4 summarizes the data shown in Figures 4-2 to 4-5, including sample means, standard deviations, and 95 percent probability ranges of inter-test variability. As noted previously, the engines were typically tested several times. The number of tests per engine ranges from 3 to 23.

Table 4-4. Summary of Steady-State and Transient Engine Dynamometer Test Measurements for PM, NO_x, CO, and HC Emissions for Heavy Duty Diesel Engines Fueled with Petroleum Diesel.

Pollutant	Cycle	Mean (lower[a]- upper[b]) (g/bhp-hr)	St. dev. [c] (g/bhp-hr)	Number of Tests, N[d]	Number of Engines	Avg. No. of Tests per Engine
PM	JAP13	0.052 (0.028, 0.098)	0.032	17	6	3
	R49	0.086 (0.052, 0.102)	0.011	205	9	23
	FTP	0.171 (0.060, 0.479)	0.120	317	14	23
	FTP(hot)	0.212 (0.064, 0.339)	0.094	110	16	7
NO_x	JAP13	7.74 (4.84, 10.0)	1.53	17	6	3
	R49	5.04 (4.20, 5.88)	0.420	205	9	23
	FTP	4.79 (3.94, 5.56)	0.766	317	14	23
	FTP(hot)	4.56 (3.85, 5.28)	0.344	110	16	7
CO	JAP13	0.449 (0.187, 0.850)	0.177	17	6	3
	R49	0.434 (0.270, 0.580)	0.082	205	9	23
	FTP	1.59 (0.553, 2.65)	0.649	317	14	23
	FTP(hot)	1.50 (0.950, 3.06)	0.512	110	16	7
HC	JAP13	0.075 (0.037, 0.200)	0.051	17	6	3
	R49	0.195 (0.054, 0.387)	0.114	205	9	23
	FTP	0.297 (0.005, 1.16)	0.297	317	14	23
	FTP(hot)	0.331 (0.150, 1.30)	0.224	110	16	7

[a] Lower bound of the 95% Probability Range for inter-test variability (2.5^{th} percentile)
[b] Upper bound of the 95% Probability Range for inter-test variability (97.5^{th} percentile)
[c] Standard Deviation, [d]: Sample Size for the number of tests

Source : References are described in Table 4-1.

4.3 Emission Results for Soy-Based B100

Soy-based B100 blend stock emission results based on the EPA (2002) database are reported in units of g/bhp-hr. Only measurements from transient test cycles are available. Table 4-5 summarizes the available measurement data in terms of the engines and cycles tested. Figures 4-6 through 4-10 display the test data in terms of CDFs for PM, NO_x, CO, HC, and CO_2 emissions, respectively.

For PM emissions, there is substantially overlap between the CDFs of the test data from the FTP and hot-start FTP test cycles, although the latter has lower average emissions. For NO_x, there is also substantial overlap between the two CDFs, but the hot-start FTP has higher average emissions. The test results are similar for both cycles for CO and HC. There was relatively little variability in the CO_2 emission rate on either test cycle. The range of variation of only about 20 g/bhp-hr is small compared to a typical emission value of approximately 550 g/bhp-hr. Overall, it appears that the hot-start FTP cycle had slightly lower PM and slightly higher NO_x, but approximately the same CO, HC, and CO_2 emissions. This might imply that generally hotter engine conditions lead to slightly higher NO_x emissions while also producing slightly better combustion efficiency and, thus, less PM.

The emissions measurements for soy-based B100 blend stock are summarized in Table 4-6.

Table 4-5. Summary of Tests Cycles versus Selected Heavy Duty Diesel Engines using Soy-based B100.

Engine Company	Engine Series	Model Year	FTP	FTP(hot)
CATERPILLAR	CAT 3406E	1995	X	X
CUMMINS	N14	1994	X	
	N14	1995	X	
DETROIT	SERIES 50	1995	X	
	SERIES 50	1996	X	
	SERIES 60	1991		X
	SERIES 60	1991		X
	SERIES 60	1991		X
	SERIES 60	1991		X
	SERIES 60	1991		X
	SERIES 60	1991		X
NAVISTAR	T444E	1994		X

Source : References are described in Table 4-1.

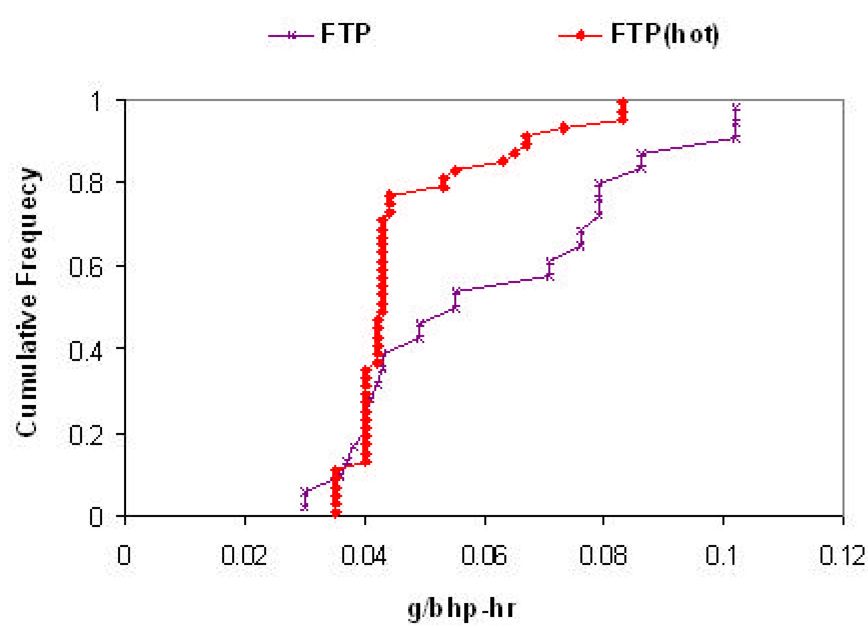


Figure 4-6. Inter-vehicle Variability in PM emissions (g/bhp-hr) for Soy-based B100-Fueled Vehicles in Two Transient Engine Dynamometer Test Cycles (FTP, FTP(hot)).

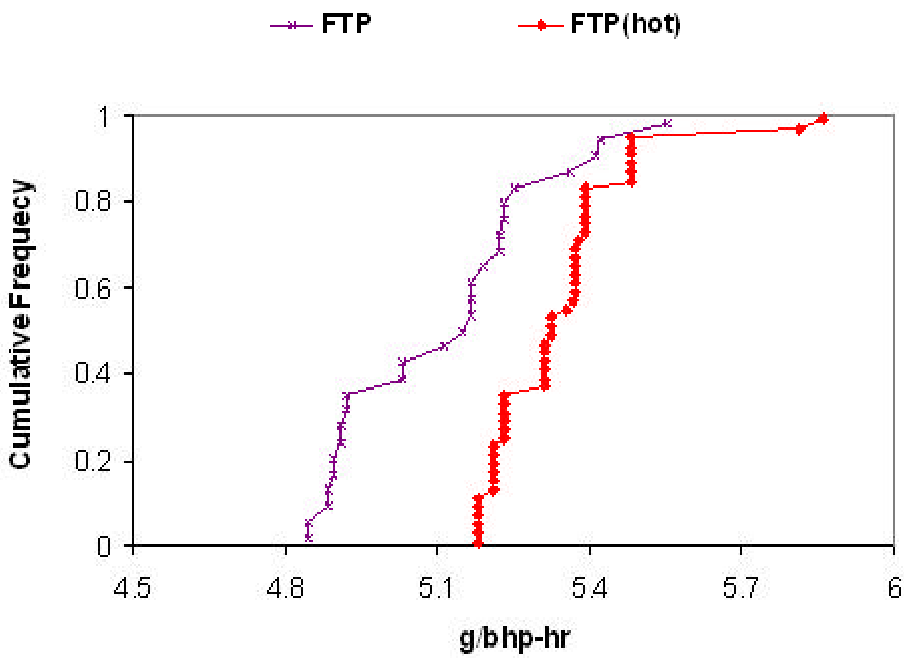


Figure 4-7. Inter-vehicle Variability in NO_x emissions (g/bhp-hr) for Soy-based B100-Fueled Vehicles in Two Transient Engine Dynamometer Test Cycles (FTP, FTP(hot)).

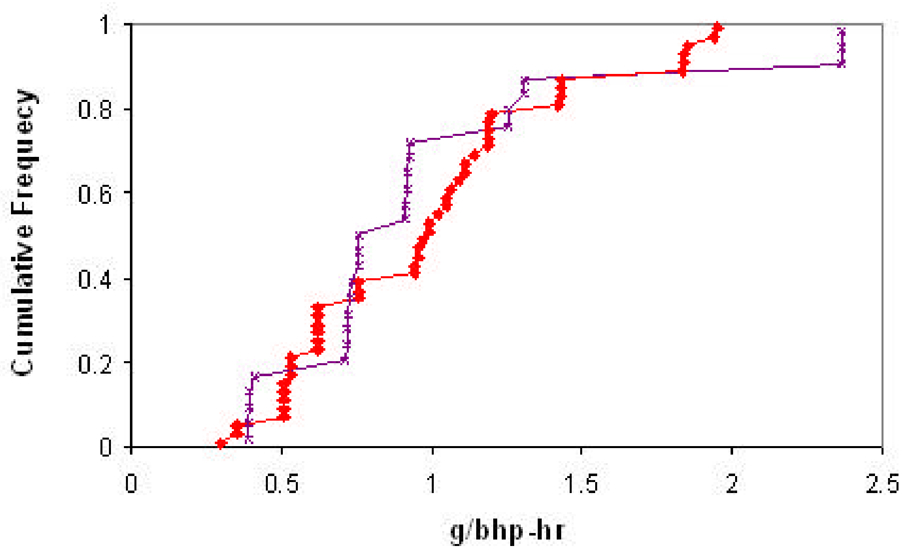


Figure 4-8. Inter-vehicle Variability in CO emissions (g/bhp-hr) for Soy-based B100-Fueled Vehicles in Two Transient Test Engine Dynamometer Cycles (FTP, FTP(hot)).

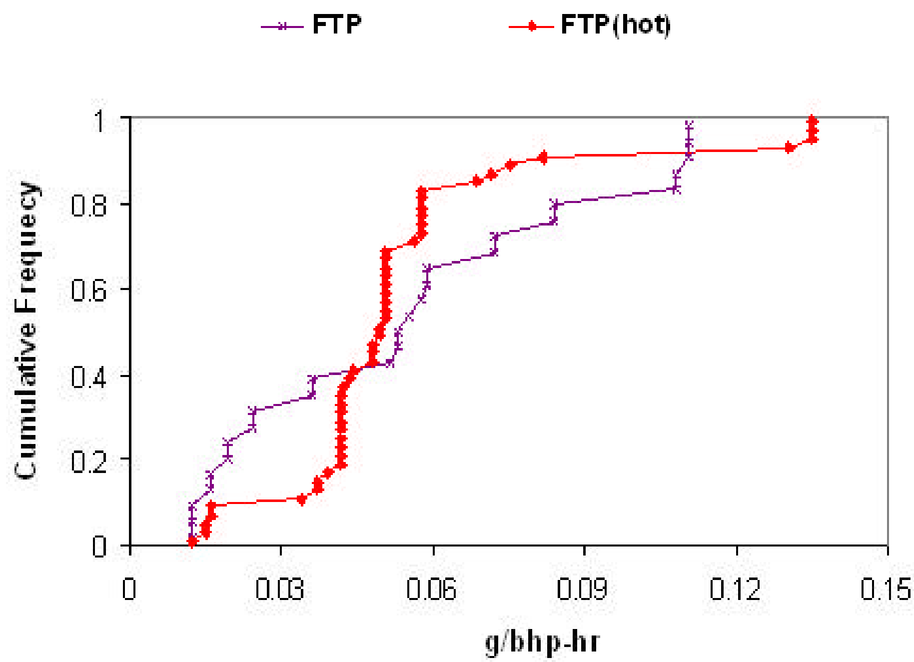


Figure 4-9. Inter-vehicle Variability in HC emissions (g/bhp-hr) for Soy-based B100-Fueled Vehicles in Two Transient Engine Dynamometer Test Cycles (FTP, FTP(hot)).

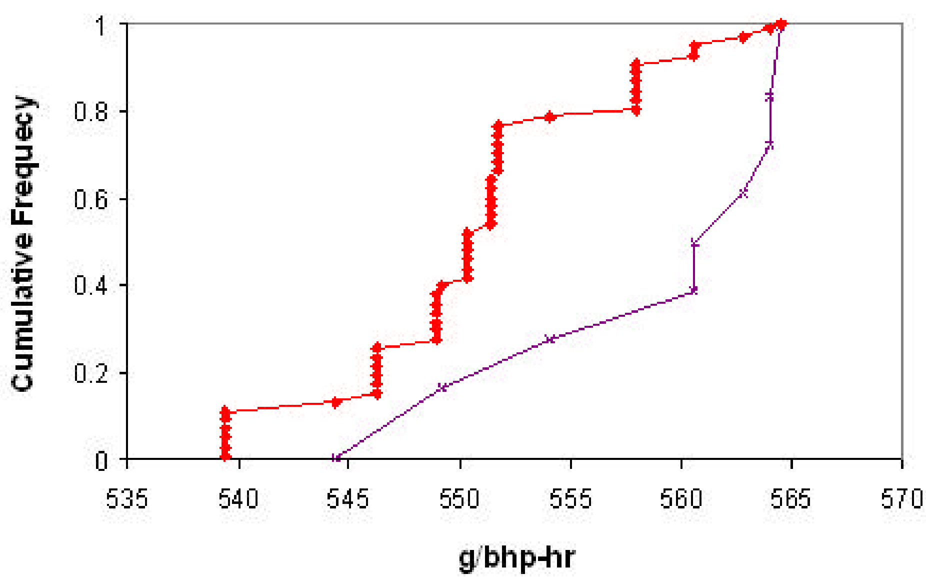


Figure 4-10. Inter-vehicle Variability in CO_2 emissions (g/bhp-hr) for Soy-based B100-Fueled Vehicles in Two Transient Engine Dynamometer Test Cycles (FTP, FTP(hot)).

Source : References are described in Table 4-1.

Table 4-6. Summary of Transient Engine Dynamometer Test Measurements for PM, NO_x, CO, HC and CO_2 Emissions for Heavy Duty Diesel Engines Fueled with B100 Blend Stock.

Pollutant	Cycle	Mean (lower[a],upper[b]) (g/bhp-hr)	Std Dev[c] (g/bhp-hr)	N[d]	Number of Engines	Avg. No. of Tests per Engine
PM	FTP	0.061 (0.030, 0.102)	0.023	27	5	5
	FTP(hot)	0.047 (0.035, 0.083)	0.013	50	8	7
NO_x	FTP	5.11 (4.85, 5.42)	0.199	27	5	5
	FTP(hot)	5.34 (5.18, 5.81)	0.140	50	8	7
CO	FTP	0.975 (0.390, 2.36)	0.567	27	5	5
	FTP(hot)	0.989 (0.350, 1.94)	0.448	50	8	7
HC	FTP	0.055 (0.012, 0.110)	0.035	27	5	5
	FTP(hot)	0.053 (0.015, 0.135)	0.028	50	8	7
CO_2	FTP	558 (544, 564)	7.32	9	5	2
	FTP(hot)	551 (539, 563)	6.36	50	8	7

[a] Lower bound of the 95% Probability Range for inter-test variability (2.5th percentile)
[b] Upper bound of the 95% Probability Range for inter-test variability (97.5th percentile)
[c] Standard Deviation, [d]: Sample Size for the number of tests

Source : References are described in Table 4-1.

4.4 Emission results for Soy-based B20

For soy-based B20 fuel, transient engine dynamometer test data are available for 13 engines as summarized in Table 4-7. Cumulative distribution functions for inter-test variability are shown for PM, NO_x, CO, HC, and CO_2 in Figures 4-11 through 4-15, respectively. For the FTP, one test was performed on each of eight engines, whereas there is a larger test sample size for the hot-start FTP. Given the small sample size for the FTP, it is difficult to draw any conclusive inferences whem making comparisons with the hot-start FTP. In general, and especially taking into account the small sample sizes, there is substantial overlap and comparability of results for emission rates of PM, NO_x, CO, and HC. For CO_2, although the graph provides a visual impression of a difference in results, the difference is not substantial. The average difference in CO_2 emissions is approximately 40 g/bhp-hr compared to a typical emission rate of approximately 580 g/bhp-hr.

The emissions measurements are summarized in Table 4-8.

Table 4-7. Summary of Tests Cycles versus Selected Heavy Duty Diesel Engines using Soy-based B20

Engine Company	Engine Series	Model Year	FTP	FTP(hot)
CATERPILLAR	CAT 3406E	1995	X	X
CUMMINS	B5.9	1993	X	
	B5.9	1994	X	
	N14	1994	X	
	N14	1995	X	
DETROIT	SERIES 50	1995	X	
	SERIES 60	1991	X	X
	SERIES 60	1991	X	X
	SERIES 60	1991		X
	SERIES 60	1991		X
	SERIES 60	1991		X
	SERIES 60	1991		X
NAVISTAR	T444E	1994		X

Source : References are described in Table 4-1.

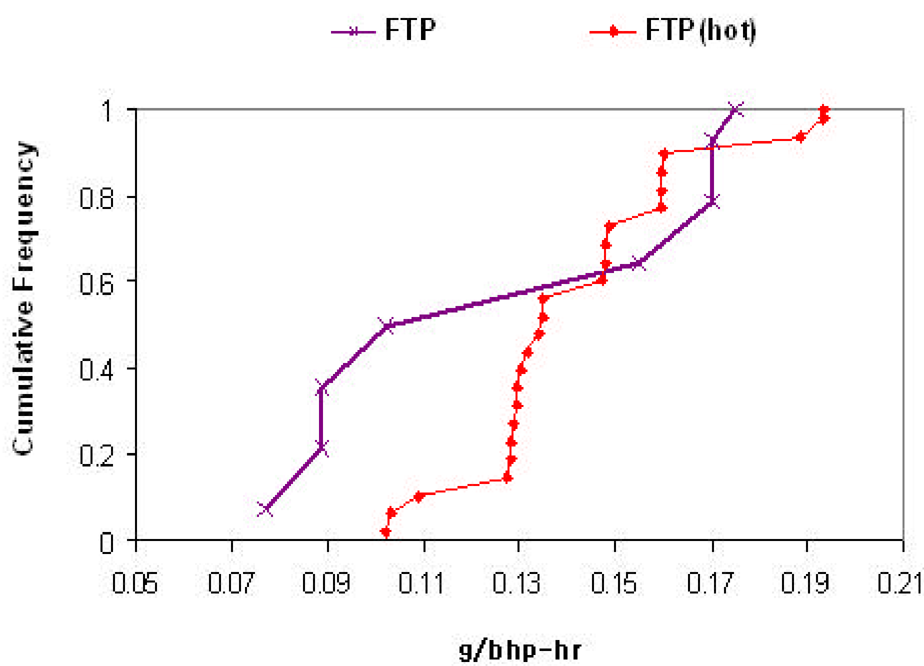


Figure 4-11. Inter-vehicle Variability in PM emissions (g/bhp-hr) for Soy-based B20-Fueled Vehicles in Two Transient Engine Dynamometer Test Cycles (FTP, FTP(hot)).

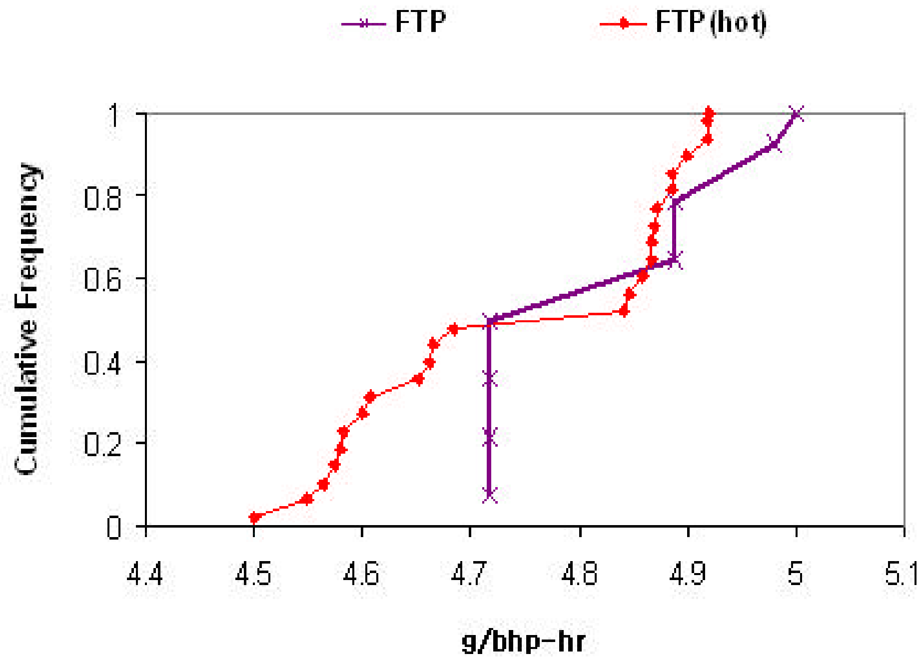


Figure 4-12. Inter-vehicle Variability in NO_x emissions (g/bhp-hr) for Soy-based B20-Fueled Vehicles in Two Transient Engine Dynamometer Test Cycles (FTP, FTP(hot)).

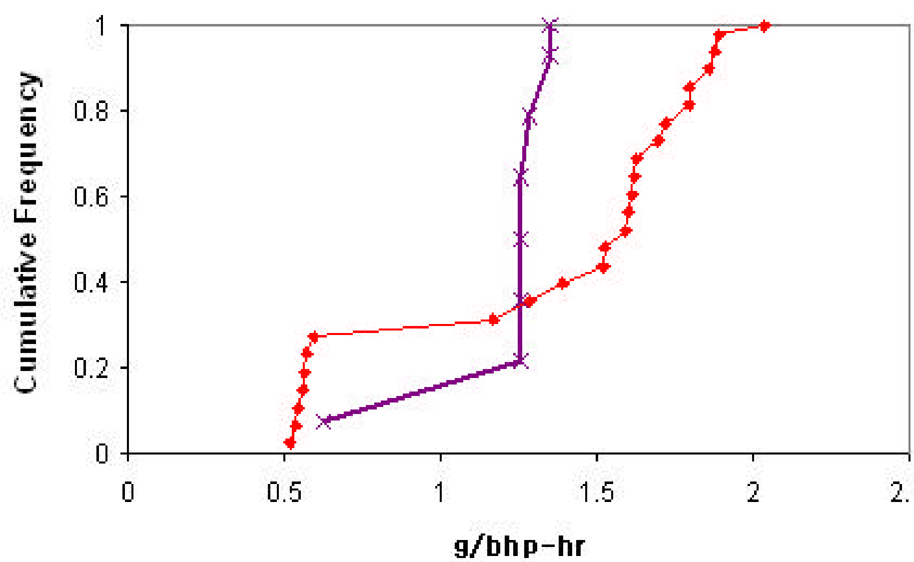


Figure 4-13. Inter-vehicle Variability in CO emissions (g/bhp-hr) for Soy-based B20-Fueled Vehicles in Two Transient Engine Dynamometer Test Cycles (FTP, FTP(hot)).

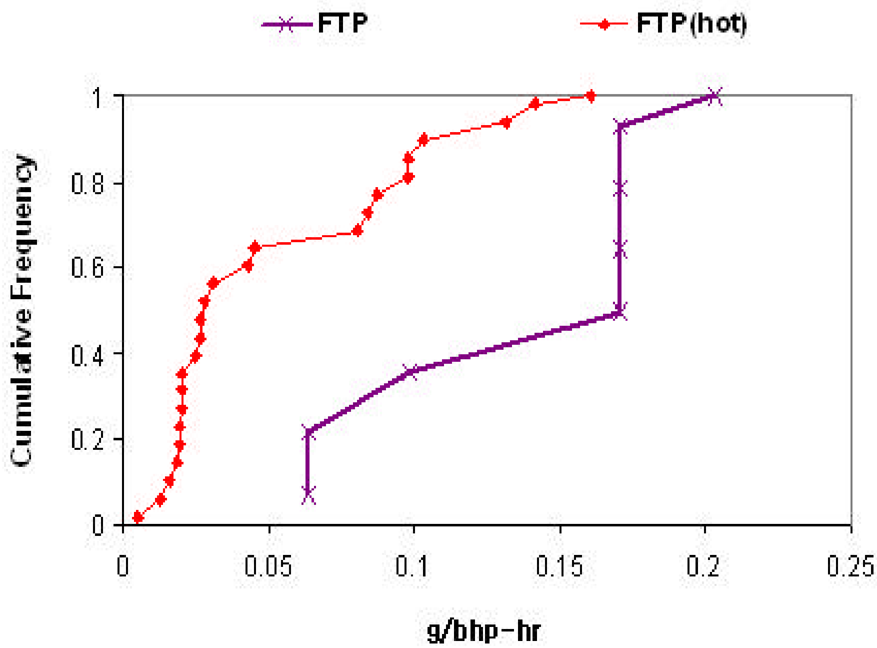


Figure 4-14. Inter-vehicle Variability in HC emissions (g/bhp-hr) for Soy-based B20-Fueled Vehicles in Two Transient Engine Dynamometer Test Cycles (FTP, FTP(hot)).

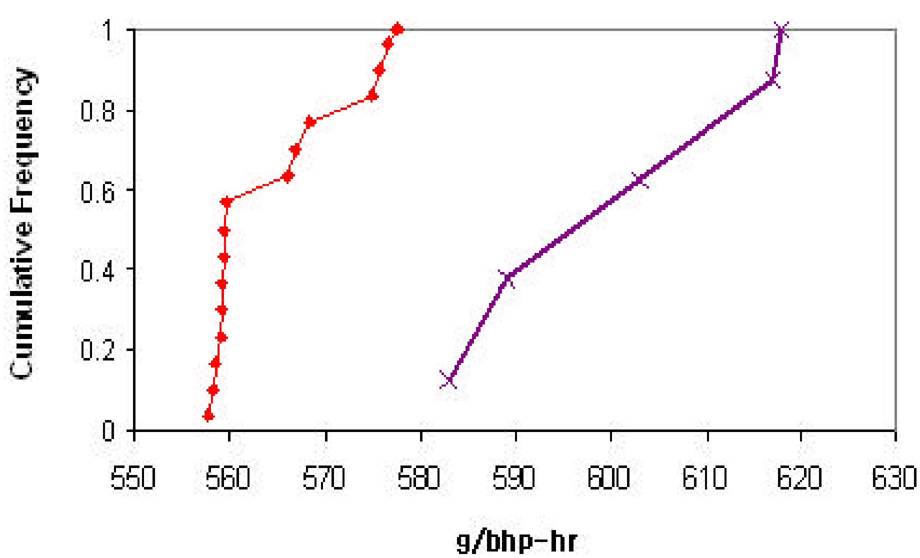


Figure 4-15. Inter-vehicle Variability in CO_2 emissions (g/bhp-hr) for Soy-based B20-Fueled Vehicles in Two Transient Engine Dynamometer Test Cycles (FTP, FTP(hot)).

Source : References are described in Table 4-1.

Table 4-8. Summary of Steady-State and Transient Engine Dynamometer Test Measurements for PM, NO_x, CO, HC and CO_2 Emissions for Heavy Duty Diesel Engines Fueled with B20 Biodiesel.

Pollutant	Cycle	Mean (lower[a]-upper[b]) (g/bhp-hr)	St. dev.[c] (g/bhp-hr)	N[d]	Number of Engines	Avg. No. of Tests per Engine
PM	FTP	0.128 (0.077, 0.173)	0.043	8	8	1
	FTP(hot)	0.142 (0.102, 0.193)	0.025	25	8	3
NO_x	FTP	4.83 (4.72, 5.00)	0.126	8	8	1
	FTP(hot)	4.75 (4.50, 4.92)	0.148	25	8	3
CO	FTP	1.20 (0.621, 1.35)	0.238	8	8	1
	FTP(hot)	1.34 (0.520, 1.89)	0.534	25	8	3
HC	FTP	0.139 (0.064, 0.203)	0.055	8	8	1
	FTP(hot)	0.055 (0.005, 0.141)	0.046	25	8	3
CO_2	FTP	602 (583, 618)	15.9	5	5	1
	FTP(hot)	565 (558, 577)	7.58	16	8	2

[a] Lower bound of the 95% Probability Range for inter-test variability (2.5th percentile)
[b] Upper bound of the 95% Probability Range for inter-test variability (97.5th percentile)
[c] Standard Deviation, [d]: Sample Size for the number of tests

Source : References are described in Table 4-1.

4.5 Comparison of Emissions for Petroleum Diesel and Biodiesel Fuels

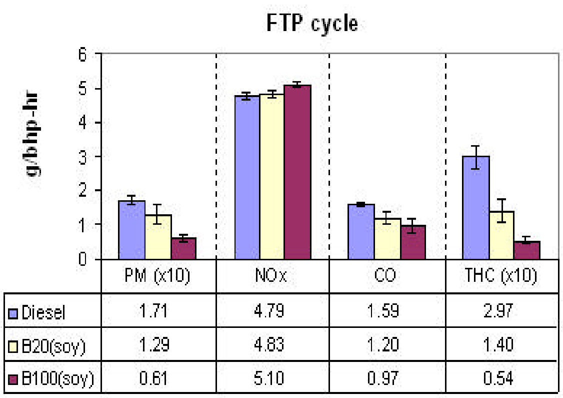
The emission data reported in Section 4.2, 4.3, 4.4 for petroleum diesel, soy-based B100 blend stock, and soy-based fuel, repectively, are compared in Figure 4-16.

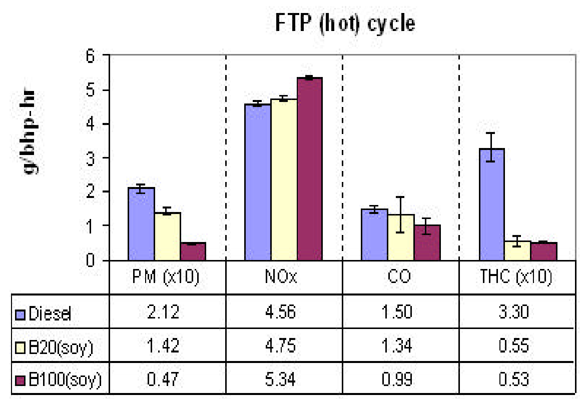
Figure 4-16 summarizes a comparison of the mean emissions of the selected engines for each of four pollutants, PM, NO_x, CO, and HC, and for three fuels, petroleum diesel, soy-based B20 biodiesel, and soy-based B100 blend stock, when vehicles were operated on the FTP cycle. Figure 4-16 provides a similar comparison for the FTP (hot) cycle. CO_2 data are not shown because CO_2 emissions were not reported for the tests based on petroleum diesel. The 95 percent confidence intervals of the mean emissions are shown. For the FTP cycle, the reductions in PM, CO, and HC emissions when comparing petroleum diesel and B100 blend stock are statistically significant, as is the increase in NO_x emissions. For the FTP (hot) cycle, the findings are qualitatively similar.

Based upon this analysis, the typical differences in average emissions for vehicles fueled with soy-based B20 biodiesel versus petroleum diesel are as follows: 1 to 4 percent increase in NO_x;

25 to 33 percent decrease in PM; 11 to 25 percent decrease in CO; and 53 to 83 percent decrease in hydrocarbons. The differences in emissions when comparing B20 versus petroleum diesel appear to be consistent. However, the question remains as to whether these differences occur under real-world duty cycles, as opposed to standardized test cycles.

For purposes of comparison, Table 4-9 summarizes the average changes in emissions for specific types of diesel engines when comparing either soy-based B20 biodiesel or soy-based B100 blend stock versus petroleum diesel (No. 2) with respect to NO_x, PM, CO, and HC. The data reported in Table 4-9 are based upon a review of data published in references summarized by EPA (2002). These comparisons were stratified based upon the engine model year and whether the engine was 2-stroke or 4-stroke. The means and standard deviations of the percent differences were obtained based upon an analysis of data collected from the literature. The percentage changes in emissions for the most recent model year, 4-stroke engines represented in the EPA data base are estimated to be a 12 percent decrease in PM, 2.8 percent increase in NO_x, 15.2 percent decrease in CO, and 24 percent decrease in HC. An overall average among all engine types is that emissions decreased on B20 versus petroleum diesel by 10 percent for PM, 11 percent for CO, and 21 percent for HC, but increased by 2 percent for NO_x.





FTP	PM	NO_X	CO	THC
D2/B20	-25 %	0.8%	-25%	-53 %
D2/B100	-64%	6.5%	-39 %	-82 %

FTP(hot)	PM	NO_X	CO	THC
D2/B20	-33 %	4.2%	-11%	- 83%
D2/B100	-78 %	17%	-34%	-84%

Figure 4-16 Comparison of Mean Emissions and 95 Percent Confidence Intervals in Mean Emissions for PM, NO_x, CO, and HC Emissions on Vehicles Fueled with Petroleum Diesel, Soy-based B20 Biodiesel, and Soy-Based B100 Blend Stock and Operated on the FTP and FTP (hot) test Cycle.

Source : References are described in Table 4-1.

Table 4-9. Summary of the Difference in Emissions Between Soy-Based B20 Biodiesel versus Petroleum Diesel (Distillate No. 2), and Soy-Based B100 Blend Stock versus Petroleum Diesel, Based upon Analysis of Data Reported by EPA (2002)

Engine type/ Model Year	Fuel Pair	PM	NO_x	CO	THC
B20 Emission Effects					
2-stroke<1991	Pet.D[a]/B20	-1.80 %	3.20 %	-13.9 %	-20.9 %
2-stroke1991+	Pet.D[a] /B20	-17.8 %	3.90 %	-12.0 %	-17.5 %
4-stroke<1991	Pet.D[a] /B20	-15.7 %	2.90 %	-13.6 %	-12.2 %
4-stroke 1991~3	Pet.D[a] /B20	-15.7 %	-0.900 %	-12.0 %	-2.80 %
4-stroke 1994	Pet.D[a] /B20	-9.80 %	2.80 %	-15.2 %	-24.0 %
Mean		-12.2 %	2.38 %	-13.3 %	-15.5 %
SD[b]		6.51 %	1.88 %	1.36 %	8.33 %
EPA (2002) Avg.		-10.1 %	2.00 %	-11.0 %	-21.1 %
B100 Emission Effects					
2-stroke 1991+	Pet.D[a] / B100	-33.0 %	19.6 %	-42.4 %	-72.7%
4-stroke 1991-3	Pet.D[a] / B100	-68.3 %	13.3 %	-41.8 %	-38.7%
4-stroke 1994	Pet.D[a] / B100	-36.6 %	9.9 %	-41.5 %	-76.3%
Mean		-46.0 %	14.3 %	-41.9 %	-62.6 %
SD[b]		19.4 %	4.92 %	0.460 %	20.8 %
EPA (2002) Avg.		-47.2 %	10.3 %	-48.1 %	-67.4%

[a] petroleum diesel fuel (No. 2), [b] Standard Deviation

Although the percentage differences estimated here for the stratified analysis of 4-stroke engines in the range of 150 hp to 450 hp, as shown in Figure 4-16, are different from the estimates summarized in Table 4-9, they have qualitative similarities. In particular, in either case, the emissions of PM, CO, and HC are estimated to decrease, and the emissions of NO_x are estimated to increase. The percentage increase in NO_x emissions is relatively small compared to the percentage decrease in emissions of the other pollutants. The possible reasons as to why the percentage differences are not the same for the analysis shown in Figure 4-16 versus the data reported in Table 4-9 could include the following: (1) a different stratification was used for the engines; (2) comparisons were made only in cases where the same test procedure was repeated for each fuel; and (3) there might be differences in how multiple tests of the same engine were weighted in each case. However, despite the differences in percentage estimates, a robust conclusion from dynamometer test data appears to be that the use of B20 fuel leads to lower emission rates of PM, CO, and HC and a slight increase in NO_x emissions.

4.6 Conclusions

A review of available engine dynamometer test data for a variety of diesel engines indicates that there is a reduction in the emission rate of PM, CO, and HC and an increase in the emission rate of NO_x. These results are based upon analysis of a database complied by the U.S. EPA. EPA has analyzed the data by general categories of engine types. An overall average among all engine types is that emissions decreased on B20 versus petroleum diesel by 10 percent for PM, 11 percent for CO, and 21 percent for HC, but increased by 2 percent for NO_x. In a new analysis of the EPA data conducted as part of this work, a specific category of engines was analyzed. The typical differences in average emissions for vehicles fueled with soy-based B20 biodiesel versus petroleum diesel were found to be: 1 to 4 percent increase in NO_x; 25 to 33 percent decrease in PM; 11 to 25 percent decrease in CO; and 53 to 83 percent decrease in hydrocarbons. The latter set of comparisons was limited to test cycles for which emissions were measured for each of the two fuels, and thus was confined to transient engine dynamometer FTP tests. Despite the qualitative differences in comparisons between the two fuels depending on what engine categories and test procedures are considered, a general finding appears to be that there is a consistent decrease in emissions of PM, CO, and HC and a consistent small increase in NO_x emissions. However, the test procedures may not be representative of real world activity patterns, as decscribed in Chapter 3. As mentioned in Chapter 2, emissions can be influenced substantially by the activity pattern of the vehicle and engine. Therefore, there is a need to further evaluate the differences in emissions for B20 biodiesel versus petroleum diesel under real world conditions.

5.0 METHOD AND INSTRUMENTATION FOR REAL WORLD MEASUREMENT OF FUEL USE AND EMISSIONS

The portable emissions measurement system (PEMS) that is used for real world in-use data collection in this project is the OEM-2100 "Montana" system manufactured by Clean Air Technologies International, Inc. This chapter provides a description of the Montana system, including operating software, data acquisition hardware, and Global Position System (GPS), as well as descriptions of procedures for calibration and for system setup and operation.

5.1 Description of the Montana System

The OEM-2100 Montana system is comprised of a gas analyzer, a PM measurement system, an engine diagnostic scanner, a global position system (GPS), and an on-board computer. The gas analyzer measures the volume percentage of CO, CO_2, HC, NO, and O_2 in the vehicle exhaust. The PM measurement capability includes a laser light scattering detector and a sample conditioning system. The engine scanner is connected to the data link of electronically controlled vehicles, from which engine and vehicle data may be downloaded during vehicle operation. For vehicles without electronic control, a temporarily mounted sensor array is used instead to measure engine data such as RPM and intake air pressure, and intake air temperature in order to estimate air and fuel use (Vojtisek-Lom and Allsop, 2001). The applicability of the system for non-electronically controlled vehicles depends on the ease with which it is possible to obtain measurements of vacuum pressures in the intake manifold. A GPS system measures vehicle position. The on-board computer synchronizes the incoming emissions, engine, and GPS data. Intake airflow, exhaust flow, and mass emissions are estimated using a method reported by Vojtisek-Lom and Cobb (1997).

The gases and pollutants measured include O_2, HC, CO, CO_2, NO, and PM using the following detection methods:

- HC, CO and CO_2 using non-dispersive infrared (NDIR). The accuracy for CO and CO_2 are excellent. The accuracy of the HC measurement depends on type of fuel used.
- NO measured using electrochemical cell. On most vehicles, NO_x can be inferred from NO. On diesel engines with CRT traps, NO, NO_2, and NO_x can be inferred by simultaneous measurement of NO before and after the trap
- PM is measured using light scattering, with measurement ranging from ambient levels to low double digits opacity

All pollutants are measured continuously, on a second-by-second basis. Where analyzer modules require periodic zero and/or span calibration, two modules are used in parallel.

Exhaust flow is calculated from engine operating data, known engine and fuel properties, and exhaust gas concentrations. The engine operating data is acquired from electronically controlled vehicles through the Engine Control Unit (ECU) diagnostic port.

The Montana System is designed to measure emissions during the actual use of the vehicle or equipment in its regular daily operation. The system is inherently safe and has been used on shuttle, school and transit buses during their regular operation, with passengers on board.

The complete system comes in two weatherproof plastic cases, one of which contains the monitoring system itself, and the other of which contains sample inlet and exhaust lines, tie-down straps, AC adapter, power and data cables, various electronic engine diagnostic link connectors, sensor array, calibration gas pressure regulator and other parts. The monitoring system weighs approximately 35 lbs., and is routinely transported as a carry-on luggage on commercial flights. The system typically runs off of the 12V DC vehicle electrical system, using the cigarette lighter outlet. The power consumption is 5-8 Amps at 13.8 V DC.

5.2 Operating Software

The Montana System includes a laptop computer that is used to collect and synchronize data obtained from the engine scanner, gas analyzers, and GPS system. Data from all three of these sources are reported on a second-by-second basis. The computer is controlled either by touching the screen or plugging in a keyboard. Upon startup, the computer queries the user regarding information about the test vehicle, fuel used, test characteristics, weather conditions, and operating information. Most of this information is for identification purposes. However, the fuel type and composition, engine displacement, sample delivery delays, unit configuration, intake air sensor configuration, and volumetric efficiency are critical inputs that affect the accuracy of the reported emission rates. The details of the definition and significance of each of these are detailed in the Operation Manual of the instrument (CATI, 2003).

The software provides a continuous display of data during normal operation, including gas analyzer data, engine scanner data, GPS data, and calculated quantities including the emission rate in units of mass per time. The following parameters are typically available at screen of unit on a second-by-second basis: Road speed, engine rpm, turbocharger boost pressure, concentrations of the measured pollutants, exhaust flow, air fuel ratio, fuel consumption, mass flow rates of the measured pollutants. The data are available in ASCII text, comma-delimited format, but can be supplied in any user-defined format on demand.

The user can define the beginning and end of different test segments, as well as enter user-defined flags (i.e., encountering a certain traffic condition). Total time, distance, fuel consumption and emissions are calculated for each defined test segment. The labeling of test segments is done using a toggle switch to start a new "bag" or to end a "bag." The term "bag" is borrowed from conventional methods for collecting tailpipe emissions in large tedlar bags as part of dynamometer-based approaches. In the Montana system, exhaust is continuously sampled and is not stored. The operating software integrates the distance, fuel use, and emissions over the duration of each bag and creates a summary report. The use of the "bag" labels is optional.

5.3 Validation and Calibration

The Montana System gas analyzer utilizes a two-point calibration system that includes "zero" calibration and "span" calibration.

Zero calibration is performed using ambient air at frequent intervals (every 5-15 minutes at power up, every 30 minutes once fully warmed up). Although zero-air stored in bottles or generated using an external zero-air generator can be used, it is believed that the ambient air pollutant levels are negligible compared to those found in undiluted exhaust; therefore, ambient air is viewed as sufficient for most conditions. For zero calibration purposes, it is assumed that ambient air contains 20.9 vol-% oxygen, and no NO, HC, or CO. CO_2 levels in ambient air are approximately 300-400 ppm, which are negligible compared to the typical levels of CO_2 in exhaust gases.

Span calibration is performed using a BAR-90 low concentration calibration gas mixture, which has a known gas composition. The calibration gas includes a mixture of known concentrations of CO_2, CO, NO, and hydrocarbons, with the balance being N_2. Span gas calibration is recommended once every three months. The gas analyzer NDIR subsystem used in the gas analyzers is very stable and tends not to drift significantly from their span calibrations.

Data from several laboratories using various vehicles and fuels suggests that when the Montana System is operated simultaneously with the laboratory system, the difference is typically less than 10% for aggregate mass NO_x and CO_2. The accuracy of HC and CO measurements depends on the fuel used and on the emission levels (Vojtisek-Lom and Allsop, 2001).

Data from the EPA laboratory in Ann Arbor, MI, also shows that the difference between the portable system and two laboratory systems (modal and bag sampling) was comparable to the differences between the two laboratory systems.

5.4 System Setup and Operation

The procedures for setting up and operating the Montana system are briefly described in this section.

The time to install the instrument in a typical truck is approximately one hour. Figure 5-1 illustrates several aspects of the installation of the PEMS, using the example of a utility truck. The portable instrument is shown, including its placement inside the vehicle and the data connection to the engine diagnostic link located under the dashboard near the driver's door. Figure 5-2 illustrates some of the connections made external to the passenger cabin, including connection to the vehicle battery (located beneath the driver's door) using alligator clips, routing of hoses and cables using ties to secure these to the chassis, and the location of the exhaust pipe and gas sampling probes. Alternatively, power can be obtained via connection with the cigarette lighter inside the cabin of the vehicle. Figure 5-3 displays the routing of sampling hoses to the instrument via the passenger window, the hose used to collect outside air for reference purposes, and an external side view of the vehicle in motion after PEMS installation. The side view includes notation of the relative locations of the on-board diagnostic link (inside the vehicle), the battery, the exhaust pipe, and the routing of hoses and cables. Figure 5-4 is a photograph of the instrumented vehicle as it was leaving the NCDOT maintenance yard.

To operate Montana system, the user must enter several important input variables. The actual data entered into the Montana system are summarized in Chapter 6 in Table 6-1. For example, engine displacement is needed in order to calculate the exhaust flow with instantaneous engine speed, intake air temperature, and intake air pressure (CATI, 2003).

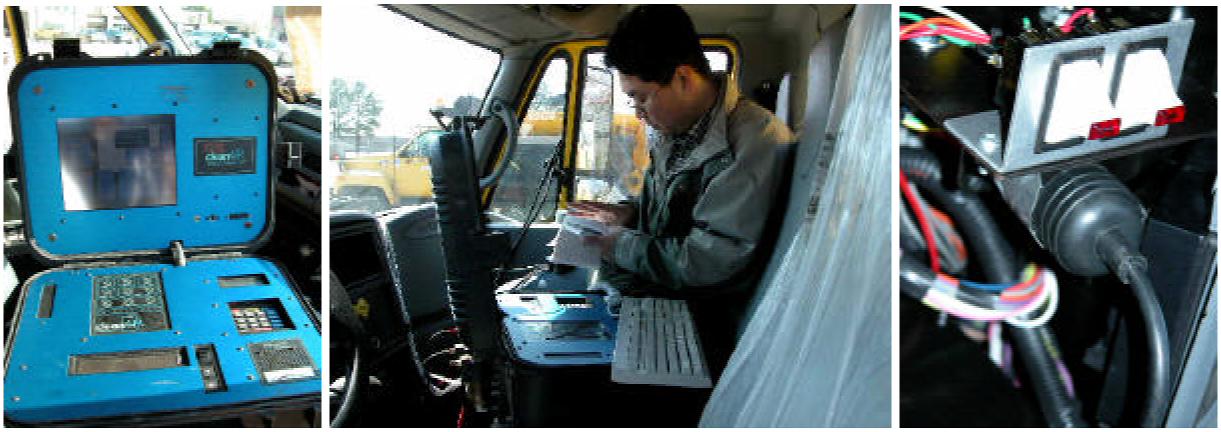


Figure 5-1. Installation of the portable emissions measurement system (PEMS) in a NCDOT heavy duty diesel vehicle*: (a) the portable unit on a passenger seat; (b) entering vehicle data into the PEMS; (c) engine diagnostic link using a 9-pin Deutsch connector.*

Figure 5-2. Installation of the portable emissions measurement system (PEMS) in a NCDOT heavy duty diesel vehicle: (a) accessing power from the vehicle battery; (b) routing hoses and cables along the chassis using ties; (c) sampling exhaust gases using a probe secured with a hose clamp.

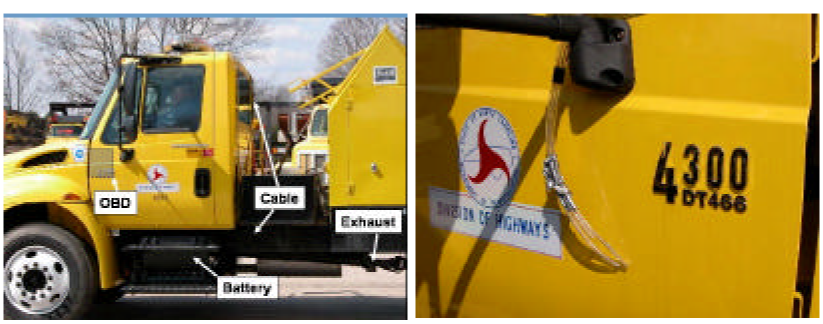


Figure 5-3. Installation of the portable emissions measurement system (PEMS) in a NCDOT heavy duty diesel vehicle*: (a) routing sampling hoses through the window, secured with ties; (b) obtaining outdoor air for "zeroing"; (c) side-view of truck in motion, illustrating relative locations of the on-board diagnostic link (inside the vehicle), battery, exhaust, and cables/hoses.*

Figure 5-4. Instrumented NCDOT vehicle in motion as it leaves the maintenance yard after installation of the portable emissions measurement system.

After completing all installation steps, the instrument needs to warm up for approximately 30~ 45 minutes. This time period is recommended in order to ensure consistency of measurements made by the instrument (CATI, 2003).

During testing, periodic checks of the system status are recommended. For example, the security of all connections with the vehicle should be evaluated. This can be done by determining whether engine data is updated on the instrument display in an appropriate manner, whether the gas concentrations are reasonable, and whether the instrument is receiving power. If the engine data are "frozen" or missing, then it will be necessary to reinstall the engine diagnostic data cable or to reboot the engine scanner. If the CO_2 gas concentration is very low, then there could be a leakage in the sampling line and therefore inspection and repositioning of the sampling line may be indicated. Chapter 7 provides more detail on diagnosing problems with the system and how they can be corrected.

After collecting data, it is recommended that the instrument be operated for an additional 20 minutes while sampling ambient air in order to help clear out the sampling gas path of the instrument. This additional procedure is expected to help maintain proper operation (CATI, 2003).

6.0 STUDY DESIGN FOR FIELD DATA COLLECTION

The purpose of this chapter is to discuss the factors involved in designing a study involving field data collection of real world in-use emissions, with a focus on dump trucks. Key factors in developing a study design include defining the study objective, selecting vehicles, identifying duty cycles of interest and scheduling data collection to capture these, selecting drivers, selecting sites and routes, and selecting fuels. Each of these major factors is described in the following sections, followed by a summary.

6.1 Objective

The objective of the field study was developed in close consultation with the NCDOT Equipment and Inventory Control Unit and with the project advisory committee. The objective is to answer the following key questions:

- What are the baseline real-world, in-use emissions and fuel use during actual operation of the selected vehicles under typical duty cycles?
- What factors contribute the most to episodes of high emissions and/or fuel use?
- How do emissions and fuel use compare for vehicles fueled with B20 biodiesel versus petroleum diesel?
- How do emissions and fuel use compare for loaded versus unloaded vehicles?
- How do emissions and fuel use compare for different sizes of vehicles (i.e. single rear axle versus tandem dump trucks)?
- How do emissions and fuel use compare for different engine designs, based upon comparison of engines developed under Tier 1 and Tier 2 emission regulations?

In order to answer these key questions, a field study was developed that has several key characteristics. For each of the vehicle and engine combinations listed below, measurements were made for each of B20 and petroleum diesel fuels, and for both unloaded and loaded conditions:

- Single rear axle vehicles with Tier 1 engines
- Single rear axle vehicles with Tier 2 engines
- Tandem vehicles with Tier 1 engines
- Tandem vehicles with Tier 2 engines

An in-use study is an observational, rather than a controlled, study. Thus, it is not possible to control all of the sources of variability that affect emissions. In fact, it is the real-world variability in ambient, traffic, and site conditions, as well as vehicle condition and driver behavior, that are of interest in this type of study, because they lead to variability in actual emissions and fuel use. As noted in Chapter 3, typical methods for measuring emissions and fuel economy rely on standardized test cycles, which are not representative of actual duty cycles in the real world. Thus, this study has the advantage of producing real world data. The existence of variability in various conditions that affect emissions and fuel economy imply that data must be collected for adequately large samples in order to obtain reliable estimates.

The objectives motivate instrumentation of existing NCDOT vehicles and data collection during normal duty cycles. Thus, the drivers for the vehicles were the same NCDOT personnel who currently operate these vehicles. The routes were based upon the service requirements of the vehicle. With the GPS system that is part of the portable on-board instrumentation, the actual route traveled by the vehicle were stored in terms of second-by-second x, y, and z coordinates. Because there is variability in traffic conditions and environmental factors, measurements were repeated for a given vehicle/driver combination for several duty cycles in order to obtain a statistically stable estimate of the mean emission rates for each pollutant and for specific driving modes. Thus, data were collected over a day with same driver/vehicle. In one day, there were typically 3 to 5 complete duty cycles per vehicle.

In order to satisfy the objective to compare emissions and fuel use for two different fuels, data collection was repeated for a given vehicle on two separate days, each with a different fuel. Where possible, NCDOT was able to schedule the same driver for both days of testing on the same vehicle. However, operational constraints faced by NCDOT led to the use of different drivers for the same vehicle in a few instances.

The selection of a truck and driver was coordinated with NCDOT via the NCDOT Research and Development Unit, the NCDOT Equipment and Inventory Control Unit, and NCDOT Division 5 personnel.

6.2 Vehicle Selection

Data collection was conducted for both single rear axle and tandem dump trucks, and for both Tier 1 and Tier 2 engines. This section briefly summarizes the characteristics of the vehicles that were included in the final field study. In total, there were 13 vehicles that were tested, but final data are reported only for 12. One of the vehicles was available during the time period that testing was conducted on B20 fuel. However, because of an accident not related to this project, the vehicle was not available for the second day of testing using petroleum diesel fuel.

Table 6-1 summarizes input data required for Monata system for each vehicle. Furthermore, the fuel properties that were input to the Montana system are shown in Table 6-2. The table indicates the NCDOT vehicle identification number that is painted on the front bumper, the model year, the engine type (Tier 1 or Tier 2), the engine model. These vehicles were selected in order to represent the four combinations of vehicle type and engine type that are required as part of the study design. The project resources were sufficient to test a total of approximately 12 vehicles on both fuels. During the time period of this study, the new Tier 2 vehicles were just becoming available. Only two Tier 2 vehicles of each of the single rear axle and tandem types were available in time for this study. Thus, a total of four Tier 2 vehicles were tested. The remainder of the tested vehicle fleet includes 4 Tier 1 rear single axle trucks and 4 Tier 1 tandems. The tandems are heavier vehicles than the single axles, both in terms of the rated Gross Vehicle Weight (GVW) and the actual unloaded weight of the vehicle.

Table 6-3 summarizes the characteristics of the engines for the tested vehicles. All of the engines are fuel-injected, turbo-charged, in-line 6 cylinder engines with pressure ratios ranging from 16:1 to 18:1. For the tandem dump trucks, there are two types of Tier 1 and one type of Tier 2 engines. For the single rear axle dump trucks, there is one type of Tier 1 and one type of Tier 2 engine. The tandem engines are rated at 305 to 350 horsepower, versus 195 to 220 horsepower for the single rear axle vehicles. The engines for the heavier tandems have more torque, displacement, and weight than those for the smaller single rear axle trucks. For example, the engine displacement ranges from 10.8 to 12.8 liters with 9 manual gears for the tandems versus only 7.2 to 7.6 liters with 6 manual gears for the single rear axle trucks.

Table 6-1. Vehicle Description and Input Data for Montana System for Each Vehicles

Vehicle Type	Vehicle Number	Model Year	Engine Displacement	Turbo Charged	Power Rating (*hP @ rpm*)	Torque Rating (*ft-lb @ rpm*)	GVW[a] (*lb*)	AVNW[b] (*ton*)	Engine Model
Double Rear Axle (Tandem) Dump Trucks	0507	1998	10.2	Yes	305@1,150	1,150@1,200	50,000	10.8	M 11+
	0513[c]	1999	10.2	Yes	305@1,150	1,150@1,200	50,000	10.8	M 11+
	0578	2000	10.2	Yes	305@2,100	1,350@2,100	50,000	10.8	ISM 305V+
	0579	2000	10.2	Yes	305@2,100	1,350@2,100	50,000	10.8	ISM 305V+
	0580	2000	10.2	Yes	305@2,100	1,350@2,100	50,000	10.8	ISM 350V+
	0125	2004	12.8	Yes	350@1,900	1,350@1,150	50,000	10.8	MBE 4000
	0126	2004	12.8	Yes	350@1,900	1,350@1,150	50,000	10.8	MBE 4000
Single Rear Axle Dump Trucks	4743	2000	7.2	Yes	195@2,200	450@1,440	33,000	7.2	CAT 3126
	4750	2000	7.2	Yes	195@2,200	450@1,440	33,000	7.2	CAT 3126
	4869	2001	7.2	Yes	195@2,200	450@1,440	33,000	7.2	CAT 3126
	4876	2001	7.2	Yes	195@2,200	450@1,440	33,000	7.2	CAT 3126
	6117	2004	7.6	Yes	220@2,600	540@2,600	33,000	7.2	DT 466
	6123	2004	7.6	Yes	220@2,600	540@2,600	33,000	7.2	DT 466

[a] Gross Vehicle Weight: This is the maximum recommended weight for a vehicle, including: the weight of the vehicle itself, passengers, and all cargo.
[b] Actual Vehicle Net Weight: the weight of the vehicle without a load, obtained based upon measurement at a truck scale
[c] Vehicle 0513 was available for testing only on B20 biodiesel. Therefore, this vehicle is not included in the final data base for purposes of comparing emissions and fuel use for B20 versus petroleum diesel fuels.

Table 6-2 Fuel Property Input Data into Montana System

	Fuel composition by mass			Fuel density (g/gallon)
	C (%)	H (%)	O (%)	
Petroleum Diesel	86.4	13.6	0.00	3,180
B20 Biodiesel	84.5	13.3	2.20	3,220

Table 6-3. Description of Engine Specifications for Tested Vehicles[a]

Vehicle Type	Tier 1 Tandem Diesel Engines		Tier 2 Tandem Diesel Engine	Tier 1 Single Axle Engine	Tier 2 Single Axle Engine
Engine Manufacturer	Cummins	Cummins	Mercedes-Benz	Caterpillar	International
Engine Model	ISM 350v+	M11+	MBE 4000	CAT 3126	DT 466
Displacement(*l*)	10.8	10.8	12.8	7.2	7.6
Power Rating (*hP*)	305@ 2,100	305@1,150	350@1,900	195@2,200	220@2,600
Torque Rating (*ft-lb*)	1,350@ 2,100	1,150@1,200	1,350@1,150	450@1,440	540@2,600
Bore x Stroke(in)	4.9x5.8	4.92x5.35	5.03x6.53	4.33x5.0	4.56x4.68
Configuration	In-line 6 Cylinder	In-line 6 Cylinder	In-line 6 Cylinder	In-line 6 Cylinder	In-line 6 Cylinder
Transmissions	9 manual	9 manual	9 manual	6 manual	6 manual
Injection	Direct	Direct	Direct	Direct	Direct
Compression Ratio	16.3:1	-	17.75:1	-	16.4:1
Dry Weight(*lb*)	2,070	-	2,117	1,250	1,425

[a] Data are shown where available.
Source: Cummins ISM 350V+ driver's manual (2000), Cummins M11+ Driver's manual (1998), Caterpillar 3136 driver's manual (2000), MBE 4000 driver's manual (2004), International DT 466 manual (2004).

Examples of each of the four types of vehicle/engine combinations tested in the field study are shown in Figures 6-1 through 6-4. Figure 6-1 shows a typical single rear axle dump truck with a Tier 1 engine. Figure 6-2 shows a typical tandem dump truck with a Tier 1 engine. Figures 6-3 and 6-4 show a single rear axle and a tandem, respectively, with Tier 2 engines.

Figure 6-1. Front and Side Views of a Tier 1 Single Rear Axle Dump Truck (7.2 *l* engine displacement)

Figure 6-2. Front and Side Views of a Tier 1 Double Rear Axle (Tandem) Dump Truck (10.8 *l* engine displacement)

Figure 6-3. Front and Side Views of a Tier 2 Single Rear Axle Dump Truck (7.6 *l* engine displacement)

Figure 6-4. Front and Side Views of a Tier 2 Double Rear Axle (Tandem) Dump Truck (12.8 *l* engine displacement)

6.3 Duty Cycles and Scheduling

The duty cycle for a dump truck typically includes driving to a location at which the truck is loaded with material, driving to another location where the truck is unloaded, and repeating this cycle of events until it is time to return to the maintenance yard at the end of the work shift. Operating speeds varied from zero mph (idle) to approximately 65 mph (on highways). Data were collected continuously over a period of the entire working day. During the summer, the work day typically started at 7:00 AM and ended at 3:00 PM. During the winter, the work day was typically from 7:30 AM to 3:30 PM. The tested vehicles traveled primarily in the North Carolina areas of Raleigh, Garner, and Fuquay-Varina. At some point during the workday, the vehicle was taken to a scale in order to weight the truck both with and without a load.

The locations of vehicle activity varied from day-to-day. Thus, the specific route driven and the amount of time spent driving varied. However, any of the duty cycles can be characterized based upon component parts, such as modes associated with vehicle motion and other operating modes associated with idling and dumping. Thus, any duty cycle can be described as an appropriately weighted combination of the following modes: idle, acceleration (low, medium, high), cruise (low, medium, high) deceleration, and dumping. Other than "dumping," which refers to a vehicle discharging its load at a particular location, the other modes can be associated with a vehicle that is either loaded or unloaded. The number of duty cycles measured for each vehicle on each test date is summarized in Table 6-4. There is an average of approximately 4.5 duty cycles per vehicle per day. The actual number of duty cycles per vehicle per day varies from 2 to 12. A total of 109 duty cycles were captured during the course of the field study.

The weight of an unloaded truck includes the vehicle, spreader equipment (if used), fuel in the fuel tank, driver and passenger, and the emissions measurement equipment. The emissions measurement equipment was accompanied by an NCSU graduate research assistant who rode as a passenger in the cab. A loaded truck includes all of the same components plus whatever load is carried in the bed of the truck. Therefore, the difference in the weight of a loaded versus unloaded truck is approximately the weight of the load. There also can be some difference in the weight of fuel remaining in the tank between the time that the vehicle was weighed loaded versus unloaded. However, the change in fuel weight is small compared to the change in the weight of the load.

On average, the load weight was approximately the same for both fuels for a given vehicle, but differed by approximately plus or minus one ton when comparing among vehicles. Because of different task requirements on different dates, it was not possible to exactly reproduce the same load for a given truck for each of the two fuels. There was variation in the materials carried by the trucks, which included stone, sand, dirt, asphalt, and wood. In light of this variation, the relative agreement in the load weight for a given truck operated on each of the two fuels is deemed to be good.

NCDOT controls the scheduling of the vehicles and does not permanently assign a driver to a specific vehicle. For 7 of the 12 vehicles tested, it was possible to have the same driver for each day of testing on both fuels. In the other cases, a different driver was used for the same vehicle on each of the two days of testing.

When the field study began, all vehicles were already fueled with B20 biodiesel. Therefore, a decision was made to test all 12 vehicles first on biodiesel, and then switch to petroleum diesel. Thus, measurements on B20 were made during the time period of late July through early October of 2004. Measurements were made on petroleum diesel during the period from October through December. To switch fuels, NCDOT dedicated a fuel storage tank to petroleum diesel and ran the vehicles through at least one full tank, and refilled again, prior to field measurements.

Scheduling is potentially an important consideration when comparing emissions for the two fuels, especially for NO_x. NO_x emissions are typically sensitive to ambient humidity. Higher absolute humidity tends to decrease peak flame temperatures and lower the NO_x emissions. The available dynamometer-based data for comparing B20 and petroleum diesel fuels implies that NO_x emissions might be higher for B20. For logistical reasons of dealing with the fuel supply and the time required to refuel vehicles between measurements, it was not possible to collect data on B20 and petroleum diesel at the same time for a given vehicle. Typically, the B20 measurements were made during warmer and more humid (on average, on an absolute basis) summer months and the petroleum diesel measurements were made for cooler and less humid (on average, on an absolute basis) autumn months as summariszed in Table 6-5. Note that the absolute humidity decreases with temperature even for a constant relative humidity. The implications of measurements made during different seasons are further discussed in Chapter 8.

Table 6-4. Summary of Test Schedule, Number of Duty Cycles, Type of Load, and Load Weight

Vehicle Type	Vehicle Number	B20		Pet. Diesel[c]		Number of Cycle		Load Type		Load Weight (tons)	
		Driver	Date	Driver	Date	B20[a]	PD[b]	B20[a]	PD[b]	B20[a]	PD[b]
Tandem	**0507**	Kirby	09/01	Kirby	11/08	4	7	Wood	stone	13.8	14.6
	0578	Joe	08/05	Charles	10/28	4	4	Asphalt	Dirt	15.1	14.1
	0579	Ron	07/27	Ron	10/15	7	2	Sand	Sand	14.7	14.8
	0580	Keeven	08/25	Keeven	10/05	4	3	Asphalt	Asphalt	15.2	16.7
	0125	Keeven	12/07	Keeven	11/30	4	4	Stone	Stone	14.3	14.5
	0126	Charles	12/02	Charles	12/01	4	5	Stone	Stone	13.2	12.8
Single Axle	**4743**	David	08/10	Keeven	10/21	4	3	Sand	Stone	7.12	8.06
	4750	Mike	10/08	Ricky	11/02	2	5	Dirt	Wood	7.10	5.98
	4869	Howard	08/31	David	10/27	2	2	Sand	Dirt	7.74	5.94
	4870	James	08/20	Scott	10/29	5	6	Dirt	Stone	7.10	7.86
	6117	Todd	08/17	Todd	10/20	7	5	Dirt	Stone	7.14	6.83
	6123	Willard	10/06	Willard	11/03	4	12	Dirt	Dirt	7.20	5.85

[a] Soy-based B20 Fuel, [b] Petroleum Diesel Fuel, [d] Actual fuel consumption (gallon/days)

Table 6-5. Ambient Conditions and Engine Intake Data information For Each Vehicle and Day of Testing.

	Pressure (hPa)		Temperature (°F)		Relative Humidity(%)		Speed(SD[a]) [mph]		MAP(SD[a]) [kPa]		IAT(SD[a]) [°C]	
Vehicle Number	B20	PD	B20	PD	B20	PD	B20	PD	B20	PD	B20	PD
0507	994	996	79	65	74	45	32.5 (18.2)	33.5 (12.2)	180 (38.1)	147 (38.2)	36.3 (3.35)	33.5 (4.22)
0578	999	997	82	62	67	62	34.6 (13.6)	38.7 (13.6)	177 (36.9)	185 (53.1)	44.4 (3.31)	33.6 (3.97)
0579	998	996	88	66	63	60	33.7 (15.7)	39.4 (14.20)	182 (55.7)	199 (44.5)	38.7 (7.21)	37.7 (5.35)
0580	995	997	80	69	50	53	36.8 (15.6)	35.7 (17.5)	189 (26.3)	189 (29.4)	34.1 (4.13)	35.0 (4.29)
0125	996	996	72	60	71	41	41.5 (15.2)	31.5 (12.6)	189 (29.5)	185 (32.5)	35.1 (3.50)	35.1 (4.12)
0126	995	997	58	60	27	31	44.5 (13.8)	44.5 (14.4)	185 (26.5)	187 (29.8)	35.0 (4.21)	36.3 (3.85)
4743	997	995	85	61	53	83	44.9 (19.4)	38.4 (14.9)	171 (47.6)	147 (28.0)	34.2 (7.18)	34.4 (4.85)
4750	996	997	74	76	37	71	39.8 (15.1)	39.5 (13.4)	178 (37.9)	154 (22.1)	35.3 (4.87)	33.4 (1.88)
4869	997	997	85	63	59	75	38.6(17.1)	37.2 (13.9)	158 (40.2)	135 (20.3)	34.3 (3.65)	20.5 (0.530)
4870	998	998	89	63	53	81	34.1 (16.9)	32.6 (14.2)	160 (45.0)	155 (39.1)	38.0 (3.14)	20.6 (1.04)
6117	995	997	83	61	58	90	30.5 (15.9)	39.3 (13.9)	167 (51.7)	181 (43.6)	45.6 (3.65)	37.8 (3.72)
6123	996	997	66	77	47	64	40.3 (16.9)	30.5 (12.5)	198 (39.7)	198 (25.2)	38.0 (3.48)	37.0 (1.10)

[a] Standard Deviation

6.4 Driver Selection

For the field measurements, vehicles were operated by drivers assigned by NCDOT. These drivers performed their normal duty cycles. A total of 13 drivers participated in the field data collection effort. Of these, six were available to operate a vehicle on both B20 biodiesel and petroleum, and one of these six drivers operated two different vehicles on both fuels. Thus, the comparisons of fuel use and emission between the two fuels are based upon approximately the same driver behavior for a total of seven vehicles, including five of the tandems and two of the single rear-axle vehicles. Six drivers drove only one vehicle operated on one fuel, and another driver drove two different vehicles but did not repeat testing for the same vehicle with different fuels. Thus, there are five vehicles for which the measurements for B20 and petroleum diesel were made by different drivers.

It is possible that differences in driver behavior might exist among the drivers, and that differences, if they exist, might lead to differences in fuel use or emissions that are not attributable to fuel or vehicle characteristics. However, an informal observation is that all of the drivers are professionals, and they operate the vehicle in a responsible manner.

6.5 Site / Route Selection

On-board data collection is flexible in terms of site and route selection compared to other measurement methods, as described in Chapter 3. Selection of sites and routes for on-board data collection was determined by the normal work requirements of NCDOT. According to the NCDOT work schedule, I-440, US 1, Holly Spring Road and US 401 were traveled more than other roads. I-440 is the beltline of Raleigh-Cary area and US 1 was driven mostly to visit Apex and near southwestern part of Raleigh. Holly Spring Road and US 401 which are located at the south middle of Figure 6-5 were traveled to go to Fuquay-Varina and Garner area. Every morning, all 12 selected vehicles started at the NCDOT Division 5 maintenance yard which is marked as star in Figure 6-5. This yard is located at Blue Ridge and Trinity Roads in Raleigh, NC. The duty cycles of these vehicles typically included travel to locations in Raleigh, Garner, or Fuquay-Varina within Wake County, NC. The majority of the runs involved mostly driving on paved roads because the main purpose of the duty cycle was road patching and widening roads. However, in some cases, short periods of travel off-road were included as part of the duty cycle, such as for roads that were not yet paved. An example of the latter is Pearl Road near Garner, NC.

Figure 6-5 displays a graphical summary of all of the routes that were included in the field data collection effort for the 12 vehicles that were tested on both fuels. There are some line segments in the southern part of the Figure 6-5. These segments of data occurred because of unexpected loss of power of the instrument or other instrument problem, which lead to a loss of GPS and other data. Therefore, the routes covered by the vehicle during the period of loss of data are not included in Figure 6-5.

Figure 6-5. Vicinity and Detailed Map of the Geographic Area of In-Use Field Measurements, Showing all Routes and Sites

Map source : http://www.visitraleigh.com

6.6 Fuel Selection

Because a key objective of this project is compare fuel use and emissions for B20 biodiesel versus petroleum diesel, each of the selected vehicles was tested for one day while fueled with B20 and for one day while fueled with petroleum diesel. NCDOT provided the fuel for all vehicles, and was responsible for fueling the vehicles. The typical properties of B20 and petroleum diesel are given in Section 2.4.

6.7 Summary of Field Study

The field study design is based upon clearly stated objectives that are based upon a need for real world in-use data pertaining to multiple types of vehicles, engines, fuels, loads, and operating modes. Four categories of dump trucks were selected for testing, including: (1) single rear axle with Tier 1 engines; (2) single rear axle with Tier 2 engines; (3) tandems with Tier 1 engines; and (4) tandems with Tier 2 engines. The tandems have a significantly higher GVW than the single-axles, and typically have engines with larger displacement, more horsepower, more torque, and more weight. A total of 12 vehicles were included in the measurement program.

This study is unique in that it is based upon operation of vehicles during their normal duty cycles. Thus, the study design must deal with the variation that can occur from day-to-day depending upon the specific routes, loads, and activities of each vehicle. In order to obtain an adequate sample of data, each test was conducted over the course of an entire workshift. Each workshift included, on average, 4.5 duty cycles. Each actual duty cycle is comprised of a uniquely weighted combination of nine operating modes (idle, three levels of acceleration, three levels of cruise, deceleration, and dumping).

A typical duty cycle includes obtaining a load at an origin, delivering the load to a destination, dumping the load, and returning to an origin to obtain a new load. The cycle is repeated. Each vehicle was measured on each day of data collection both with and without a load. The average weight of a typical load was approximately 14.5 tons for the tandems and 7.0 tons for the single rear-axle trucks.

Each of the 12 vehicles was tested for one day on B20 biodiesel and for one day on petroleum diesel, for a total of 24 days of field measurements. The vehicles were operated by drivers assigned by NCDOT. The study relied upon and greatly benefited from the cooperation of professional drivers who conducted their normal work while NCSU collected data. NCDOT does not permanently assign a driver with a specific vehicle. However, NCDOT was able to schedule the same driver and vehicle combination for both fuels for seven of the vehicles, which facilitates comparisons between the two fuels. All of the drivers operated the vehicle in a professional and responsible manner. It is possible that different drivers might have different weighted combinations of operating modes. However, even when a vehicle was operated by one driver for one fuel and a different driver for the other fuel, it is likely that the results can be compared on the basis of individual operating modes.

All of the data collection occurred in Wake County, North Carolina. Data were collected for vehicles operated on B20 biodiesel fuel during more humid (on average) months than when data were collected for petroleum diesel. NO_x emissions in particular may be sensitive to ambient humidity. The implications of the differences in ambient conditions with respect to interpretation of field study results are further discussed in Chapter 8, based upon a humidity correction factor presented in Chapter 2.

7.0 METHODS FOR DATA SCREENING AND EMISSIONS ESTIMATION

In this chapter, methods for data post processing are discussed. This work is important in developing an accurate database, and it includes developing protocols for data post-processing, discussion of possible errors in the dataset, and methods for making corrections.

7.1 Data Screening

This section briefly describes the process by which data are collected and reported to a database.

7.1.1 Determination of Screening Steps

Each run of data collected by the Montana system is summarized in a comma separated-format file (.csv). The raw data format is converted to a Microsoft Excel spreadsheet format for ease of data analysis in the laboratory. Traffic/test event information is recorded in a notebook during testing. After the post-processing process, the data includes: vehicle speed (mph); distance traveled (mile); acceleration (mph/sec); engine RPM; coolant temperature (°F); intake air flow (g/sec); dry exhaust flow (g/sec); fuel flow (g/sec); fuel economy (g/mile); NO concentration (ppm); HC concentration (ppm); CO concentration (volume percent); CO_2 concentration (volume percent); O_2 concentration (volume percent); Fuel use (g/sec); NO mass emissions (g/sec); HC mass emissions (g/sec); CO mass emissions (g/sec); CO_2 mass emissions (g/sec); and GPS x, y coordinates. Information on the vehicle, driver, and weather conditions are reported in a summary sheet of the file.

The typical problems that can be encountered are

- Engine Data Errors
- Gas Analyzer Errors
- Zeroing
- Negative Emission Values
- Loss of Power to Instrument
- Gas Concentration Error

These errors are discussed in more detail in the following sections.

7.1.2 Procedures for Applying Screening Steps to Raw Data

For quality assurance purposes, the combined data set for a vehicle run is screened to check for errors or possible problems. If errors are identified, they are either corrected or the data set is not used for data analysis. First, the types of errors typically encountered are described followed by a discussion of methods for making corrections.

The predominant types of errors or problems include:

***Engine Data Errors*:**

On occasion, communication between the vehicle's onboard computer and the engine scanner may be lost, leading to loss of data. Sometimes the loss of connection is because of a physical loss of electrical contact, while in other cases it appears to be a malfunction of the vehicle's on-board diagnostic system. This rarely happens. However, when it happens, this error can be solved easily by rebooting the system in the field. After rebooting, the computer begins logging a new data file automatically. Thus, when this is noticed in the field, this error can be addressed. Loss of engine data is also obvious from the data file, since the missing data are evident and any calculations of emission rates are clearly invalid.

(1) Acceleration

Based on Hallmark *et al.* (1998), acceleration cannot be over 10 mph/s for heavy duty diesel vehicles. Therefore, if acceleration is found to be greater than 10 mph/s, it needs to be investigated. When an acceleration over 10 mph/s occurs, the data immediately before and after the second(s) during which these implausible accelerations occurred are removed from the database. This type of error occurred very rarely, affecting only a few seconds of data.

(2) Unusual Engine RPM

Engine RPM typically varies from not less than 600 RPM during idling to about 3,000 RPM during most kinds of vehicle operation. As a conservative estimate, the bounds for possible engine RPM were set as greater than or equal to 600 RPM and less than or equal to 10,000 RPM (Yu and Qiao, 2004). Thus, if engine RPM is less than 600 or greater than 10,000 RPM, those data need to be removed for the further data analysis. However, this problem did not occur in any of the data collected in this project.

(3) Engine RPM Freezing

"Freezing" refers to situations in which a value that is expected to change dynamically on a second-by-second basis remains constant over an unacceptably or implausibly long period of time. Engine RPM tends to fluctuate on a second-by-second basis even if the engine is running at approximately constant RPM. Therefore, we performed a check to identify situations in which engine RPM remained constant for more than three seconds. This problem occurred only in situations where the engine scanner became physically disconnected from the data logging computer. This type of error was rare.

Double Gas Analyzer Errors:

Montana has two gas analyzers, which are referred to as "benches." Most of the time, both benches are in use. Occasionally, one bench is taken off-line for "zeroing," as described in Chapter 6. Therefore, most of the time, the emissions measurements from each of the two benches can be compared to evaluate the consistency between the two. If both benches are producing consistent measurements, then the measurements from both are averaged to arrive at a single estimate on a second-by-second basis of the emissions of each pollutant.

When the relative error in the emissions measurement between both benches is within five percent, and if no other errors are detected, then an average value is calculated based upon both of the benches.

However, if the relative error exceeds five percent, then further assessment of data quality is indicated. A discrepancy in measurements might be due to any of the following: (a) a leakage in the sample line leading to one bench; (b) overheating of one of the benches; or (c) problems with the sampling pump for one of the benches, leading to inadequate flow. If one of these problems is identified for one of the benches, then only data obtained from the other bench was used for emissions estimation. A test log was kept that identified unusual transient incidents that occurred during field testing. When problems were identified in the field, then attempts were made to resolve the problems in the field. For example, if a leak or overheating problem was detected during data collection, then the problem was fixed and testing resumed. Data recorded during the period when a leak or overheating event occurred were not included in any further analyses.

Zeroing Procedure

For data quality control and assurance purpose, each gas analyzer bench of is zeroed alternatively every 15 minutes. While zeroing, the gas analyzer will intake ambient air instead of tailpipe emissions. More information regarding the zeroing procedure is given in Chapter 5.3.

After zeroing is finished, a solenoid valve changes the intake from ambient air to the tailpipe. There is a period of transition when this occurs. In particular, the oxygen sensor needs several seconds to respond the switching of gases, since there is a large change in oxygen concentration when this switch occurs. To allow adequate time for a complete purging of the previous gas source from the system, a time delay of 10 seconds is assumed. Thus, for 10 seconds before zeroing begins, the time period of zeroing, and 10 seconds after zeroing ends, data for the bench involved in zeroing are excluded from calculations of emission rates, and the emission rates are estimated based only upon the other bench.

Negative Emissions Values

Because of random measurement errors, on occasion some of the measured concentrations will have negative values that are not statistically different from zero or a small positive value. Diesel vehicles typically produce HC emission less than gasoline vehicle does (Durbin *et al.*, 2000). Thus, it is frequently the case that HC emission measurements are very low and not substantially different from zero. Negative values of emissions estimates were assumed to be zero and were replaced with a numerical value of zero.

Loss of Power to Instrument

A loss of power to the instrument resulted in a complete loss of data collection during the time period when power was not available. However, the system saves data up to the point at which the power loss occurs. All of the tested vehicles had manual transmissions. A typical cause of power loss was stalling of the engine due to a problem shifting. Such problems typically occur when going from idle into first gear, or for the lower gears. After a loss of power, the instrument needs to be rebooted, which takes approximately five to ten minutes. During the power loss and rebooting, no data can be collected.

7.2 Method of Estimation of Modal Emission Rates

The objective of this section is to present a methodology for deriving modal emission rates from data. The first section provides methodological overview and theory, upon which the analyses in the later sections are based.

7.2.1 Methodological Overview

Modal emission rates have been used in other projects as a way of evaluating variability in emissions (e.g., Frey *et al*., 2001, 2002). Modal emission rates can be developed on the basis of a second-by-second speed profile, whether obtained from dynamometer measurements or from on-board measurements during real-world vehicle operations. Modes can be defined based on a variety of criteria, such as speed, acceleration, combinations of both, or calculated quantities such as engine power demand. The latter is the product of speed and acceleration. The second-by-second data are classified into a mode that is defined by a range of values for the selected criterion (e.g., speed, acceleration, combinations of both, or other quantities). An average emission rate is estimated for each mode. A comparison of average emissions for different modes provides insight into the amount of variation in average emissions that can be accounted for by the modal definitions. A set of modal definitions is given stronger preference if it can produce a wider range of variability when comparing the modal averages.

The definition of modes in this work is based upon Frey *et al.* (2002), who analyzed second-by-second data for diesel transit buses and found that average emissions were significantly different when comparing idle, acceleration, cruise, and deceleration modes. However, the modal definitions were refined in this work to provide higher resolution pertaining to different levels of acceleration or cruising, and to incorporate activity patterns unique to dump trucks, such as dumping the load in the rear bed.

7.2.2 Development of Modal Definitions

Vehicle activity, emissions, and fuel use were evaluated initially based upon time traces. A time trace depicts an emission or fuel usage rate versus time. The time traces typically indicate that there is a significant contribution to total emissions from short-term events that occur within the trip. Thus, a modal approach to analysis was deemed to be useful for purposes of disaggregating the vehicle activity profile and gaining insights into short term events that might have different influences on total emissions.

The definition of each driving modes has been developed for the modal emissions analysis methods in which trips are divided into 9 driving modes (e.g., acceleration (low, medium, high), cruise (low, medium, high), deceleration, idle, dumping) and in which average emissions and fuel use are estimated separately for each mode. The calculation of modal emissions rates provides a consistent basis for comparison of different trips. The criteria for each mode are listed below:

- Idle (speed = 0, Acceleration = 0)
- Acceleration (Acceleration = Speed increases by 1 mph in 1 sec)
  - "Low Acceleration" (Power Demand = 20)
  - "Medium Acceleration" (20 < Power Demand = 50)
  - "High Acceleration" (Power Demand > 50)

    (Power Demand = Speed x Acceleration)
- Cruise
  - "Low Cruise" (speed < 30 mph)
  - "Medium Cruise" (30 mph = speed < 45 mph)
  - "High Cruise" (speed = 45 mph)
- Deceleration (negative of acceleration)
- Dumping

7.2.3 Validation of Fuel Use

Fuel use is estimated by the Montana system based upon a calculation involving assumptions regarding engine volumetric efficiency and data reported by the electronic control unit regarding intake air temperature, manifold air pressure, and engine RPM. It is possible that there are uncertainties or errors in these data. Thus, there is a need to validate the fuel usage estimates from the Montana system by comparison to independent data.

The amount of fuel added to the vehicle at the end of each day of duty was metered by a fueling pump at the NCDOT Division 5 maintenance yard. The vehicle was fueled prior to testing at the beginning of a duty shift, and was refueled at the end of the shift. Thus, the amount of fuel added at the end of the shift represents the amount of fuel consumed during the shift. The metered number of gallons of fuel was compared to the total number of gallons of fuel estimated based upon summing second-by-second estimates of the Montana system.

Although this comparison is subject to some limitations, it is a practical way to determine if the overall fuel use estimated by the Montana system agrees with the fueling records of NCDOT. The benefit of such a comparison is that it can provide confidence that the flow rates estimated by the Montana system are reasonable. Furthermore, since CO_2 emissions are highly correlated with fuel flow, validation of fuel flow also provides credibility regarding the CO_2 emission values. Some of the limitations of this comparison might include the following: (a) the vehicle's fuel tank might be "topped off" at exactly the same level from one filling to the next; (b) some vehicle idling occurs while the Montana system is warming up; and (c) some vehicle operation may occur at times when the Montana system is recovering from a power loss or other data collection outage. Whether these possible limitations might be important can be inferred based upon the comparison presented in Chapter 8.

7.2.4 Summary and Conclusions

Methods for screening the data collected in the field, and for making corrections or deletions to deal with data problems, were developed and applied. The screening methods are categorized based upon their cause or implications as being related to engine data, gas analyzer data, zeroing procedure, negative emissions values, loss of power, and low concentration. The goal of these screening methods is to create a database that is as free of errors as possible. These errors can involve loss of input data streams, loss of power, data values that are out of range, or data problems associated with operational problems that can occur from time to time (e.g., overheating of a gas analyzer bench). In most cases, the diagnostic checks made during field data collection and during analysis of data from the field identified particularly types of errors only infrequently.

Once a quality assured database has been developed, then methods were applied for analyzing the data. In order to compare emissions between vehicles, loads, and fuels, a set of operating modes was developed that allow any activity pattern to be disaggregated. The modes include idle, three levels of acceleration, three levels of cruise, deceleration, and dumping. Average emissions rates are estimated for each mode based upon binning of second-by-second data. The binning criteria include speed, acceleration, and engine power demand, in various combinations, depending upon the mode. The dumping mode refers to lifting of the rear bed of the truck, which typically occurs during stationary or low speed operation of the truck.

A methodology for partial validation of the Montana system data was developed based upon comparing fuel use estimated by the Montana system with measured fuel use.

8.0 RESULTS FOR REAL WORLD FUEL USE AND MODAL EMISSION RATES FOR PETROLEUM DIESEL AND B20 BIODIESEL FUEL

This chapter provides the results of the field data collection study based upon measurements made using the Montana system described in Chapter 5, the study design described in Chapter 6, and the methods for data screening and analysis described in Chapter 7. First, an assessment is made of the validity of the fuel use and CO_2 emissions estimates from the Montana system. Subsequently, results are presented in more detail for each of the vehicle groups, including: (a) single rear axle dump trucks with Tier 1 engines; (b) double rear-axle (tandem) dump trucks with Tier 1 engines; (c) single rear axle dump trucks with Tier 2engines; and (d) double rear-axle (tandem) dump trucks with Tier 2 engines. For each vehicle group, a comparison is made of emissions for each of the operating modes, for loaded versus unloaded operation, between vehicles, and for B20 biodiesel versus petroleum diesel fuels.

8.1 Results for Validation of Fuel Use

The purpose of this section is to validate the mass flow estimates obtained from the Montana system by comparing the fuel consumption estimated by the Montana system with the actual fuel consumption measured by NCDOT. The Montana system estimates fuel consumption based upon a mass balance of inlet fuel and air to the engine and outlet exhaust flow. These flow rates are estimated based upon the engine displacement, an assumed volumetric efficiency, and three variables that are measured on a second-by-second basis: (1) engine RPM; (2) inlet air temperature; and (3) manifold air pressure. These latter three variables are reported by the electronic interface of the vehicle. In addition, information regarding the measured exhaust gas composition is used to infer the fuel-to-air ratio. Thus, a comparison of the fuel flow estimated by the Montana system with that measured by NCDOT helps to validate the approaches used in the Montana system to estimate the mass flow not only of the fuel, but also of the inlet air and the exhaust gas, since these three mass flows are inter-related.

Table 8-1 summarizes the fuel use for each of the 12 tested vehicles for both B20 biodiesel and petroleum diesel, including the “actual” fuel consumption as measured by NCDOT and the “measured” fuel consumption as estimated by the Montana system. In the morning of a testing day, the fuel tank for the vehicle was full. The actual fuel use is the amount of fuel added to the tank at the end of the duty shift. The actual fuel use is subject to some error, in that the tank might not be “topped off” at exactly the same amount in the morning versus the afternoon refilling. The measured fuel use is based upon summing the gram per second fuel consumption estimates of the Montana system for all seconds for which data were collected. The measured fuel use is subject to the following possible errors: (1) the Montana system may not have collected data for all times that the engine was operated, such as because of the need to warm-up the Montana system or because of a loss of signal during data collection; and (2) the measured fuel use is subject to measurement errors associated with the quality of the data from the electronic data link and from the gas analyzers.

Figure 8-1 provides a graphical comparison of the measured versus actual fuel use based upon the data in Table 8-1, including both B20 biodiesel and petroleum diesel. The accuracy of the results are indicated in terms of how closely the slope of the trend line approaches an ideal value of 1.0 and how closely the intercept of the trend line approaches an ideal value of 0. The precision of the results are indicated by the magnitude of the coefficient of determination. The results shown in the figure are nearly identical to what the ideal results should be. For example, the slope of 0.9957 is very close to the desired value of 1.0, and the intercept of only 0.0479 gallons is small relative to the typical amount of fuel consumed during a testing day, which ranged from approximately 11 to 32 gallons. Thus, the measured fuel consumption values are accurate with respect to the actual values. Furthermore, the coefficient of determination is nearly 1.0, indicating that the results are precise. On average, the measured fuel consumption differs by the actual fuel consumption by less than 0.7 percent, which is likely to be well within the measurement errors of either the actual or the measured values.

Table 8-1 The Actual and Measured Fuel Use for Each Vehicle per days of testing.

Vehicle Number	B20		Pet. Diesel[c]		Fuel Use (gallons/day)			
					B20[a]		PD[b]	
	Driver	Date	Driver	Date	A[d]	M[e]	A[d]	M[e]
0507	Kirby	09/01	Kirby	11/08	19.0	18.8	34.0	33.6
0578	Joe	08/05	Charles	10/28	22.0	21.9	26.6	26.6
0579	Ron	07/27	Ron	10/15	28.0	28.2	18.0	17.5
0580	Keeven	08/25	Keeven	10/05	18.0	17.8	21.0	21.0
0125	Keeven	12/07	Keeven	11/30	27.0	26.6	17.2	16.8
0126	Charles	12/02	Charles	12/01	32.1	32.5	31.0	30.6
4743	David	08/10	Keeven	10/21	11.0	11.0	11.0	11.3
4750	Mike	10/08	Ricky	11/02	12.0	11.8	13.5	13.5
4869	Howard	08/31	David	10/27	13.3	13.7	6.24	6.22
4870	James	08/20	Scott	10/29	12.0	11.9	9.50	9.56
6117	Todd	08/17	Todd	10/20	14.0	13.8	22.0	21.5
6123	Willard	10/06	Willard	11/03	13.0	12.4	14.0	13.8

[a] : Soy-based B20 Fuel [b, c] : Petroleum Diesel Fuel [d] : Actual fuel consumption (gallon/days)
[e] : Measured fuel consumption based upon the Montana system (gallon/days)

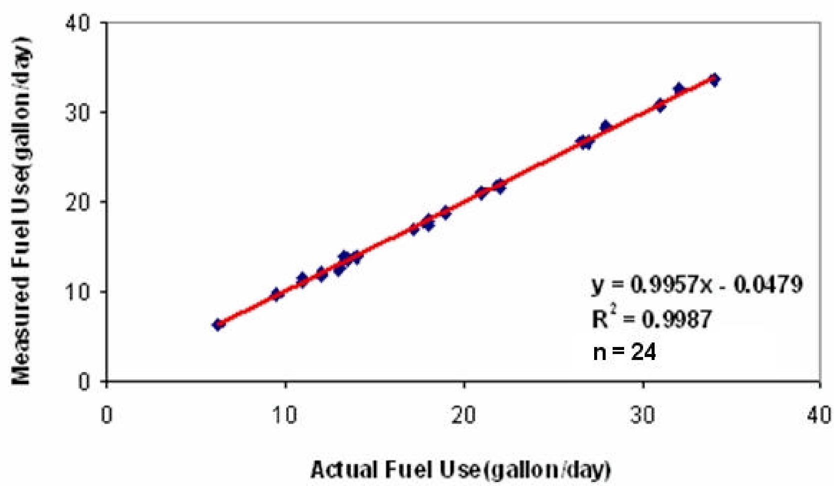


Figure 8-1 Regression Analysis between Measured fuel use and Actual fuel use

The comparison of the measured versus actual fuel use implies that, despite any errors or uncertainties in these data, there is excellent agreement between these values. This comparison implies that the average mass balance estimates of the Montana system are both accurate and precise.

8.2 Single Rear-Axle Dump Trucks - Tier 1 (Petroleum Diesel / B20 Biodiesel)

This section presents the results of measurements made on single rear-axle dump trucks with Tier 1 engines, fueled with each of petroleum diesel and B20 biodiesel.

The fuel use and emissions of these vehicles were measured during real world duty cycles. These duty cycles are characterized in Figures 8-2 and 8-3 for vehicles fueled with petroleum diesel and B20 biodiesel, respectively. In each figure, there is a separate graph for unloaded and loaded vehicle operation. The figures quantify the percentage contribution of each operating mode to the total amount of time, distance, fuel consumption, and emissions of NO, HC, CO, CO_2, and PM.

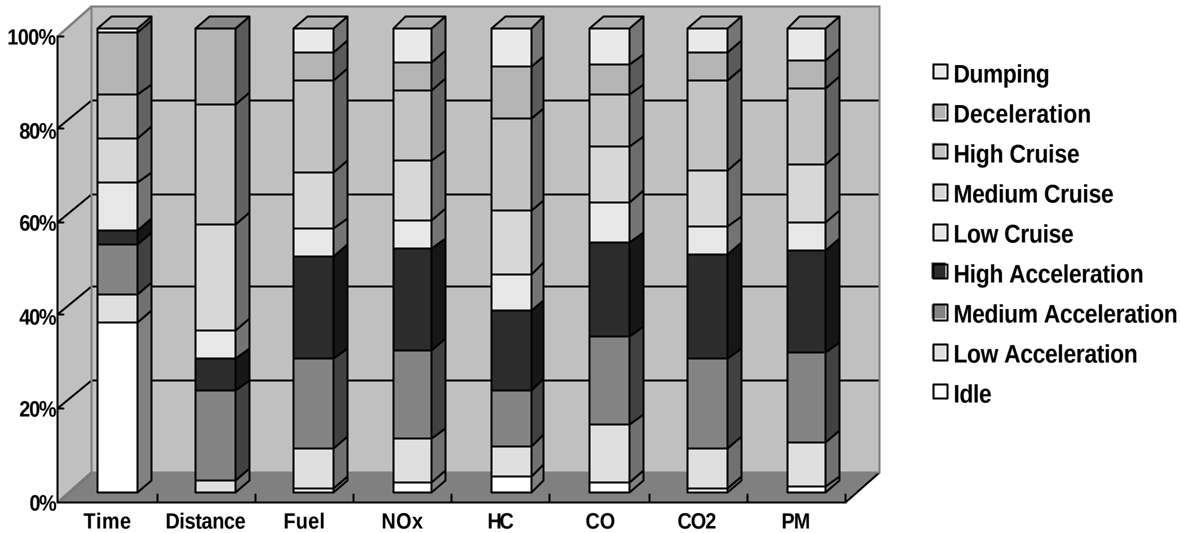
The idling operating mode typically has the greatest share of the total time of the duty cycle, compared to any other mode. Idle comprises from approximately 35 to nearly 60 percent of the vehicle operating time. The three acceleration modes, including low, medium, and high accelerations, typically account for approximately 10 to 15 percent of the total amount of operating time. The three cruising modes, including low, medium, and high cruise, account for approximately 20 to 30 percent of the total operating time. The deceleration mode accounts for approximately 10 percent of the operating time. For loaded vehicles, the dumping mode accounts for approximately one percent of the operating time.

The implications of these duty cycle summaries are that the vehicles spend a significant amount of time idling. This would be expected in situations where the vehicle is waiting to receive a load or is waiting for its turn to dump a load. The acceleration, cruise, and deceleration modes are primarily associated with over-the-road travel. The dumping mode occurs at the jobsite.

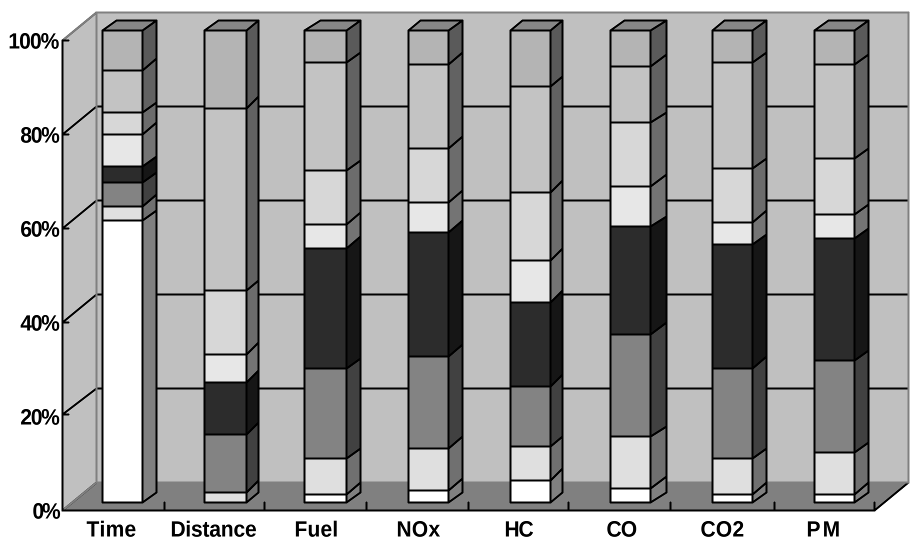
In terms of distance driven during the duty cycle, idling makes no contribution. The three cruising modes account for almost 60 percent of the distance driven. The three acceleration modes account for approximately 25 percent of the distance driven. Approximately 20 percent of the distance driven occurs during decelerations.

The fuel consumption is primarily determined by the acceleration and cruising operating modes, which combined account for approximately 85 to 90 percent of the total fuel consumption. The modes that make the largest individual contribution to fuel consumption include medium and high acceleration and medium and high cruise. These modes typically have a larger engine power demand than the others. Idling contributes only a few percent of the total fuel consumption. For loaded vehicles, the dumping mode accounts for approximately five percent of fuel consumption.

Approximately 80 percent of the NO emissions for unloaded vehicles, and nearly 90 percent of the NO emissions for loaded vehicles, are primarily attributable to the acceleration and cruising modes. Of these modes, the medium and high cruise and the medium and high accelerations have the greatest contributions. The total contribution from acceleration tends to be greater than that from cruising. For loaded vehicles, the dumping mode contributes approximately five percent to the total NO emissions, whereas idling contributes approximately one percent. One

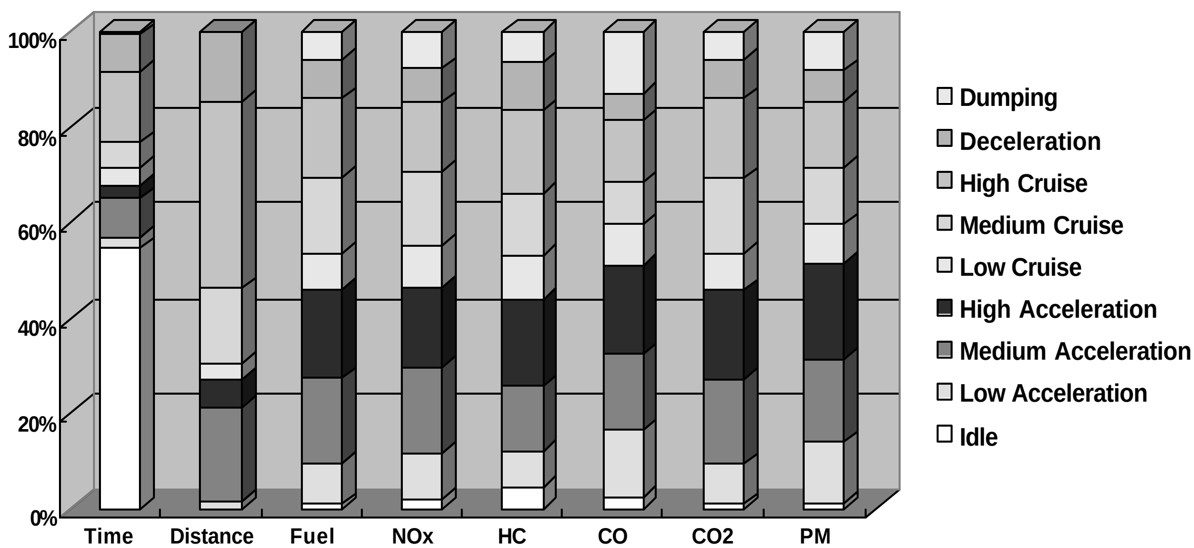


(a) Loaded

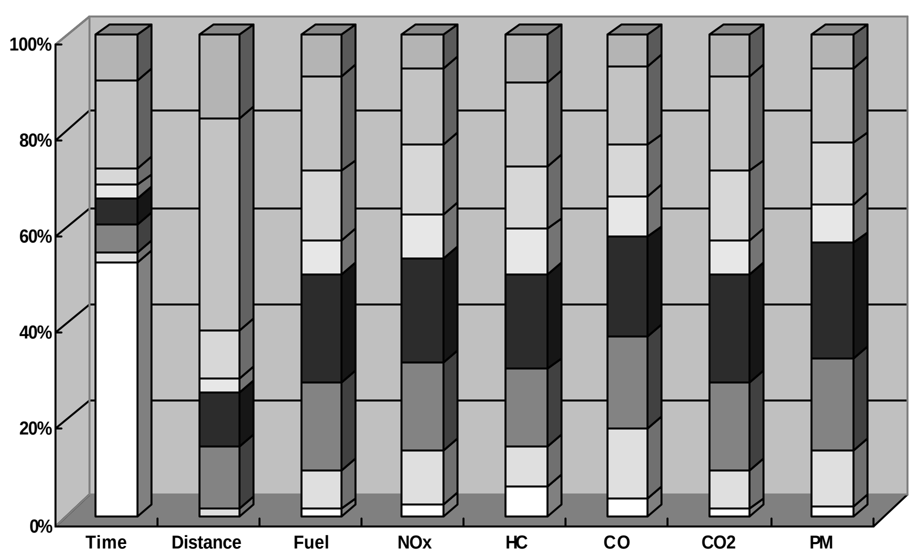


(b) Unloaded

Figure 8-2 Distribution of Time, Distance, Fuel Use, and Emissions by modes for Tier 1 Single axle dump trucks fueled with Petroleum diesel.



(a) Loaded



(b) Unloaded

Figure 8-3 Distribution of Time, Distance, Fuel Use, and Emissions by modes for Tier 1 Single

Axle dump trucks fueled with Soy-Based B20

reason that the dumping mode contributes more to NO emissions is that the engine is under a larger load compared to idling, even though in both of these modes the vehicle is approximately stationary.

For the other pollutants, including HC, CO, CO_2, and PM, there is some variation regarding the percentage contribution of each mode to the total emissions. HC emissions have a larger contribution from the idle mode than do other pollutants, although the total contribution in this case is only approximately five percent. The contribution of the cruising, deceleration, and dumping modes tends to be somewhat larger for HC, and the contribution from the acceleration modes is somewhat smaller, compared to NO. Conversely, the CO emissions tend to have a larger contribution from the acceleration modes than do either HC or NO. The distribution of CO_2 emissions by mode is approximately the same as that for fuel consumption, since the vast majority of carbon in the fuel is emitted as CO_2. Thus, there is approximately a linear relationship between fuel consumption and CO_2 emissions. The distribution of PM by operating mode is qualitatively similar to that of other pollutant, with the largest contributions associated with modes that have the highest engine power demand. These modes include medium and high cruise and medium and high acceleration.

More detail regarding the emissions of the single rear-axle vehicles with Tier 1 engines is shown in Table 8-2 for petroleum diesel and in Table 8-3 for B20 biodiesel. These tables report the average fuel consumption and emission rates in mass per time units for each vehicle, operating mode, and for unloaded and loaded operations.

Taking Table 8-2 as an example, the average fuel consumption rates vary among the operating modes. For example, for Vehicle 4869, the average fuel consumption when unloaded varies from as little as 0.258 grams per second during idling to as much as 4.84 grams per second during high acceleration. The ratio of the highest to lowest modal fuel consumption rates in this case is, therefore, 18.9. The average fuel consumption during high cruise is nearly as high as that for high acceleration, with a value of 4.48 grams per second.

The average fuel consumption increases when comparing low, medium, and high accelerations. Similarly, the average fuel consumption increases when comparing low, medium, and high cruise modes. Typically, the average fuel consumption is greater for the acceleration modes than for the cruise modes. Presumably, the engine is under greater power demand during acceleration, thereby leading to higher fuel consumption.

The fuel consumption during deceleration is typically greater than during idling and comparable to either low acceleration or low cruise. There are at least two possible reasons for this. One is that the engine may still be under some load during deceleration. The other is that there may be some lag effect, in which emissions in a given second are influenced by activity that may have occurred several seconds earlier. Thus, if the vehicle changes from cruising to deceleration, there may be some lag effect in which the emissions are influenced by the cruising that recently occurred.

For each vehicle, two types of average fuel consumption rates are estimated. The “Equal Weight Average” is estimated assuming equal time spent in each of the operating modes. Although this is not true of the real-world duty cycles, an equally weighted average enables comparisons between vehicles even though their actual duty cycles may have differed. In contrast, an "Empirical Weight Average" is also shown. This average is based upon the actual percentage of time that the vehicle spent in each of the operating modes based upon the real world duty cycle.

Table 8-2. Preliminary Average Fuel Use and Emission Rates on a Per Time Basis by Driving Mode, Vehicle, and Load for Tier 1 Single Axle Dump Trucks (Petroleum Diesel)

		Unloaded					**Loaded**					
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	Ratio[c]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**		
Fuel (g/sec)	Idle	0.259	0.281	0.258	0.239	0.259	0.261	0.306	0.307	0.246	0.280	1.08
	Low Acceleration	1.27	1.53	1.16	1.35	1.33	1.99	1.89	2.04	1.93	1.96	1.48
	Medium Acceleration	2.74	4.52	3.13	3.69	3.52	3.68	5.61	4.50	4.63	4.61	1.31
	High Acceleration	3.26	5.20	4.84	5.41	4.68	3.77	6.35	5.64	5.95	5.43	1.16
	Low Cruise	0.813	1.15	0.757	0.774	0.873	1.38	1.26	1.51	1.09	1.31	1.50
	Medium Cruise	2.02	2.49	1.86	1.71	2.02	2.57	3.69	2.42	3.18	2.96	1.47
	High Cruise	2.93	4.61	4.48	4.66	4.17	3.37	4.95	4.92	6.01	4.81	1.15
	Deceleration	0.857	1.19	1.67	0.971	1.17	1.11	1.26	1.89	1.22	1.37	1.17
	Dumping						1.53	1.39	1.09	1.21	1.30	
	Equal Weight Avg[b]	1.77	2.62	2.27	2.35	2.25	2.18	2.97	2.70	2.83	2.67	1.19
	Empirical Weight Avg[d]	0.962	2.07	0.704	0.998	1.18	1.32	2.91	2.19	1.42	1.96	1.66
NO_x (g/sec)	Idle	0.017	0.018	0.019	0.016	0.018	0.019	0.019	0.021	0.017	0.019	1.07
	Low Acceleration	0.072	0.049	0.055	0.054	0.058	0.105	0.066	0.098	0.076	0.086	1.50
	Medium Acceleration	0.131	0.111	0.134	0.137	0.128	0.174	0.143	0.204	0.179	0.175	1.36
	High Acceleration	0.178	0.144	0.182	0.190	0.174	0.182	0.152	0.249	0.212	0.199	1.15
	Low Cruise	0.049	0.044	0.037	0.037	0.042	0.075	0.050	0.061	0.048	0.059	1.41
	Medium Cruise	0.100	0.068	0.073	0.064	0.076	0.124	0.100	0.101	0.133	0.115	1.50
	High Cruise	0.102	0.106	0.131	0.121	0.115	0.112	0.116	0.144	0.184	0.139	1.21
	Deceleration	0.044	0.038	0.059	0.040	0.045	0.066	0.045	0.062	0.055	0.057	1.25
	Dumping						0.102	0.052	0.061	0.057	0.068	
	Equal Weight Avg[b]	0.087	0.072	0.086	0.082	0.082	0.107	0.083	0.111	0.107	0.102	1.24
	Empirical Weight Avg[d]	0.047	0.058	0.033	0.039	0.044	0.068	0.079	0.092	0.056	0.074	1.66

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table 8-2. Continued

		Unloaded					Loaded					
	Driving Mode[a]	Vehicle Number 4743	4750	4869	4870	Avg[b]	Vehicle Number 4743	4750	4869	4870	Avg[b]	Ratio[c]
HC (mg/sec)	Idle	1.38	1.17	0.764	0.688	0.999	1.53	1.25	0.788	0.718	1.07	1.07
	Low Acceleration	1.66	1.70	1.02	1.38	1.44	1.74	2.22	1.47	1.56	1.75	1.21
	Medium Acceleration	2.35	4.52	1.50	2.55	2.73	2.77	5.34	2.18	3.04	3.33	1.22
	High Acceleration	3.04	5.48	2.74	3.53	3.70	4.21	5.85	3.55	4.41	4.50	1.22
	Low Cruise	2.53	2.09	1.56	1.30	1.87	3.24	2.19	1.85	1.55	2.21	1.18
	Medium Cruise	5.13	3.53	1.54	2.56	3.19	6.58	4.28	2.18	2.96	4.00	1.25
	High Cruise	6.67	5.46	2.48	4.41	4.76	8.93	5.74	3.46	4.78	5.73	1.20
	Deceleration	4.34	2.66	1.54	1.73	2.57	6.05	3.00	2.13	2.14	3.33	1.30
	Dumping						7.32	2.21	0.452	1.82	2.95	
	Equal Weight Avg[b]	3.39	3.33	1.64	2.27	2.66	4.71	3.56	2.01	2.55	3.21	1.21
	Empirical Weight Avg[d]	2.59	2.90	0.973	1.29	1.94	3.25	3.67	1.80	1.56	2.57	1.33
CO (mg/sec)	Idle	5.43	4.34	4.38	4.47	4.65	5.66	4.59	4.69	4.85	4.95	1.06
	Low Acceleration	17.6	14.1	18.5	16.1	16.6	28.5	21.4	31.5	24.3	26.4	1.59
	Medium Acceleration	32.5	28.8	36.6	41.4	34.8	36.5	32.1	52.0	43.8	41.1	1.18
	High Acceleration	40.3	35.2	35.7	31.4	35.7	45.7	40.4	46.5	39.5	43.0	1.21
	Low Cruise	18.2	11.9	12.2	11.6	13.5	24.4	13.9	23.5	16.1	19.5	1.44
	Medium Cruise	24.4	18.0	17.7	24.7	21.2	27.6	19.4	28.5	26.8	25.6	1.21
	High Cruise	23.9	20.9	14.8	16.1	18.9	30.4	23.7	21.2	19.5	23.7	1.25
	Deceleration	14.4	11.0	9.71	10.8	11.5	16.9	13.3	14.7	11.5	14.1	1.23
	Dumping						24.7	19.3	12.2	13.8	17.5	
	Equal Weight Avg[b]	22.1	18.0	18.7	19.6	19.6	26.7	20.9	26.1	22.2	24.0	1.22
	Empirical Weight Avg[d]	12.9	14.1	7.12	9.37	10.9	16.9	18.9	23.6	12.2	17.9	1.65

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table 8-2. Continued

		Unloaded					Loaded					
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	Ratio[c]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**		
CO_2 (g/sec)	Idle	0.811	0.880	0.806	0.747	0.811	0.824	0.958	0.960	0.769	0.878	1.08
	Low Acceleration	3.99	4.80	3.66	4.25	4.18	6.25	5.90	6.42	6.07	6.17	1.48
	Medium Acceleration	8.60	14.2	9.83	11.6	11.1	11.6	17.7	14.1	14.6	14.5	1.31
	High Acceleration	10.2	16.8	15.3	17.1	14.8	11.9	20.0	17.8	19.2	17.2	1.16
	Low Cruise	2.55	3.61	2.37	2.43	2.74	4.35	3.95	4.73	3.41	4.11	1.50
	Medium Cruise	6.36	7.84	5.86	5.38	6.36	8.10	11.6	7.60	10.0	9.34	1.47
	High Cruise	9.23	14.1	14.1	14.7	13.0	10.6	14.5	15.9	18.0	14.8	1.13
	Deceleration	2.69	3.75	5.26	3.04	3.69	3.48	3.96	5.99	3.83	4.31	1.17
	Dumping						4.83	4.35	3.42	3.81	4.10	
	Equal Weight Avg[b]	5.55	8.25	7.15	7.41	7.09	6.88	9.22	8.55	8.86	8.38	1.18
	Empirical Weight Avg[d]	3.02	6.46	2.21	3.14	3.71	4.15	8.92	6.91	4.41	6.10	1.64
PM (mg/sec)	Idle	0.095	0.059	0.049	0.071	0.069	0.099	0.072	0.050	0.073	0.074	1.07
	Low Acceleration	0.370	0.311	0.384	0.460	0.381	0.550	0.415	0.651	0.662	0.570	1.50
	Medium Acceleration	0.740	0.645	0.917	1.10	0.851	1.00	0.885	1.24	1.30	1.11	1.30
	High Acceleration	1.14	0.947	1.15	1.26	1.12	1.22	1.01	1.41	1.47	1.28	1.14
	Low Cruise	0.215	0.208	0.188	0.251	0.216	0.415	0.235	0.451	0.385	0.371	1.72
	Medium Cruise	0.478	0.352	0.635	0.605	0.518	0.683	0.551	0.691	0.920	0.711	1.37
	High Cruise	0.791	0.609	0.976	1.08	0.865	0.882	0.626	1.11	1.26	0.970	1.12
	Deceleration	0.311	0.221	0.399	0.324	0.314	0.413	0.236	0.420	0.372	0.360	1.15
	Dumping						0.445	0.411	0.317	0.406	0.395	
	Equal Weight Avg[b]	0.518	0.419	0.587	0.645	0.542	0.634	0.493	0.705	0.761	0.648	1.20
	Empirical Weight Avg[d]	0.280	0.323	0.163	0.275	0.260	0.384	0.448	0.576	0.378	0.446	1.71

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes
[c]: Loaded / Unloaded
[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table 8-3. Preliminary Average Fuel Use and Emission Rates on a Per Time Basis by Driving Mode, Vehicle, and Load for Tier 1 Single Axle Dump Trucks (Soy Based B20)

		Unloaded					**Loaded**					
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	Ratio[c]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**		
Fuel (g/sec)	Idle	0.429	0.255	0.281	0.253	0.304	0.445	0.260	0.290	0.311	0.326	1.07
	Low Acceleration	2.42	1.60	1.62	1.62	1.81	3.00	2.59	2.02	2.11	2.43	1.34
	Medium Acceleration	5.02	3.50	3.08	4.03	3.91	5.76	4.46	4.32	5.29	4.96	1.27
	High Acceleration	5.78	4.14	4.49	4.73	4.79	6.55	4.80	4.76	4.89	5.25	1.10
	Low Cruise	1.53	1.91	1.46	1.20	1.53	2.80	2.90	1.66	1.60	2.24	1.47
	Medium Cruise	4.00	3.03	2.17	3.24	3.11	5.16	3.81	4.06	4.68	4.43	1.42
	High Cruise	5.65	4.01	3.95	3.52	4.28	6.09	4.48	4.30	3.94	4.70	1.10
	Deceleration	2.43	1.55	1.72	1.46	1.79	3.40	1.76	2.63	1.51	2.32	1.30
	Dumping						2.40	1.70	1.29	1.30	1.67	
	Equal Weight Avg[b]	3.41	2.50	2.35	2.51	2.69	3.96	2.97	2.82	2.85	3.15	1.17
	Empirical Weight Avg[d]	4.11	0.403	1.33	1.76	1.90	4.14	1.73	1.26	1.30	2.11	1.11
NO_x (g/sec)	Idle	0.018	0.020	0.008	0.008	0.013	0.018	0.022	0.008	0.009	0.014	1.05
	Low Acceleration	0.067	0.078	0.036	0.034	0.054	0.087	0.087	0.052	0.043	0.067	1.25
	Medium Acceleration	0.114	0.118	0.059	0.072	0.091	0.135	0.147	0.081	0.101	0.116	1.28
	High Acceleration	0.120	0.136	0.074	0.080	0.103	0.133	0.162	0.078	0.090	0.115	1.13
	Low Cruise	0.055	0.081	0.029	0.025	0.047	0.074	0.103	0.031	0.035	0.061	1.28
	Medium Cruise	0.096	0.106	0.038	0.054	0.074	0.116	0.135	0.067	0.095	0.103	1.41
	High Cruise	0.100	0.113	0.054	0.049	0.079	0.138	0.125	0.065	0.067	0.099	1.25
	Deceleration	0.043	0.050	0.025	0.020	0.034	0.058	0.059	0.041	0.028	0.046	1.35
	Dumping						0.073	0.075	0.034	0.036	0.054	
	Equal Weight Avg[b]	0.077	0.088	0.040	0.043	0.062	0.092	0.102	0.051	0.056	0.075	1.22
	Empirical Weight Avg[d]	0.081	0.024	0.024	0.030	0.039	0.093	0.064	0.023	0.027	0.050	1.32

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes
[c]: Loaded / Unloaded
[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table 8-3. Continued

		Unloaded					Loaded					
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	Ratio[c]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**		
HC (mg/sec)	Idle	0.981	0.927	0.670	0.566	0.785	1.09	0.946	0.697	0.654	0.847	1.08
	Low Acceleration	1.68	1.03	0.867	0.979	1.14	2.05	1.53	1.22	1.25	1.51	1.33
	Medium Acceleration	2.42	1.92	1.95	1.92	2.05	3.25	2.37	2.06	2.64	2.58	1.26
	High Acceleration	3.33	2.03	2.13	2.74	2.56	4.08	3.93	3.11	2.81	3.48	1.36
	Low Cruise	1.68	1.17	1.29	0.898	1.26	2.00	1.55	1.45	1.88	1.72	1.36
	Medium Cruise	2.08	1.31	1.50	1.76	1.66	2.24	3.27	1.88	2.33	2.43	1.46
	High Cruise	3.17	1.25	2.67	2.31	2.35	3.98	3.16	3.63	2.59	3.34	1.42
	Deceleration	1.66	0.746	1.65	1.16	1.30	1.86	1.73	2.37	1.57	1.89	1.45
	Dumping						1.49	0.898	1.41	1.06	1.21	
	Equal Weight Avg[b]	2.13	1.30	1.59	1.54	1.64	2.45	2.15	1.98	1.87	2.11	1.29
	Empirical Weight Avg[d]	2.47	0.948	1.19	1.26	1.47	2.73	1.62	1.27	1.13	1.69	1.15
CO (mg/sec)	Idle	4.12	3.24	4.93	4.39	4.17	4.34	3.31	5.32	5.02	4.50	1.08
	Low Acceleration	24.6	15.1	14.4	15.0	17.3	29.3	22.6	21.0	18.6	22.9	1.33
	Medium Acceleration	30.5	20.9	22.4	16.1	22.5	33.0	24.2	26.7	20.3	26.0	1.16
	High Acceleration	33.2	24.9	23.4	16.5	24.5	39.8	30.3	32.7	21.4	31.0	1.27
	Low Cruise	10.0	12.7	9.29	7.79	9.94	19.2	14.5	13.2	8.51	13.9	1.39
	Medium Cruise	17.0	12.6	10.5	9.14	12.3	18.7	15.4	14.5	10.2	14.7	1.20
	High Cruise	18.9	22.7	22.3	12.3	19.0	19.5	25.9	24.7	15.7	21.5	1.13
	Deceleration	10.2	8.98	7.39	4.90	7.86	12.6	9.31	9.92	5.76	9.40	1.20
	Dumping						12.4	17.1	27.0	25.1	20.4	
	Equal Weight Avg[b]	18.6	15.1	14.3	10.8	14.7	21.0	18.1	19.5	14.5	18.3	1.24
	Empirical Weight Avg[d]	17.7	4.01	9.59	8.12	9.86	17.7	10.5	9.82	7.68	11.4	1.16

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table 8-3. Continued

	Driving Mode[a]	Unloaded: Vehicle Number 4743	Unloaded: Vehicle Number 4750	Unloaded: Vehicle Number 4869	Unloaded: Vehicle Number 4870	Unloaded: Avg[b]	Loaded: Vehicle Number 4743	Loaded: Vehicle Number 4750	Loaded: Vehicle Number 4869	Loaded: Vehicle Number 4870	Loaded: Avg[b]	Ratio[c]
CO_2 (g/sec)	Idle	1.32	0.780	0.859	0.775	0.932	1.36	0.798	0.888	0.951	1.00	1.07
	Low Acceleration	7.43	4.92	4.97	5.00	5.58	9.20	7.98	6.21	6.50	7.47	1.34
	Medium Acceleration	15.5	10.8	9.48	12.4	12.0	17.7	13.8	13.4	16.3	15.3	1.27
	High Acceleration	17.8	12.8	13.9	14.6	14.8	20.2	14.8	14.7	15.1	16.2	1.10
	Low Cruise	4.71	5.87	4.48	3.71	4.69	8.62	8.95	5.18	4.92	6.92	1.47
	Medium Cruise	12.3	9.37	6.68	10.0	9.59	15.9	11.8	12.5	14.5	13.7	1.43
	High Cruise	17.4	12.4	12.2	10.9	13.2	18.8	14.4	13.3	11.9	14.6	1.10
	Deceleration	7.50	4.77	5.32	4.50	5.52	10.5	5.42	8.12	4.67	7.18	1.30
	Dumping						7.38	5.24	4.01	3.97	5.15	
	Equal Weight Avg[b]	10.5	7.71	7.23	7.74	8.30	12.2	9.24	8.70	8.75	9.72	1.17
	Empirical Weight Avg[d]	12.7	1.24	4.11	5.42	5.86	12.8	5.40	3.89	4.01	6.52	1.11
PM (mg/sec)	Idle	0.073	0.040	0.074	0.078	0.066	0.079	0.042	0.076	0.080	0.069	1.04
	Low Acceleration	0.403	0.391	0.470	0.513	0.444	0.696	0.580	0.638	0.572	0.622	1.40
	Medium Acceleration	0.787	0.659	0.691	0.766	0.726	0.900	0.757	0.783	0.923	0.841	1.16
	High Acceleration	0.940	0.947	0.813	0.908	0.902	1.01	0.989	0.984	0.986	0.993	1.10
	Low Cruise	0.183	0.470	0.326	0.300	0.320	0.356	0.508	0.329	0.365	0.389	1.22
	Medium Cruise	0.427	0.545	0.387	0.529	0.472	0.557	0.585	0.596	0.618	0.589	1.25
	High Cruise	0.612	0.623	0.632	0.503	0.593	0.682	0.751	0.661	0.583	0.669	1.13
	Deceleration	0.236	0.275	0.295	0.224	0.257	0.306	0.311	0.399	0.267	0.321	1.25
	Dumping						0.332	0.422	0.504	0.340	0.400	
	Equal Weight Avg[b]	0.458	0.494	0.461	0.478	0.473	0.547	0.549	0.552	0.526	0.544	1.15
	Empirical Weight Avg[d]	0.502	0.069	0.257	0.317	0.286	0.512	0.296	0.232	0.240	0.320	1.12

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table 8-4. The Ratio of B20 to Petroleum Diesel by Driving Mode, and individual Vehicles for Tier 1 Single Axle Dump Trucks

	Driving Mode[a]	Unloaded					Loaded				
		Vehicle Number				Avg[b]	Vehicle Number				Avg[b]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**	
Fuel	Idle	1.66	0.905	1.09	1.06	1.17	1.71	0.851	0.946	1.26	1.17
	Low Acceleration	1.90	1.04	1.40	1.20	1.37	1.51	1.37	0.991	1.09	1.24
	Medium Acceleration	1.83	0.773	0.982	1.09	1.11	1.56	0.795	0.960	1.14	1.08
	High Acceleration	1.77	0.797	0.928	0.874	1.02	1.74	0.756	0.845	0.822	0.967
	Low Cruise	1.89	1.66	1.93	1.56	1.75	2.02	2.31	1.10	1.47	1.71
	Medium Cruise	1.98	1.22	1.16	1.89	1.54	2.01	1.03	1.68	1.47	1.49
	High Cruise	1.93	0.871	0.883	0.755	1.03	1.81	0.904	0.872	0.655	0.976
	Deceleration	2.84	1.30	1.03	1.50	1.53	3.07	1.40	1.39	1.24	1.70
	Dumping						1.57	1.23	1.19	1.07	1.28
	Equal Weight Avg[b]	1.93	0.953	1.03	1.07	1.19	1.81	1.00	1.04	1.01	1.18
	Empirical Weight Avg[c]	4.27	0.195	1.89	1.76	1.61	3.14	0.595	0.575	0.915	1.08
NO_x	Idle	1.06	1.11	0.421	0.500	0.743	0.947	1.16	0.381	0.529	0.750
	Low Acceleration	0.931	1.59	0.655	0.630	0.935	0.829	1.32	0.531	0.566	0.780
	Medium Acceleration	0.870	1.06	0.440	0.526	0.708	0.776	1.03	0.397	0.564	0.663
	High Acceleration	0.674	0.944	0.407	0.421	0.591	0.731	1.07	0.313	0.425	0.579
	Low Cruise	1.12	1.84	0.784	0.676	1.13	0.987	2.06	0.508	0.729	1.04
	Medium Cruise	0.960	1.56	0.521	0.844	0.964	0.935	1.35	0.663	0.714	0.902
	High Cruise	0.980	1.07	0.412	0.405	0.687	1.23	1.08	0.451	0.364	0.710
	Deceleration	0.977	1.32	0.424	0.500	0.751	0.879	1.31	0.661	0.509	0.807
	Dumping						0.716	1.44	0.557	0.632	0.794
	Equal Weight Avg[b]	0.889	1.22	0.464	0.522	0.757	0.863	1.24	0.459	0.524	0.739
	Empirical Weight Avg[c]	1.71	0.418	0.723	0.767	0.891	1.36	0.811	0.251	0.484	0.704

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table 8-4. Continued

		Unloaded					Loaded				
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**	
HC	Idle	0.707	0.795	0.878	0.824	0.786	0.715	0.759	0.885	0.910	0.792
	Low Acceleration	1.01	0.606	0.850	0.709	0.791	1.18	0.689	0.833	0.801	0.866
	Medium Acceleration	1.03	0.425	1.30	0.754	0.752	1.17	0.444	0.940	0.868	0.774
	High Acceleration	1.10	0.370	0.777	0.776	0.692	0.969	0.672	0.876	0.637	0.773
	Low Cruise	0.666	0.560	0.829	0.692	0.675	0.617	0.707	0.784	1.21	0.779
	Medium Cruise	0.406	0.370	0.973	0.686	0.521	0.341	0.765	0.863	0.787	0.608
	High Cruise	0.475	0.228	1.08	0.523	0.494	0.446	0.551	1.05	0.543	0.584
	Deceleration	0.382	0.280	1.07	0.671	0.507	0.308	0.578	1.11	0.736	0.566
	Dumping						0.204	0.406	3.16	0.581	0.412
	Equal Weight Avg[b]	0.627	0.390	0.968	0.680	0.617	0.661	0.605	0.988	0.731	0.659
	Empirical Weight Avg[c]	0.954	0.327	1.22	0.977	0.758	0.840	0.441	0.706	0.724	0.658
CO	Idle	0.759	0.746	1.13	0.983	0.896	0.768	0.720	1.14	1.04	0.909
	Low Acceleration	1.40	1.07	0.778	0.929	1.04	1.03	1.06	0.670	0.771	0.866
	Medium Acceleration	0.938	0.726	0.611	0.389	0.645	0.904	0.754	0.513	0.463	0.634
	High Acceleration	0.824	0.707	0.655	0.525	0.687	0.871	0.750	0.703	0.542	0.722
	Low Cruise	0.549	1.06	0.759	0.672	0.737	0.785	1.05	0.561	0.529	0.711
	Medium Cruise	0.695	0.700	0.591	0.370	0.580	0.676	0.796	0.509	0.381	0.575
	High Cruise	0.789	1.08	1.51	0.765	1.01	0.641	1.09	1.17	0.806	0.906
	Deceleration	0.708	0.813	0.763	0.456	0.686	0.747	0.699	0.675	0.500	0.666
	Dumping						0.505	0.886	2.21	1.82	1.17
	Equal Weight Avg[b]	0.840	0.839	0.765	0.550	0.750	0.786	0.865	0.745	0.653	0.761
	Empirical Weight Avg[c]	1.37	0.284	1.35	0.867	0.905	1.05	0.556	0.416	0.630	0.637

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table 8-4. Continued

		Unloaded					Loaded				
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]
		4743	4750	4869	4870		4743	4750	4869	4870	
CO_2	Idle	1.62	0.887	1.07	1.04	1.15	1.66	0.833	0.925	1.24	1.14
	Low Acceleration	1.86	1.03	1.36	1.18	1.34	1.47	1.35	0.967	1.07	1.21
	Medium Acceleration	1.80	0.759	0.964	1.07	1.09	1.53	0.777	0.947	1.12	1.05
	High Acceleration	1.75	0.761	0.908	0.854	1.00	1.70	0.740	0.828	0.787	0.941
	Low Cruise	1.84	1.63	1.89	1.53	1.71	1.98	2.27	1.09	1.44	1.68
	Medium Cruise	1.94	1.20	1.14	1.86	1.51	1.97	1.01	1.65	1.44	1.46
	High Cruise	1.89	0.989	0.864	0.739	1.05	1.77	1.05	0.835	0.659	1.00
	Deceleration	2.79	1.27	1.01	1.48	1.50	3.01	1.37	1.36	1.22	1.66
	Dumping						1.53	1.20	1.17	1.04	1.25
	Equal Weight Avg[b]	1.89	0.957	1.01	1.04	1.18	1.77	1.01	1.02	0.988	1.16
	Empirical Weight Avg[c]	4.22	0.192	1.86	1.73	1.58	3.08	0.616	0.563	0.909	1.07
PM	Idle	0.766	0.676	1.53	1.09	0.967	0.793	0.578	1.51	1.09	0.936
	Low Acceleration	1.09	1.26	1.22	1.12	1.17	1.27	1.40	0.976	0.864	1.09
	Medium Acceleration	1.06	1.02	0.754	0.696	0.853	0.900	0.855	0.631	0.710	0.760
	High Acceleration	0.825	1.00	0.707	0.721	0.802	0.831	0.979	0.698	0.671	0.777
	Low Cruise	0.853	2.26	1.73	1.19	1.48	0.857	2.16	0.728	0.949	1.05
	Medium Cruise	0.892	1.55	0.610	0.875	0.912	0.815	1.06	0.862	0.672	0.828
	High Cruise	0.774	1.02	0.647	0.464	0.685	0.772	1.20	0.593	0.463	0.689
	Deceleration	0.760	1.24	0.738	0.691	0.821	0.742	1.32	0.951	0.718	0.891
	Dumping						0.745	1.03	1.59	0.836	1.01
	Equal Weight Avg[b]	0.884	1.18	0.785	0.741	0.872	0.862	1.11	0.783	0.691	0.838
	Empirical Weight Avg[c]	1.79	0.214	1.58	1.15	1.10	1.33	0.661	0.403	0.635	0.717

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Because these percentages varied from one vehicle to the next, the empirically weighted averages cannot be easily compared between vehicles. However, these averages provide insight into the empirically-based real world average emissions that one could expect.

As an example of the difference between the equal weight average and the empirical weight average, consider the fuel consumption for unloaded vehicles on petroleum diesel fuel. The equal weight average among the four tested vehicles is 2.25 g/sec versus an empirical weight average of only 1.18 g/sec. The empirical weight average has a greater contribution from the idling mode than does the equal weight average, which leads to a lower overall fuel consumption rate.

There is considerable inter-vehicle variability in the modal fuel consumption rates. For example, even though the average fuel consumption rate for unloaded petroleum fueled vehicles during high acceleration is 4.68 grams per second, the rate varies from as low as 3.26 grams per second to as high as 5.41 grams per second among the four vehicles. The inter-vehicle variability implies that it is necessary to make measurements on a sample of vehicles and average them in order to obtain fuel consumption and emission rates that might be applicable to groups or fleets of vehicles.

When loaded, single rear-axle trucks weigh approximately twice as much as their unloaded weight. When comparing loaded versus unloaded operations, the fuel consumption rate increases by approximately 8 to 50 percent among the eight operating modes that are common to both. The estimated increase in the fuel consumption during idling is relatively small. In reality, it is not expected that fuel consumption during idling should be a function of vehicle load. The small change implied here could simply be the result of an autocorrelation or lag effect, in which fuel use during idling could be influenced to some extent by fuel use that occurred several seconds earlier when the vehicle might have been in another operating mode during which the engine was under load. The increase in fuel consumption for the other modes is significant, implying a greater engine power demand.

The results in Table 8-2 for emissions of NO, HC, CO, CO_2 and PM indicate that emissions are sensitive to the operating mode and to vehicle load. Furthermore, there is inter-vehicle variability in emissions when comparing a given mode and load. The average NO emissions for unloaded vehicles vary from 0.174 mg/sec at high acceleration to 0.018 mg/sec at idle, or by a ratio of nearly 10. For loaded vehicles, the corresponding rates are 0.199 mg/sec and 0.019 mg/sec, or a ratio slightly greater than 10. The highest emission rates occur during high acceleration, medium acceleration, and high cruise. The emission rate during the dumping mode is 3.6 times larger than that during idling on a mass per time basis. NO emissions are significantly higher for loaded versus unloaded operations.

The trends for HC emissions are slightly different than for NO in that the highest emission rate occurs for high cruise, not high acceleration. The average HC emission rate during high cruise is approximately a factor of five greater than that during idling, which as the lowest average HC emission rate. Thus, the overall relative range of variability in HC emissions is not as great as that for NO. HC emissions are significantly greater for loaded versus unloaded operation.

CO emissions have a different pattern than either NO or HC emissions. The highest average CO emission rates occur during high acceleration, but the average emission rate during medium acceleration is nearly as large. Of the cruising modes, the average emission rate is highest during medium cruising, although the emission rate during high cruising is nearly as large. The CO emissions vary by a factor of approximately 7 to 9 when comparing the highest and lowest average emission rates. Typically, idle has the lowest average emission rate. Deceleration and dumping have emission rates approximately three times greater than that of idling. The cruising emission rates are approximately three to five times greater than during idling. The acceleration emission rates are approximately four to nine times greater than during idling. CO emissions are approximately 20 percent greater during loaded operation versus unloaded operation.

Because CO_2 emissions are approximately a linear function of fuel consumption, as previously noted, the patterns and trends for CO_2 emissions are approximately the same as for fuel consumption.

The PM emissions tend to be highest for the high acceleration mode, and lowest for the idle mode. These two modes differ by a factor of approximately 16 to 17 for unloaded and loaded operations. The average PM emissions for the high acceleration, medium acceleration, and high cruise are comparable within approximately 25 percent. The low acceleration, low cruise, deceleration, and dumping modes have average emission rates ranging from 0.216 mg/sec to 0.570 mg/sec, which are significantly smaller than the highest emission modes and are significantly greater than the idling emissions. Loaded vehicles have larger PM emission rates than unloaded vehicles.

The trends described above for Table 8-2, which were based on tests with petroleum diesel, are generally application to the results obtained from tests on B20 biodiesel, as given in Table 8-3. In general, there is significant variation in fuel consumption and emissions among the operating modes. On average, fuel consumption and emissions are approximately 20 to 30 percent greater for loaded versus unloaded vehicles. There is inter-vehicle variability in fuel consumption and emissions.

The fuel consumption and emissions for B20 biodiesel versus petroleum diesel are compared in Table 8-4 by vehicle, operating mode, and load. Each number in the table is the ratio of the mass per time rate for a vehicle fueled on B20 biodiesel to that of the same vehicle (or same group of vehicles, in the case of an average) fueled on petroleum diesel. Ratios greater than one imply a greater mass flow rate for B20 biodiesel and, conversely, ratios less than one imply a smaller mass flow rate for B20 biodiesel.

Fuel consumption and CO_2 emissions are expected to be slightly higher for B20 biodiesel than for petroleum diesel. B20 biodiesel has approximately 3 percent less energy density on a mass basis and approximately 2 percent less energy density on a volume basis than does petroleum diesel. Therefore, we expect a slight increase in the mass flow rate of fuel for B20 biodiesel compared to petroleum diesel. Furthermore, B20 biodiesel has approximately 1 percent greater carbon intensity per BTU of fuel. Therefore, we expect a small increase in CO_2 emissions compared to that of petroleum diesel. However, a portion of the carbon in B20 biodiesel is from renewable sources; therefore, the *net* carbon emissions may be less than that of petroleum diesel. However, a complete estimate of net carbon emissions should take into account CO_2 emissions associated with the life cycle of production of the soy-based blend stock. This has not been addressed here.

As expected, there is a slight increase in fuel consumption and in CO_2 emissions as indicated in Table 8-4. The results here imply an average increase in fuel consumption of 18 to 19 percent, based upon the equal weight averages. This increase is much higher than expected. However, there is significant inter-vehicle variability in emissions. Furthermore, there is one vehicle, Number 4743, that appears to be an outlier. When tested on August 10, 2004, vehicle Number 4743 was connected to a trailer. Thus, its fuel use and emissions were higher than for other vehicles because it had a greater load. However, the weight of the trailer could not be included in the measurement of vehicle weight given the configuration of the scale used. If vehicle Number 4743 is excluded from the comparison, then the estimated increase in fuel consumption is only 2 percent, which is approximately the expected change. Similarly, the estimated change in CO_2 emissions is biased by the very high ratio for vehicle Number 4743. If this vehicle is ignored, then the CO_2 emissions are approximately the same on both fuels.

For NO emissions, the overall average emissions on B20 are approximately 25 percent lower than for petroleum diesel, based on the equal weight averages. For one vehicle, Number 4750, the average emissions were typically higher for B20 biodiesel than for petroleum diesel. Thus, there is considerable inter-vehicle variability. For purposes of estimating a fleet average, it is important to consider data from multiple vehicles. The average ratio of B20 to petroleum diesel NO emissions are lowest for the modes with the highest engine power demand, including the medium and high acceleration and high cruise modes. Conversely, the average ratios are highest for the low and medium acceleration modes, and for the low acceleration modes the NO emissions for B20 appear to be higher than for petroleum diesel.

The variation in the ratio of NO emissions for B20 versus petroleum by operating mode implies that whether the average NO emissions for one fuel are lower compared to the other fuel would depend on the operating mode. For example, the real world duty cycles observed in the field study included a significant amount of time in idling, with important contributes from the medium and high cruise and medium and high accelerations. These modes tend to have lower ratios of NO for B20 versus petroleum diesel. By comparison, if a duty cycle had a large contribution from the low cruise mode, then the overall average NO emissions for B20 might be higher than for petroleum diesel.

Another possible factor that was not explored in this study is that the distribution of total NO emissions might differ for B20 biodiesel versus petroleum diesel, and might also differ by mode. The Montana system measures NO, which is the largest component of NO. Typically, NO_x emissions are 95 percent (on a volume basis) in the form of NO. However, if the ratio of NO to total NO_x were to change as a result of different fuel characteristics or operating modes, then a comparison based only on NO might be inaccurate. There were no reports based on comparison of B20 versus petroleum diesel that have indicated that this may be a problem. However, in the future, consideration should be given to a field study to evaluate whether NO_x emissions are a linear function of NO emissions in order to confirm whether the insights obtained here regarding NO are applicable to total NO_x.

The HC emissions were generally lower for B20 biodiesel than for petroleum diesel. The average ratios were lowest for medium cruise and deceleration, and highest for idle and low acceleration. Of the four vehicles, three had modal and average ratios significantly less than one, while one vehicle had an average ratio of 0.97 to 0.99 when comparing unloaded and loaded. In general, when averaged across vehicles, HC emissions were lower for B20 than petroleum diesel for all operating modes and regardless of load.

Table 8-5. Percentage Change in Fuel Use and Emissions Comparing B20 Biodiesel to Petroleum Diesel for Single Rear Axle Dump Trucks with Tier 1 Engines.

	Tier 1 Single Rear-Axle Dump Truck		
	Unloaded (%)	Loaded (%)	Average (%)
Fuel Use	20 (2)[a]	18 (2)[a]	19 (2)[a]
NO	-24 (-22)[b]	-26 (-24)[b]	-25 (-23)[b]
HC	-38	-34	-36
CO	-25	-24	-24
CO_2	18 (0)[b]	16 (0)[b]	17 (0)[b]
PM	-13	-16	-14

[a]: Differences calculated excluding vehicle Number 4743, which towed a trailer when tested on B20 biodiesel.

[b]: Applied the NO_x humidity correction factor for diesel engines based on 40 CFR Chapter I Section 86.1342-90 (2003).

For CO, the average ratio of emissions on B20 versus petroleum diesel was less than one for each vehicle and for nearly all of the modes, with the minor exception of low acceleration and high cruise for the unloaded case. The ratios for these latter were in the range of 1.01 to 1.04, which are not statistically significantly different from a value of 1.0. Typically, the ratios were lowest for the medium acceleration and medium cruise modes, and were highest for the idle, low acceleration, and high cruise modes.

For PM, the average ratio of emissions on B20 versus petroleum diesel was less than one for three of the four vehicles and for most of the operating modes, when averaged across vehicles. The ratios were highest for vehicle 4750 and for the operating modes of idle, low acceleration, low cruise, and dumping. These four modes all have relatively low engine power demand. In contrast, the ratios tended to be the lowest for modes with the highest engine power demand, including high acceleration and high cruise.

An overall average comparison of the two fuels is given in Table 8-5. These comparisons include all vehicles. However, as noted previously, and as indicated in parentheses in the table, the comparisons of fuel use and CO_2 emissions imply little or no difference between the fuels when one vehicle is excluded from the analysis. That vehicle, 4743, had significantly different duty cycles and loads when comparing the two days of testing, each on a different fuel. Therefore, the differences in duty cycles and loads confound the comparison of fuel consumption and CO_2 emissions.

When comparing NO emissions that were measured on different days for the same vehicle, consideration was given to the effect that ambient humidity could have on the emission estimates. Therefore, a humidity correction factor was applied to the NO emission estimates. The humidity correction is described in Chapter 2. The percentage change in NO emissions is shown both without and with the humidity correction. Overall, the emissions of NO, HC, CO, and PM were found to decrease for B20 biodiesel versus petroleum diesel. These findings are influenced in part by the real world duty cycles observed in the field. As noted earlier, for some operating modes, NO emissions might increase on B20 versus petroleum diesel, but for the weighted combination of operating modes observed in the field, and for an equal weighting of these operating modes, a net decrease in NO emissions is found.

The next section presents results for tandem dump trucks with Tier 1 engines.

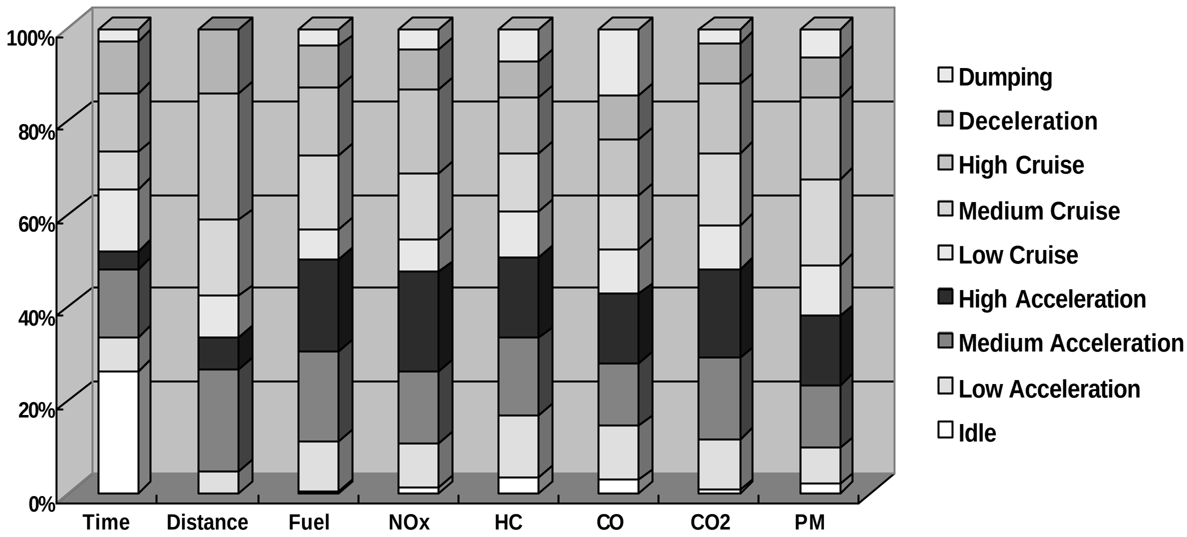
8.3 Double Rear Axle (Tandem) Dump Trucks - Tier 1 (Petroleum Diesel / B20 Biodiesel)

In this section, the typical duty cycles, fuel consumption and emission rates, and comparison of fuel consumption and emissions for B20 biodiesel versus petroleum diesel are presented. The previous section provided a detailed discussion regarding the interpretation of these data. It is assumed that the reader has read the previous section. Therefore, this section will be more brief in that it will highlight any key differences with respect to the insights obtained based upon the single rear axle vehicles with Tier 1 engines. These insights include the following:

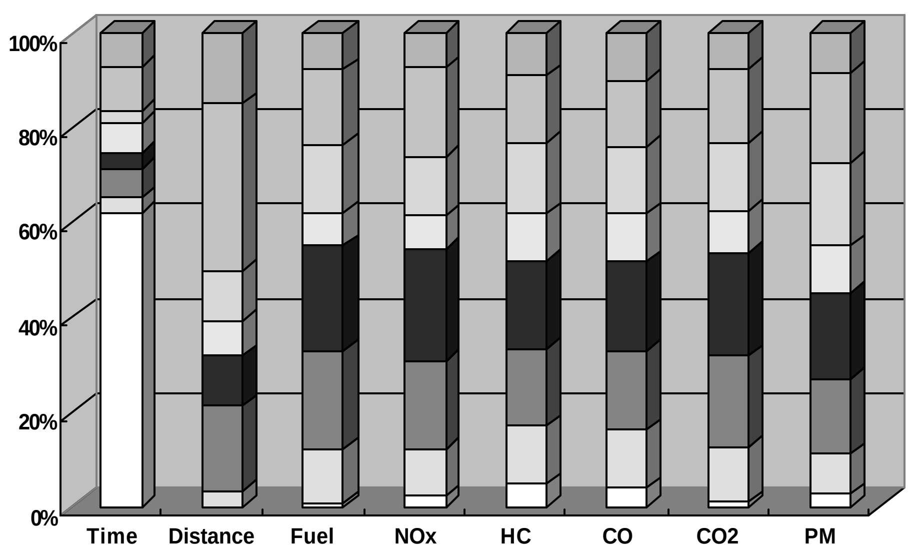
- There is significant variability in fuel consumption and emissions among the operating modes
- The trends of emissions among the operating modes differ among the pollutants.
- There is inter-vehicle variability in fuel use and emissions, some of which is related to operating conditions (e.g., duty cycle, load)
- Fuel use and emissions are higher for loaded versus unloaded operations.
- Typically, fuel use and CO_2 emissions are comparable or slightly higher for B20 biodiesel versus petroleum diesel fuel.
- Typically, for the single-rear axle dump trucks with Tier 1 engines, emissions of NO, HC, CO, and PM are lower for B20 biodiesel versus petroleum diesel. However, for the tandem dump trucks with Tier 1 engines, the emissions of CO and PM did not change significantly, on average. The emissions of NO and HC decreased significantly.

The average duty cycles for unloaded and loaded tandems are shown in Figure 8-4 for petroleum diesel and Figure 8-5 for B20 biodiesel. There is some variability in the activity patterns. For example, the amount of time spent idling was only 25 percent for loaded vehicles fueled with petroleum diesel but was as high as 60 percent for unloaded vehicles fuel with petroleum diesel or for loaded vehicles fueled with B20 biodiesel. The distribution of operating mode by distance was approximately similar for the tandems as for the single rear-axle trucks, with a large contribution from the high cruise mode. Similarly, the contribution of the acceleration modes to fuel consumption, and to emissions, was generally in greater proportion that the contribution of these modes to either time or distance of the duty cycles. The CO_2 and fuel consumption distributions were similar. HC and CO emissions tended to have a larger contribution from low power demand modes such as idle, dumping, low acceleration, and low cruise, than did the NO emissions. To a first approximation, the distribution of emissions of any of the pollutants is comparable to the distribution of fuel consumption by mode. However, as shown by data given in the appendix, there is significant variability in emission rates even on a mass per gallon of fuel consumed basis.

Tables 8-6 and 8-7 provide results for the modal emission rates by vehicle and load, for petroleum diesel and for B20 biodiesel, respectively. Table 8-8 summarizes the ratio of fuel use

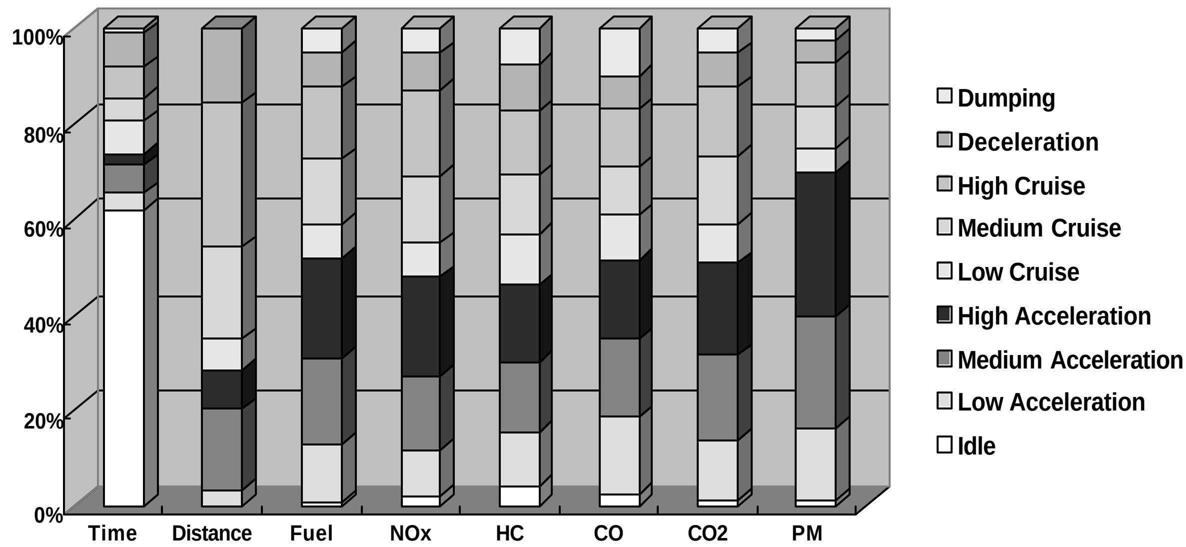


(a) Loaded

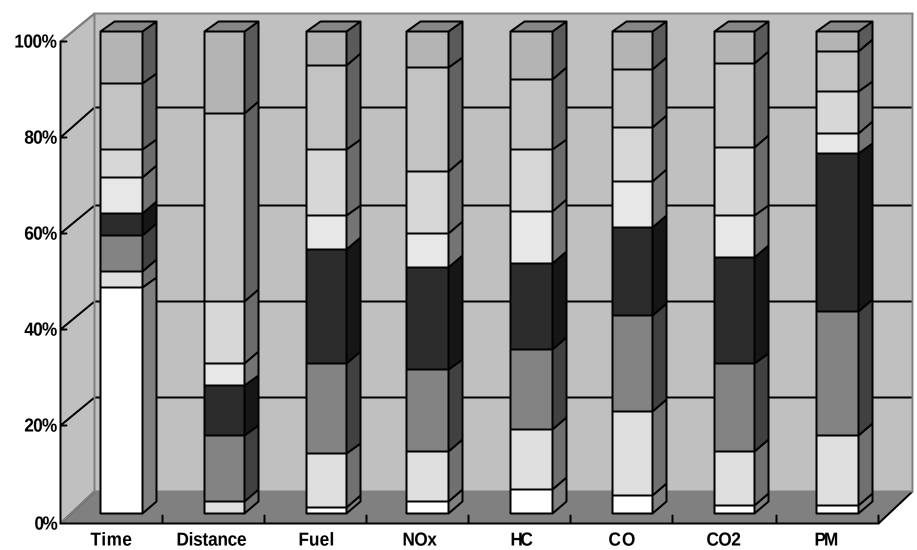


(a) Unloaded

Figure 8-4 Distribution of Time, Distance, Fuel Use, and Emissions by modes for Tier 1 Tandems dump trucks fueled with Petroleum diesel



(a) Loaded



(b) Unloaded

Figure 8-5 Distribution of Time, Distance, Fuel Use, and Emissions by modes for Tier 1 Tandems dump trucks fueled with Soy-Based B20

Table 8-6. Preliminary Average Fuel Use and Emission Rates on a Per Time Basis by Driving Mode, Vehicle, and Load for Tier 1 Tandem Dump Trucks (Petroleum Diesel)

		Unloaded					**Loaded**					
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	Ratio[c]
		0507	**0578**	**0579**	**0580**		**0507**	**0578**	**0579**	**0580**		
Fuel (g/sec)	Idle	0.284	0.267	0.209	0.430	0.298	0.305	0.290	0.225	0.440	0.315	1.06
	Low Acceleration	2.56	2.46	2.88	3.45	2.84	3.38	3.16	4.35	3.81	3.68	1.30
	Medium Acceleration	5.44	4.43	3.35	6.03	4.81	6.57	5.30	5.72	7.17	6.19	1.29
	High Acceleration	5.85	5.04	4.32	6.59	5.45	6.80	6.12	5.98	7.65	6.64	1.22
	Low Cruise	1.82	1.95	2.15	2.68	2.15	2.80	2.88	4.08	3.35	3.28	1.52
	Medium Cruise	3.75	3.03	4.08	3.10	3.49	6.10	4.99	5.32	4.75	5.29	1.52
	High Cruise	4.67	3.51	3.75	3.49	3.86	5.48	4.90	5.07	5.65	5.28	1.37
	Deceleration	1.97	1.49	2.23	1.58	1.82	2.87	2.13	4.15	2.59	2.94	1.62
	Dumping						1.38	1.38	0.805	1.18	1.19	
	Equal Weight Avg[b]	3.29	2.77	2.87	3.42	3.09	3.97	3.46	3.97	4.07	3.86	1.25
	Empirical Weight Avg[d]	2.28	1.30	1.12	1.28	1.50	3.88	2.81	4.30	2.36	3.34	2.23
NO_x (g/sec)	Idle	0.024	0.020	0.016	0.017	0.019	0.024	0.021	0.019	0.017	0.021	1.06
	Low Acceleration	0.099	0.078	0.085	0.108	0.093	0.158	0.109	0.145	0.117	0.132	1.43
	Medium Acceleration	0.206	0.141	0.140	0.177	0.166	0.301	0.194	0.196	0.185	0.219	1.32
	High Acceleration	0.250	0.177	0.199	0.225	0.213	0.355	0.253	0.267	0.296	0.293	1.38
	Low Cruise	0.063	0.083	0.066	0.036	0.062	0.118	0.121	0.101	0.056	0.099	1.60
	Medium Cruise	0.150	0.105	0.123	0.087	0.116	0.309	0.193	0.189	0.127	0.205	1.76
	High Cruise	0.249	0.124	0.193	0.121	0.172	0.334	0.303	0.206	0.182	0.256	1.49
	Deceleration	0.085	0.051	0.084	0.048	0.067	0.160	0.127	0.138	0.076	0.125	1.87
	Dumping						0.066	0.074	0.049	0.043	0.058	
	Equal Weight Avg[b]	0.141	0.097	0.113	0.102	0.113	0.203	0.155	0.146	0.122	0.156	1.38
	Empirical Weight Avg[d]	0.107	0.052	0.052	0.037	0.062	0.198	0.135	0.158	0.061	0.138	2.22

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table 8-6. Continued

	Driving Mode[a]	Unloaded					Loaded					
		Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	Ratio[c]
		0507	0578	0579	0580		0507	0578	0579	0580		
HC (mg/sec)	Idle	1.85	3.19	2.22	2.12	2.35	1.92	3.47	2.39	2.30	2.52	1.07
	Low Acceleration	7.53	6.16	3.45	7.57	6.18	10.2	6.70	12.9	8.20	9.50	1.54
	Medium Acceleration	8.78	7.86	4.59	10.5	7.94	10.8	8.84	14.1	12.1	11.5	1.44
	High Acceleration	9.90	8.34	6.12	11.7	9.01	10.9	10.4	16.4	12.2	12.5	1.38
	Low Cruise	5.40	6.32	4.20	3.85	4.94	7.50	9.74	7.80	4.04	7.27	1.47
	Medium Cruise	6.40	11.3	8.57	3.45	7.44	7.64	13.0	10.4	5.36	9.10	1.22
	High Cruise	7.31	11.4	5.45	4.52	7.17	7.77	13.7	8.82	5.48	8.94	1.25
	Deceleration	4.26	7.77	3.46	2.54	4.51	4.67	9.52	6.42	2.84	5.86	1.30
	Dumping						4.76	8.96	3.59	3.36	5.17	
	Equal Weight Avg[b]	6.43	7.80	4.76	5.79	6.19	7.36	9.37	9.20	6.21	8.03	1.30
	Empirical Weight Avg[d]	4.67	5.26	3.06	3.13	4.03	7.09	8.27	9.61	4.13	7.27	1.81
CO (mg/sec)	Idle	4.44	8.65	2.13	4.15	4.84	4.74	8.88	2.60	4.35	5.14	1.06
	Low Acceleration	11.3	14.2	10.5	19.0	13.7	17.4	16.6	18.1	21.6	18.4	1.34
	Medium Acceleration	18.1	16.3	16.3	23.5	18.5	20.5	17.9	18.9	28.6	21.5	1.16
	High Acceleration	19.1	18.5	15.8	31.5	21.2	20.9	22.8	19.2	33.9	24.2	1.14
	Low Cruise	10.4	12.4	10.5	11.5	11.2	14.2	17.5	14.2	16.4	15.6	1.39
	Medium Cruise	12.7	23.4	12.7	16.0	16.2	14.4	26.0	14.9	20.0	18.8	1.16
	High Cruise	12.9	24.8	13.0	12.5	15.8	15.4	27.3	17.9	19.0	19.9	1.26
	Deceleration	9.71	15.1	8.99	11.3	11.3	11.9	20.6	15.5	13.7	15.4	1.37
	Dumping						23.2	36.8	16.3	16.5	23.2	
	Equal Weight Avg[b]	12.3	16.7	11.3	16.2	14.1	15.8	21.6	15.3	19.3	18.0	1.28
	Empirical Weight Avg[d]	9.38	12.3	5.32	7.58	8.64	14.3	17.6	15.4	12.5	14.9	1.73

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table 8-6. Continued

		Unloaded					Loaded					
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	Ratio[c]
		0507	0578	0579	0580		0507	0578	0579	0580		
CO_2 (g/sec)	Idle	0.886	0.861	0.655	1.34	0.936	0.989	0.919	0.725	1.39	1.01	1.07
	Low Acceleration	8.26	7.92	9.24	10.9	9.08	11.4	10.1	13.9	12.1	11.9	1.31
	Medium Acceleration	17.2	14.0	10.8	18.7	15.2	20.6	16.8	18.7	22.6	19.7	1.30
	High Acceleration	18.1	15.9	14.2	20.2	17.1	21.8	19.4	19.2	24.1	21.1	1.24
	Low Cruise	5.64	6.32	7.12	8.54	6.91	8.89	9.10	13.5	10.5	10.5	1.52
	Medium Cruise	11.4	9.50	13.6	9.82	11.1	19.5	15.8	16.8	15.2	16.8	1.52
	High Cruise	14.4	11.1	12.0	11.1	12.1	18.1	15.5	16.3	17.7	16.9	1.39
	Deceleration	6.22	4.69	7.03	5.01	5.74	9.07	6.71	13.3	8.21	9.33	1.63
	Dumping						4.43	4.32	2.59	3.72	3.76	
	Equal Weight Avg[b]	10.3	8.78	9.32	10.7	9.77	12.8	11.0	12.8	12.8	12.3	1.26
	Empirical Weight Avg[d]	7.10	4.11	3.62	4.02	4.71	12.4	8.88	13.9	7.45	10.7	2.26
PM (mg/sec)	Idle	0.105	0.224	0.297	0.099	0.181	0.106	0.234	0.312	0.128	0.195	1.08
	Low Acceleration	0.476	0.452	0.444	0.464	0.459	0.650	0.626	1.14	0.498	0.730	1.59
	Medium Acceleration	0.856	0.769	0.904	0.926	0.864	1.04	0.896	1.22	1.22	1.09	1.27
	High Acceleration	0.988	0.934	0.891	1.05	0.966	1.25	1.16	1.18	1.26	1.21	1.26
	Low Cruise	0.225	1.31	1.35	0.182	0.765	0.385	1.80	2.28	0.493	1.24	1.62
	Medium Cruise	0.436	1.72	2.11	0.594	1.22	0.743	2.83	3.51	1.00	2.02	1.66
	High Cruise	0.498	1.81	2.52	0.614	1.36	0.548	2.41	3.42	1.22	1.90	1.40
	Deceleration	0.223	0.732	1.13	0.240	0.581	0.337	1.45	1.38	0.543	0.929	1.60
	Dumping						0.178	0.908	1.65	0.235	0.742	
	Equal Weight Avg[b]	0.476	0.994	1.21	0.521	0.799	0.582	1.37	1.79	0.733	1.12	1.40
	Empirical Weight Avg[d]	0.337	0.572	0.691	0.196	0.449	0.550	1.21	1.86	0.414	1.01	2.25

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
  - Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
  - Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes
[c]: Loaded / Unloaded
[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table 8-7. Preliminary Average Fuel Use and Emission Rates on a Per Time Basis by Driving Mode, Vehicle, and Load for Tier 1 Tandem Dump Trucks (Soy Based B20)

		Unloaded					**Loaded**					
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	Ratio[c]
		0507	**0578**	**0579**	**0580**		**0507**	**0578**	**0579**	**0580**		
Fuel (g/sec)	Idle	0.308	0.409	0.442	0.337	0.374	0.309	0.411	0.445	0.388	0.388	1.04
	Low Acceleration	2.81	3.78	3.35	1.78	2.93	4.15	4.35	4.65	3.55	4.18	1.43
	Medium Acceleration	4.69	4.85	5.25	3.48	4.57	5.45	7.25	6.40	4.79	5.97	1.31
	High Acceleration	5.53	5.85	6.71	4.34	5.61	6.35	7.44	7.30	5.10	6.55	1.17
	Low Cruise	1.70	3.35	2.75	0.981	2.20	1.78	3.84	3.38	1.89	2.72	1.24
	Medium Cruise	2.96	3.95	4.33	3.18	3.61	3.78	5.47	5.16	4.52	4.73	1.31
	High Cruise	3.58	4.32	5.44	4.00	4.33	3.89	5.13	6.14	4.50	4.91	1.13
	Deceleration	1.35	1.18	2.38	1.48	1.60	1.73	2.05	2.86	2.58	2.31	1.44
	Dumping						1.48	2.35	2.17	1.21	1.80	
	Equal Weight Avg[b]	2.87	3.46	3.83	2.45	3.15	3.21	4.25	4.28	3.17	3.73	1.18
	Empirical Weight Avg[d]	2.56	2.11	1.85	1.30	1.95	1.53	2.29	2.68	0.943	1.86	0.95
NO_x (g/sec)	Idle	0.017	0.019	0.023	0.016	0.019	0.019	0.019	0.023	0.016	0.019	1.03
	Low Acceleration	0.069	0.095	0.078	0.055	0.074	0.074	0.106	0.104	0.092	0.094	1.27
	Medium Acceleration	0.119	0.136	0.134	0.098	0.122	0.135	0.213	0.164	0.118	0.158	1.29
	High Acceleration	0.160	0.152	0.187	0.125	0.156	0.176	0.269	0.191	0.186	0.206	1.32
	Low Cruise	0.045	0.058	0.072	0.033	0.052	0.048	0.098	0.094	0.048	0.072	1.39
	Medium Cruise	0.081	0.101	0.108	0.080	0.093	0.101	0.207	0.142	0.117	0.142	1.53
	High Cruise	0.132	0.164	0.224	0.112	0.158	0.159	0.203	0.228	0.137	0.182	1.15
	Deceleration	0.044	0.058	0.070	0.044	0.054	0.057	0.090	0.085	0.070	0.075	1.39
	Dumping						0.041	0.055	0.075	0.040	0.053	
	Equal Weight Avg[b]	0.083	0.098	0.112	0.070	0.091	0.090	0.140	0.123	0.091	0.111	1.22
	Empirical Weight Avg[d]	0.080	0.066	0.062	0.041	0.062	0.049	0.079	0.082	0.030	0.060	0.97

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table 8-7. Continued

	Driving Mode[a]	Unloaded					Loaded					Ratio[c]
		Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	
		0507	0578	0579	0580		0507	0578	0579	0580		
HC (mg/sec)	Idle	1.11	2.25	1.62	1.77	1.69	1.53	2.29	1.65	1.81	1.82	1.08
	Low Acceleration	4.02	5.40	4.58	2.57	4.14	4.59	5.90	5.25	3.92	4.92	1.19
	Medium Acceleration	5.40	7.60	5.84	3.66	5.63	6.41	8.72	6.21	4.83	6.54	1.16
	High Acceleration	5.61	7.43	6.28	4.57	5.97	6.56	9.31	6.70	5.49	7.02	1.18
	Low Cruise	3.33	5.81	3.37	2.43	3.74	3.77	6.52	4.50	4.08	4.72	1.26
	Medium Cruise	3.70	6.06	4.26	3.37	4.35	4.09	8.04	5.61	4.29	5.51	1.27
	High Cruise	4.03	6.98	4.99	3.69	4.92	4.52	8.32	6.81	4.25	5.97	1.21
	Deceleration	2.46	4.51	4.12	2.32	3.35	3.24	4.66	5.01	3.75	4.17	1.24
	Dumping						3.16	4.51	3.01	2.95	3.41	
	Equal Weight Avg[b]	3.71	5.76	4.38	3.05	4.22	4.21	6.47	4.97	3.93	4.90	1.16
	Empirical Weight Avg[d]	3.44	4.33	2.77	2.33	3.19	2.69	4.42	3.69	2.22	3.25	1.02
CO (mg/sec)	Idle	3.58	4.93	4.24	4.32	4.27	4.00	5.26	4.34	4.41	4.50	1.06
	Low Acceleration	16.9	25.6	25.2	17.8	21.4	19.5	28.6	28.9	25.1	25.5	1.19
	Medium Acceleration	18.2	28.6	27.3	19.8	23.5	22.2	30.1	29.0	23.6	26.2	1.12
	High Acceleration	17.3	28.6	25.9	19.6	22.8	19.9	35.4	28.4	23.1	26.7	1.17
	Low Cruise	8.86	13.7	11.0	10.8	11.1	12.0	16.2	14.0	17.2	14.9	1.34
	Medium Cruise	10.9	14.4	12.0	16.0	13.3	12.5	18.4	14.6	18.2	15.9	1.20
	High Cruise	13.2	17.7	14.5	12.0	14.3	17.4	22.2	18.0	19.7	19.3	1.35
	Deceleration	7.37	9.81	8.25	10.6	9.00	9.04	12.5	11.0	13.5	11.5	1.28
	Dumping						17.1	16.3	14.0	14.3	15.4	
	Equal Weight Avg[b]	12.0	17.9	16.1	13.9	15.0	14.8	20.5	18.0	17.7	17.8	1.19
	Empirical Weight Avg[d]	10.7	12.1	8.67	8.30	9.93	8.41	12.4	11.9	6.88	9.89	1.00

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table 8-7. Continued

		Unloaded					Loaded					
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	Ratio[c]
		0507	**0578**	**0579**	**0580**		**0507**	**0578**	**0579**	**0580**		
CO_2 (g/sec)	Idle	0.946	1.41	1.39	1.03	1.19	0.947	1.43	1.43	1.17	1.24	1.04
	Low Acceleration	8.65	12.8	10.5	5.49	9.37	12.7	14.8	14.4	10.9	13.2	1.41
	Medium Acceleration	14.5	16.3	16.6	10.7	14.5	16.8	24.9	20.4	14.8	19.2	1.32
	High Acceleration	17.1	19.8	21.4	13.4	17.9	19.6	25.4	22.6	15.4	20.8	1.16
	Low Cruise	5.24	11.7	8.61	3.01	7.15	5.42	13.4	11.0	5.74	8.89	1.24
	Medium Cruise	9.13	13.8	13.8	9.82	11.6	11.6	18.4	16.5	13.7	15.1	1.29
	High Cruise	11.1	14.7	17.1	12.3	13.8	12.0	18.2	19.1	13.7	15.7	1.14
	Deceleration	4.17	4.01	7.55	4.54	5.07	5.10	7.02	8.85	7.89	7.22	1.42
	Dumping						4.55	8.17	6.73	3.72	5.79	
	Equal Weight Avg[b]	8.84	11.8	12.1	7.54	10.1	9.86	14.6	13.4	9.67	11.9	1.18
	Empirical Weight Avg[d]	7.90	7.21	5.84	3.99	6.23	4.70	7.93	8.45	2.87	5.98	0.96
PM (mg/sec)	Idle	0.061	0.119	0.106	0.063	0.087	0.073	0.121	0.109	0.071	0.093	1.07
	Low Acceleration	0.487	2.30	1.47	0.270	1.13	0.533	3.03	2.13	0.511	1.55	1.37
	Medium Acceleration	0.827	3.34	2.62	0.664	1.86	0.903	4.12	3.32	0.849	2.30	1.24
	High Acceleration	0.980	3.67	3.63	0.947	2.31	1.01	4.53	3.86	1.69	2.77	1.20
	Low Cruise	0.259	0.282	0.303	0.121	0.241	0.319	0.410	0.542	0.277	0.387	1.60
	Medium Cruise	0.376	0.442	0.719	0.396	0.483	0.556	0.765	0.776	0.563	0.665	1.38
	High Cruise	0.339	0.476	0.551	0.409	0.444	0.547	0.591	0.792	0.683	0.653	1.47
	Deceleration	0.164	0.248	0.383	0.160	0.239	0.172	0.371	0.518	0.361	0.356	1.49
	Dumping						0.183	0.259	0.12	0.132	0.173	
	Equal Weight Avg[b]	0.436	1.36	1.22	0.379	0.849	0.478	1.58	1.35	0.571	0.995	1.17
	Empirical Weight Avg[d]	0.354	0.749	0.481	0.185	0.442	0.245	0.711	0.778	0.154	0.472	1.07

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table 8-8. The Ratio of B20 to Petroleum Diesel by Driving Mode and individual Vehicles for Tier 1 Tandem Dump Trucks

		Unloaded					**Loaded**				
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]
		0507	**0578**	**0579**	**0580**		**0507**	**0578**	**0579**	**0580**	
Fuel	Idle	1.08	1.53	2.11	0.78	1.26	1.01	1.42	1.98	0.88	1.23
	Low Acceleration	1.10	1.54	1.16	0.516	1.03	1.23	1.38	1.07	0.932	1.14
	Medium Acceleration	0.862	1.09	1.57	0.577	0.949	0.830	1.37	1.12	0.668	0.965
	High Acceleration	0.946	1.16	1.55	0.659	1.03	0.934	1.22	1.22	0.667	0.986
	Low Cruise	0.936	1.72	1.28	0.366	1.02	0.636	1.33	0.828	0.564	0.831
	Medium Cruise	0.789	1.30	1.06	1.03	1.03	0.620	1.10	0.970	0.951	0.894
	High Cruise	0.765	1.23	1.45	1.15	1.12	0.709	1.05	1.21	0.796	0.932
	Deceleration	0.686	0.792	1.07	0.934	0.879	0.603	0.962	0.689	1.00	0.785
	Dumping						1.07	1.71	2.70	1.03	1.52
	Equal Weight Avg[b]	0.870	1.25	1.33	0.716	1.02	0.810	1.23	1.08	0.780	0.965
	Empirical Weight Avg[c]	1.12	1.63	1.64	1.01	1.31	0.396	0.816	0.624	0.399	0.558
NO_x	Idle	0.727	0.919	1.42	0.946	0.970	0.798	0.870	1.18	0.930	0.935
	Low Acceleration	0.697	1.22	0.918	0.509	0.803	0.468	0.972	0.717	0.786	0.711
	Medium Acceleration	0.578	0.965	0.957	0.554	0.733	0.449	1.10	0.837	0.638	0.719
	High Acceleration	0.640	0.859	0.940	0.556	0.733	0.496	1.06	0.715	0.628	0.702
	Low Cruise	0.724	0.700	1.08	0.911	0.838	0.403	0.814	0.934	0.848	0.727
	Medium Cruise	0.539	0.954	0.879	0.925	0.795	0.326	1.07	0.751	0.921	0.692
	High Cruise	0.530	1.33	1.16	0.920	0.919	0.476	0.670	1.11	0.752	0.709
	Deceleration	0.514	1.14	0.840	0.929	0.809	0.355	0.704	0.617	0.920	0.601
	Dumping						0.617	0.750	1.52	0.919	0.907
	Equal Weight Avg[b]	0.593	1.00	0.989	0.688	0.801	0.443	0.902	0.844	0.749	0.710
	Empirical Weight Avg[c]	0.750	1.27	1.19	1.10	1.00	0.249	0.585	0.522	0.497	0.437

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table 8-8. Continued

		Unloaded					Loaded				
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]
		0507	**0578**	**0579**	**0580**		**0507**	**0578**	**0579**	**0580**	
HC	Idle	0.596	0.706	0.731	0.835	0.720	0.795	0.660	0.691	0.787	0.722
	Low Acceleration	0.534	0.876	1.33	0.339	0.670	0.450	0.881	0.407	0.478	0.517
	Medium Acceleration	0.615	0.968	1.27	0.348	0.709	0.594	0.986	0.440	0.399	0.571
	High Acceleration	0.566	0.891	1.03	0.390	0.662	0.600	0.897	0.409	0.450	0.562
	Low Cruise	0.617	0.920	0.803	0.630	0.756	0.503	0.669	0.577	1.01	0.649
	Medium Cruise	0.578	0.535	0.497	0.977	0.584	0.535	0.617	0.540	0.800	0.605
	High Cruise	0.551	0.613	0.915	0.816	0.686	0.582	0.608	0.772	0.775	0.668
	Deceleration	0.577	0.580	1.19	0.914	0.743	0.694	0.490	0.780	1.32	0.711
	Dumping						0.664	0.503	0.838	0.878	0.659
	Equal Weight Avg[b]	0.577	0.738	0.921	0.527	0.682	0.572	0.691	0.540	0.633	0.609
	Empirical Weight Avg[c]	0.716	0.823	0.907	0.745	0.793	0.379	0.535	0.384	0.577	0.447
CO	Idle	0.806	0.570	1.99	1.04	0.881	0.844	0.592	1.67	1.01	0.875
	Low Acceleration	1.49	1.80	2.40	0.936	1.55	1.12	1.72	1.60	1.16	1.39
	Medium Acceleration	1.01	1.75	1.68	0.841	1.27	1.09	1.68	1.53	0.825	1.22
	High Acceleration	0.904	1.54	1.64	0.623	1.08	0.950	1.55	1.48	0.681	1.10
	Low Cruise	0.852	1.11	1.05	0.939	0.992	0.845	0.926	0.990	1.05	0.955
	Medium Cruise	0.859	0.613	0.944	0.998	0.821	0.869	0.708	0.980	0.908	0.846
	High Cruise	1.03	0.714	1.11	0.960	0.909	1.13	0.813	1.01	1.04	0.972
	Deceleration	0.759	0.651	0.918	0.938	0.799	0.758	0.607	0.710	0.989	0.747
	Dumping						0.737	0.442	0.859	0.872	0.665
	Equal Weight Avg[b]	0.977	1.07	1.43	0.856	1.06	0.937	0.952	1.18	0.915	0.987
	Empirical Weight Avg[c]	1.14	0.983	1.63	1.09	1.15	0.587	0.704	0.773	0.552	0.662

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes
[c]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table 8-8. Continued

	Driving Mode[a]	**Unloaded**					**Loaded**				
		Vehicle Number				Avg[b]	Vehicle Number				Avg[b]
		0507	**0578**	**0579**	**0580**		**0507**	**0578**	**0579**	**0580**	
CO_2	Idle	1.07	1.64	2.12	0.769	1.28	0.958	1.56	1.97	0.841	1.24
	Low Acceleration	1.05	1.62	1.14	0.504	1.03	1.11	1.46	1.04	0.901	1.11
	Medium Acceleration	0.841	1.17	1.55	0.572	0.958	0.816	1.48	1.09	0.655	0.977
	High Acceleration	0.944	1.25	1.51	0.663	1.05	0.899	1.31	1.18	0.639	0.983
	Low Cruise	0.929	1.85	1.21	0.353	1.03	0.610	1.47	0.815	0.547	0.847
	Medium Cruise	0.801	1.45	1.01	1.00	1.05	0.595	1.17	0.983	0.901	0.895
	High Cruise	0.767	1.33	1.43	1.11	1.14	0.663	1.17	1.17	0.773	0.932
	Deceleration	0.671	0.855	1.07	0.907	0.884	0.563	1.05	0.663	0.961	0.773
	Dumping						1.03	1.89	2.60	1.00	1.54
	Equal Weight Avg[b]	0.862	1.35	1.30	0.704	1.03	0.773	1.34	1.05	0.753	0.965
	Empirical Weight Avg[c]	1.11	1.75	1.61	0.993	1.32	0.378	0.893	0.609	0.385	0.561
PM	Idle	0.578	0.530	0.357	0.634	0.480	0.689	0.518	0.349	0.553	0.479
	Low Acceleration	1.02	5.10	3.32	0.582	2.47	0.820	4.85	1.86	1.03	2.13
	Medium Acceleration	0.966	4.34	2.89	0.717	2.15	0.868	4.60	2.72	0.696	2.10
	High Acceleration	0.992	3.93	4.07	0.903	2.39	0.809	3.91	3.27	1.34	2.29
	Low Cruise	1.15	0.215	0.226	0.666	0.315	0.829	0.228	0.238	0.561	0.312
	Medium Cruise	0.862	0.257	0.341	0.666	0.397	0.749	0.271	0.221	0.562	0.329
	High Cruise	0.680	0.263	0.218	0.666	0.326	0.999	0.245	0.232	0.562	0.344
	Deceleration	0.736	0.339	0.339	0.668	0.411	0.511	0.256	0.374	0.666	0.383
	Dumping						1.03	0.285	0.073	0.560	0.234
	Equal Weight Avg[b]	0.917	1.37	1.01	0.727	1.06	0.821	1.15	0.756	0.780	0.890
	Empirical Weight Avg[c]	1.05	1.31	0.695	0.946	0.985	0.446	0.587	0.419	0.372	0.468

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

and emissions for B20 biodiesel versus petroleum diesel.

As noted in the case of the single rear-axle trucks, there is substantial variability in fuel consumption and emission rates when comparing the operating modes. For example, when comparing the highest average modal emission rate with the lowest average modal emission rate:

- Fuel consumption and CO_2 emissions vary by a factor of 18 to 21 for petroleum diesel and 15 to 17 for B20 biodiesel, when comparing high acceleration to idle.
- NO emissions vary by a factor of 11 to 14 for petroleum diesel and 8 to 11 for B20 biodiesel, when comparing high acceleration to idle. , when comparing high acceleration to idle.
- HC emissions vary by a factor of 3.8 to 5.0 for petroleum diesel and 3.5 to 3.9 for B20 biodiesel, when comparing high acceleration to idle.
- CO emissions vary by a factor of 4.4 to 4.7 for petroleum diesel and 5.5 to 5.9 for B20 biodiesel, when comparing high acceleration to idle.
- PM emissions vary by a factor of 7.5 to 10.3 for petroleum diesel and 26 to 30 for B20 biodiesel, when comparing high cruise or high acceleration (as appropriate) to idle.

Thus, the inter-modal variability in CO_2, NO, and PM emissions tends to be the highest, and the variability in CO and HC emissions tends to be the lowest.

In general, the modal fuel consumption and emission rates compare as follows:

- Idle always has the lowest fuel consumption and emissions rates.
- Deceleration fuel consumption and emission rates are greater than those of idling, and can be comparable to low cruise. This suggests that either the engine is still under some load during deceleration, that there is a lag effect associated with engine performance and emissions in previous seconds, or some combination of both.
- With the exception of CO, the fuel consumption and emissions during the dumping mode are typically less than that during deceleration but greater than that during idle. For CO, the dumping mode average emissions are greater than those during deceleration.
- The higher power demand modes of high acceleration, medium acceleration, high cruise, and medium cruise typically have the highest average fuel consumption rates and emission rates for NO, HC, CO, CO_2, and PM. The main exceptions to this are that: (a) for CO the dumping and low acceleration modes also tend to have relatively high emission rates; and (b) for HC either the low cruise or the low acceleration modes can have relatively high emission rates.
- Typically, among the acceleration modes, fuel consumption and emissions increase in order from low to medium to high. However, for CO, the average emission rates for the medium and the high acceleration modes are approximately the same.
- Typically, among the cruise modes, fuel consumption and emissions increase in order from low to medium to high. However, in most cases, there is not a significant difference between medium and high cruise for fuel consumption and CO_2 emissions. Furthermore, CO, HC, and PM emissions are either approximately the same or are slightly lower for high cruise than for medium cruise. These results imply that the tandems, which are

significantly heavier than the single rear-axle trucks, may experience significant engine power demand even at medium cruising and thus there is as great of a relative difference between medium and high cruise modes compared to the other vehicle type.

The fuel use and emissions are greater for the loaded vehicles versus the unloaded vehicles. When compared on the basis of modes that are common to loaded and unloaded operations (i.e. all modes except dumping), the average fuel consumption and emissions increase by approximately 30 percent for loaded versus unloaded vehicles. On average, the weight of a loaded tandem is approximately a factor of 2.34 greater than the unloaded weight.

When comparing fuel consumption and emissions on B20 biodiesel versus petroleum diesel, the following trends are observed:

- On average, fuel consumption and CO_2 emissions differ by only a few percent. These differences are not statistically significant. As noted earlier, differences of approximately 1 to 2 percent are expected. The findings are consistent with these expectations.
- NO emissions decrease, on average, by approximately 20 to 30 percent, depending on vehicle load. The decrease is larger for loaded vehicles. For two of the vehicles, NO emissions decreased consistently for all modes. For the other two vehicles, NO emissions did not change, on average, when the vehicle was unloaded but they decreased by approximately 10 to 15 percent when the vehicle was loaded. There was not a consistent pattern regarding which of the modes had the lowest or highest emissions ratios.
- HC emissions decreased, on average, for all four vehicles, and the decrease was slightly greater for loaded versus unloaded vehicles. The decrease was approximately consistent among all of the modes, varying among ratios of approximately 0.6 to 0.75 in most cases, and between 0.5 and 0.8 in all cases.
- CO emissions did not demonstrate a significant change. CO emissions generally increased for all three acceleration modes, but generally decreased for all other modes. Thus, whether the average CO emissions would increase or decrease would depend upon the weighting of the modes in a particular duty cycle. If the modes are equally weighted, then there is approximately no change in CO emissions. If empirical weights based upon the observed duty cycles are used, CO emissions increase for the unloaded case but decrease substantially for the loaded case.
- The ratio of PM emissions for B20 versus petroleum diesel was sensitive to the operating mode. For the three acceleration modes, the PM emission rate approximately doubled. However, for the other modes, the PM emission rate decreased by approximately 60 percent. Thus, the overall average change in PM emission for a duty cycle will be dependent upon the weights given to the modes. For the case of unloaded trucks, there was an average increase of 6 percent in PM emissions, which is not likely to be significant. For loaded trucks, there was approximately a 10 percent decrease. However, if empirical, rather than equal, weights are used for the modes, the differences change substantially.

As summarized in Table 8-9, the results for the tandems with Tier 1 engines imply no significant overall change in fuel consumption or in emissions of CO_2, CO, or PM. However, a significant decrease was observed in emissions of NO and HC. An exception is that PM emissions for loaded vehicles appear to have a small but perhaps significant decrease. When a humidity correction factor is applied to the NO emission estimates, as described in Chapter 2, the estimated decrease in NO emissions is approximately 12 percent on average. The estimated decrease in HC emissions is approximately 35 percent. As noted in the previous section, the Montana system measures only NO, and not total NO_x.

Table 8-9. Percentage Change in Fuel Use and Emissions Comparing B20 Biodiesel to Petroleum Diesel for Tandem Dump Trucks with Tier 1 Engines

	Tier 1 Tandem Dump Truck		
	Unloaded (%)	Loaded (%)	Average (%)
Fuel Use	1.9	-3.4	-0.7
NO	-19 (-6.5)[a]	-29 (-18) [a]	-24 (-12) [a]
HC	-32	-39	-35
CO	6.4	-1.1	2.6
CO_2	3.4	-3.3	0.1
PM	6.3	-11	-2.5

[a]: Applied the NO_x humidity correction factor for diesel engines based on 40 CFR Chapter I Section 86.1342-90 (2003).

8.4 New Single Rear Axle Dump Trucks - Tier 2 (2004) (Petroleum Diesel / B20 Biodiesel)

This section focuses on data collected for two vehicles that were new at the time that testing occurred. Both vehicles were 2004 model year single-rear axle dump trucks with Tier 2 engines. The typical duty cycles, fuel consumption and emission rates, and comparison of fuel consumption and emissions for B20 biodiesel versus petroleum diesel are presented. This section briefly highlights key insights obtained from these data. These insights include the following:

- There is significant variability in fuel consumption and emissions among the operating modes
- The trends of emissions among the operating modes differ among the pollutants.
- There is inter-vehicle variability in fuel use and emissions, some of which is related to operating conditions (e.g., duty cycle, load)
- Fuel use and emissions are higher for loaded versus unloaded operations.
- Typically, fuel use and CO_2 emissions are comparable for B20 biodiesel versus petroleum diesel fuel.
- Typically, for the single rear axle vehicles with either Tier 1 and Tier 2 engines,

emissions of NO, HC, CO, and PM are lower for B20 biodiesel versus petroleum diesel. However, the reduction in NO emissions for the Tier 2 engines was relative small and in some cases was not statistically significant.

The average duty cycles for unloaded and loaded single rear-axle trucks with Tier 2 engines are shown in Figure 8-6 for petroleum diesel and Figure 8-7 for B20 biodiesel. There is some variability in the activity patterns. For example, the amount of time spent idling was approximately 50 to 60 percent during the duty cycles when the vehicles were fueled with petroleum diesel but was only approximately 15 to 30 percent when the vehicles were fueled with B20 biodiesel. These differences are not because of the fuels; they are simply artifacts of different work locations at the times that each of the fuels were used.

Although there is a substantial apparent difference in the duty cycles with respect to the amount of time spent in each mode, the duty cycles associated with each of the two fuels are more similar when compared on the basis of distance. For example, in all cases, the three cruise modes contribute approximately 50 to 60 percent of the distance driven, the three deceleration modes contribute approximately 20 to 30 percent of the distance driven, and the deceleration mode contributes approximately 20 to 25 percent of the distance driven.

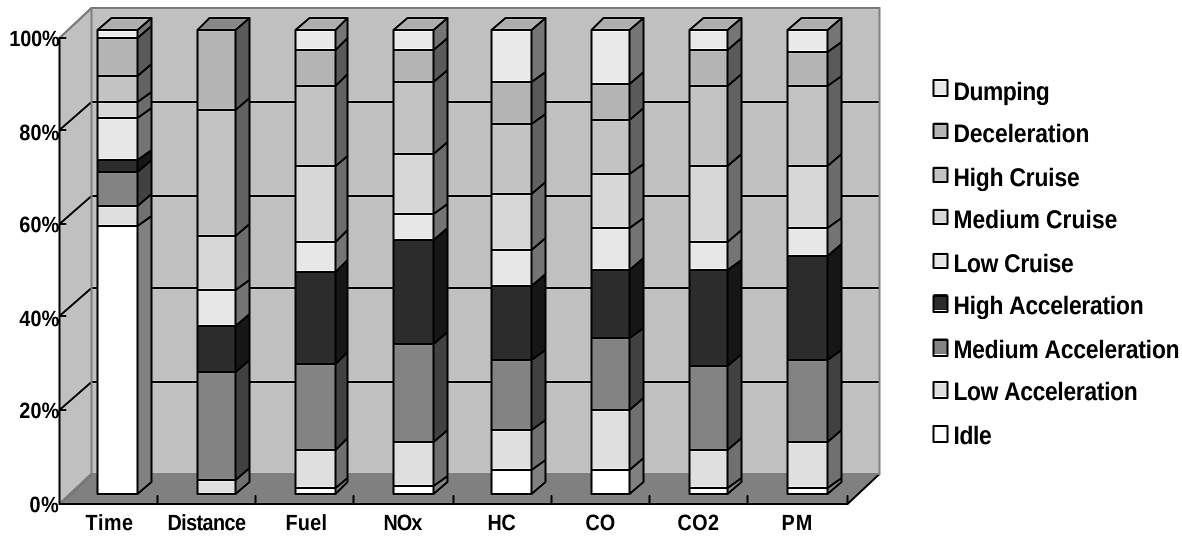
When comparing the duty cycles on the basis of the distribution of fuel use by operating mode, these cycles appear to be even more similar regardless of the fuel used or whether the vehicle was loaded or unloaded. For example, idling contributes only a few percent of the fuel use, the three acceleration modes contribute 45 to 50 percent, the three cruise modes contribute approximately 40 to 45 percent, and deceleration contributes approximately 10 percent. Of course, for the loaded vehicles, the dumping mode has a contribution, but this contribution is only approximately 5 percent.

The percentage contribution of the acceleration modes to NO emissions is greater than their contribution to time, distance, or fuel consumption, implying that the emission rates during acceleration are greater than for other modes. For HC, the proportional contribution to total emissions from the low speed cruise, deceleration, and (in the case of loaded vehicles only) dumping is slightly greater than that for fuel use, implying that the rate of HC emissions tends to be greater for these modes relative to the fuel consumption. When comparing fuel consumption and CO emissions, there is a proportionally greater contribution to CO emissions from the operating modes of idling, dumping (for loaded vehicles only), low acceleration, and low cruise. The distribution of CO_2 emissions and fuel consumption by mode is approximately the same, as expected. PM emissions appear to have slightly higher sensitivity to the high acceleration mode compared to fuel use.

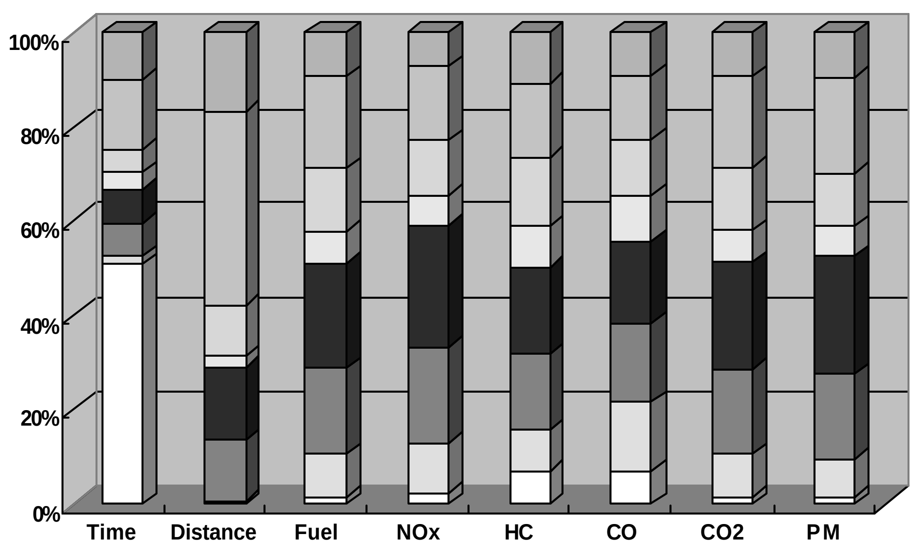
Tables 8-10 and 8-11 provide results for the modal emission rates by vehicle and load, for petroleum diesel and for B20 biodiesel, respectively. Table 8-12 summarizes the ratio of fuel use and emissions for B20 biodiesel versus petroleum diesel.

As noted for the previous vehicle groups, there is substantial variability in fuel consumption and emission rates when comparing the operating modes. For example, when comparing the highest average modal emission rate with the lowest average modal emission rate:

- Fuel consumption and CO_2 emissions vary by a factor of 15 to 16 for petroleum diesel and 12 to 14 for B20 biodiesel, when comparing high acceleration to idle.

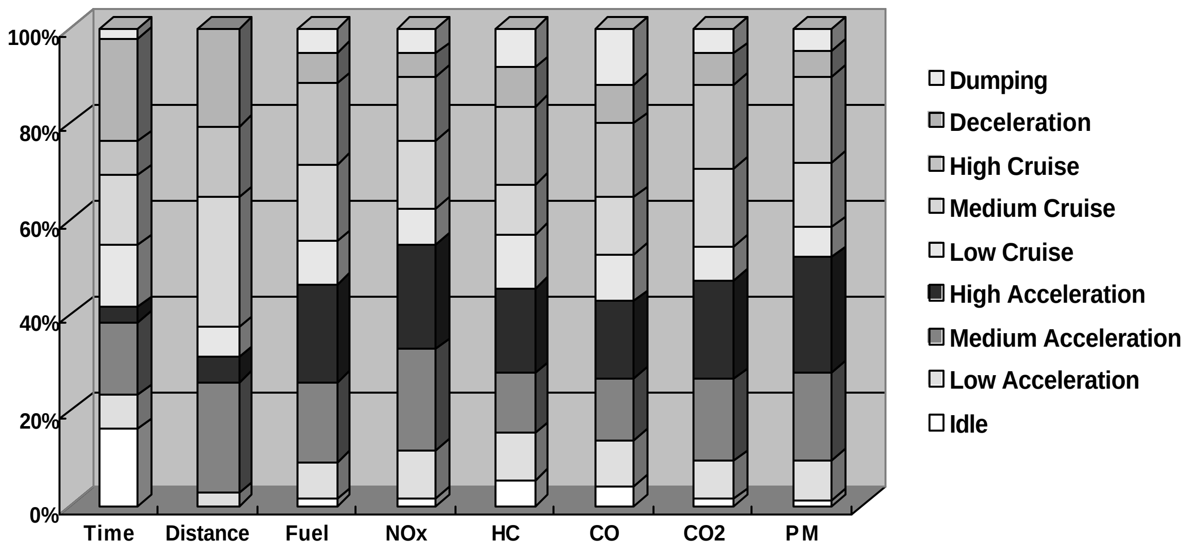


(a) Loaded

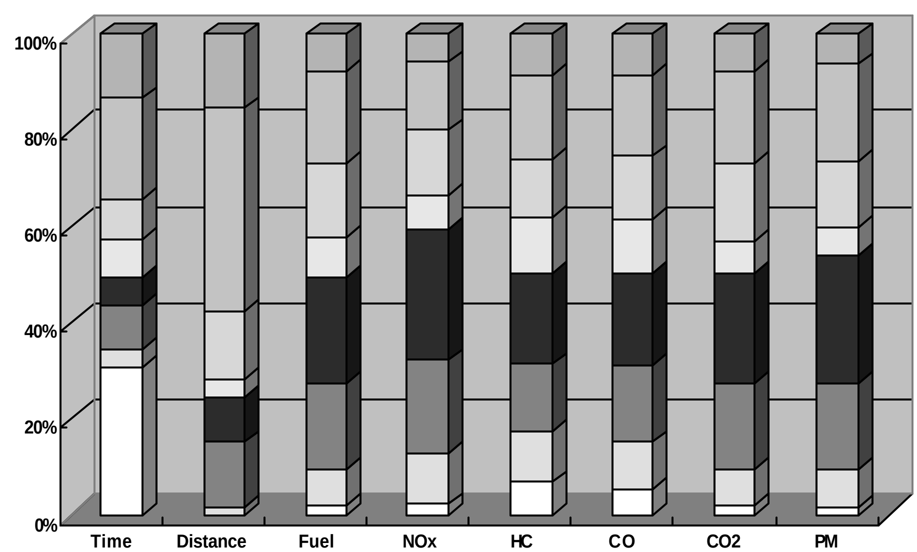


(b) Unloaded

Figure 8-6 Distribution of Time, Distance, Fuel Use, and Emissions by modes for Tier 2 Single Axle dump trucks fueled with Petroleum diesel



(a) Loaded



(b) Unloaded

Figure 8-7 Distribution of Time, Distance, Fuel Use, and Emissions by modes for Tier 2 Single Axle dump trucks fueled with Soy-Based B20

Table 8-10. Preliminary Average Fuel Use and Emission Rates on a Per Time Basis by Driving Mode, Vehicle, and Load for Tier 2 Single Axle Dump Trucks (Petroleum Diesel)

		Unloaded			**Loaded**			
	Driving Mode[a]	Vehicle Number **6117**	Vehicle Number **6123**	Avg[b]	Vehicle Number **6117**	Vehicle Number **6123**	Avg[b]	Ratio[c]
Fuel (g/sec)	Idle	0.262	0.297	0.279	0.272	0.331	0.301	1.08
	Low Acceleration	1.81	1.50	1.66	1.94	1.92	1.93	1.16
	Medium Acceleration	3.28	3.27	3.28	4.16	4.31	4.24	1.29
	High Acceleration	4.26	3.75	4.01	5.12	4.22	4.67	1.17
	Low Cruise	1.22	1.22	1.22	1.41	1.43	1.42	1.16
	Medium Cruise	2.25	2.48	2.36	3.38	4.14	3.76	1.59
	High Cruise	3.30	3.76	3.53	3.59	4.49	4.04	1.14
	Deceleration	1.36	1.89	1.63	1.53	2.12	1.82	1.12
	Dumping				1.03	1.05	1.04	
	Equal Weight Avg[b]	2.22	2.27	2.25	2.49	2.67	2.58	1.15
	Empirical Weight Avg[d]	1.47	1.59	1.53	1.44	1.21	1.32	0.86
NO_x (g/sec)	Idle	0.012	0.014	0.013	0.013	0.015	0.014	1.09
	Low Acceleration	0.062	0.064	0.063	0.074	0.085	0.080	1.26
	Medium Acceleration	0.109	0.129	0.119	0.156	0.188	0.172	1.45
	High Acceleration	0.155	0.146	0.151	0.196	0.164	0.180	1.20
	Low Cruise	0.034	0.043	0.038	0.042	0.049	0.045	1.18
	Medium Cruise	0.064	0.072	0.068	0.098	0.116	0.107	1.56
	High Cruise	0.078	0.103	0.091	0.104	0.150	0.127	1.40
	Deceleration	0.038	0.048	0.043	0.049	0.064	0.056	1.32
	Dumping				0.033	0.040	0.036	
	Equal Weight Avg[b]	0.069	0.077	0.073	0.085	0.097	0.091	1.24
	Empirical Weight Avg[d]	0.047	0.051	0.049	0.050	0.046	0.048	0.98
HC (mg/sec)	Idle	1.46	1.55	1.50	1.52	1.56	1.54	1.03
	Low Acceleration	2.05	1.74	1.90	2.49	2.76	2.62	1.38
	Medium Acceleration	3.57	3.43	3.50	3.88	5.22	4.55	1.30
	High Acceleration	3.98	3.87	3.93	4.28	5.55	4.92	1.25
	Low Cruise	1.97	1.76	1.86	2.44	2.30	2.37	1.27
	Medium Cruise	2.98	3.27	3.13	3.40	3.87	3.63	1.16
	High Cruise	3.66	3.18	3.42	4.12	4.85	4.48	1.31
	Deceleration	2.48	2.08	2.28	3.03	2.45	2.74	1.20
	Dumping				4.58	2.36	3.47	
	Equal Weight Avg[b]	2.77	2.61	2.69	3.30	3.44	3.37	1.25
	Empirical Weight Avg[d]	2.31	2.22	2.26	2.39	2.24	2.31	1.02

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table 8-10. Continued

	Driving Mode[a]	Unloaded: Vehicle Number 6117	Unloaded: Vehicle Number 6123	Unloaded: Avg[b]	Loaded: Vehicle Number 6117	Loaded: Vehicle Number 6123	Loaded: Avg[b]	Ratio[c]
CO (mg/sec)	Idle	6.42	5.19	5.81	6.80	5.35	6.08	1.05
	Low Acceleration	12.6	12.1	12.4	14.6	14.4	14.5	1.17
	Medium Acceleration	14.3	14.1	14.2	16.4	18.2	17.3	1.22
	High Acceleration	15.9	13.2	14.6	18.6	14.7	16.7	1.14
	Low Cruise	8.77	7.42	8.10	9.93	10.2	10.1	1.24
	Medium Cruise	8.94	11.0	9.98	11.8	13.5	12.6	1.27
	High Cruise	11.3	11.4	11.4	12.7	14.0	13.3	1.17
	Deceleration	7.81	6.86	7.33	9.13	8.81	8.97	1.22
	Dumping				17.4	9.03	13.2	
	Equal Weight Avg[b]	10.8	10.2	10.5	13.0	12.0	12.5	1.20
	Empirical Weight Avg[d]	8.92	7.89	8.41	9.62	8.00	8.01	1.05
CO_2 (g/sec)	Idle	0.814	0.926	0.870	0.847	1.03	0.941	1.08
	Low Acceleration	5.71	4.73	5.22	6.09	6.04	6.07	1.16
	Medium Acceleration	10.3	10.3	10.3	13.0	13.6	13.3	1.29
	High Acceleration	13.8	11.8	12.8	16.7	13.2	15.0	1.17
	Low Cruise	3.85	3.85	3.85	4.75	4.19	4.47	1.16
	Medium Cruise	7.09	7.81	7.45	10.7	13.1	11.9	1.59
	High Cruise	10.4	11.9	11.2	11.3	14.2	12.8	1.14
	Deceleration	4.29	5.96	5.13	4.80	6.68	5.74	1.12
	Dumping				3.22	3.29	3.25	
	Equal Weight Avg[b]	7.03	7.16	7.10	7.93	8.36	8.15	1.15
	Empirical Weight Avg[d]	4.66	5.01	4.83	4.56	3.77	4.16	0.86
PM (mg/sec)	Idle	0.047	0.064	0.056	0.053	0.068	0.061	1.09
	Low Acceleration	0.336	0.231	0.284	0.397	0.558	0.478	1.68
	Medium Acceleration	0.758	0.541	0.650	0.793	0.863	0.828	1.27
	High Acceleration	0.921	0.854	0.888	1.20	0.991	1.10	1.23
	Low Cruise	0.292	0.175	0.233	0.351	0.215	0.283	1.21
	Medium Cruise	0.456	0.362	0.409	0.663	0.629	0.646	1.58
	High Cruise	0.720	0.731	0.726	0.759	0.851	0.805	1.11
	Deceleration	0.374	0.283	0.328	0.422	0.312	0.367	1.12
	Dumping				0.315	0.168	0.241	
	Equal Weight Avg[b]	0.488	0.405	0.447	0.550	0.517	0.534	1.20
	Empirical Weight Avg[d]	0.326	0.298	0.312	0.309	0.233	0.271	0.87

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table 8-11. Preliminary Average Fuel Use and Emission Rates on a Per Time Basis by Driving Mode, Vehicle, and Load for Tier 2 Single Axle Dump Trucks (Soy Based B20)

		Unloaded			**Loaded**			
	Driving Mode[a]	Vehicle Number **6117**	Vehicle Number **6123**	Avg[b]	Vehicle Number **6117**	Vehicle Number **6123**	Avg[b]	Ratio[c]
Fuel (g/sec)	Idle	0.360	0.246	0.303	0.374	0.286	0.330	1.09
	Low Acceleration	1.67	1.00	1.33	1.77	1.79	1.78	1.33
	Medium Acceleration	2.80	3.18	2.99	3.52	4.37	3.94	1.32
	High Acceleration	3.49	3.98	3.74	4.58	4.80	4.69	1.25
	Low Cruise	1.39	1.48	1.43	1.87	2.13	2.00	1.40
	Medium Cruise	2.17	3.20	2.69	2.86	4.69	3.77	1.40
	High Cruise	2.99	3.44	3.22	3.35	4.70	4.02	1.25
	Deceleration	1.35	1.21	1.28	1.42	1.61	1.51	1.18
	Dumping				1.18	1.06	1.12	
	Equal Weight Avg[b]	2.03	2.22	2.12	2.32	2.83	2.58	1.21
	Empirical Weight Avg[d]	1.59	2.04	1.81	1.88	2.94	2.41	1.33
NO_x (g/sec)	Idle	0.012	0.012	0.012	0.012	0.013	0.013	1.03
	Low Acceleration	0.052	0.052	0.052	0.059	0.094	0.077	1.47
	Medium Acceleration	0.074	0.134	0.104	0.112	0.229	0.171	1.64
	High Acceleration	0.097	0.194	0.146	0.105	0.248	0.177	1.21
	Low Cruise	0.034	0.039	0.036	0.038	0.084	0.061	1.68
	Medium Cruise	0.048	0.099	0.073	0.082	0.141	0.111	1.52
	High Cruise	0.057	0.094	0.076	0.067	0.140	0.103	1.37
	Deceleration	0.024	0.033	0.029	0.028	0.054	0.041	1.43
	Dumping				0.035	0.036	0.036	
	Equal Weight Avg[b]	0.050	0.082	0.066	0.060	0.115	0.088	1.33
	Empirical Weight Avg[d]	0.038	0.065	0.051	0.051	0.115	0.083	1.61
HC (mg/sec)	Idle	1.21	1.23	1.22	1.29	1.33	1.31	1.07
	Low Acceleration	2.44	1.65	2.04	2.93	1.79	2.36	1.15
	Medium Acceleration	3.19	2.06	2.62	3.35	2.61	2.98	1.14
	High Acceleration	3.71	3.20	3.46	4.53	3.94	4.24	1.23
	Low Cruise	3.06	1.56	2.31	3.59	1.94	2.77	1.20
	Medium Cruise	2.50	2.01	2.25	2.80	2.30	2.55	1.13
	High Cruise	3.93	2.64	3.29	4.80	3.05	3.93	1.20
	Deceleration	1.99	1.22	1.61	2.43	1.46	1.94	1.21
	Dumping				1.44	2.35	1.89	
	Equal Weight Avg[b]	2.75	1.95	2.35	3.02	2.31	2.66	1.13
	Empirical Weight Avg[d]	2.29	1.92	2.11	2.59	2.12	2.36	1.12

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table 8-11. Continued

	Driving Mode[a]	Unloaded: Vehicle Number 6117	Unloaded: Vehicle Number 6123	Unloaded: Avg[b]	Loaded: Vehicle Number 6117	Loaded: Vehicle Number 6123	Loaded: Avg[b]	Ratio[c]
CO (mg/sec)	Idle	4.46	3.63	4.04	4.54	3.81	4.17	1.03
	Low Acceleration	8.61	5.67	7.14	10.3	8.68	9.49	1.33
	Medium Acceleration	12.7	10.8	11.8	14.2	12.3	13.3	1.13
	High Acceleration	14.5	13.3	13.9	16.7	15.4	16.1	1.15
	Low Cruise	10.7	5.89	8.30	13.3	6.52	9.91	1.19
	Medium Cruise	8.82	10.6	9.70	10.4	13.0	11.7	1.21
	High Cruise	11.3	13.4	12.4	14.5	16.4	15.4	1.25
	Deceleration	6.47	5.76	6.12	8.94	7.84	8.39	1.37
	Dumping				15.1	8.48	11.8	
	Equal Weight Avg[b]	9.70	8.63	9.17	12.0	10.3	11.1	1.21
	Empirical Weight Avg[d]	8.12	8.62	8.37	9.82	10.1	9.95	1.19
CO_2 (g/sec)	Idle	1.10	0.753	0.928	1.16	0.873	1.02	1.09
	Low Acceleration	5.14	3.08	4.11	5.44	5.51	5.48	1.33
	Medium Acceleration	8.64	9.80	9.20	10.9	13.5	12.2	1.32
	High Acceleration	10.8	12.3	11.5	13.2	15.7	14.5	1.25
	Low Cruise	4.26	4.56	4.41	5.62	6.60	6.11	1.39
	Medium Cruise	6.70	9.90	8.30	8.83	14.4	11.6	1.40
	High Cruise	9.23	10.6	9.93	10.3	14.5	12.4	1.25
	Deceleration	4.18	3.74	3.96	4.37	4.98	4.68	1.18
	Dumping				3.63	3.25	3.44	
	Equal Weight Avg[b]	6.25	6.85	6.55	7.05	8.81	7.93	1.21
	Empirical Weight Avg[d]	4.90	6.30	5.60	5.77	9.09	7.43	1.33
PM (mg/sec)	Idle	0.058	0.038	0.048	0.063	0.048	0.055	1.15
	Low Acceleration	0.380	0.121	0.251	0.412	0.258	0.335	1.34
	Medium Acceleration	0.587	0.455	0.521	0.798	0.640	0.719	1.38
	High Acceleration	0.852	0.701	0.777	0.936	0.915	0.926	1.19
	Low Cruise	0.281	0.102	0.191	0.305	0.200	0.252	1.32
	Medium Cruise	0.371	0.406	0.388	0.541	0.516	0.528	1.36
	High Cruise	0.593	0.575	0.584	0.714	0.661	0.687	1.18
	Deceleration	0.207	0.160	0.183	0.240	0.198	0.219	1.19
	Dumping				0.199	0.164	0.181	
	Equal Weight Avg[b]	0.416	0.320	0.368	0.468	0.400	0.434	1.18
	Empirical Weight Avg[d]	0.311	0.310	0.310	0.373	0.381	0.377	1.22

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.

- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table 8-12. The Ratio of B20 to Petroleum Diesel by Driving Mode and individual Vehicles for Tier 2 Single Axle Dump Trucks

		Unloaded			**Loaded**		
	Driving Mode[a]	Vehicle Number		Avg[b]	Vehicle Number		Avg[b]
		6117	**6123**		**6117**	**6123**	
Fuel	Idle	1.38	0.830	1.09	1.38	0.866	1.10
	Low Acceleration	0.922	0.665	0.806	0.913	0.934	0.923
	Medium Acceleration	0.854	0.973	0.913	0.846	1.01	0.931
	High Acceleration	0.820	1.06	0.933	0.895	1.14	1.00
	Low Cruise	1.13	1.21	1.17	1.33	1.49	1.41
	Medium Cruise	0.966	1.29	1.14	0.846	1.13	1.00
	High Cruise	0.906	0.915	0.911	0.933	1.05	0.997
	Deceleration	0.993	0.643	0.790	0.927	0.760	0.830
	Dumping				1.15	1.01	1.08
	Equal Weight Avg[b]	0.914	0.977	0.946	0.933	1.06	0.998
	Empirical Weight Avg[c]	1.08	1.28	1.19	1.31	2.43	1.82
NO_x	Idle	1.00	0.857	0.923	0.923	0.867	0.857
	Low Acceleration	0.839	0.813	0.825	0.797	1.11	0.962
	Medium Acceleration	0.679	1.04	0.874	0.718	1.22	0.991
	High Acceleration	0.626	1.33	0.967	0.536	1.51	0.981
	Low Cruise	1.00	0.907	0.947	0.905	1.71	1.36
	Medium Cruise	0.750	1.38	1.07	0.837	1.22	1.04
	High Cruise	0.731	0.913	0.834	0.644	0.933	0.811
	Deceleration	0.632	0.688	0.663	0.571	0.844	0.732
	Dumping				1.06	0.900	0.986
	Equal Weight Avg[b]	0.721	1.06	0.901	0.703	1.19	0.964
	Empirical Weight Avg[c]	0.818	1.25	1.04	1.01	2.50	1.72
HC	Idle	0.828	0.795	0.811	0.846	0.850	0.848
	Low Acceleration	1.19	0.948	1.08	1.18	0.649	0.900
	Medium Acceleration	0.894	0.599	0.749	0.863	0.500	0.655
	High Acceleration	0.932	0.827	0.880	1.06	0.710	0.862
	Low Cruise	1.56	0.886	1.24	1.47	0.843	1.17
	Medium Cruise	0.837	0.615	0.721	0.825	0.595	0.703
	High Cruise	1.07	0.831	0.961	1.17	0.630	0.876
	Deceleration	0.802	0.586	0.703	0.801	0.596	0.709
	Dumping				0.314	0.993	0.545
	Equal Weight Avg[b]	0.994	0.746	0.874	0.913	0.672	0.790
	Empirical Weight Avg[c]	0.993	0.865	0.930	1.08	0.948	1.02

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table 8-12 Continued

		Unloaded			Loaded		
	Driving Mode[a]	Vehicle Number		Avg[b]	Vehicle Number		Avg[b]
		6117	**6123**		**6117**	**6123**	
CO	Idle	0.695	0.698	0.696	0.668	0.711	0.687
	Low Acceleration	0.683	0.469	0.578	0.705	0.603	0.654
	Medium Acceleration	0.888	0.769	0.829	0.866	0.676	0.766
	High Acceleration	0.913	1.01	0.955	0.898	1.05	0.964
	Low Cruise	1.22	0.794	1.02	1.34	0.638	0.984
	Medium Cruise	0.986	0.960	0.972	0.883	0.965	0.927
	High Cruise	0.998	1.18	1.09	1.14	1.18	1.16
	Deceleration	0.829	0.840	0.834	0.979	0.889	0.935
	Dumping				0.866	0.939	0.891
	Equal Weight Avg[b]	0.902	0.849	0.877	0.920	0.857	0.886
	Empirical Weight Avg[c]	0.910	1.09	0.996	1.02	1.26	1.23
CO_2	Idle	1.36	0.813	1.07	1.37	0.843	1.08
	Low Acceleration	0.899	0.651	0.787	0.893	0.912	0.903
	Medium Acceleration	0.839	0.954	0.896	0.839	0.992	0.918
	High Acceleration	0.781	1.04	0.902	0.790	1.19	0.967
	Low Cruise	1.11	0.705	0.906	1.13	1.05	1.09
	Medium Cruise	0.945	1.27	1.11	0.827	1.10	0.978
	High Cruise	0.886	0.896	0.891	0.908	1.03	0.973
	Deceleration	0.972	0.628	0.772	0.910	0.745	0.814
	Dumping				1.13	0.988	1.06
	Equal Weight Avg[b]	0.889	0.925	0.907	0.885	1.02	0.957
	Empirical Weight Avg[c]	1.05	1.26	1.46	1.27	2.41	1.78
PM	Idle	1.23	0.593	0.864	1.17	0.702	0.907
	Low Acceleration	1.13	0.524	0.884	1.04	0.462	0.702
	Medium Acceleration	0.774	0.841	0.802	1.01	0.742	0.868
	High Acceleration	0.925	0.821	0.875	0.780	0.923	0.845
	Low Cruise	0.961	0.582	0.819	0.869	0.930	0.892
	Medium Cruise	0.814	1.12	0.950	0.816	0.819	0.818
	High Cruise	0.823	0.787	0.805	0.942	0.776	0.854
	Deceleration	0.553	0.567	0.559	0.568	0.632	0.595
	Dumping				0.632	0.973	0.750
	Equal Weight Avg[b]	0.852	0.789	0.824	0.849	0.773	0.812
	Empirical Weight Avg[c]	0.954	1.04	0.996	1.21	1.64	1.39

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded.

- NO emissions vary by a factor of 12 to 13 for petroleum diesel and 12 to 14 for B20 biodiesel, when comparing high acceleration to idle.
- HC emissions vary by a factor of 2.6 to 3.2 for petroleum diesel and 2.8 to 3.2 for B20 biodiesel, when comparing high acceleration to idle.
- CO emissions vary by a factor of 2.5 to 2.8 for petroleum diesel and 3.4 to 3.9 for B20 biodiesel, when comparing either high or medium acceleration to idle.
- PM emissions vary by a factor of 16 to 18 for petroleum diesel and 16 to 17 for B20 biodiesel, when comparing high acceleration to idle.

Thus, the inter-modal variability in CO_2, NO, and PM emissions tends to be the highest, and the variability in CO and HC emissions tends to be the lowest.

In general, the modal fuel consumption and emission rates compare as follows:

- Idle always has the lowest fuel consumption and emissions rates.
- Deceleration fuel consumption and emission rates are greater than those of idling, and can be comparable to low cruise. For petroleum diesel, the deceleration fuel consumption and emission rates tend to be slightly larger than those for low cruise, whereas for B20 biodiesel they tend to be slightly smaller. However, the fact that they are consistently greater than for idling suggests that either the engine is still under some load during deceleration, that there is a lag effect associated with engine performance and emissions in previous seconds, or some combination of both.
- The fuel consumption and emissions during the dumping mode are typically less than that during deceleration but greater than that during idle. For HC on petroleum diesel, and for CO on both fuels, the dumping mode average emissions are greater than those during deceleration. For HC on B20 biodiesel, the dumping and deceleration modes have approximately the same rate.
- The higher power demand modes of high acceleration, medium acceleration, high cruise, and medium cruise typically have the highest average fuel consumption rates and emission rates for NO, HC, CO, CO_2, and PM. The main exceptions to this are that: (a) for CO the dumping and low acceleration modes also tend to have relatively high emission rates; and (b) for HC either the low cruise or the low acceleration modes can have relatively high emission rates.
- Typically, among the acceleration modes, fuel consumption and emissions increase in order from low to medium to high. However, for CO, the average emission rates for the medium and the high acceleration modes are approximately the same in some cases.
- Typically, among the cruise modes, fuel consumption and emissions increase in order from low to medium to high. The only exception is that for NO emissions on B20 biodiesel the emission rates are similar for medium and high cruise modes.

The fuel use and emissions are greater for the loaded vehicles versus the unloaded vehicles. When compared on the basis of modes that are common to loaded and unloaded operations (i.e. all modes except dumping), the average fuel consumption and emissions increase by approximately 20 percent for loaded versus unloaded vehicles. On average, the weight of a loaded single rear-axle truck is approximately a factor of 2 greater than the unloaded weight.

Table 8-13. Percentage Change in Fuel Use and Emissions Comparing B20 Biodiesel to Petroleum Diesel for Single Rear Axle Dump Trucks with Tier 2 Engines.

	Tier 2 Single Rear-Axle Dump Truck		
	Unloaded (%)	Loaded (%)	Average (%)
Fuel Use	-5.8	0	-2.9
NO	-10 (-12)[a]	-3.3 (-7.6)[a]	-6.4 (-9.9)[a]
HC	-13	-21	-17
CO	-13	-11	-12
CO_2	-7.7	-2.7	-5.2
PM	-18	-19	-18

[a]: Applied the NO_x humidity correction factor for diesel engines based on 40 CFR Chapter I Section 86.1342-90 (2003).

When comparing fuel consumption and emissions on B20 biodiesel versus petroleum diesel, the following trends are observed:

- On average, fuel consumption and CO_2 emissions differ by only a few percent. These differences are not statistically significant. As noted earlier, differences of approximately 1 to 2 percent are expected. The findings are consistent with these expectations.
- NO emissions decrease, on average, by approximately 6 percent. However, for one of the vehicles, the NO emissions decreased by approximately 30 percent, whereas for the other vehicle, the NO emissions increased by approximately 12 percent, if the modes are equally weighted. The low cruise mode appears to more consistently have a higher ratio when comparing the two fuels, whereas the deceleration mode consistently had a low ratio.
- HC emissions decreased, on average, for both vehicles, and the decrease was slightly greater for loaded versus unloaded vehicles. However, in one case, the decrease was negligible. Overall, the average decrease is approximately 17 percent.
- CO emissions consistently decreased for both vehicles and for both loaded and unloaded operations. The decrease was approximately 8 to 15 percent in each case, with an average of 12 percent.
- When averaging results between the two vehicles, the ratio of PM emissions for B20 versus petroleum diesel was consistently less than one for all modes and, when averaged across all modes for each vehicle, was consistently less than one for both vehicles and both loads. The overall average decrease in PM emissions was approximately 18 percent.

As summarized in Table 8-13, the results for the single rear-axle vehicles with Tier 2 engines imply no significant overall change in fuel consumption or in emissions of CO_2. There is a small estimated average reduction in NO emissions of approximately 6 percent, or of approximately 10 percent when corrected for ambient humidity. The average reduction in emissions of CO, HC, and PM ranged from approximately 12 to 18 percent. These data suggest that for these vehicles there is a consistent pattern of a modest reduction in emission rates of NO, CO, HC, and PM when switching from petroleum diesel to B20 biodiesel

8.5 New Double Rear Axle (Tandem) Dump Trucks - Tier 2 (2004) (Petroleum Diesel / B20 Biodiesel)

This section focuses on data collected for two vehicles that were new at the time that testing occurred. Both vehicles were 2004 model year tandem dump trucks with Tier 2 engines. The typical duty cycles, fuel consumption and emission rates, and comparison of fuel consumption and emissions for B20 biodiesel versus petroleum diesel are presented. This section briefly highlights key insights obtained from these data. These insights include the following:

- There is significant variability in fuel consumption and emissions among the operating modes.
- The trends of emissions among the operating modes differ among the pollutants.
- There is inter-vehicle variability in fuel use and emissions, some of which is related to operating conditions (e.g., duty cycle, load)
- Fuel use and emissions are higher for loaded versus unloaded operations.
- Typically, fuel use and CO_2 emissions are slightly higher for B20 biodiesel versus petroleum diesel fuel.
- Unlike some of the other vehicle groups, for this vehicle group there is comparatively little difference in emissions when comparing the two fuels. Emissions of NO, CO, and PM are approximately the same, and CO emissions decrease slightly.

The average duty cycles for unloaded and loaded tandem trucks with Tier 2 engines are shown in Figure 8-8 for petroleum diesel and Figure 8-9 for B20 biodiesel. There is some variability in the activity patterns. For example, the amount of time spent idling was approximately 20 to 25 percent in most cases except for unloaded vehicles while using petroleum fuel, for which idling occurred approximately 40 percent of the time. For these vehicles, there was a substantial amount of activity at high cruise, representing highway driving, particularly on the days when the vehicles were fueled with biodiesel.

On a distance basis, the high cruise mode accounted for 50 to 60 percent on the days of testing with petroleum diesel and 70 to 80 percent for biodiesel. However, although there is substantial variability when comparing the duty cycles on a time or distance basis, the comparison of the two fuels and of loaded versus unloaded operations appears to be more similar when done on a fuel consumption basis. The high acceleration mode typically accounts for as much or more fuel consumption than does the high cruise mode, even though the amount of time spent and the distance associated with the former is substantially smaller. The four operating modes of medium acceleration, high acceleration, medium cruise, and high cruise have approximately similar contributions to the total fuel use. The idle mode has the smallest contribution to fuel use.

When comparing the distribution of modes for fuel versus that for NO emissions, the NO emissions have a somewhat larger contribution from the three acceleration modes, from the idle mode, and from the dumping mode in the case of loaded vehicles. For HC, the trends appear to be different for petroleum diesel compared to biodiesel. For example, for petroleum diesel, HC emissions are influenced by the deceleration and dumping modes more so than in the case of biodiesel. However, this may be a result of differences in the activity patterns, rather than differences that have to do with the fuels.

In general, CO emissions are less influenced by the acceleration modes than for other pollutants and are more influenced by the cruising modes. CO_2 emissions are influenced by the operating modes in the same proportions as for fuel consumption. PM emissions appear to be more sensitive to the acceleration modes, and particularly the high acceleration, compared to other pollutants.

Tables 8-15 and 8-11 provide results for the modal emission rates by vehicle and load, for petroleum diesel and for B20 biodiesel, respectively. Table 8-12 summarizes the ratio of fuel use and emissions for B20 biodiesel versus petroleum diesel.

As noted for the previous vehicle groups, there is substantial variability in fuel consumption and emission rates when comparing the operating modes. For example, when comparing the highest average modal emission rate with the lowest average modal emission rate:

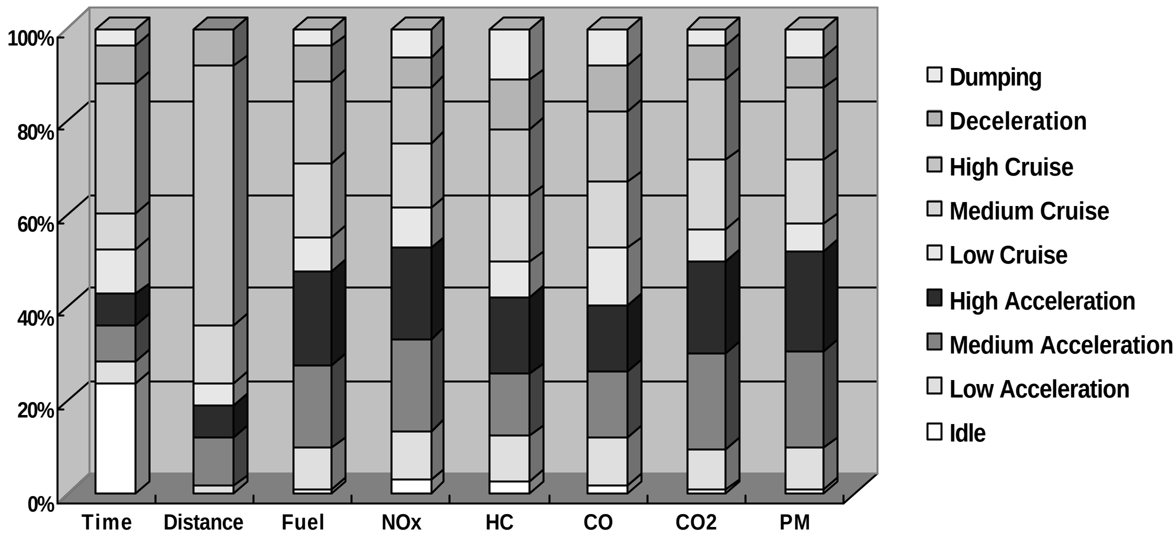
- Fuel consumption and CO_2 emissions vary by a factor of 17 to 20 for petroleum diesel and 12 to 26 for B20 biodiesel, when comparing high acceleration to idle.
- NO emissions vary by a factor of 6 for petroleum diesel and 5.3 to 6.7 for B20 biodiesel, when comparing high or medium acceleration to idle.
- HC emissions vary by a factor of 3.4 to 5.5 for petroleum diesel and 4.7 to 6.8 for B20 biodiesel, when comparing high acceleration to idle.
- CO emissions vary by a factor of 7.3 to 7.8 for petroleum diesel and 6.7 to 7.5 for B20 biodiesel, when comparing either high acceleration or high cruise to idle.
- PM emissions vary by a factor of 19 to 22 for petroleum diesel and 20 to 22 for B20 biodiesel, when comparing high acceleration to idle.

Thus, the inter-modal variability in CO_2 and PM emissions tends to be the highest, and the variability in NO, CO and HC emissions tends to be the lowest. This is somewhat different than for other groups, in which the variation in NO emissions was substantially greater than that for CO and HC.

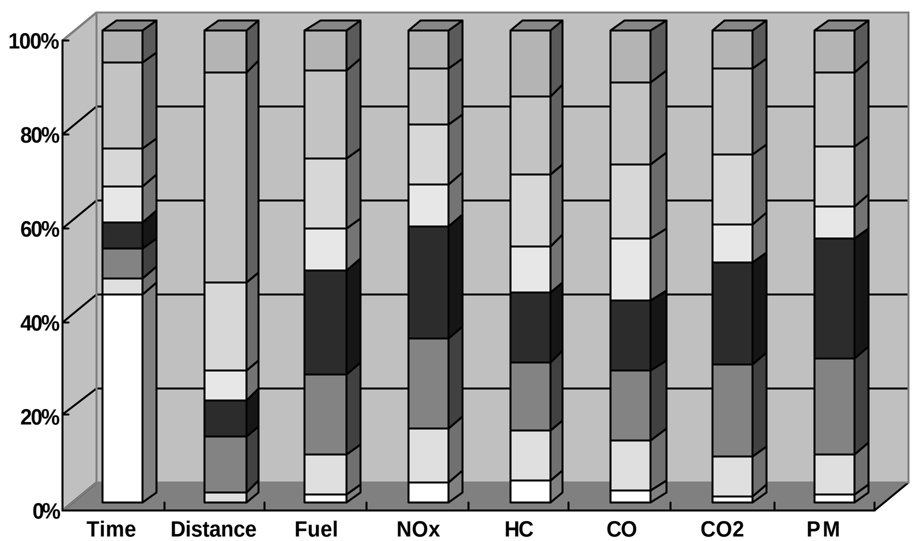
In general, the modal fuel consumption and emission rates compare as follows:

- Idle always has the lowest fuel consumption and emissions rates.
- Deceleration fuel consumption and emission rates are greater than those of idling, and can be comparable to low cruise.
- The fuel consumption and emissions during the dumping mode are greater than that during idle and approximately comparable to that during deceleration.

The higher power demand modes of high acceleration, medium acceleration, high cruise, and medium cruise typically have the highest average fuel consumption rates and emission rates for NO, HC, CO, CO_2, and PM.

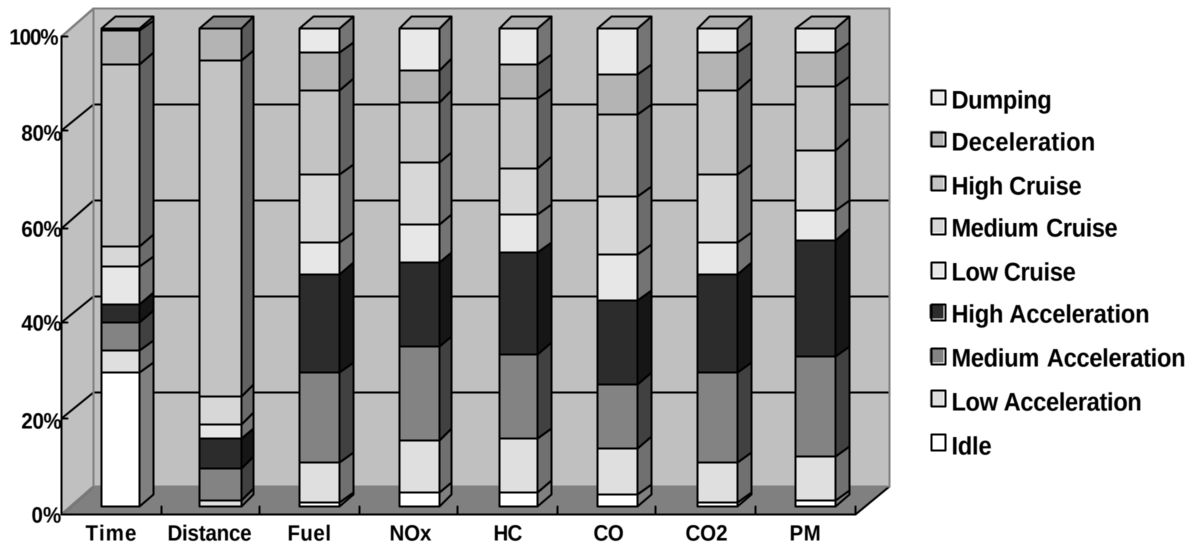


(a) Loaded

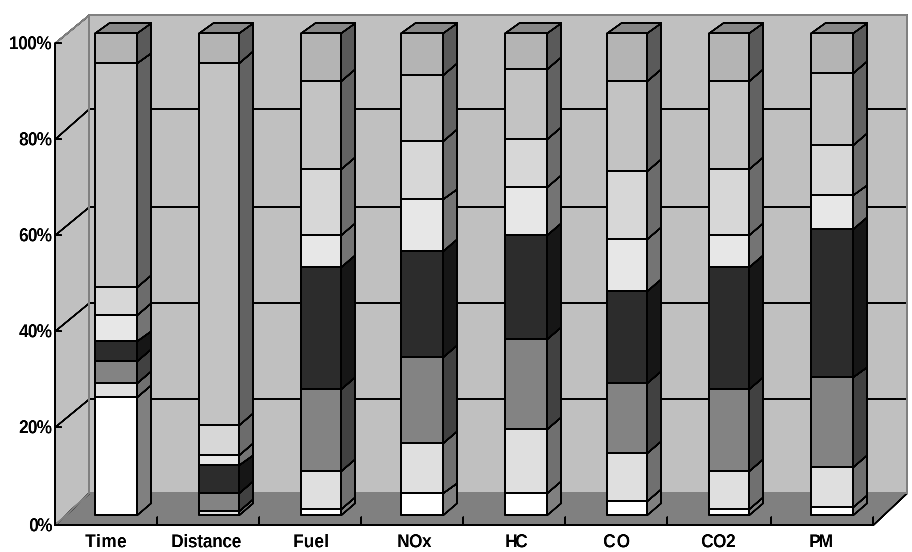


(b) Unloaded

Figure 8-8 Distribution of Time, Distance, Fuel Use, and Emissions by modes for Tier 2 Tandems dump trucks fueled with Petroleum diesel



(a) Loaded



(b) Unloaded

Figure 8-9 Distribution of Time, Distance, Fuel Use, and Emissions by modes for Tier 2 Tandems dump trucks fueled with Soy-Based B20

Table 8-14. Preliminary Average Fuel Use and Emission Rates on a Per Time Basis by Driving Mode, Vehicle, and Load for Tier 2 Tandem Dump Trucks (Petroleum Diesel)

		Unloaded			Loaded			
	Driving Mode[a]	Vehicle Number 0125	Vehicle Number 0126	Avg[b]	Vehicle Number 0125	Vehicle Number 0126	Avg[b]	Ratio[c]
Fuel (g/sec)	Idle	0.398	0.377	0.388	0.411	0.392	0.401	1.04
	Low Acceleration	2.14	3.12	2.63	2.84	4.35	3.60	1.37
	Medium Acceleration	4.70	5.33	5.02	6.58	7.62	7.10	1.42
	High Acceleration	6.44	6.68	6.56	8.65	7.47	8.06	1.23
	Low Cruise	2.33	2.72	2.53	2.68	3.07	2.88	1.14
	Medium Cruise	3.84	5.14	4.49	5.92	6.42	6.17	1.38
	High Cruise	5.59	5.58	5.58	5.65	8.84	7.24	1.30
	Deceleration	1.99	2.80	2.39	2.62	3.54	3.08	1.29
	Dumping				0.584	2.64	1.61	
	Equal Weight Avg[b]	3.43	3.97	3.70	3.99	4.93	4.46	1.21
	Empirical Weight Avg[d]	2.12	3.13	2.62	3.09	6.03	4.56	1.74
NO_x (g/sec)	Idle	0.019	0.024	0.021	0.020	0.026	0.023	1.07
	Low Acceleration	0.052	0.070	0.061	0.064	0.094	0.079	1.30
	Medium Acceleration	0.082	0.123	0.103	0.134	0.156	0.145	1.41
	High Acceleration	0.133	0.114	0.124	0.158	0.133	0.146	1.18
	Low Cruise	0.038	0.052	0.045	0.063	0.061	0.062	1.37
	Medium Cruise	0.056	0.081	0.068	0.102	0.104	0.103	1.51
	High Cruise	0.057	0.069	0.063	0.073	0.109	0.091	1.45
	Deceleration	0.036	0.046	0.041	0.045	0.053	0.049	1.19
	Dumping				0.021	0.074	0.048	
	Equal Weight Avg[b]	0.059	0.072	0.066	0.076	0.090	0.083	1.26
	Empirical Weight Avg[d]	0.039	0.054	0.047	0.059	0.092	0.076	1.62
HC (mg/sec)	Idle	2.11	1.51	1.81	2.25	1.61	1.93	1.06
	Low Acceleration	4.01	4.62	4.32	5.25	7.06	6.16	1.43
	Medium Acceleration	5.32	6.51	5.92	9.19	7.56	8.37	1.42
	High Acceleration	6.49	5.78	6.14	11.8	9.47	10.6	1.73
	Low Cruise	3.52	4.55	4.03	4.86	4.83	4.85	1.20
	Medium Cruise	5.36	6.97	6.17	9.66	8.52	9.09	1.47
	High Cruise	7.12	6.57	6.84	10.8	7.92	9.34	1.36
	Deceleration	4.74	6.42	5.58	6.06	7.59	6.82	1.22
	Dumping				5.22	9.02	7.12	
	Equal Weight Avg[b]	4.83	5.37	5.10	7.23	7.06	7.15	1.40
	Empirical Weight Avg[d]	3.69	4.27	3.98	6.09	6.84	6.47	1.63

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table 8-14. Continued

	Driving Mode[a]	Unloaded Vehicle Number 0125	Unloaded Vehicle Number 0126	Unloaded Avg[b]	Loaded Vehicle Number 0125	Loaded Vehicle Number 0126	Loaded Avg[b]	Ratio[c]
CO (mg/sec)	Idle	4.66	4.11	4.38	4.71	4.55	4.63	1.06
	Low Acceleration	15.4	22.6	19.0	20.6	27.4	24.0	1.26
	Medium Acceleration	23.1	30.3	26.7	29.3	40.6	35.0	1.31
	High Acceleration	25.5	27.4	26.5	31.0	37.6	34.3	1.30
	Low Cruise	16.0	32.0	24.0	19.5	38.3	28.9	1.20
	Medium Cruise	24.4	33.1	28.8	29.0	39.2	34.1	1.18
	High Cruise	28.3	35.3	31.8	32.2	40.5	36.3	1.14
	Deceleration	16.2	21.7	19.0	19.3	27.1	23.2	1.22
	Dumping				16.5	22.4	19.5	
	Equal Weight Avg[b]	19.2	25.8	22.5	22.5	30.9	26.7	1.19
	Empirical Weight Avg[d]	13.4	20.4	16.9	18.6	32.6	25.6	1.51
CO_2 (g/sec)	Idle	1.16	1.18	1.17	1.18	1.26	1.22	1.04
	Low Acceleration	6.74	9.83	8.29	8.95	13.7	11.3	1.37
	Medium Acceleration	14.8	17.0	15.9	21.1	24.3	22.7	1.43
	High Acceleration	20.3	21.1	20.7	27.3	23.6	25.4	1.23
	Low Cruise	7.34	8.57	7.95	8.44	9.67	9.06	1.14
	Medium Cruise	12.1	16.2	14.2	18.7	20.3	19.5	1.38
	High Cruise	17.6	17.6	17.6	17.8	27.9	22.9	1.30
	Deceleration	6.27	8.81	7.54	8.27	11.2	9.73	1.29
	Dumping				1.81	8.31	5.06	
	Equal Weight Avg[b]	10.8	12.5	11.7	12.6	15.6	14.1	1.21
	Empirical Weight Avg[d]	6.63	9.86	8.25	9.72	19.1	14.4	1.75
PM (mg/sec)	Idle	0.051	0.074	0.062	0.054	0.078	0.066	1.06
	Low Acceleration	0.312	0.500	0.406	0.503	0.723	0.613	1.51
	Medium Acceleration	0.786	1.07	0.930	1.28	1.52	1.40	1.50
	High Acceleration	1.21	1.09	1.15	1.70	1.22	1.46	1.27
	Low Cruise	0.272	0.341	0.307	0.422	0.401	0.412	1.34
	Medium Cruise	0.539	0.621	0.580	0.901	0.972	0.937	1.61
	High Cruise	0.770	0.666	0.718	1.03	1.06	1.04	1.45
	Deceleration	0.355	0.403	0.379	0.433	0.477	0.455	1.20
	Dumping				0.344	0.502	0.423	
	Equal Weight Avg[b]	0.537	0.596	0.566	0.741	0.772	0.756	1.34
	Empirical Weight Avg[d]	0.314	0.432	0.373	0.549	0.831	0.690	1.85

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table 8-15. Preliminary Average Fuel Consumption and Emission Rates on a Per Time Basis by Driving Mode, Vehicle, and Load for Tier 2 Tandem Dump Trucks (Soy Based B20)

		Unloaded			**Loaded**			
	Driving Mode[a]	Vehicle Number		Avg[b]	Vehicle Number		Avg[b]	Ratio[c]
		0125	**0126**		**0125**	**0126**		
Fuel (g/sec)	Idle	0.391	0.321	0.356	0.407	0.337	0.372	1.05
	Low Acceleration	2.13	2.81	2.47	3.37	4.01	3.69	1.49
	Medium Acceleration	4.65	6.44	5.54	7.89	9.29	8.59	1.55
	High Acceleration	7.07	8.78	7.93	8.78	10.2	9.49	1.20
	Low Cruise	1.98	2.37	2.17	2.83	3.13	2.98	1.37
	Medium Cruise	3.90	4.69	4.29	6.57	6.42	6.49	1.51
	High Cruise	5.61	5.88	5.75	7.77	8.25	8.01	1.39
	Deceleration	2.75	3.40	3.08	3.30	4.04	3.67	1.19
	Dumping				1.85	2.87	2.36	
	Equal Weight Avg[b]	3.56	4.34	3.95	4.75	5.39	5.07	1.28
	Empirical Weight Avg[d]	4.08	3.72	3.90	4.62	5.41	5.02	1.29
NO_x (g/sec)	Idle	0.020	0.023	0.022	0.021	0.025	0.022	1.03
	Low Acceleration	0.048	0.066	0.057	0.073	0.089	0.081	1.42
	Medium Acceleration	0.076	0.115	0.096	0.130	0.164	0.147	1.54
	High Acceleration	0.100	0.132	0.116	0.115	0.150	0.133	1.14
	Low Cruise	0.051	0.059	0.055	0.054	0.066	0.060	1.09
	Medium Cruise	0.060	0.072	0.066	0.091	0.106	0.099	1.49
	High Cruise	0.067	0.074	0.071	0.080	0.109	0.095	1.34
	Deceleration	0.037	0.051	0.044	0.042	0.063	0.053	1.19
	Dumping				0.043	0.094	0.069	
	Equal Weight Avg[b]	0.057	0.074	0.066	0.072	0.096	0.084	1.28
	Empirical Weight Avg[d]	0.057	0.058	0.057	0.062	0.085	0.074	1.30
HC (mg/sec)	Idle	2.14	1.51	1.82	2.25	1.73	1.99	1.09
	Low Acceleration	3.53	7.21	5.37	5.73	8.31	7.02	1.31
	Medium Acceleration	6.09	9.10	7.60	12.0	10.9	11.5	1.51
	High Acceleration	8.82	8.29	8.55	13.5	13.6	13.6	1.59
	Low Cruise	3.70	3.97	3.84	5.83	4.59	5.21	1.36
	Medium Cruise	4.16	3.89	4.02	6.84	5.83	6.34	1.57
	High Cruise	5.64	5.98	5.81	12.5	6.28	9.41	1.62
	Deceleration	2.90	2.82	2.86	4.82	4.36	4.59	1.61
	Dumping				4.82	5.33	5.07	
	Equal Weight Avg[b]	4.62	5.35	4.98	7.60	6.77	7.18	1.44
	Empirical Weight Avg[d]	4.72	4.33	4.52	7.73	5.50	6.62	1.46

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table 8-15. Continued

	Driving Mode[a]	Unloaded Vehicle Number 0125	Unloaded Vehicle Number 0126	Unloaded Avg[b]	Loaded Vehicle Number 0125	Loaded Vehicle Number 0126	Loaded Avg[b]	Ratio[c]
CO (mg/sec)	Idle	5.41	3.78	4.60	5.67	3.95	4.81	1.05
	Low Acceleration	16.5	15.3	15.9	24.3	18.6	21.5	1.35
	Medium Acceleration	22.5	23.1	22.8	28.5	27.7	28.1	1.23
	High Acceleration	29.6	32.1	30.8	38.4	35.4	36.9	1.20
	Low Cruise	16.0	18.0	17.0	21.8	18.5	20.2	1.18
	Medium Cruise	23.9	20.8	22.4	28.3	24.8	26.6	1.19
	High Cruise	26.3	32.9	29.6	35.2	36.5	35.8	1.21
	Deceleration	13.5	17.9	15.7	15.7	20.6	18.2	1.16
	Dumping				16.3	24.2	20.3	
	Equal Weight Avg[b]	19.2	20.5	19.9	23.8	23.4	23.6	1.19
	Empirical Weight Avg[d]	20.8	20.5	20.6	22.8	23.9	23.3	1.13
CO_2 (g/sec)	Idle	1.19	0.984	1.09	1.22	1.07	1.15	1.05
	Low Acceleration	6.57	8.65	7.61	10.4	12.4	11.4	1.49
	Medium Acceleration	14.3	19.9	17.1	24.3	28.7	26.5	1.55
	High Acceleration	21.8	27.1	24.5	27.1	31.5	29.3	1.20
	Low Cruise	6.08	7.30	6.69	8.73	9.65	9.19	1.37
	Medium Cruise	12.0	14.5	13.2	20.3	19.8	20.0	1.51
	High Cruise	17.3	18.1	17.7	24.0	25.5	24.7	1.39
	Deceleration	8.48	10.5	9.48	10.2	12.5	11.3	1.19
	Dumping				5.69	8.81	7.25	
	Equal Weight Avg[b]	11.0	13.4	12.2	14.7	16.6	15.7	1.29
	Empirical Weight Avg[d]	12.6	11.5	12.0	14.3	16.7	15.5	1.29
PM (mg/sec)	Idle	0.076	0.058	0.067	0.077	0.060	0.069	1.02
	Low Acceleration	0.317	0.394	0.356	0.622	0.527	0.575	1.62
	Medium Acceleration	0.780	0.822	0.800	1.39	1.21	1.30	1.63
	High Acceleration	1.44	1.21	1.32	1.57	1.49	1.53	1.16
	Low Cruise	0.327	0.275	0.301	0.404	0.336	0.370	1.23
	Medium Cruise	0.513	0.400	0.457	0.819	0.774	0.797	1.74
	High Cruise	0.738	0.591	0.664	0.810	0.847	0.827	1.24
	Deceleration	0.248	0.412	0.330	0.367	0.478	0.422	1.28
	Dumping				0.052	0.638	0.345	
	Equal Weight Avg[b]	0.555	0.520	0.537	0.679	0.707	0.693	1.29
	Empirical Weight Avg[d]	0.568	0.404	0.486	0.579	0.613	0.596	1.23

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table 8-16 The Ratio of B20 to Petroleum Diesel by Driving Mode and individual Vehicles for Tier 2 Tandem Dump Trucks

	Driving Mode[a]	Unloaded: Vehicle Number 0125	Unloaded: Vehicle Number 0126	Unloaded: Avg[b]	Loaded: Vehicle Number 0125	Loaded: Vehicle Number 0126	Loaded: Avg[b]
Fuel	Idle	0.982	0.852	0.918	0.991	0.861	0.927
	Low Acceleration	1.00	0.901	0.940	1.18	0.921	1.03
	Medium Acceleration	0.988	1.21	1.11	1.20	1.22	1.21
	High Acceleration	1.10	1.31	1.21	1.02	1.37	1.18
	Low Cruise	0.849	0.870	0.860	1.06	1.02	1.04
	Medium Cruise	1.01	0.913	0.957	1.11	1.00	1.05
	High Cruise	1.01	1.05	1.03	1.38	0.933	1.11
	Deceleration	1.38	1.22	1.29	1.26	1.14	1.19
	Dumping				3.17	1.08	1.46
	Equal Weight Avg[b]	1.04	1.09	1.07	1.19	1.09	1.14
	Empirical Weight Avg[c]	1.93	1.19	1.49	1.50	0.897	1.10
NO_x	Idle	1.08	0.945	1.00	1.04	0.964	0.963
	Low Acceleration	0.923	0.943	0.934	1.14	0.947	1.03
	Medium Acceleration	0.927	0.935	0.932	0.970	1.05	1.01
	High Acceleration	0.752	1.16	0.939	0.728	1.13	0.911
	Low Cruise	1.33	1.12	1.21	0.866	1.08	0.974
	Medium Cruise	1.08	0.887	0.965	0.888	1.02	0.954
	High Cruise	1.19	1.08	1.13	1.10	1.00	1.04
	Deceleration	1.02	1.11	1.07	0.918	1.19	1.06
	Dumping				1.99	1.27	1.43
	Equal Weight Avg[b]	0.972	1.02	1.00	0.953	1.07	1.02
	Empirical Weight Avg[c]	1.45	1.07	1.23	1.06	0.920	0.975
HC	Idle	1.01	1.00	1.01	1.00	1.07	1.03
	Low Acceleration	0.879	1.56	1.24	1.09	1.18	1.14
	Medium Acceleration	1.14	1.40	1.28	1.31	1.44	1.37
	High Acceleration	1.36	1.43	1.39	1.15	1.44	1.28
	Low Cruise	1.05	0.873	0.952	1.20	0.950	1.07
	Medium Cruise	0.776	0.558	0.653	0.708	0.684	0.697
	High Cruise	0.793	0.910	0.849	1.16	0.794	1.01
	Deceleration	0.612	0.439	0.512	0.796	0.574	0.673
	Dumping				0.923	0.591	0.713
	Equal Weight Avg[b]	0.956	0.996	0.977	1.05	0.958	1.01
	Empirical Weight Avg[c]	1.28	1.01	1.14	1.27	0.804	1.02

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

(Continue on Next Page)

Table 8-16 Continued

	Driving Mode[a]	Unloaded: Vehicle Number 0125	Unloaded: Vehicle Number 0126	Unloaded: Avg[b]	Loaded: Vehicle Number 0125	Loaded: Vehicle Number 0126	Loaded: Avg[b]
CO	Idle	1.16	0.921	1.05	1.20	0.867	1.04
	Low Acceleration	1.07	0.677	0.838	1.18	0.680	0.895
	Medium Acceleration	0.974	0.762	0.854	0.972	0.682	0.804
	High Acceleration	1.16	1.17	1.17	1.24	0.941	1.08
	Low Cruise	1.00	0.545	0.694	1.12	0.484	0.698
	Medium Cruise	0.980	0.650	0.793	0.975	0.633	0.778
	High Cruise	0.930	0.934	0.932	1.09	0.900	0.986
	Deceleration	0.829	0.824	0.826	0.813	0.759	0.782
	Dumping				0.990	1.08	1.04
	Equal Weight Avg[b]	1.00	0.794	0.882	1.06	0.757	0.885
	Empirical Weight Avg[c]	1.55	1.00	1.22	1.22	0.731	0.909
CO_2	Idle	1.03	0.832	0.928	1.03	0.854	0.941
	Low Acceleration	0.975	0.880	0.919	1.16	0.902	1.00
	Medium Acceleration	0.968	1.17	1.07	1.15	1.18	1.17
	High Acceleration	1.08	1.29	1.18	0.993	1.34	1.15
	Low Cruise	0.829	0.851	0.841	1.03	1.00	1.01
	Medium Cruise	0.992	0.893	0.935	1.08	0.978	1.03
	High Cruise	0.982	1.03	1.01	1.35	0.912	1.08
	Deceleration	1.35	1.19	1.26	1.23	1.12	1.16
	Dumping				3.15	1.06	1.43
	Equal Weight Avg[b]	1.02	1.07	1.04	1.16	1.07	1.11
	Empirical Weight Avg[c]	1.90	1.16	1.46	1.47	0.877	1.08
PM	Idle	1.50	0.781	1.07	1.43	0.768	1.04
	Low Acceleration	1.02	0.788	0.876	1.24	0.729	0.937
	Medium Acceleration	0.994	0.763	0.860	1.09	0.797	0.930
	High Acceleration	1.19	1.11	1.15	0.924	1.22	1.05
	Low Cruise	1.20	0.806	0.981	0.955	0.839	0.899
	Medium Cruise	0.952	0.644	0.787	0.909	0.797	0.851
	High Cruise	0.957	0.887	0.925	0.783	0.802	0.793
	Deceleration	0.700	1.02	0.872	0.847	1.00	0.928
	Dumping				0.152	1.27	0.815
	Equal Weight Avg[b]	1.03	0.872	0.949	0.916	0.916	0.916
	Empirical Weight Avg[c]	1.81	0.935	1.30	1.05	0.737	0.864

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

- Typically, among the acceleration modes, fuel consumption and emissions increase in order from low to medium to high. For both fuels, an exception is that NO emission rates were approximately the same for both medium and high cruise modes. For petroleum diesel, CO and PM emission rates were approximately the same for these same two modes.
- Typically, among the cruise modes, fuel consumption and emissions increase in order from low to medium to high. The only exception is that for NO emissions on both fuels the emission rates are similar for medium and high cruise modes.

The fuel use and emissions are greater for the loaded vehicles versus the unloaded vehicles. When compared on the basis of modes that are common to loaded and unloaded operations (i.e. all modes except dumping), the average fuel consumption and emissions rates increase by approximately 30 percent for loaded versus unloaded vehicles. On average, the weight of a loaded tandem truck is approximately a factor of 2.4 greater than the unloaded weight.

When comparing fuel consumption and emissions on B20 biodiesel versus petroleum diesel, the following trends are observed:

- On average, the fuel consumption rate increased for both vehicles and for both unloaded and loaded operations. However, the average increase in fuel consumption appears to be greater for loaded operation. The high acceleration and the deceleration modes appeared to be most strongly associated with the increase in fuel use. It is possible that under high power demand, and for heavier vehicle weights, there is a stronger effect of increasing the fuel consumption to compensate for the lower energy density of B20 biodiesel compared to that of petroleum diesel. The overall increase in fuel consumption averaged 10 percent, which is larger than expected.
- The CO_2 emission rate increased, with an overall average increase of 4.2 percent. This is also slightly higher than expected. The increase in average CO2 emission rate was consistently higher for both vehicles and for both loads.
- Average NO emission rates decreased slightly for one vehicle and increased slightly for another, with an overall average decrease of less than one percent, which is not statistically significant. When corrected for humidity, the average change is estimated to be an increase of 6 percent, but this change is also not likely to be significant.
- HC emissions did not change significantly for either vehicle or for either load. The overall average change was insignificant.
- CO emissions appeared to be approximately unchanged for one vehicle and to decrease by approximately 20 percent for the other vehicle. The overall average change was a decrease of 12 percent.
- PM emissions decreased slightly, on average, for one vehicle, and somewhat more substantially for the other vehicle, for an overall average decrease of 7 percent.

As summarized in Table 8-17, the results for the tandem vehicles with Tier 2 engines imply a slight increase in fuel consumption and CO_2 emissions, approximately no change in NO and HC emissions, and small decreases in emissions of PM and CO.

Table 8-17. Percentage Change in Fuel Use and Emissions Comparing B20 Biodiesel to Petroleum Diesel for Tandem Dump Trucks with Tier 2 Engines.

	Tier 2 Tandem Dump Truck		
	Unloaded (%)	Loaded (%)	Average (%)
Fuel Use	6.8	14	10
NO	0 (5.2)[a]	1.2 (6.8)[a]	0.6 (6.0)[a]
HC	-2.4	0.4	-1.0
CO	-12	-12	-12
CO_2	0.8	7.5	4.2
PM	-5.1	-8.3	-6.7

[a]: Applied the NO_x humidity correction factor for diesel engines based on 40 CFR Chapter I Section 86.1342-90 (2003).

8.6 Summary

The previous four sections have individually provided and discussed the results of field measurements for each of four vehicle groups. This section provides an overall summary of the change in fuel consumption and emissions rate associated with switching from petroleum diesel to B20 biodiesel. The average percentage change in fuel consumption and emissions rate is shown in Table 8-18 for each of the four vehicle groups tested.

In general, fuel consumption increased only slightly for B20 biodiesel versus petroleum diesel. As noted earlier, one of the single rear-axle vehicles with a Tier 1 engine towed a trailer, which biases the comparisons for this group. When this one vehicle, number 4743, is excluded, the average change in fuel consumption for this vehicle group is approximately as expected. The results for the other vehicle groups are approximately insignificant. Overall, the results imply a slight increase in fuel consumption, as expected. Similarly, when vehicle 4743 is excluded from the comparison, the results imply an insignificant change in CO_2 emission rates.

In general, the emissions rate of NO, HC, CO, and PM decreased for three out of four vehicle groups, and for one group there was approximately no significant change. The emissions rate of all four of these pollutants decreased significantly for the single rear-axle trucks.

The average NO emissions rate decreased significantly for the single rear-axle trucks, including both Tier 1 and Tier 2 engines. The average NO emissions rate decreased slightly for the tandems with Tier 1 engines and increased slightly for the tandems with Tier 2 engines. However, the latter is not likely to be statistically significant. Therefore, the results imply that NO emissions rate either had no significant change or decreased, depending on the vehicle group. It appears to be the case that the Tier 2 engines had a smaller change in NO emissions rate, on average, than did the Tier 1 engines.

Table 8-18. The Percentage Change in Average Fuel Consumption and Emission Rates by Vehicle Type for B20 Biodiesel Versus Petroleum Diesel.

	Single Rear-Axle Dump Truck		Tandem Dump Truck	
	Tier 1	Tier 2	Tier 1	Tier 2
Fuel Use	19 (2)[a]	-2.9	-0.7	10
NO	-25 (-23)[b]	-6.4 (-9.9)[b]	-24 (-12)[b]	0.6 (6.0)[b]
HC	-36	-17	-35	-1.0
CO	-24	-12	2.6	-12
CO_2	17 (0)[a]	-5.2	0.1	4.2
PM	-14	-18	-2.5	-6.7

[a] Average change when one vehicle, that towed a trailer, was excluded from the comparison.

[b] Applied the NO_x humidity correction factor for diesel engines based on 40 CFR Chapter I Section 86.1342-90 (2003).

Table 8-19. Average Percentage Change in Average Fuel Consumption and Emission Rates for all Four Vehicle Types for B20 Biodiesel versus Petroleum Diesel, for Unloaded and Loaded Vehicles.

	Unloaded	Loaded	Average
Fuel Use	5.6 (1.1)[a]	7.1 (3.0)[a]	6.3 (2.1)[a]
NO	-13 (-8.9)[b]	-14 (-11)[b]	-14 (-10)[b]
HC	-21	-23	-22
CO	-11	-12	-11
CO_2	3.6 (-1.0)[a]	4.4 (0.5)[a]	4.0 (-0.5)[a]
PM	-7.3	-14	-10

[a] Average change when one vehicle, that towed a trailer, was excluded from the comparison.

[b] Applied the NO_x humidity correction factor for diesel engines based on 40 CFR Chapter I Section 86.1342-90 (2003).

The HC emission rates decreased more for the Tier 1 engines than for the Tier 2 engines, on average. For the tandems with Tier 2 engines, the average change in HC emissions rate was insignificant.

For CO emission rates, there is not a clear pattern regarding the change when comparing the two fuels for the different vehicle groups. The greatest percentage decrease was for the smaller trucks with the older engines. The average decrease for the newer vehicles was approximately the same for both the single rear-axle and tandems. The average change in CO emission rate for the older tandems was insignificant.

For PM, there were insignificant to modest reductions in average emissions rates, with the largest decreases occurring for the single rear axle vehicles.

Table 8-19 summarizes the change in average fuel consumption and emission rates when averaged over all four vehicle groups. The average changes in fuel consumption and CO_2 emissions rates imply a slight increase in both. A slight increase is expected, because of differences in the fuel properties, as previously discussed.

The average decrease in NO emissions rate is 10 percent. Data reported elsewhere imply, on average, that NO_x emissions rate increase by approximately 2 percent for B20 biodiesel versus petroleum diesel.

There are at least three possible reasons for the observed decrease in NO emissions rate and why this appears to be different from previously reported comparisons. One is that the distribution of time in different operating modes is different for the real world duty cycles versus the laboratory dynamometer cycles. The data obtained in this study imply that the ratio of NO emissions rate on B20 biodiesel to petroleum diesel depend on the operating mode. For example, low cruise tends to produce higher NO emissions rate on B20 biodiesel than does the high acceleration mode, whereas high acceleration, on average, had a lower NO emissions rate for B20 biodiesel versus petroleum diesel for all four vehicle groups. Thus, driving cycles that have more emphasis on modal activity similar to low cruise might imply higher NO on B20 biodiesel, whereas those with less emphasis on this type of activity might imply lower NO emissions rate. The duty cycles of this work were measured in the field and thus are representative of real world in-use activity patterns.

Measurements were made of NO but not of total NO_x. It could be the case that the ratio of NO_2 to NO varies either by operating mode, for different fuels, or for combinations of both. The PEMS used in this project does not have a capability to measure NO_2 or total NO_x. However, it could be possible to obtain supplemental equipment to make measurements of NO and total NO_x for comparison with the PEMS measurements. Data in the literature imply that engine-out emissions rate of NO_x typically are comprised of only 5 to 8 percent, on average, of NO_2, with the majority of the NO_x in the form of NO_2. However, there are little data available at this time to characterize the ratio of NO_2 to NO_x as a function of operating mode.

A third consideration is that others have reported that NO_x emissions rate tend to decrease for B20 biodiesel versus petroleum diesel if the biodiesel conforms to the applicable ASTM standard. However, if the glycerin content of biodiesel exceeds the standard, apparently NO_x emissions rate may increase. The observation in this study of a reduction in average NO emission rates could imply that the biodiesel fuel used here has low glycerin content; otherwise, an increase in NO emission rate would be expected.

The observed decrease in NO emission rates was slightly higher for loaded vehicles than for unloaded vehicles, suggesting that vehicle weight influences the emission rates differently for the two fuels.

The average HC emission rates were decreased by 22 percent for B20 biodiesel versus petroleum diesel. This average change is comparable to the 21 percent decrease reported in reported in Table 4-9 based upon analysis of dynamometer data compiled by EPA. HC emission rates appeared to consistently decrease for all operating modes for those vehicle groups in which a significant overall average decrease occurred. These groups include single rear-axle vehicles with Tier 1 engines and tandem vehicles with Tier 1 engines. This implies that the change in HC emission rates would be less sensitive to the duty cycle than appears to be the case for NO. In general, HC emission rates are less variable than those of other pollutants, which also implies that the emissions rates are more consistent across operating modes for a given fuel.

The average CO emission rate decreased by 11 percent, which is the same relative change estimated based upon data compiled by EPA as shown in Table 4-9. There appears to be significant variability across vehicles and operating modes regarding the percentage change in average emissions rate on an operating mode- and vehicle-specific basis. However, it is typically the case that the percentage decrease in average emissions rates for many of the modes significantly outweighs more modest increases, if any, that occur for some of the modes. For example, on average across all vehicle groups, the idling, medium acceleration, low cruise, medium cruise, and deceleration modes have decreases in emissions rate, whereas other modes have approximately the same average emissions rate on both fuels. The difference in CO emissions rate between the two fuels is not as sensitive to the proportion of different operating modes in a duty cycle as is the case for NO.

The average change in PM emission rate was a decrease of 10 percent, which is comparable to the estimate based upon dynamometer data that is shown in Table 4-9. When averaged over the four vehicle groups, PM emissions rates were lower for B20 biodiesel versus petroleum diesel for the idle, low cruise, medium cruise, high cruise, and deceleration modes for both unloaded and loaded vehicles, and for the dumping mode for loaded vehicles. PM emissions rate tended to be higher on B20 biodiesel for the acceleration modes. Thus, the overall average change in PM emissions rate could have some sensitivity to the proportion of the operating modes in a given duty cycle. However, it is clear from these data that the average decrease in the overall PM emission rate is based upon representative duty cycles for these types of vehicles.

The Appendix provides additional data and summaries that facilitate many other types of comparisons. For example, the average fuel consumption and emission rates for each of the four vehicle groups are compared in Table A-1. In general, the tandems have higher mass per time fuel consumption and CO_2 emission rates than the single rear axle-vehicles, as expected. The average mass per time emission rates of HC and PM are also higher for tandems than for single rear-axle trucks. For NO, the average mass emission rates are higher for the tandems with Tier 1 engines compared to the single rear-axle vehicles with Tier 1 engines, but the average emission rates are approximately similar for both single rear-axle and tandem trucks with Tier 2 engines. For CO, the emission rates of the tandems are lower than for single rear axle for the Tier 1 engines, but higher for the Tier 2 engines.

The Tier 2 engines typically have approximately the same or lower average emission rates compared to Tier 1 engines, for a given size of vehicle, for NO and PM regardless of vehicle load or fuel type.

Other information in the Appendices includes:

- Distribution of time, distance, fuel consumption, and total emissions by operating mode for each vehicle and fuel and for loaded and unloaded operation. These data were used to prepare many of the figures shown in this chapter.
- Sample size for each vehicle, operating mode, and fuel for unloaded and unloaded

operations. The same size refers to the number of seconds of data collected. Typically, a total of approximately 14,000 (3.9 hours) to 18,000 (5.0 hours) seconds of data were collected on a given test day.

- Average speed for each operating mode for a given vehicle, load, and fuel. For example, the following average speeds were typically observed for a given vehicle type and load:
  - Idle: 0 mph (by definition)
  - Low acceleration: 7.4 to 10.7 mph
  - Medium acceleration: 30.8 to 35.4 mph
  - High acceleration: 36.1 to 44.3 mph, but in some cases as low as 30.8 mph or as high as 48.9 mph
  - Low cruise: 8.6 to 14.4 mph
  - Medium cruise: 37.2 to 40.5 mph
  - High cruise: 47.6 to 54.7 mph
  - Deceleration: 21.2 to 31.5 mph
  - Dumping: approximately 0 mph
- Standard deviation of the mass per time fuel consumption and emission rates by vehicle, load, mode, and fuel
- Relative standard error (RSE) of the mass per time fuel consumption and emission rates by vehicle, load, mode, and fuel. The RSE is the standard deviation divided by the mean and the square root of the sample size. The RSE provides an indication of the uncertainty in the data associated with statistical random sampling error. The RSE typically is between 1 and 4 percent for most of the mass per time estimates of fuel consumption and emissions for an operating mode.
- Fuel consumption and emission rates on a mass per mile basis for all operating modes except idle and dumping, for which no distance was driven. Although on a mass per time basis, typically the high acceleration mode has the highest fuel consumption and emission rates, on a mass per mile driven basis, modes such as low acceleration and low cruise had the highest rates. This is because the average speed of these two modes are substantially lower than for other operating modes (excluding idle and dumping), and thus the emissions that take place during these operating modes are associated with a smaller proportion of miles driven than for other modes.
- Emission rates on a mass per gallon of fuel consumed basis. The relative range of variation in emission rates on a mass per gallon basis tends to be less than that on a mass per time basis, but the relative range of variation is not negligible. For example, for unloaded tandems with Tier 1 engines, the ratio of the highest to the lowest modal emission rate on a per gallon basis is 2.2 for NO, 5.2 for HC, 4.4 for CO, and 4.3 for HC. Because most of the carbon in the fuel is emitted as CO_2, the per gallon emission rate of CO_2 is approximately constant with a typical value of 10 kg CO_2 per gallon of fuel. For the other pollutants, the emission rates on a per gallon basis tend to be highest for idle. However, the amount of fuel consumed during idling is smaller than for other modes, and the total contribution of idling to overall emissions is relatively small, as previously discussed.
- Comparison of the average mass per mile fuel consumption and emission rates for each

of the four vehicle groups. These comparisons demonstrate that: (a) the tandems have higher fuel consumption than the single rear axle trucks; (b) the average NO emissions for the Tier 2 versus Tier 1 engines are lower for tandems and approximately similar for single rear axle trucks; (c) PM emissions are lower for both vehicle sizes, and for both unloaded and unloaded operations, when comparing Tier 2 versus Tier 1 engines; (d) for CO, the emissions tend to go down for single rear axle vehicles but increase for tandems when comparing Tier 2 versus Tier 1 engines; and (e) emissions of HC are approximately twice as high for the tandems as for the single rear axle vehicles.

- Comparisons of the average mass per gallon emission rates for each of the four vehicle groups. The comparisons show that: (a) NO emissions are a per gallon basis are typically lower for the tandems than the single-rear axle; (b) NO emissions tend to decrease for the Tier 2 versus Tier 1 engines, except for single rear axle vehicles fueled with B20 biodiesel; (c) average HC emissions rates vary from approximately 3 to 10 g/gallon and tend to be higher for tandems; however, there is not a consistent trend when comparing Tier 2 versus Tier 1 engines; (d) average CO emissions rates vary from approximately 18 to 26 g/gallon, and are approximately similar among the vehicle groups except for single rear-axle vehicles with Tier 1 engines, for which the rate is approximately 36 g/gallon; (e) for PM, the average emission rates are lower for Tier 2 versus Tier 1 engines; furthermore, although the rates are higher for tandems versus single rear-axle trucks with Tier 1 engines, the rates are lower for tandems versus single rear-axle trucks for Tier 1 engines, implying a greater reduction in PM for Tier 2 versus Tier 1 engines for the tandems; and (f) the effect of vehicle load is typically less pronounced for emission rates on a mass per gallon basis than on a mass per time or mass per mile basis.

- Ratios of emission rates on a mass per gallon of fuel consumed basis for B20 biodiesel versus petroleum diesel. On average for all 12 tested vehicles, the emissions of each pollutant decrease as follows: 13 percent (corrected) for NO; 28 percent for HC, 21 percent for CO, and 24 percent for HC. CO_2 emissions are approximately unchanged. The decrease in emissions is approximately four to nine percentage points higher for loaded versus unloaded vehicles. The average decrease is substantially higher for vehicles with Tier 1 engines than for vehicles with Tier 2 engines. For example, corrected NO emissions decrease by 24 percent, on average, for Tier 1 engines and only 2 percent, on average, for Tier 2 engines.

- Appendix II contains graphs illustrating the ratio of fuel use and emissions rates on B20 biodiesel versus petroleum diesel by driving mode and vehicle type, the ratio of fuel use and emissions rates for loaded versus unloaded vehicles, the mass per time emission rates by vehicle type, operating mode, and fuel for loaded vehicles, ratio of NO corrected emission rates on a mass per time basis by vehicle group and operating mode, average percentage increase in fuel use and emission rates for loaded versus unloaded vehicles and ratio of average fuel use and emission for B20 biodiesel versus petroleum diesel by vehicle type for both unloaded and loaded vehicles. Many of these results are summarized elsewhere.

- On average, loaded vehicles have mass per time fuel consumption and emission rates that are 26 percent higher for single rear axle vehicles regardless of fuel type and that are 30 to 35 percent higher for tandems depending on the fuel type.

In the next section, as a means for evaluating the data collected in this study, the emission rates measured during the field study are compared with engine dynamometer data.

9.0 COMPARISON OF DATA COLLECTED IN THE FIELD STUDY TO PUBLISHED DYNAMOMETER DATA

The purpose of this chapter is to compare the data collected in the field study of this project with published dynamometer data in order to determine the key similarities and differences, and to evaluate any key differences with respect to the duty cycles of the field study versus the test cycles for the dynamometer-based measurements. This type of comparison is intended to evaluate the credibility of the field data.

9.1 Criteria for Choosing Data Sources

The dynamometer data selected for comparison to the data collected in the field study are described in detail in Chapter 4. The dynamometer data are for 28 engines ranging from 150 to 450 horsepower and rated engine speeds of 1,600 to 3,000 RPM. These engines were tested on an engine dynamometer, and emissions were reported in units of grams of pollutant emitted per brake horsepower hour. As summarized in Tables 4-4 and 4-8 for petroleum diesel and B20 biodiesel, respectively, these engines were tested on a number of test cycles. However, the test cycles common to both fuels include the FTP and the hot-start FTP. Typically, 14 to 16 engines were tested for petroleum diesel on these cycles, and only 8 engines were tested for B20 biodiesel. Because the FTP is a transient test, these dynamometer test results may tend to be more realistic than for other tests based upon steady state modes. However, the activity pattern of the engine dynamometer FTP is not identical to that observed in the field during this study.

The emissions data from the dynamometer tests is based upon one data point per engine. Each data point represents the average emissions for one engine. The variability in the emission rates between engines represents the inter-engine variability in average emissions over the test cycle. In contrast, the data collected during the field study are second-by-second data. The field study data, therefore, represent both intra-engine variability over time for a given engine, as well as inter-engine variability when comparing results for different vehicles. Furthermore, the field study data are based upon testing of the entire vehicle, including the engine and chassis. These differences must be borne in mind when comparing data from the two data sources.

9.2 Units Conversion to Enable Comparisons

For this comparison, we made use of a conversion factor that can be found in the Emissions Factors for Locomotives, EPA420-F-97-051, to convert gram/sec to g/bhp-hr for each pollutants. This conversion equation was developed especially for this project.

$$ER = \frac{EF \times r \times C}{m_{fuel} \times BSFC} \qquad (9\text{-}1)$$

Where,

ER = Emission rate, g/bhp-hr
EF = Emission factor from PEMS, g/sec
r = Fuel density, 0.84 g/ml for conventional diesel fuel
C = Conversion factor, 3,785 ml/gallon
m_{fuel} = Fuel flow, g/sec

BSFC = Brake Specific Fuel Consumption from EPA420-F-97-051, 20.8 bhp-hr/gal

Using Equation 9-1, the emission rates measured during the field study were converted to a g/bhp-hr basis. Because the dynamometer data are for an entire test cycle, the comparison to the field study data is on the basis of all of the data collected over the entire duty cycle. These data are summarized in Table 9-1 for measurements based on petroleum diesel and in Table 9-2 for measurements made based on B20 biodiesel. For each of four pollutants, including PM, NO, CO, and HC, data are given for four vehicle categories.

The data are summarized in terms of the mean emission rate, and 95 percent probability range of all of the second-by-second data collected among all of the vehicles tested in a group. For example, in Table 9-1, there are 66,960 seconds of data for single rear-axle vehicles with Tier 1 engines, because a total of 4 vehicles were tested. For PM emissions from this category of vehicles, the mean emission rate is 0.038 g/bhp-hr and the 95 percent probability range is 0.015 to 0.114 g/bhp-hr. The range is asymmetric with respect to the mean because emission rates must be non-negative and because there is a substantial amount of both intra-vehicle and inter-vehicle variability. Thus, the distribution of emission rates for the second-by-second data is typically positively skewed.

9.3 Comparison of PEMS Data to Existing Data

The data summarized in Tables 9-1 and 9-2, based on the field study, are compared with engine dynamometer data that are given in Tables 4-4 and 4-8. In Chapter 4, the mean emission rates were estimated based upon evaluation of inter-engine variability for typically 8 to 16 engines tested on the FTP and hot-start FTP cycles. The methodology for comparison of the dynamometer and PEMS data is illustrated first with a detailed example, followed by a summary of results for other cases.

For engines fueled with petroleum diesel, the average PM emissions for the FTP dynamometer test was 0.17 g/bhp-hr, with a 95 percent probability range for inter-test variability of 0.06 to 0.48 g/bhp-hr. From the PEMS data, the average emission rate ranged from 0.026 to 0.201 g/bhp-hr, depending on the vehicle group. Thus, in one case, the mean emissions based upon PEMS data was comparable to that from the dynamometer data, but in other cases the mean emissions based upon the PEMS data were significantly lower than those based upon dynamometer data. This result was also true when comparing PEMS data to the hot-start FTP data.

For one vehicle group, the comparison of PEMS versus dynamometer data indicates substantial agreement. For example, for tandems with Tier 1 engines, the mean emission rate is 0.20 g/bhp-hr, which is similar to the dynamometer means of 0.17 from the FTP and 0.21 from the hot-start FTP. The 95 percent probability range of the PEMS data is 0.009 to 0.943 g/bhp-hr, which encloses the 95 percent probability range of the dynamometer data. In this case, it is expected that the PEMS data should typically produce a wider range than the dynamometer data. The PEMS data are based upon second-by-second data. There is typically much more variation in emissions on a second-by-second basis than when averaging over an entire test cycle. Furthermore, the PEMS data include a combination of intra-engine and inter-engine variability, whereas the dynamometer data only include intra-engine variability.

Table 9-1. Summary table of g/bhp-hr basis, fueled with petroleum diesel fuel in heavy duty diesel vehicles.

Pollutant	Cycle/Vehicle Type		Mean (g/bhp-hr)	95% Probability Range (g/bhp-hr)		Standard Deviation (g/bhp-hr)	Number of Data
				Lower (2.5%)	Upper (97.5%)		
PM	Tier 1	Single Axle	0.038	0.015	0.114	0.035	66,960
		Tandem	0.201	0.009	0.943	0.351	71,858
	Tier 2	Single Axle	0.043	0.015	0.213	0.088	39,183
		Tandem	0.026	0.009	0.075	0.018	39,840
NO	Tier 1	Single Axle	8.98	2.81	20.3	5.43	66,960
		Tandem	10.5	2.62	30.4	8.74	71,858
	Tier 2	Single Axle	7.16	2.59	19.1	4.45	39,183
		Tandem	5.53	1.28	12.2	2.98	39,840
CO	Tier 1	Single Axle	2.42	0.462	7.82	2.56	66,960
		Tandem	1.51	0.231	8.77	3.43	71,858
	Tier 2	Single Axle	2.29	0.120	5.84	1.78	39,183
		Tandem	1.76	0.273	5.17	1.56	39,840
HC	Tier 1	Single Axle	0.469	0.043	1.77	0.640	66,960
		Tandem	1.17	0.038	3.28	1.00	71,858
	Tier 2	Single Axle	0.644	0.046	2.40	0.859	39,183
		Tandem	0.510	0.024	2.06	0.801	39,840

Table 9-2. Summary table of g/bhp-hr basis, fueled with soy-based B20 fuel in heavy duty diesel vehicles.

Pollutant	Cycle/Vehicle Type		Mean (g/bhp-hr)	95% Probability Range (g/bhp-hr)		Standard Deviation (g/bhp-hr)	Number of Data
				Lower (2.5%)	Upper (97.5%)		
PM	Tier 1	Single Axle	0.041	0.012	0.114	0.021	55,290
		Tandem	0.060	0.001	0.194	0.063	71,195
	Tier 2	Single Axle	0.042	0.008	0.187	0.068	21,364
		Tandem	0.024	0.010	0.068	0.021	39,452
NO	Tier 1	Single Axle	6.31	1.54	16.5	4.48	55,290
		Tandem	9.35	0.209	65.8	20.5	71,195
	Tier 2	Single Axle	6.78	1.35	25.3	8.42	21,364
		Tandem	4.59	1.13	12.8	3.80	39,452
CO	Tier 1	Single Axle	2.85	0.166	15.3	6.12	55,290
		Tandem	2.24	0.025	20.1	5.68	71,195
	Tier 2	Single Axle	1.66	0.129	7.55	2.88	21,364
		Tandem	1.21	0.224	3.19	0.921	39,452
HC	Tier 1	Single Axle	1.15	0.094	7.22	3.00	55,290
		Tandem	0.939	0.025	7.90	2.32	71,195
	Tier 2	Single Axle	0.490	0.029	2.57	0.982	21,364

		Tandem	0.413	0.018	1.71	0.610	39,452

For the other three vehicle groups, the PM emissions based upon the PEMS data are at or below the low end of the dynamometer data. This result is not surprising for Tier 2 engines, since the dynamometer testing was based upon Tier 1 or older engines. Thus, it is expected that the PM emission rate should be lower for the Tier 2 engines than for the engines used in the dynamometer tests.

For NO emission rates for petroleum diesel fueled vehicles, the PEMS data had higher average values than the dynamometer data, and the 95 percent probability ranges were from approximately 2.6 to 30 g/bhp-hr for three of the groups, and from 1.3 to 12 g/bhp-hr for the Tier 2 engines on tandems. It is likely that the higher NO emissions observed in the field can be attributed to differences in the duty cycle. For example, the duty cycles typically featured a significant amount of time in medium acceleration, high acceleration, medium cruise, and high cruise modes, which tend to have higher NO emission rates than for other modes. The FTP test generally represents milder operating conditions. The wider range of variability in emissions from the PEMS data is associated with the shorter averaging time, the incorporation of both intra- and inter-engine variability, and differing emphasis on operating modes that would tend to produce a wider variation in emissions than might be the case for the FTP.

For CO emission rates for petroleum fueled vehicles, there was general agreement regarding the mean emission rates. As noted in Chapter 8, the average CO emissions tend to be less sensitive to the proportion of time spent in different operating modes, and thus it is not surprising that there is more agreement for CO than for NO when comparing PEMS and dynamometer data. The average emission rates from the FTP tests were 1.5 to 1.6 g/bhp-hr, with a range of approximately 0.5 to 3.1 g/bhp-hr. For the PEMS data, the average emission rates varied from 1.5 to 2.4 g/bhp-hr, which is within the range of the dynamometer data. The 95 percent probability ranges of the PEMS data were much wider than those of the dynamometer data, with a typical range of approximately 0.1 to 8.8 g/bhp-hr. The wider range is expected, for reasons discussed above.

For petroleum diesel, there is approximate agreement in the HC emission rates when comparing dynamometer data and PEMS data. The mean emission rates based upon the FTP tests are approximately 0.3 g/bhp-hr, with a typical range of 0.1 to 1.3 g/bhp-hr. For all four of the vehicle groups, the average HC emission rate is within the range of the dynamometer data. The range of variability in the PEMS data tends to be larger, for reasons previously discussed. The general concordance between the PEMS and dynamometer data for HC is somewhat surprising because the PEMS using NDIR for the HC measurement. NDIR does well at responding to straight-chain hydrocarbons, but the response decreases for more complex HC molecules. Therefore, it is expected that the HC measurements from NDIR might be biased lower than the true HC emissions estimates. However, the general agreement between the NDIR measurements of the PEMS and the dynamometer measurements suggests that possibly this bias might not be large for these types of vehicles, engines, and fuel.

For B20 biodiesel fuel, the PM emission rate for the tandems with Tier 1 engines appear to be comparable to the dynamometer data, with a similar mean value. The PM emission rates for the other vehicle groups tend to be lower. It would be expected to have lower emission rates for the Tier 2 engines than for the engines in the dynamometer database. Thus, in general, the comparison of the two data sets appears to be reasonable and is also similar to the comparison described above for diesel fuel.

The NO emission rates for the PEMS data tend to be higher than those for the dynamometer data for B20 biodiesel. The comparison is qualitatively similar to that for petroleum diesel. Of the various pollutants, NO emission rates appear to be the most sensitive to the distribution of operating modes within a duty cycle or test procedure, and thus would be expected to consistently have the largest differences when comparing these two different types of data.

CO emissions tend to be higher for the PEMS data than for the dynamometer data for the case of B20 biodiesel fuel. This may be in part because there was relatively little variability in CO emissions among the 8 engines tested on the dynamometer. A qualitatively similar result was found for the comparison of HC emissions, which were higher on average for the PEMS data than for the dynamometer data. However, for both CO and HC, the 95 percent probability ranges of the PEMS data overlapped with those for the dynamometer data; typically, the range of the PEMS data encloses the range of the dynamometer data. In the sense that there is overlap in the ranges of the two data sets, there is qualitative agreement even though the means do not necessarily agree.

9.4 Conclusion

For petroleum diesel, the comparison of PEMS and dynamometer data suggests general agreement for CO and HC, higher NO emissions, and lower PM emissions. The higher NO emissions might be attributable to differences in duty cycles. The lower PM emissions might be attributable to the effectiveness of Tier 2 engines in reducing emission rates relative to older engines.

For B20 biodiesel, the comparison of PEMS and dynamometer data suggest that the Tier 2 engines have lower PM emission rates than the older engines in the dynamometer data base, as expected, that NO emissions tend to be higher for the real world duty cycles than for the FTP test, and that the CO and HC emissions have approximately agreement regarding the ranges of values between the two data sets.

Thus, the comparison of PEMS data to dynamometer data provides some confidence that the PEMS data are reasonable with respect to absolute emission values. For example, despite the fact that the HC measurement is based on NDIR, and thus might be biased low, the HC emission rates obtained from the PEMS data are typically as large or larger than those from the dynamometer data. The PEMS measurements for NO are based upon NO only, whereas the dynamometer measurements are based upon both NO and NO_2. However, the fact that the PEMS estimates of NO emissions (reported on an equivalent mass basis in terms of NO_2) are at least as large, and typically larger, than for the dynamometer data, suggests that the vast majority of NO_x emissions are in the form of NO. However, this assumption could be verified based on additional measurements.

Diesel engines are typically considered a significant emission source of PM and NO_x, and emissions of CO and HC are generally lower than for other mobile sources, such as those fueled with gasoline. There was approximately qualitative agreement in the emission rates for CO and HC when comparing the PEMS and dynamometer data. Overall, the PEMS data compare reasonably well and appropriately to the engine dynamometer data.

10.0 FINDINGS AND RECOMMENDATIONS

The objectives of this project were to: (1) characterize the baseline real-world in-use emissions of selected heavy duty vehicles, including those fueled with B20 biodiesel, during normal duty cycles; (2) characterize the episodic nature of emissions and fuel use; (3) identify factors responsible for variability in emissions and fuel use; and (4) developed recommended strategies for reducing fuel use and emissions.

Based upon a literature review, some of the key factors influencing vehicle emissions were found to be engine design, vehicle weight, vehicle load, vehicle activity patterns (including speed, acceleration, and operating modes), ambient conditions, and fuel properties. Some of the key fuel properties that might influence emissions include fuel density, cetane number, elemental composition, distillation range, aromatic content, heating value, and viscosity. In addition, some fuel properties might influence handling, such as cloud point and pour point. Petroleum diesel and B20 biodiesel differ with respect to many of these properties. The results of the literature review suggested that key factors to consider in design of a field study include vehicle weight, engine design, load, fuel, and operating mode. Furthermore, ambient conditions should be taken into account when comparing NO emission rates measured on different days.

A variety of methods can be used to measure vehicle emissions. These include dynamometer tests, tunnel studies, remote sensing, and on-board instrumentation. The latter was selected as the preferred method because it enables characterization of real world duty cycles and simultaneous measurement of emissions that occur during actual use.

The available data for comparing emission rates between B20 biodiesel and petroleum diesel are based upon engine dynamometer measurements. The U.S. EPA has compiled a database of this type of data. Based upon these data, the emission rate of NO_x is estimated to increase by 2 percent, whereas the emission rates of CO, HC, and PM are estimated to decrease by 11, 21, and 10 percent, respectively. However, these data are based on test procedures that are not likely to representative of real world duty cycles. Furthermore, these data are average emissions for an entire test cycle, and do not enable evaluation of the episodic nature of fuel use and emissions. Thus, there was a need for a field study of in-use emissions on a second-by-second basis during actual duty cycles.

Key factors in developing a study design for field data collection include vehicle selection, duty cycles and scheduling, driver selection, site and route selection, and fuel selection. Vehicle selection took into account two vehicle sizes, including single-rear axle dump trucks of 33,000 gross vehicle weight (GVW) and tandem dump trucks of 50,000 GVW. The study design was based upon collecting one operating shift of data for each vehicle for each of two fuels, including B20 biodiesel and petroleum diesel. The selection of sites, routes, and duty cycles was based on the duty requirements of NCDOT. The drivers of the vehicles were assigned by NCDOT to conduct normal tasks for delivery of materials to sites. Thus, the deployment of the portable emissions measurement system (PEMS) was conducted in such a manner as to observe typically duty cycles during actual operation of the vehicles.

The field study produced a substantial amount of second-by-second data regarding vehicle activity, engine data, fuel use, and emissions. In fact, there are over one-third of a million seconds of data. As a critical part of quality control, steps were taken to carefully review the data prior to any analysis in order to identify any problems in the data and either correct or remove the errant data. In general, diagnostic checks of the data identified particular types of problems only infrequently. Once a quality assured data base was developed, these data were processed in order to estimate average fuel consumption and emission rates on a modal basis. Furthermore, a methodology for validating the fuel use estimates of the PEMS was developed based upon comparison to the amount of fuel consumed as documented by NCDOT.

The main results of the field study measurements are the following:

- There is substantial variability in fuel use and emission rates by operating mode regardless of whether these are analyzed in terms of mass per time, mass per mile driven, or mass per gallon of fuel consumed. The mass per time approach was the most useful for this work because it enabled evaluation of the contribution of each second of operation in a given mode to the total fuel use and total emissions. However, for purposes of developing emission inventories in the future, NCDOT may find that the mass per gallon of fuel consumed emission factors are more useful in that the total amount of fuel consumed is easier to measure and document than the amount of time spent or the distance driven.
- There are extensive data from this study regarding the distribution of operating modes for a typical duty cycle with respect to time, distance, fuel consumption, and emissions. These data can be used to improve emissions inventories in combination with the modal emission factors by more appropriately weighting the modal emission rates.
- The baseline real-world in-use emissions of a selected set of diesel trucks were characterized based upon PEMS measurements during normal duty cycles. These data were partially validated with respect to fuel consumption and were compared with engine dynamometer data. These consistency checks provide some degree of confidence regarding the reasonableness of the PEMS data.
- The episodic nature of fuel use and emission rates was confirmed based upon comparison of the average emission rates for different operating modes. For example, on a mass per time basis, there was typically a factor of 4 to 20 when comparing the mode with the highest rate to the mode with the lowest rate. In many cases, the high acceleration mode had the highest mass per time rate and the idle mode had the lowest mass per time rate, but there are some exceptions depending on the pollutant.
- Factors that were responsible in the observed variability in fuel use and emissions include: operating mode, vehicle size, engine type, vehicle weight, and fuel. The role of operating mode is summarized above. Vehicle size and weight clearly influenced fuel use and emissions. Fuel use and CO_2 emissions increase with vehicle size and weight. The emissions of other pollutants typically, but not always, increased by size and weight.
- In some cases, the type of engine clearly had a significant role. In particular, NO and PM emission rates were typically lower for Tier 2 engines than for Tier 1 engines.
- Vehicle load leads to an increase in fuel use and emissions for a given vehicle on an individual basis or for groups of vehicles on an average basis. For the smaller single rear-axle vehicles, there was approximately a 26 percent increase in fuel use and emissions associated with an averaging doubling of vehicle weight. For the larger tandems, the vehicle weight with a load increases by approximately 140% and produces an increase in average fuel use and emission rates of 30 to 35 percent.

- The emission rates on B20 biodiesel were typically lower than those for petroleum diesel for NO, CO, HC, and PM. The finding for NO is somewhat different than that based upon engine dynamometer data reported by EPA, but an analysis of average emission rates by operating mode suggests that the average NO emission rate for a duty cycle is sensitive to the proportional contribution of each mode to the total. Therefore, a finding is that whether NO emissions appear to increase or decrease when comparing the fuels depends, at least on part, on what duty cycles are used for making the comparison.
- For CO, HC, and PM, the average percentage change in emission rates from the field study was comparable to that estimated based upon data reported by EPA.

Based upon the results of the study, the following recommendations are made:

- The emissions of greatest concern from diesel trucks are NO_x and PM, particularly because this type of emission source tends to have a higher emission rate for these pollutants than other sources and because these two pollutants contribute significantly to ambient air qualities that are governed by the National Ambient Air Quality Standards (NAAQS). Therefore, it is recommended that owners and operators of fleets of these types of emission sources characterize the emission rates and the emission inventories for their fleets, using real-world representative data where possible.
- It is clear from the comparison of PEMS data to dynamometer data that, while there is some consistency or comparability, the former can lead to estimates of emissions that are higher than those obtained from the latter at least in part because real world duty cycles are more challenging than the test cycles used for dynamometer testing, and because the former are based upon testing of the entire vehicle and not just the engine. Thus, the collection and interpretation of real-world in-use data for duty cycles, as well as for emissions, is recommended for other significant categories of vehicles aside from single rear-axle and tandem dump trucks.
- Similarly, the difference in results when comparing B20 biodiesel versus petroleum imply that different results can be obtained depending in part on the duty or test cycle, further emphasizing the need for characterization and use of realistic duty cycles when making estimates and comparisons of emissions.
- The findings that average emission rates were reduced when vehicles were fueled with B20 biodiesel versus petroleum diesel suggests that there is a benefit to the use of biodiesel fuel in terms of emissions that occur within the airsheds where the vehicles operate. Thus, the substitution of B20 biodiesel for petroleum diesel should be evaluated as an option for reducing tailpipe emissions especially in airsheds where attainment of the NAAQS for NO_2 and PM may be of concern.
- Other factors that influence vehicle emissions, such as vehicle load and operating mode, provide insight into situations that can produce high emissions. For example, the highest emission rates would be expected to occur for a vehicle that is in medium or high acceleration and carrying a load. To the extent that the vehicle duty cycle could be modified to accommodate extenuating circumstances, such as to manage or reduce emissions on a day that might be subject to an exceedence of the NAAQS for NO_2 or PM, an effort could be made to moderate acceleration rates in order to reduce the total emissions for a duty cycle. However, on a day when it is unlikely that an exceedence of

the NAAQS might occur, such measures would be unnecessary.

- Although the trucks tested in this study spent a significant amount of time idling, the total fuel use and emissions associated with idling was a small fraction of the total fuel use and emissions for the entire duty cycle. Nonetheless, on a mass per gallon of fuel consumed basis, the emission rate during idling can be relatively large. Therefore, consideration could be given to reducing fuel use and emissions by reducing the amount of time spent idling. For example, if it can be predicted that the truck will sit idle for an extended period of time, then guidelines could be developed regarding when and for how long to shut down the engine.

Overall, all of the key project objectives are satisfied based upon the findings and recommendations of this study.

Any study has some limitations that could motivate future work to expand the scope of the analysis or to apply improved methods. A few limitations of this study imply recommendations for future work:

- This study did not address the life cycle emissions associated with production and distribution of either B20 biodiesel or petroleum diesel. Thus, although the tailpipe emissions at the location of end-use of the fuel may be lower for B20 biodiesel, this study does not establish whether the life cycle emissions are lower or the geographic and temperal scales of emissions associated with fuel production and distribution.
- This study was based upon measurement of NO. In future work, it would be appropriate to measure the ratio of NO to total NO_x to verify whether the findings here for NO are fully applicable to total NO_x. This could be done either by adding instrumentation during field measurements to measure total NO_x or NO_2, or by using the PEMS simultaneously with a dynamometer in order to compare both measurement systems.
- The overall vehicle sample size of 12 is relatively small compared to the in-use fleet. Furthermore, the sample size of only two Tier 2 tandem and two Tier 2 single rear-axle vehicles, including among the 12 vehicles tested, is small. Thus, it is appropriate to consider expanding data collection to a larger number of vehicles.
- This study did not consider occupational exposures to emissions, especially during idling. The benefits of shortening or avoiding long periods of idling with respect to human occupational exposures may be of importance, in addition to the relatively small benefits of reductions in total fuel use and total emissions. The effect of reducing idling emission on human exposures could be evaluated in future work.

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Appendix I

List of Tables

Table A-1. Summary of Fuel Consumption and Emission Rates on a Per Time Basis by Driving Mode, Vehicle Type, and Load for Petroleum Diesel

	Driving Mode[a]	**Unloaded**				**Loaded**				**Ratio**[b]			
		Single Axle		Tandem		Single Axle		Tandem		Single Axle		Tandem	
		Tier1	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**
Fuel (g/sec)	Idle	0.259	0.279	0.298	0.388	0.280	0.301	0.315	0.401	1.08	1.08	1.06	1.03
	Low Acceleration	1.33	1.66	2.84	2.63	1.96	1.93	3.68	3.60	1.47	1.16	1.30	1.37
	Medium Acceleration	3.52	3.28	4.81	5.02	4.61	4.24	6.19	7.10	1.31	1.29	1.29	1.41
	High Acceleration	4.68	4.01	5.45	6.56	5.43	4.67	6.64	8.06	1.16	1.16	1.22	1.23
	Low Cruise	0.873	1.22	2.15	2.53	1.31	1.42	3.28	2.88	1.50	1.16	1.53	1.14
	Medium Cruise	2.02	2.36	3.49	4.49	2.96	3.76	5.29	6.17	1.47	1.59	1.52	1.37
	High Cruise	4.17	3.53	3.86	5.58	4.81	4.04	5.28	7.24	1.15	1.14	1.37	1.30
	Deceleration	1.17	1.63	1.82	2.39	1.37	1.82	2.94	3.08	1.17	1.12	1.62	1.29
	Dumping					1.30	1.04	1.19	1.61				
	Equal Weight Avg[c]	2.25	2.25	3.09	3.70	2.67	2.58	3.86	4.46	1.19	1.15	1.25	1.21
	Empirical Weight Avg[d]	1.18	1.53	1.50	2.62	1.96	1.32	3.34	4.56	1.66	0.86	2.23	1.74
NO_x (g/sec)	Idle	0.018	0.013	0.019	0.021	0.019	0.014	0.021	0.023	1.06	1.08	1.11	1.10
	Low Acceleration	0.058	0.063	0.093	0.061	0.086	0.080	0.132	0.079	1.48	1.27	1.42	1.30
	Medium Acceleration	0.128	0.119	0.166	0.103	0.175	0.172	0.219	0.145	1.37	1.45	1.32	1.41
	High Acceleration	0.174	0.151	0.213	0.124	0.199	0.180	0.293	0.146	1.14	1.19	1.38	1.18
	Low Cruise	0.042	0.038	0.062	0.045	0.059	0.045	0.099	0.062	1.40	1.18	1.60	1.38
	Medium Cruise	0.076	0.068	0.116	0.068	0.115	0.107	0.205	0.103	1.51	1.57	1.77	1.51
	High Cruise	0.115	0.091	0.172	0.063	0.139	0.127	0.256	0.091	1.21	1.40	1.49	1.44
	Deceleration	0.045	0.043	0.067	0.041	0.057	0.056	0.125	0.049	1.27	1.30	1.87	1.20
	Dumping					0.068	0.036	0.058	0.048				
	Equal Weight Avg[c]	0.082	0.073	0.113	0.066	0.102	0.091	0.156	0.083	1.24	1.25	1.38	1.26
	Empirical Weight Avg[d]	0.044	0.049	0.062	0.047	0.074	0.048	0.138	0.076	1.68	0.98	2.23	1.62

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Loaded / Unloaded
[c]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes
[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

(Continue on Next Page)

Table A-1. Continued

	Driving Mode[a]	Unloaded Single Axle Tier1	Unloaded Single Axle Tier2	Unloaded Tandem Tier1	Unloaded Tandem Tier2	Loaded Single Axle Tier1	Loaded Single Axle Tier2	Loaded Tandem Tier1	Loaded Tandem Tier2	Ratio[b] Single Axle Tier1	Ratio[b] Single Axle Tier2	Ratio[b] Tandem Tier1	Ratio[b] Tandem Tier2
HC (mg/sec)	Idle	0.999	1.50	2.35	1.81	1.07	1.54	2.52	1.93	1.07	1.03	1.07	1.07
	Low Acceleration	1.44	1.90	6.18	4.32	1.75	2.62	9.50	6.16	1.22	1.38	1.54	1.43
	Medium Acceleration	2.73	3.50	7.94	5.92	3.33	4.55	11.5	8.37	1.22	1.30	1.45	1.41
	High Acceleration	3.70	3.93	9.01	6.14	4.50	4.92	12.5	10.6	1.22	1.25	1.39	1.73
	Low Cruise	1.87	1.86	4.94	4.03	2.21	2.37	7.27	4.85	1.18	1.27	1.47	1.20
	Medium Cruise	3.19	3.13	7.44	6.17	4.00	3.63	9.10	9.09	1.25	1.16	1.22	1.47
	High Cruise	4.76	3.42	7.17	6.84	5.73	4.48	8.94	9.34	1.20	1.31	1.25	1.37
	Deceleration	2.57	2.28	4.51	5.58	3.33	2.74	5.86	6.82	1.30	1.20	1.30	1.22
	Dumping					2.95	3.47	5.17	7.12				
	Equal Weight Avg[c]	2.66	2.69	6.19	5.10	3.21	3.37	8.03	7.15	1.21	1.25	1.30	1.40
	Empirical Weight Avg[d]	1.94	2.26	4.03	3.98	2.57	2.31	7.27	6.47	1.32	1.02	1.80	1.63
CO (mg/sec)	Idle	4.65	5.81	4.84	4.38	4.95	6.08	5.14	4.63	1.06	1.05	1.06	1.06
	Low Acceleration	16.6	12.4	13.7	19.0	26.4	14.5	18.4	24.0	1.59	1.17	1.34	1.26
	Medium Acceleration	34.8	14.2	18.5	26.7	41.1	17.3	21.5	35.0	1.18	1.22	1.16	1.31
	High Acceleration	35.7	14.6	21.2	26.5	43.0	16.7	24.2	34.3	1.20	1.14	1.14	1.29
	Low Cruise	13.5	8.10	11.2	24.0	19.5	10.1	15.6	28.9	1.44	1.25	1.39	1.20
	Medium Cruise	21.2	9.98	16.2	28.8	25.6	12.6	18.8	34.1	1.21	1.26	1.16	1.18
	High Cruise	18.9	11.4	15.8	31.8	23.7	13.3	19.9	36.3	1.25	1.17	1.26	1.14
	Deceleration	11.5	7.33	11.3	19.0	14.1	8.97	15.4	23.2	1.23	1.22	1.36	1.22
	Dumping					17.5	13.2	23.2	19.5				
	Equal Weight Avg[c]	19.6	10.5	14.1	22.5	24.0	12.5	18.0	26.7	1.22	1.19	1.28	1.19
	Empirical Weight Avg[d]	10.9	8.41	8.64	16.9	17.9	8.01	14.9	25.6	1.64	0.95	1.72	1.51

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Loaded / Unloaded

[c]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-1. Continued

		Unloaded				**Loaded**				**Ratio**[b]			
	Driving Mode[a]	Single Axle		Tandem		Single Axle		Tandem		Single Axle		Tandem	
		Tier1	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**
CO_2 (g/sec)	Idle	0.811	0.870	0.936	1.17	0.878	0.941	1.01	1.22	1.08	1.08	1.08	1.04
	Low Acceleration	4.18	5.22	9.08	8.29	6.20	6.07	11.9	11.3	1.48	1.16	1.31	1.36
	Medium Acceleration	11.1	10.3	15.2	15.9	14.5	13.3	19.7	27.0	1.31	1.29	1.30	1.70
	High Acceleration	14.8	12.8	17.1	20.7	17.2	15.0	21.1	25.4	1.16	1.17	1.23	1.23
	Low Cruise	2.74	3.85	6.91	7.95	4.11	4.47	10.5	9.06	1.50	1.16	1.52	1.14
	Medium Cruise	6.36	7.45	11.1	14.2	9.34	11.9	16.8	19.5	1.47	1.60	1.51	1.37
	High Cruise	13.0	11.2	12.1	17.6	14.8	12.8	16.9	22.9	1.14	1.14	1.40	1.30
	Deceleration	3.69	5.13	5.74	7.54	4.31	5.74	9.33	9.73	1.17	1.12	1.63	1.29
	Dumping					4.10	3.25	3.76	5.06				
	Equal Weight Avg[c]	7.04	7.10	9.77	12.1	8.38	8.15	12.3	14.6	1.19	1.15	1.26	1.21
	Empirical Weight Avg[d]	3.71	4.83	4.71	8.33	6.10	4.16	10.7	14.7	1.64	0.86	2.27	1.76
PM (mg/sec)	Idle	0.069	0.056	0.181	0.062	0.074	0.061	0.195	0.066	1.07	1.09	1.08	1.06
	Low Acceleration	0.381	0.284	0.459	0.406	0.570	0.478	0.730	0.613	1.50	1.68	1.59	1.51
	Medium Acceleration	0.851	0.650	0.864	0.930	1.11	0.828	1.09	1.40	1.30	1.27	1.26	1.51
	High Acceleration	1.12	0.888	0.966	1.15	1.28	1.10	1.21	1.46	1.14	1.24	1.25	1.27
	Low Cruise	0.216	0.233	0.765	0.307	0.371	0.283	1.24	0.412	1.72	1.21	1.62	1.34
	Medium Cruise	0.518	0.409	1.22	0.580	0.711	0.646	2.02	0.937	1.37	1.58	1.66	1.62
	High Cruise	0.865	0.726	1.36	0.718	0.970	0.805	1.90	1.04	1.12	1.11	1.40	1.45
	Deceleration	0.314	0.328	0.581	0.379	0.360	0.367	0.929	0.455	1.15	1.12	1.60	1.20
	Dumping					0.395	0.241	0.742	0.423				
	Equal Weight Avg[c]	0.542	0.447	0.799	0.566	0.648	0.534	1.12	0.756	1.20	1.19	1.40	1.34
	Empirical Weight Avg[d]	0.260	0.312	0.449	0.373	0.446	0.271	1.01	0.690	1.72	0.87	2.25	1.85

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Loaded / Unloaded
[c]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes
[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table A-2. Summary of Fuel Consumption and Emission Rates on a Per Time Basis by Driving Mode, Vehicle Type, and Load for Soy-Based B20

		Unloaded				Loaded				Ratio[b]			
	Driving Mode[a]	Single Axle		Tandem		Single Axle		Tandem		Single Axle		Tandem	
		Tier1	Tier2	Tier1	Tier2	Tier1	Tier2	Tier1	Tier2	Tier1	Tier2	Tier1	Tier2
Fuel (g/sec)	Idle	0.304	0.303	0.374	0.356	0.326	0.330	0.388	0.372	1.07	1.09	1.04	1.04
	Low Acceleration	1.81	1.33	2.93	2.47	2.43	1.78	4.18	3.69	1.34	1.34	1.43	1.49
	Medium Acceleration	3.91	2.99	4.57	5.54	4.96	3.94	5.97	8.59	1.27	1.32	1.31	1.55
	High Acceleration	4.79	3.74	5.61	7.93	5.25	4.69	6.55	9.49	1.10	1.25	1.17	1.20
	Low Cruise	1.53	1.43	2.20	2.17	2.24	2.00	2.72	2.98	1.46	1.40	1.24	1.37
	Medium Cruise	3.11	2.69	3.61	4.29	4.43	3.77	4.73	6.49	1.42	1.40	1.31	1.51
	High Cruise	4.28	3.22	4.33	5.75	4.70	4.02	4.91	8.01	1.10	1.25	1.13	1.39
	Deceleration	1.79	1.28	1.60	3.08	2.32	1.51	2.31	3.67	1.30	1.18	1.44	1.19
	Dumping					1.67	1.12	1.80	2.36				
	Equal Weight Avg[c]	2.69	2.12	3.15	3.95	3.15	2.58	3.73	5.07	1.17	1.22	1.18	1.28
	Empirical Weight Avg[d]	1.90	1.81	1.95	3.90	2.11	2.41	1.86	5.02	1.11	1.33	0.95	1.29
NO_x (g/sec)	Idle	0.013	0.012	0.019	0.022	0.014	0.012	0.019	0.022	1.08	1.00	1.00	1.00
	Low Acceleration	0.054	0.052	0.074	0.057	0.067	0.077	0.094	0.081	1.24	1.48	1.27	1.42
	Medium Acceleration	0.091	0.104	0.122	0.096	0.116	0.171	0.158	0.147	1.27	1.64	1.30	1.53
	High Acceleration	0.104	0.146	0.156	0.116	0.115	0.177	0.206	0.133	1.11	1.21	1.32	1.15
	Low Cruise	0.047	0.036	0.052	0.055	0.061	0.061	0.072	0.060	1.30	1.69	1.38	1.09
	Medium Cruise	0.074	0.073	0.093	0.066	0.103	0.111	0.142	0.099	1.39	1.52	1.53	1.50
	High Cruise	0.079	0.076	0.158	0.071	0.099	0.103	0.182	0.095	1.25	1.36	1.15	1.34
	Deceleration	0.034	0.029	0.054	0.044	0.046	0.041	0.075	0.053	1.35	1.41	1.39	1.20
	Dumping					0.054	0.036	0.053	0.069				
	Equal Weight Avg[c]	0.062	0.066	0.091	0.066	0.075	0.088	0.111	0.084	1.21	1.33	1.22	1.27
	Empirical Weight Avg[d]	0.040	0.051	0.062	0.057	0.050	0.083	0.060	0.074	1.25	1.63	0.97	1.30

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Loaded / Unloaded

[c]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-2. Continued

	Driving Mode[a]	Unloaded				Loaded				Ratio[b]			
		Single Axle		Tandem		Single Axle		Tandem		Single Axle		Tandem	
		Tier1	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**
HC (mg/sec)	Idle	0.785	1.22	1.69	1.82	0.847	1.31	1.82	1.99	1.08	1.07	1.08	1.09
	Low Acceleration	1.14	2.04	4.14	5.37	1.51	2.36	4.92	7.02	1.32	1.16	1.19	1.31
	Medium Acceleration	2.05	2.62	5.63	7.60	2.58	2.98	6.54	11.5	1.26	1.14	1.16	1.51
	High Acceleration	2.56	3.46	5.97	8.55	3.48	4.24	7.02	13.6	1.36	1.23	1.18	1.59
	Low Cruise	1.26	2.31	3.74	3.84	1.72	2.77	4.72	5.21	1.37	1.20	1.26	1.36
	Medium Cruise	1.66	2.25	4.35	4.02	2.43	2.55	5.51	6.34	1.46	1.13	1.27	1.58
	High Cruise	2.35	3.29	4.92	5.81	3.34	3.93	5.97	9.41	1.42	1.19	1.21	1.62
	Deceleration	1.30	1.61	3.35	2.86	1.89	1.94	4.17	4.59	1.45	1.20	1.24	1.60
	Dumping					1.21	1.89	3.41	5.07				
	Equal Weight Avg[c]	1.64	2.35	4.22	4.98	2.11	2.66	4.90	7.18	1.29	1.13	1.16	1.44
	Empirical Weight Avg[d]	1.47	2.11	3.19	4.52	1.69	2.36	3.25	6.62	1.15	1.12	1.02	1.46
CO (mg/sec)	Idle	4.17	4.04	4.27	4.60	4.50	4.17	4.50	4.81	1.08	1.03	1.05	1.05
	Low Acceleration	17.3	7.14	21.4	15.9	22.9	9.49	25.5	21.5	1.32	1.33	1.19	1.35
	Medium Acceleration	22.5	11.8	23.5	22.8	26.0	13.3	26.2	28.1	1.16	1.13	1.11	1.23
	High Acceleration	24.5	13.9	22.8	30.8	31.0	16.1	26.7	36.9	1.27	1.16	1.17	1.20
	Low Cruise	9.94	8.30	11.1	17.0	13.9	9.91	14.9	20.2	1.40	1.19	1.34	1.19
	Medium Cruise	12.3	9.70	13.3	22.4	14.7	11.7	15.9	26.6	1.20	1.21	1.20	1.19
	High Cruise	19.0	12.4	14.3	29.6	21.5	15.4	19.3	35.8	1.13	1.24	1.35	1.21
	Deceleration	7.86	6.12	9.00	15.7	9.40	8.39	11.5	18.2	1.20	1.37	1.28	1.16
	Dumping					20.4	11.8	15.4	20.3				
	Equal Weight Avg[c]	14.7	9.17	15.0	19.9	18.3	11.1	17.8	23.6	1.24	1.21	1.19	1.19
	Empirical Weight Avg[d]	9.86	8.37	9.93	20.6	11.4	9.95	9.89	23.3	1.16	1.19	1.00	1.13

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Loaded / Unloaded

[c]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-2. Continued

	Driving Mode[a]	Unloaded Single Axle Tier1	Unloaded Single Axle Tier2	Unloaded Tandem Tier1	Unloaded Tandem Tier2	Loaded Single Axle Tier1	Loaded Single Axle Tier2	Loaded Tandem Tier1	Loaded Tandem Tier2	Ratio[b] Single Axle Tier1	Ratio[b] Single Axle Tier2	Ratio[b] Tandem Tier1	Ratio[b] Tandem Tier2
CO_2 (g/sec)	Idle	0.932	0.928	1.19	1.09	1.00	1.02	1.24	1.15	1.07	1.10	1.04	1.06
	Low Acceleration	5.58	4.11	9.37	7.63	7.47	5.48	13.2	11.4	1.34	1.33	1.41	1.49
	Medium Acceleration	12.0	9.20	14.5	17.1	15.3	12.2	19.2	26.5	1.28	1.33	1.32	1.55
	High Acceleration	14.8	11.5	17.9	24.5	16.2	14.5	20.8	29.3	1.09	1.26	1.16	1.20
	Low Cruise	4.69	4.41	7.15	6.69	6.92	6.11	8.89	9.19	1.48	1.39	1.24	1.37
	Medium Cruise	9.59	8.30	11.6	13.2	13.7	11.6	15.1	20.0	1.43	1.40	1.30	1.52
	High Cruise	13.2	9.93	13.8	17.7	14.6	12.4	15.7	24.7	1.11	1.25	1.14	1.40
	Deceleration	5.52	3.96	5.07	9.48	7.18	4.68	7.22	11.3	1.30	1.18	1.42	1.19
	Dumping					5.15	3.44	5.79	7.25				
	Equal Weight Avg[c]	8.30	6.55	10.1	12.2	9.72	7.93	11.9	15.7	1.17	1.21	1.18	1.29
	Empirical Weight Avg[d]	5.86	5.60	6.23	12.0	6.52	7.43	5.98	15.5	1.11	1.33	0.96	1.29
PM (mg/sec)	Idle	0.066	0.048	0.087	0.067	0.069	0.055	0.093	0.069	1.05	1.15	1.07	1.03
	Low Acceleration	0.444	0.251	1.13	0.356	0.622	0.335	1.55	0.575	1.40	1.33	1.37	1.62
	Medium Acceleration	0.726	0.521	1.86	0.800	0.841	0.719	2.30	1.30	1.16	1.38	1.24	1.63
	High Acceleration	0.902	0.777	2.31	1.32	0.993	0.926	2.77	1.53	1.10	1.19	1.20	1.16
	Low Cruise	0.320	0.191	0.241	0.301	0.389	0.252	0.387	0.370	1.22	1.32	1.61	1.23
	Medium Cruise	0.472	0.388	0.483	0.457	0.589	0.528	0.665	0.797	1.25	1.36	1.38	1.74
	High Cruise	0.593	0.584	0.444	0.664	0.669	0.687	0.653	0.827	1.13	1.18	1.47	1.25
	Deceleration	0.257	0.183	0.239	0.330	0.321	0.219	0.356	0.422	1.25	1.20	1.49	1.28
	Dumping					0.400	0.181	0.173	0.345				
	Equal Weight Avg[c]	0.473	0.368	0.849	0.537	0.544	0.434	0.995	0.693	1.15	1.18	1.17	1.29
	Empirical Weight Avg[d]	0.286	0.310	0.442	0.486	0.320	0.377	0.472	0.596	1.12	1.22	1.07	1.23

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Loaded / Unloaded
[c]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes
[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table A-3. Distribution of Total Fuel Consumption and Emission by Driving Mode and Load for Tier 1 Tandem Dump Trucks (Petroleum Diesel)

		Unloaded					Loaded				
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]
		0507	**0578**	**0579**	**0580**		**0507**	**0578**	**0579**	**0580**	
Time (%)	Idle	45.5	64.1	69.5	70.2	62.3	16.2	32.2	13.7	43.1	26.3
	Low Acceleration	3.2	2.5	2.5	4.6	3.2	8.8	7.1	5.6	8.8	7.6
	Medium Acceleration	8.4	6.0	4.7	4.8	6.0	16.7	10.7	25.9	5.3	14.7
	High Acceleration	7.2	3.4	2.1	1.2	3.5	4.3	3.5	5.4	1.2	3.6
	Low Cruise	4.8	3.7	5.9	10.4	6.2	14.1	10.3	5.1	24.4	13.5
	Medium Cruise	3.7	4.1	2.2	1.8	2.9	8.3	6.9	10.4	5.4	7.8
	High Cruise	16.0	9.4	10.0	0.4	9.0	14.1	16.2	20.2	0.5	12.8
	Deceleration	11.3	6.8	3.1	6.7	7.0	15.3	12.1	9.6	9.2	11.6
	Dumping						2.2	1.1	4.1	2.2	2.4
Distance (%)	Idle										
	Low Acceleration	1.3	2.0	2.1	8.8	3.5	3.9	3.3	2.4	9.1	4.7
	Medium Acceleration	13.3	15.8	14.7	27.3	17.8	22.5	15.0	29.8	21.1	22.1
	High Acceleration	15.6	11.1	8.5	8.1	10.8	8.0	8.1	7.1	5.2	7.1
	Low Cruise	2.3	3.0	7.0	17.4	7.4	7.3	6.3	3.3	17.3	8.5
	Medium Cruise	7.0	12.3	7.6	14.5	10.4	13.5	12.0	13.6	26.5	16.4
	High Cruise	44.3	40.4	52.3	3.7	35.2	29.4	44.6	32.9	3.4	27.6
	Deceleration	16.2	15.5	7.8	20.2	14.9	15.4	10.8	10.9	17.5	13.7
	Dumping										

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S= speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

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Table A-3. Continued

	Driving Mode[a]	Unloaded 0507	Unloaded 0578	Unloaded 0579	Unloaded 0580	Unloaded Avg[b]	Loaded 0507	Loaded 0578	Loaded 0579	Loaded 0580	Loaded Avg[b]
Fuel (%)	Idle	1.1	1.2	0.9	1.6	1.2	0.9	0.9	0.6	1.2	0.9
	Low Acceleration	9.7	11.1	12.5	12.6	11.5	9.5	10.1	12.2	10.4	10.6
	Medium Acceleration	20.6	20.0	14.6	22.0	19.3	18.4	17.0	16.0	19.6	17.8
	High Acceleration	22.2	22.7	18.8	24.1	22.0	19.1	19.6	16.8	20.9	19.1
	Low Cruise	6.9	8.8	9.4	9.8	8.7	7.8	9.2	11.4	9.2	9.4
	Medium Cruise	14.2	13.7	17.8	11.3	14.2	17.1	16.0	14.9	13.0	15.3
	High Cruise	17.7	15.8	16.3	12.8	15.7	15.4	15.7	14.2	15.4	15.2
	Deceleration	7.5	6.7	9.7	5.8	7.4	8.1	6.8	11.6	7.1	8.4
	Dumping						3.9	4.4	2.3	3.2	3.4
NO_x (%)	Idle	2.1	2.63	1.77	2.1	2.2	1.34	1.54	1.47	1.58	1.5
	Low Acceleration	8.8	10.0	9.38	13.2	10.3	8.65	7.81	11.1	10.6	9.5
	Medium Acceleration	18.3	18.1	15.4	21.6	18.4	16.5	13.9	15.0	16.8	15.5
	High Acceleration	22.2	22.7	22.0	27.5	23.6	19.4	18.1	20.4	26.9	21.2
	Low Cruise	5.6	10.7	7.32	4.4	7.0	6.48	8.67	7.71	5.12	7.0
	Medium Cruise	13.3	13.5	13.6	10.6	12.8	16.9	13.9	14.4	11.5	14.2
	High Cruise	22.2	15.9	21.3	14.8	18.5	18.3	21.7	15.7	16.6	18.1
	Deceleration	7.5	6.52	9.26	5.8	7.3	8.75	9.13	10.5	6.90	8.8
	Dumping						3.62	5.27	3.76	3.94	4.2

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S= speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

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Table A-3. Continued

	Driving Mode[a]	Unloaded 0507	Unloaded 0578	Unloaded 0579	Unloaded 0580	Unloaded Avg[b]	Loaded 0507	Loaded 0578	Loaded 0579	Loaded 0580	Loaded Avg[b]
HC (%)	Idle	3.6	5.1	5.8	4.6	4.8	2.9	4.1	2.9	4.1	3.5
	Low Acceleration	14.6	9.9	9.1	16.4	12.5	15.4	7.9	15.6	14.7	13.4
	Medium Acceleration	17.1	12.6	12.1	22.8	16.1	16.3	10.5	17.0	21.7	16.4
	High Acceleration	19.2	13.4	16.1	25.3	18.5	16.5	12.3	19.8	21.8	17.6
	Low Cruise	10.5	10.1	11.0	8.3	10.0	11.3	11.6	9.4	7.2	9.9
	Medium Cruise	12.5	18.2	22.5	7.5	15.2	11.5	15.4	12.6	9.6	12.3
	High Cruise	14.2	18.3	14.3	9.8	14.1	11.7	16.2	10.6	9.8	12.1
	Deceleration	8.3	12.5	9.1	5.5	8.8	7.1	11.3	7.8	5.1	7.8
	Dumping						7.2	10.6	4.3	6.0	7.0
CO (%)	Idle	4.5	6.5	2.4	3.2	4.1	3.3	4.6	1.9	2.5	3.1
	Low Acceleration	11.5	10.7	11.7	14.7	12.1	12.2	8.5	13.1	12.4	11.6
	Medium Acceleration	18.3	12.2	18.1	18.1	16.7	14.3	9.2	13.7	16.4	13.4
	High Acceleration	19.4	13.9	17.6	24.4	18.8	14.7	11.7	13.9	19.5	15.0
	Low Cruise	10.6	9.3	11.7	8.9	10.1	10.0	9.0	10.3	9.4	9.7
	Medium Cruise	12.8	17.6	14.1	12.4	14.2	10.1	13.4	10.8	11.5	11.4
	High Cruise	13.1	18.6	14.4	9.6	13.9	10.8	14.1	13.0	10.9	12.2
	Deceleration	9.9	11.3	10.0	8.7	10.0	8.4	10.6	11.3	7.9	9.5
	Dumping						16.3	18.9	11.9	9.5	14.1

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
  - Cruise (Low: S<30, Medium 30=S<45, High S=45), where S= speed (mph)
  - Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

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Table A-3. Continued

	Driving Mode[a]	Unloaded 0507	Unloaded 0578	Unloaded 0579	Unloaded 0580	Unloaded Avg[b]	Loaded 0507	Loaded 0578	Loaded 0579	Loaded 0580	Loaded Avg[b]
CO_2 (%)	Idle	1.1	1.2	0.9	1.6	1.2	0.9	0.9	0.6	1.20	0.9
	Low Acceleration	10.1	11.3	12.4	12.7	11.6	9.9	10.2	12.1	10.5	10.7
	Medium Acceleration	20.9	19.9	14.4	21.8	19.3	18.0	17.0	16.3	19.6	17.7
	High Acceleration	22.0	22.6	19.0	23.6	21.8	19.0	19.7	16.7	20.9	19.1
	Low Cruise	6.9	9.0	9.5	10.0	8.9	7.8	9.2	11.7	9.1	9.5
	Medium Cruise	13.9	13.5	18.2	11.5	14.3	17.0	16.0	14.6	13.2	15.2
	High Cruise	17.5	15.8	16.1	13.0	15.6	15.8	15.7	14.2	15.3	15.2
	Deceleration	7.6	6.7	9.4	5.9	7.4	7.9	6.8	11.6	7.1	8.4
	Dumping						3.9	4.4	2.3	3.2	3.4
PM (%)	Idle	2.8	2.8	3.1	2.4	2.8	2.0	1.9	1.9	1.9	2.0
	Low Acceleration	12.5	5.7	4.6	11.1	8.5	12.4	5.1	7.11	7.6	8.0
	Medium Acceleration	22.5	9.7	9.4	22.2	15.9	19.9	7.3	7.6	18.5	13.3
	High Acceleration	26.0	11.7	9.2	25.2	18.0	23.9	9.4	7.3	19.1	14.9
	Low Cruise	5.9	16.5	14.0	4.4	10.2	7.4	14.6	14.2	7.5	10.9
	Medium Cruise	11.4	21.7	21.9	14.3	17.3	14.2	23.0	21.8	15.2	18.5
	High Cruise	13.1	22.7	26.2	14.7	19.2	10.5	19.6	21.2	18.4	17.4
	Deceleration	5.9	9.2	11.7	5.8	8.1	6.4	11.8	8.6	8.2	8.8
	Dumping						3.4	7.4	10.2	3.6	6.1

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S= speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

Table A-4. Distribution of Total Fuel Consumption and Emission by Driving Mode and Load for Tier 1 Single Axle Dump Trucks (Petroleum Diesel)

	Driving Mode[a]	Unloaded					Loaded				
		Vehicle Number				Avg[b]	Vehicle Number				Avg[b]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**	
Time (%)	Idle	57.3	35.6	80.1	66.1	59.8	47.5	18.0	23.3	58.7	36.9
	Low Acceleration	2.7	3.9	1.5	4.1	3.0	4.7	6.1	6.0	5.8	5.7
	Medium Acceleration	5.2	9.0	2.2	4.3	5.2	9.0	12.4	17.2	4.9	10.9
	High Acceleration	2.1	7.0	1.9	2.3	3.3	0.8	5.7	2.8	2.6	3.0
	Low Cruise	7.4	8.5	4.6	7.3	7.0	9.6	12.0	8.6	10.8	10.3
	Medium Cruise	8.7	5.2	1.9	2.3	4.5	18.2	4.6	14.5	2.1	9.8
	High Cruise	9.2	15.9	4.3	7.5	9.2	1.1	22.9	2.8	8.7	8.9
	Deceleration	7.4	15.0	3.7	6.3	8.1	9.0	16.9	22.1	6.3	13.6
	Dumping						0.2	1.4	2.7	0.2	1.1
Distance (%)	Idle										
	Low Acceleration	1.7	1.20	1.7	4.2	2.19	3.0	1.8	2.6	4.5	3.0
	Medium Acceleration	12.9	14.4	10.9	11.5	12.4	20.5	16.3	27.2	12.1	19.0
	High Acceleration	5.6	13.4	13.9	10.5	10.9	1.7	9.3	5.3	10.9	6.8
	Low Cruise	6.39	3.1	6.5	7.9	6.0	8.0	3.8	4.1	8.1	6.0
	Medium Cruise	25.3	9.1	11.6	8.0	13.5	50.9	6.9	28.0	6.4	23.0
	High Cruise	34.2	38.5	38.5	44.2	38.8	3.6	44.3	7.5	47.2	25.7
	Deceleration	14.0	20.3	16.9	13.9	16.3	12.4	17.5	25.3	10.7	16.5
	Dumping										

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S= speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

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Table A-4. Continued

	Driving Mode[a]	Unloaded					Loaded				
		Vehicle Number				Avg[b]	Vehicle Number				Avg[b]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**	
Fuel (%)	Idle	1.8	1.3	1.4	1.3	1.5	1.3	1.1	1.3	1.0	1.2
	Low Acceleration	9.0	7.3	6.4	7.2	7.5	10.1	7.1	8.4	7.6	8.3
	Medium Acceleration	19.4	21.6	17.2	19.6	19.4	18.7	21.0	18.5	18.2	19.1
	High Acceleration	23.0	24.8	26.7	28.8	25.8	19.2	23.8	23.2	23.4	22.4
	Low Cruise	5.8	5.5	4.2	4.1	4.9	7.0	4.7	6.2	4.3	5.6
	Medium Cruise	14.3	11.9	10.3	9.1	11.4	13.1	13.8	9.9	12.5	12.3
	High Cruise	20.7	22.0	24.7	24.8	23.0	17.1	18.6	20.3	23.6	19.9
	Deceleration	6.1	5.7	9.2	5.2	6.5	5.6	4.7	7.8	4.8	5.7
	Dumping						7.8	5.2	4.5	4.8	5.6
NO_x (%)	Idle	2.5	3.2	2.8	2.5	2.7	2.0	2.6	2.1	1.8	2.1
	Low Acceleration	10.4	8.4	8.0	8.2	8.7	11.0	8.9	9.8	7.9	9.4
	Medium Acceleration	18.9	19.1	19.4	20.8	19.6	18.2	19.2	20.4	18.6	19.1
	High Acceleration	25.7	24.8	26.4	28.8	26.4	19.0	20.4	24.9	22.1	21.6
	Low Cruise	7.0	7.7	5.3	5.6	6.4	7.9	6.8	6.1	5.0	6.4
	Medium Cruise	14.4	11.8	10.6	9.7	11.6	12.9	13.5	10.1	13.8	12.6
	High Cruise	14.7	18.3	19.0	18.4	17.6	11.7	15.6	14.4	19.2	15.2
	Deceleration	6.4	6.6	8.6	6.1	6.9	6.8	6.1	6.2	5.7	6.2
	Dumping						10.6	7.0	6.1	6.0	7.4

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S= speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

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Table A-4. Continued

		Unloaded					Loaded				
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**	
HC (%)	Idle	5.1	4.4	5.8	3.8	4.8	3.6	3.9	4.4	3.1	3.7
	Low Acceleration	6.1	6.4	7.8	7.6	7.0	4.1	6.9	8.1	6.8	6.5
	Medium Acceleration	8.7	17.0	11.4	14.0	12.8	6.5	16.6	12.1	13.2	12.1
	High Acceleration	11.2	20.6	20.9	19.4	18.0	9.9	18.2	19.7	19.2	16.8
	Low Cruise	9.3	7.9	11.9	7.2	9.0	7.7	6.8	10.3	6.7	7.9
	Medium Cruise	18.9	13.3	11.7	14.1	14.5	15.5	13.3	12.1	12.9	13.5
	High Cruise	24.6	20.5	18.9	24.3	22.1	21.1	17.9	19.2	20.8	19.7
	Deceleration	16.0	10.0	11.7	9.5	11.8	14.3	9.3	11.8	9.3	11.2
	Dumping						17.3	6.9	2.5	7.9	8.6
CO (%)	Idle	3.1	3.0	2.9	2.9	3.0	2.4	2.4	2.0	2.4	2.3
	Low Acceleration	10.0	9.8	12.4	10.3	10.6	11.9	11.4	13.4	12.1	12.2
	Medium Acceleration	18.4	19.9	24.5	26.5	22.3	15.2	17.1	22.1	21.9	19.1
	High Acceleration	22.8	24.4	23.9	20.1	22.8	19.0	21.5	19.8	19.7	20.0
	Low Cruise	10.3	8.3	8.2	7.4	8.5	10.2	7.4	10.0	8.1	8.9
	Medium Cruise	13.8	12.5	11.8	15.8	13.5	11.5	10.3	12.1	13.4	11.8
	High Cruise	13.5	14.5	9.9	10.3	12.1	12.6	12.6	9.0	9.7	11.0
	Deceleration	8.	7.7	6.5	6.9	7.3	7.0	7.1	6.3	5.8	6.5
	Dumping						10.3	10.2	5.2	6.9	8.2

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S= speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

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Table A-4. Continued

		Unloaded					Loaded				
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**	
CO_2 (%)	Idle	1.8	1.4	1.4	1.3	1.5	1.3	1.2	1.3	1.0	1.2
	Low Acceleration	9.0	7.5	6.4	7.2	7.5	10.1	7.2	8.3	7.6	8.3
	Medium Acceleration	19.4	22.0	17.2	19.6	19.5	18.7	21.5	18.3	18.3	19.2
	High Acceleration	23.0	26.1	26.7	28.9	26.1	19.2	24.3	23.1	24.1	22.7
	Low Cruise	5.8	5.6	4.2	4.1	4.9	7.0	4.8	6.2	4.3	5.6
	Medium Cruise	14.3	12.2	10.3	9.1	11.4	13.1	14.1	9.9	12.6	12.4
	High Cruise	20.8	19.5	24.7	24.8	22.4	17.1	16.8	20.7	22.6	19.3
	Deceleration	6.1	5.8	9.2	5.1	6.6	5.6	4.8	7.8	4.8	5.8
	Dumping						7.8	5.3	4.5	4.8	5.6
PM (%)	Idle	2.3	1.8	1.0	1.4	1.6	1.7	1.6	0.8	1.1	1.3
	Low Acceleration	8.9	9.3	8.2	8.9	8.8	9.6	9.3	10.3	9.7	9.7
	Medium Acceleration	17.9	19.2	19.5	21.3	19.5	17.5	19.9	19.5	19.0	19.0
	High Acceleration	27.5	28.2	24.5	24.4	26.2	21.4	22.7	22.2	21.5	22.0
	Low Cruise	5.2	6.2	4.01	4.9	5.1	7.3	5.3	7.1	5.6	6.3
	Medium Cruise	11.5	10.5	13.5	11.7	11.8	12.0	12.4	10.9	13.4	12.2
	High Cruise	19.1	18.2	20.8	21.0	19.8	15.5	14.1	17.6	18.4	16.4
	Deceleration	7.5	6.6	8.5	6.3	7.2	7.2	5.3	6.6	5.4	6.2
	Dumping						7.8	9.3	5.0	5.9	7.0

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S= speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

Table A-5. Distribution of Total Fuel Consumption and Emission by Driving Mode and Load for Tier 1 Tandem Dump Trucks (Soy Based B20)

		Unloaded					Loaded				
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]
		0507	**0578**	**0579**	**0580**		**0507**	**0578**	**0579**	**0580**	
Time (%)	Idle	21.5	46.7	61.2	57.8	46.8	61.5	55.9	47.5	82.9	61.9
	Low Acceleration	3.3	4.6	3.6	3.5	3.8	3.3	4.8	5.3	1.4	3.7
	Medium Acceleration	12.3	7.8	3.9	5.5	7.4	8.0	5.2	6.2	2.7	5.6
	High Acceleration	6.2	5.5	3.8	2.2	4.4	1.7	2.7	4.8	0.5	2.4
	Low Cruise	8.5	5.5	7.8	8.6	7.6	6.7	8.5	9.3	2.8	6.8
	Medium Cruise	8.8	6.8	3.4	3.9	5.7	5.4	4.0	5.6	4.1	4.8
	High Cruise	24.3	10.3	8.1	10.8	13.4	5.1	10.7	8.3	2.2	6.6
	Deceleration	15.1	12.9	8.1	7.7	10.9	7.5	6.6	11.5	2.9	7.1
	Dumping						0.9	1.5	1.5	0.5	1.1
Distance (%)	Idle										
	Low Acceleration	1.0	3.5	3.4	2.0	2.5	3.1	3.8	4.4	2.7	3.5
	Medium Acceleration	14.2	14.5	9.6	15.5	13.5	25.4	11.5	12.6	17.4	16.7
	High Acceleration	8.8	12.5	13.2	7.2	10.4	6.14	9.1	13.2	4.6	8.3
	Low Cruise	3.0	4.3	7.1	5.2	4.9	5.7	6.6	7.1	7.1	6.6
	Medium Cruise	12.1	15.6	11.5	12.5	12.9	19.8	10.6	14.5	31.8	19.2
	High Cruise	45.4	29.7	38.5	43.3	39.2	23.6	44.9	30.1	21.4	30.0
	Deceleration	15.5	20.0	16.7	14.3	16.6	16.2	13.6	18.2	15.0	15.7
	Dumping										

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S= speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

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Table A-5. Continued

		Unloaded					Loaded				
	Driving Mode[a]	Vehicle Number 0507	0578	0579	0580	Avg[b]	Vehicle Number 0507	0578	0579	0580	Avg[b]
Fuel (%)	Idle	1.3	1.5	1.4	1.7	1.5	1.1	1.1	1.2	1.4	1.2
	Low Acceleration	12.2	13.7	10.9	9.1	11.5	14.3	11.4	12.1	12.4	12.6
	Medium Acceleration	20.4	17.5	17.1	17.8	18.2	18.8	18.9	16.6	16.8	17.8
	High Acceleration	24.1	21.1	21.9	22.2	22.3	22.0	19.4	19.0	17.9	19.6
	Low Cruise	7.4	12.1	9.0	5.0	8.4	6.2	10.0	8.8	6.6	7.9
	Medium Cruise	12.9	14.3	14.1	16.3	14.4	13.1	14.3	13.4	15.8	14.1
	High Cruise	15.6	15.6	17.7	20.4	17.3	13.4	13.4	15.9	15.8	14.6
	Deceleration	5.9	4.3	7.8	7.5	6.4	6.0	5.4	7.4	9.0	7.0
	Dumping						5.1	6.1	5.6	4.2	5.3
NO_x (%)	Idle	2.6	2.4	2.5	2.9	2.6	2.4	1.5	2.1	2.0	2.0
	Low Acceleration	10.3	12.1	8.7	9.8	10.2	9.1	8.4	9.4	11.2	9.5
	Medium Acceleration	17.8	17.4	14.9	17.4	16.9	16.7	16.9	14.8	14.3	15.7
	High Acceleration	24.0	19.4	20.9	22.2	21.6	21.7	21.4	17.3	22.6	20.7
	Low Cruise	6.8	7.4	8.0	5.8	7.0	5.9	7.8	8.5	5.8	7.0
	Medium Cruise	12.1	12.9	12.1	14.2	12.8	12.5	16.4	12.8	14.2	14.0
	High Cruise	19.8	20.9	25.0	19.8	21.4	19.6	16.1	20.6	16.6	18.2
	Deceleration	6.5	7.4	7.9	7.9	7.4	7.0	7.1	7.7	8.5	7.6
	Dumping						5.0	4.4	6.8	4.8	5.3

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S= speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

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Table A-5. Continued

	Driving Mode[a]	Unloaded: Vehicle Number 0507	Unloaded: Vehicle Number 0578	Unloaded: Vehicle Number 0579	Unloaded: Vehicle Number 0580	Unloaded: Avg[b]	Loaded: Vehicle Number 0507	Loaded: Vehicle Number 0578	Loaded: Vehicle Number 0579	Loaded: Vehicle Number 0580	Loaded: Avg[b]
HC (%)	Idle	3.7	4.9	4.6	7.3	5.1	4.0	3.9	3.7	5.1	4.2
	Low Acceleration	13.6	11.7	13.1	10.5	12.2	12.1	10.1	11.7	11.1	11.3
	Medium Acceleration	18.2	16.5	16.7	15.0	16.6	16.9	15.0	13.9	13.7	14.9
	High Acceleration	18.9	16.1	17.9	18.7	17.9	17.3	16.0	15.0	15.5	15.9
	Low Cruise	11.2	12.6	9.6	10.0	10.9	10.0	11.2	10.1	11.5	10.7
	Medium Cruise	12.5	13.2	12.1	13.8	12.9	10.8	13.8	12.5	12.1	12.3
	High Cruise	13.6	15.2	14.2	15.1	14.5	11.9	14.3	15.2	12.0	13.4
	Deceleration	8.3	9.8	11.8	9.5	9.8	8.6	8.0	11.2	10.6	9.6
	Dumping						8.4	7.7	6.7	8.3	7.8
CO (%)	Idle	3.7	3.4	3.3	3.9	3.6	3.0	2.8	2.7	2.8	2.8
	Low Acceleration	17.5	17.8	19.7	16.0	17.8	14.6	15.5	17.8	15.8	15.9
	Medium Acceleration	18.9	19.9	21.3	17.8	19.5	16.6	16.3	17.9	14.8	16.4
	High Acceleration	17.9	19.9	20.2	17.7	18.9	14.9	19.1	17.5	14.5	16.5
	Low Cruise	9.2	9.6	8.6	9.8	9.3	9.0	8.8	8.6	10.8	9.3
	Medium Cruise	11.3	10.0	9.4	14.4	11.3	9.3	9.9	9.0	11.4	9.9
	High Cruise	13.7	12.4	11.3	10.8	12.0	13.0	12.0	11.1	12.4	12.1
	Deceleration	7.7	6.8	6.4	9.5	7.6	6.8	6.8	6.8	8.5	7.2
	Dumping						12.8	8.8	8.6	9.0	9.8

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S= speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

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Table A-5. Continued

		Unloaded					Loaded				
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]
		0507	0578	0579	0580		0507	0578	0579	0580	
CO_2 (%)	Idle	1.3	1.5	1.4	1.7	1.5	1.1	1.1	1.2	1.3	1.2
	Low Acceleration	12.2	13.5	10.9	9.1	11.4	14.3	11.2	11.9	12.5	12.5
	Medium Acceleration	20.5	17.2	17.1	17.7	18.1	18.9	18.9	16.8	17.0	17.9
	High Acceleration	24.1	21.0	22.1	22.2	22.4	22.1	19.3	18.7	17.7	19.4
	Low Cruise	7.4	12.4	8.9	5.0	8.4	6.1	10.2	9.1	6.6	8.0
	Medium Cruise	12.9	14.6	14.2	16.3	14.5	13.1	14.0	13.6	15.7	14.1
	High Cruise	15.6	15.6	17.6	20.4	17.3	13.5	13.8	15.8	15.7	14.7
	Deceleration	5.9	4.2	7.8	7.5	6.4	5.7	5.3	7.3	9.1	6.9
	Dumping						5.1	6.2	5.6	4.3	5.3
PM (%)	Idle	1.7	1.1	1.1	2.1	1.5	1.7	0.9	0.9	1.4	1.2
	Low Acceleration	13.9	21.2	15.1	8.9	14.8	12.4	21.4	17.5	9.9	15.3
	Medium Acceleration	23.7	30.7	26.7	21.9	25.8	21.0	29.0	27.3	16.5	23.5
	High Acceleration	28.1	33.8	37.1	31.3	32.6	23.5	31.9	31.7	33.0	30.0
	Low Cruise	7.4	2.6	3.1	4.0	4.3	7.4	2.9	4.5	5.4	5.0
	Medium Cruise	10.8	4.1	7.3	13.1	8.8	12.9	5.4	6.4	11.0	8.9
	High Cruise	9.7	4.4	5.6	13.5	8.3	12.7	4.2	6.5	13.3	9.2
	Deceleration	4.7	2.3	3.9	5.3	4.0	4.0	2.6	4.3	7.0	4.5
	Dumping						4.3	1.8	1.0	2.6	2.4

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S= speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

Table A-6. Distribution of Total Fuel Consumption and Emission by Driving Mode and Load for Tier 1 Single Axle Dump Trucks

(Soy Based B20)

	Driving Mode[a]	Unloaded					Loaded				
		Vehicle Number				Avg[b]	Vehicle Number				Avg[b]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**	
Time (%)	Idle	13.5	94.1	59.5	44.9	53.0	24.0	56.6	70.3	67.7	54.6
	Low Acceleration	2.9	0.6	1.7	2.6	1.9	1.9	3.0	1.7	2.6	2.3
	Medium Acceleration	7.7	1.0	6.3	8.2	5.8	10.1	11.7	4.2	7.3	8.3
	High Acceleration	11.0	0.4	3.9	6.0	5.3	6.6	1.5	1.6	0.8	2.6
	Low Cruise	4.7	0.7	2.8	3.9	3.0	3.4	3.7	3.3	4.5	3.7
	Medium Cruise	2.3	0.6	5.5	5.1	3.4	5.6	8.4	2.1	5.7	5.4
	High Cruise	43.1	1.2	11.8	16.8	18.2	35.0	8.2	11.1	4.3	14.7
	Deceleration	15.1	1.3	8.5	12.6	9.4	13.0	6.2	5.6	6.7	7.8
	Dumping						0.6	0.8	0.2	0.5	0.5
Distance (%)	Idle										
	Low Acceleration	0.6	3.5	0.9	1.0	1.5	0.5	2.0	1.5	2.6	1.6
	Medium Acceleration	6.8	18.4	13.6	14.2	13.2	10.5	28.6	13.6	27.0	19.9
	High Acceleration	13.0	7.4	10.9	12.7	11.0	9.3	3.1	7.1	3.0	5.6
	Low Cruise	1.1	6.3	2.9	1.9	3.0	1.5	3.8	3.8	5.8	3.7
	Medium Cruise	2.3	13.6	13.6	9.5	9.7	6.4	24.2	7.6	22.9	15.3
	High Cruise	63.7	31.6	40.7	41.4	44.3	58.9	27.5	50.2	21.3	39.5
	Deceleration	12.5	19.4	17.3	19.2	17.1	12.9	10.8	16.3	17.5	14.4
	Dumping										

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S= speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

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Table A-6. Continued

	Driving Mode[a]	Unloaded: Vehicle Number 4743	Unloaded: 4750	Unloaded: 4869	Unloaded: 4870	Unloaded: Avg[b]	Loaded: Vehicle Number 4743	Loaded: 4750	Loaded: 4869	Loaded: 4870	Loaded: Avg[b]
Fuel (%)	Idle	1.6	1.3	1.5	1.3	1.4	1.2	1.0	1.1	1.2	1.1
	Low Acceleration	8.9	8.0	8.6	8.1	8.4	8.4	9.7	8.0	8.2	8.6
	Medium Acceleration	18.4	17.5	16.4	20.1	18.1	16.2	16.7	17.1	20.6	17.6
	High Acceleration	21.2	20.7	23.9	23.6	22.4	18.4	17.9	18.8	19.1	18.6
	Low Cruise	5.6	9.6	7.8	6.0	7.2	7.9	10.8	6.6	6.2	7.9
	Medium Cruise	14.7	15.2	11.5	16.1	14.4	14.5	14.2	16.0	18.3	15.8
	High Cruise	20.7	20.1	21.1	17.5	19.9	17.1	16.7	17.0	15.4	16.5
	Deceleration	8.9	7.7	9.2	7.3	8.3	9.6	6.6	10.4	5.9	8.1
	Dumping						6.8	6.4	5.1	5.1	5.8
NO_x (%)	Idle	2.9	2.8	2.6	2.3	2.7	2.2	2.4	1.8	1.8	2.0
	Low Acceleration	10.9	11.1	11.0	9.9	10.7	10.5	9.5	11.5	8.5	10.0
	Medium Acceleration	18.6	16.8	18.0	21.1	18.6	16.2	16.1	17.9	20.0	17.6
	High Acceleration	19.6	19.4	23.8	23.4	21.5	16.0	17.7	16.3	17.8	17.0
	Low Cruise	9.0	11.5	8.8	7.3	9.1	8.9	11.2	6.9	6.9	8.5
	Medium Cruise	15.7	15.2	11.6	15.7	14.5	13.9	14.8	14.8	18.9	15.6
	High Cruise	16.4	16.1	16.6	14.2	15.8	16.6	13.7	14.3	13.2	14.4
	Deceleration	7.0	7.1	7.7	6.0	6.9	7.0	6.4	9.1	5.6	7.0
	Dumping						8.8	8.2	7.5	7.2	7.9

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S= speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

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Table A-6. Continued

		Unloaded					Loaded				
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**	
HC (%)	Idle	5.7	8.9	5.3	4.6	6.1	4.9	4.9	3.9	3.9	4.4
	Low Acceleration	9.9	9.9	6.8	7.9	8.6	9.3	7.9	6.8	7.4	7.9
	Medium Acceleration	14.2	18.5	15.3	15.6	15.9	14.7	12.2	11.5	15.7	13.6
	High Acceleration	19.6	19.6	16.7	22.2	19.5	18.5	20.3	17.4	16.7	18.2
	Low Cruise	9.9	11.3	10.1	7.3	9.7	9.1	8.0	8.1	11.2	9.1
	Medium Cruise	12.3	12.6	11.8	14.3	12.7	10.2	16.9	10.6	13.9	12.9
	High Cruise	18.6	12.0	21.0	18.7	17.6	18.1	16.3	20.4	15.5	17.5
	Deceleration	9.8	7.2	12.9	9.4	9.8	8.4	8.9	13.3	9.4	10.0
	Dumping						6.8	4.6	7.9	6.3	6.4
CO (%)	Idle	2.8	2.7	4.3	5.1	3.7	2.3	2.0	3.0	3.8	2.8
	Low Acceleration	16.6	12.4	12.6	17.4	14.8	15.5	13.9	12.0	14.2	13.9
	Medium Acceleration	20.5	17.3	19.5	18.7	19.0	17.5	14.9	15.3	15.5	15.8
	High Acceleration	22.4	20.5	20.4	19.2	20.6	21.1	18.6	18.7	16.4	18.7
	Low Cruise	6.7	10.5	8.1	9.0	8.6	10.2	8.9	7.5	6.5	8.3
	Medium Cruise	11.4	10.4	9.1	10.6	10.4	9.9	9.5	8.3	7.8	8.9
	High Cruise	12.7	18.7	19.5	14.3	16.3	10.3	15.9	14.1	12.0	13.1
	Deceleration	6.8	7.4	6.4	5.7	6.6	6.7	5.7	5.7	4.4	5.6
	Dumping						6.6	10.5	15.4	19.2	12.9

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
  - Cruise (Low: S<30, Medium 30=S<45, High S=45), where S= speed (mph)
  - Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

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Table A-6. Continued

	Driving Mode[a]	Unloaded					Loaded				
		Vehicle Number				Avg[b]	Vehicle Number				Avg[b]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**	
CO_2 (%)	Idle	1.6	1.3	1.5	1.3	1.4	1.2	1.0	1.1	1.2	1.1
	Low Acceleration	8.8	8.0	8.6	8.1	8.4	8.4	9.6	7.9	8.3	8.5
	Medium Acceleration	18.4	17.5	16.4	20.1	18.1	16.2	16.5	17.0	20.7	17.6
	High Acceleration	21.2	20.7	23.9	23.6	22.4	18.4	17.8	18.8	19.2	18.5
	Low Cruise	5.6	9.5	7.7	6.0	7.2	7.9	10.8	6.6	6.2	7.9
	Medium Cruise	14.7	15.2	11.6	16.2	14.4	14.5	14.1	16.0	18.4	15.8
	High Cruise	20.8	20.1	21.1	17.6	19.9	17.1	17.4	17.0	15.1	16.6
	Deceleration	8.9	7.7	9.2	7.3	8.3	9.6	6.5	10.4	5.9	8.1
	Dumping						6.7	6.3	5.1	5.0	5.8
PM (%)	Idle	2.0	1.0	2.0	2.0	1.8	1.6	0.8	1.5	1.7	1.4
	Low Acceleration	11.0	9.9	12.7	13.4	11.8	14.1	11.7	12.8	12.1	12.7
	Medium Acceleration	21.5	16.7	18.7	20.0	19.2	18.3	15.3	15.8	19.5	17.2
	High Acceleration	25.7	24.0	22.0	23.8	23.9	20.6	20.0	19.8	20.8	20.3
	Low Cruise	5.0	11.9	8.8	7.9	8.4	7.2	10.3	6.6	7.7	8.0
	Medium Cruise	11.7	13.8	10.5	13.9	12.4	11.3	11.8	12.0	13.1	12.0
	High Cruise	16.7	15.8	17.1	13.2	15.7	13.9	15.2	13.3	12.3	13.7
	Deceleration	6.5	7.0	8.0	5.9	6.8	6.2	6.3	8.0	5.6	6.5
	Dumping						6.7	8.5	10.1	7.2	8.2

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
  - Cruise (Low: S<30, Medium 30=S<45, High S=45), where S= speed (mph)
  - Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

Table A-7. Distribution of Total Fuel Consumption and Emission by Driving Mode and Load for Tier 2 Tandem Dump Trucks (Petroleum Diesel)

		Unloaded			Loaded		
	Driving Mode[a]	Vehicle Number 0125	Vehicle Number 0126	Avg[b]	Vehicle Number 0125	Vehicle Number 0126	Avg[b]
Time (%)	Idle	47.7	40.4	44.1	32.5	15.0	23.7
	Low Acceleration	4.9	2.6	3.7	5.3	4.2	4.8
	Medium Acceleration	9.6	2.8	6.2	8.7	6.9	7.8
	High Acceleration	2.2	8.9	5.6	2.1	11.1	6.6
	Low Cruise	8.3	6.8	7.6	11.7	8.2	10.0
	Medium Cruise	13.1	3.0	8.1	10.2	4.5	7.4
	High Cruise	7.0	29.4	18.2	15.9	40.2	28.0
	Deceleration	7.2	6.0	6.6	7.8	8.5	8.2
	Dumping				5.9	1.2	3.6
Distance (%)	Idle						
	Low Acceleration	3.2	1.0	2.1	2.3	1.1	1.7
	Medium Acceleration	19.9	3.8	11.8	14.4	7.2	10.8
	High Acceleration	4.4	11.2	7.8	4.6	8.3	6.5
	Low Cruise	8.1	3.8	6.0	6.5	2.7	4.6
	Medium Cruise	32.8	5.2	19.0	20.2	5.3	12.8
	High Cruise	22.2	67.6	44.9	43.4	67.5	55.4
	Deceleration	9.5	7.3	8.4	8.6	7.9	8.2
	Dumping						
Fuel (%)	Idle	1.5	1.2	1.3	1.1	0.9	1.0
	Low Acceleration	7.8	9.8	8.8	7.9	9.8	8.9
	Medium Acceleration	17.1	16.8	17.0	18.3	17.2	17.7
	High Acceleration	23.5	21.0	22.3	24.1	16.8	20.4
	Low Cruise	8.5	8.6	8.5	7.5	6.9	7.2
	Medium Cruise	14.0	16.2	15.1	16.5	14.5	15.5
	High Cruise	20.4	17.6	19.0	15.7	19.9	17.8
	Deceleration	7.3	8.8	8.0	7.3	8.0	7.6
	Dumping				1.6	6.0	3.8
NO_x (%)	Idle	4.0	4.1	4.1	2.9	3.2	3.1
	Low Acceleration	11.0	12.1	11.5	9.4	11.6	10.5
	Medium Acceleration	17.3	21.2	19.3	19.7	19.3	19.5
	High Acceleration	28.1	19.7	23.9	23.2	16.4	19.8
	Low Cruise	8.1	9.1	8.6	9.2	7.5	8.4
	Medium Cruise	11.8	14.0	12.9	15.0	12.8	13.9
	High Cruise	12.0	11.8	11.9	10.7	13.5	12.1
	Deceleration	7.6	8.0	7.8	6.7	6.6	6.6
	Dumping				3.1	9.1	6.1

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S= speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

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Table A-7. Continued

	Driving Mode[a]	Unloaded Vehicle Number 0125	Unloaded Vehicle Number 0126	Unloaded Avg[b]	Loaded Vehicle Number 0125	Loaded Vehicle Number 0126	Loaded Avg[b]
HC (%)	Idle	5.5	3.5	4.5	3.5	2.5	3.0
	Low Acceleration	10.4	10.8	10.6	8.1	11.1	9.6
	Medium Acceleration	13.8	15.2	14.5	14.1	11.9	13.0
	High Acceleration	16.8	13.5	15.1	18.1	14.9	16.5
	Low Cruise	9.1	10.6	9.8	7.5	7.6	7.5
	Medium Cruise	13.9	16.2	15.1	14.9	13.4	14.1
	High Cruise	18.4	15.3	16.9	16.5	12.5	14.5
	Deceleration	12.3	15.0	13.6	9.3	11.9	10.6
	Dumping				8.0	14.2	11.1
CO (%)	Idle	3.0	2.0	2.5	2.3	1.6	1.9
	Low Acceleration	10.0	10.9	10.5	10.2	9.9	10.0
	Medium Acceleration	15.0	14.7	14.9	14.5	14.6	14.6
	High Acceleration	16.6	13.3	14.9	15.3	13.5	14.3
	Low Cruise	10.4	16.0	13.2	9.7	13.8	12.1
	Medium Cruise	15.9	15.5	15.7	14.4	14.1	14.2
	High Cruise	18.4	17.1	17.8	15.9	14.6	15.1
	Deceleration	10.6	10.5	10.5	9.6	9.8	9.7
	Dumping				8.2	8.1	8.1
CO_2 (%)	Idle	1.3	1.1	1.2	1.0	0.9	0.9
	Low Acceleration	7.8	9.2	8.5	7.7	9.4	8.5
	Medium Acceleration	17.1	21.8	19.5	21.0	20.3	20.7
	High Acceleration	23.5	19.8	21.6	23.3	16.2	19.8
	Low Cruise	8.5	8.0	8.3	7.2	6.7	6.9
	Medium Cruise	14.0	15.2	14.6	16.0	13.9	15.0
	High Cruise	20.4	16.5	18.5	15.2	19.2	17.2
	Deceleration	7.3	8.3	7.8	7.1	7.7	7.4
	Dumping				1.5	5.7	3.6
PM (%)	Idle	1.2	1.6	1.4	0.8	1.1	1.0
	Low Acceleration	7.3	10.5	8.9	7.5	10.4	9.0
	Medium Acceleration	18.3	22.5	20.4	19.2	21.9	20.5
	High Acceleration	28.2	22.8	25.5	25.5	17.6	21.5
	Low Cruise	6.3	7.2	6.8	6.3	5.8	6.1
	Medium Cruise	12.5	13.0	12.8	13.5	14.0	13.8
	High Cruise	17.9	14.0	16.0	15.4	15.2	15.3
	Deceleration	8.3	8.5	8.4	6.5	6.9	6.7
	Dumping				5.2	7.2	6.2

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S= speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

Table A-8. Distribution of Total Fuel Consumption and Emission by Driving Mode and Load for Tier 2 Single Axle Dump Trucks (Petroleum Diesel)

		Unloaded			**Loaded**		
	Driving Mode[a]	Vehicle Number **6117**	Vehicle Number **6123**	Avg[b]	Vehicle Number **6117**	Vehicle Number **6123**	Avg[b]
Time (%)	Idle	50.0	52.2	51.1	53.1	62.0	57.6
	Low Acceleration	2.2	1.5	1.8	4.1	4.9	4.5
	Medium Acceleration	8.1	5.5	6.8	9.2	5.3	7.3
	High Acceleration	9.3	4.7	7.0	2.7	2.1	2.4
	Low Cruise	3.9	3.7	3.8	8.3	9.7	9.0
	Medium Cruise	4.8	5.0	4.9	5.4	1.5	3.4
	High Cruise	9.6	19.7	14.7	6.8	4.5	5.6
	Deceleration	12.2	7.6	9.9	8.9	7.9	8.4
	Dumping				1.4	2.1	1.8
Distance (%)	Idle						
	Low Acceleration	1.0	0.6	0.8	2.5	4.2	3.4
	Medium Acceleration	16.1	9.8	12.9	24.6	21.9	23.3
	High Acceleration	20.6	10.6	15.6	7.8	11.7	9.8
	Low Cruise	3.0	1.7	2.4	6.8	7.9	7.4
	Medium Cruise	10.3	10.7	10.5	16.6	7.3	11.9
	High Cruise	27.0	55.2	41.1	25.9	27.5	26.7
	Deceleration	22.0	11.4	16.7	15.8	19.4	17.6
	Dumping						
Fuel (%)	Idle	1.5	1.6	1.6	1.2	1.4	1.3
	Low Acceleration	10.2	8.3	9.2	8.6	8.0	8.3
	Medium Acceleration	18.5	18.0	18.2	18.6	18.0	18.3
	High Acceleration	24.0	20.6	22.3	22.8	17.6	20.2
	Low Cruise	6.9	6.7	6.8	6.3	6.0	6.1
	Medium Cruise	12.7	13.6	13.1	15.1	17.2	16.2
	High Cruise	18.6	20.7	19.7	16.0	18.7	17.3
	Deceleration	7.7	10.4	9.0	6.8	8.8	7.8
	Dumping				4.6	4.4	4.5
NO_x (%)	Idle	2.1	2.3	2.2	1.7	1.8	1.7
	Low Acceleration	11.2	10.3	10.8	9.7	9.8	9.7
	Medium Acceleration	19.8	20.8	20.3	20.4	21.6	21.0
	High Acceleration	28.1	23.6	25.8	25.6	18.8	22.2
	Low Cruise	6.1	7.0	6.5	5.5	5.6	5.5
	Medium Cruise	11.7	11.6	11.7	12.8	13.3	13.0
	High Cruise	14.2	16.7	15.4	13.6	17.3	15.5
	Deceleration	6.8	7.7	7.2	6.4	7.3	6.8
	Dumping				4.3	4.6	4.5

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S= speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

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Table A-8. Continued

	Driving Mode[a]	Unloaded: Vehicle Number 6117	Unloaded: Vehicle Number 6123	Unloaded: Avg[b]	Loaded: Vehicle Number 6117	Loaded: Vehicle Number 6123	Loaded: Avg[b]
HC (%)	Idle	6.6	7.4	7.0	5.1	5.1	5.1
	Low Acceleration	9.3	8.3	8.8	8.4	8.9	8.6
	Medium Acceleration	16.1	16.4	16.3	13.1	16.9	15.0
	High Acceleration	18.0	18.5	18.3	14.4	17.9	16.2
	Low Cruise	8.9	8.4	8.7	8.2	7.4	7.8
	Medium Cruise	13.5	15.7	14.6	11.4	12.5	12.0
	High Cruise	16.5	15.2	15.9	13.9	15.7	14.8
	Deceleration	11.2	10.0	10.6	10.2	7.9	9.1
	Dumping				15.4	7.6	11.5
CO (%)	Idle	7.5	6.4	6.9	5.8	5.0	5.4
	Low Acceleration	14.6	14.9	14.8	12.4	13.3	12.9
	Medium Acceleration	16.6	17.3	17.0	14.0	16.8	15.4
	High Acceleration	18.5	16.2	17.4	15.8	13.6	14.7
	Low Cruise	10.2	9.1	9.7	8.5	9.5	9.0
	Medium Cruise	10.4	13.6	12.0	10.1	12.5	11.3
	High Cruise	13.2	14.0	13.6	10.8	12.9	11.9
	Deceleration	9.1	8.4	8.8	7.8	8.1	8.0
	Dumping				14.9	8.3	11.6
CO_2 (%)	Idle	1.4	1.6	1.5	1.2	1.4	1.3
	Low Acceleration	10.1	8.3	9.2	8.5	8.0	8.3
	Medium Acceleration	18.3	18.0	18.1	18.1	18.1	18.1
	High Acceleration	24.5	20.6	22.6	23.4	17.5	20.5
	Low Cruise	6.8	6.7	6.8	6.7	5.6	6.1
	Medium Cruise	12.6	13.6	13.1	15.0	17.4	16.2
	High Cruise	18.5	20.8	19.6	15.9	18.8	17.4
	Deceleration	7.6	10.4	9.0	6.7	8.9	7.8
	Dumping				4.5	4.4	4.4
PM (%)	Idle	1.2	2.0	1.6	1.1	1.5	1.3
	Low Acceleration	8.6	7.1	7.9	8.0	12.0	10.0
	Medium Acceleration	19.4	16.7	18.1	16.0	18.5	17.3
	High Acceleration	23.6	26.3	25.0	24.2	21.3	22.8
	Low Cruise	7.5	5.4	6.4	7.1	4.6	5.8
	Medium Cruise	11.7	11.2	11.4	13.4	13.5	13.5
	High Cruise	18.4	22.6	20.5	15.3	18.3	16.8
	Deceleration	9.6	8.7	9.1	8.5	6.7	7.6
	Dumping				6.4	3.6	5.0

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S= speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

Table A-9. Distribution of Total Fuel Consumption and Emission by Driving Mode and Load for Tier 2 Tandem Dump Trucks (Soy Based B20)

	Driving Mode[a]	Unloaded			Loaded		
		Vehicle Number		Avg[b]	Vehicle Number		Avg[b]
		0125	**0126**		**0125**	**0126**	
Time (%)	Idle	15.2	34.0	24.6	29.4	26.1	27.8
	Low Acceleration	4.1	2.1	3.1	5.1	4.1	4.6
	Medium Acceleration	5.9	2.7	4.3	6.4	6.0	6.2
	High Acceleration	4.1	3.7	3.9	3.3	4.4	3.8
	Low Cruise	7.0	4.5	5.8	8.0	7.2	7.6
	Medium Cruise	7.4	3.8	5.6	5.9	3.0	4.4
	High Cruise	48.7	44.1	46.4	34.8	41.8	38.3
	Deceleration	7.6	5.0	6.3	6.7	6.9	6.8
	Dumping				0.6	0.6	0.6
Distance (%)	Idle						
	Low Acceleration	1.1	0.5	0.8	1.7	1.1	1.4
	Medium Acceleration	5.3	2.8	4.0	7.1	6.2	6.6
	High Acceleration	5.2	5.6	5.4	5.8	6.9	6.3
	Low Cruise	2.7	2.0	2.4	3.3	2.6	2.9
	Medium Cruise	7.6	4.8	6.2	7.9	3.6	5.7
	High Cruise	71.8	78.8	75.3	67.8	72.5	70.
	Deceleration	6.3	5.4	5.9	6.5	7.2	6.8
	Dumping						
Fuel (%)	Idle	1.4	0.9	1.1	1.0	0.7	0.8
	Low Acceleration	7.5	8.1	7.8	7.9	8.3	8.1
	Medium Acceleration	16.3	18.6	17.4	18.4	19.1	18.8
	High Acceleration	24.8	25.3	25.1	20.5	21.0	20.8
	Low Cruise	6.9	6.8	6.9	6.6	6.5	6.5
	Medium Cruise	13.7	13.5	13.6	15.4	13.2	14.3
	High Cruise	19.7	17.0	18.3	18.2	17.0	17.6
	Deceleration	9.7	9.8	9.7	7.7	8.3	8.0
	Dumping				4.3	5.9	5.1
NO_x (%)	Idle	4.5	3.8	4.2	3.2	2.9	3.0
	Low Acceleration	10.4	11.2	10.8	11.3	10.3	10.8
	Medium Acceleration	16.5	19.4	18.0	20.1	18.9	19.5
	High Acceleration	21.8	22.3	22.0	17.7	17.3	17.5
	Low Cruise	11.0	10.0	10.5	8.4	7.6	8.0
	Medium Cruise	13.1	12.2	12.6	14.0	12.2	13.1
	High Cruise	14.7	12.5	13.6	12.4	12.6	12.5
	Deceleration	8.0	8.7	8.3	6.4	7.3	6.8
	Dumping				6.6	10.8	8.7

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S= speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

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Table A-9. Continued

	Driving Mode[a]	Unloaded: Vehicle Number 0125	Unloaded: Vehicle Number 0126	Unloaded: Avg[b]	Loaded: Vehicle Number 0125	Loaded: Vehicle Number 0126	Loaded: Avg[b]
HC (%)	Idle	5.8	3.5	4.7	3.3	2.8	3.1
	Low Acceleration	9.5	16.9	13.2	8.4	13.6	11.0
	Medium Acceleration	16.5	21.3	18.9	17.6	17.9	17.7
	High Acceleration	23.8	19.4	21.6	19.8	22.3	21.1
	Low Cruise	10.0	9.3	9.7	8.5	7.5	8.0
	Medium Cruise	11.2	9.1	10.2	10.0	9.6	9.8
	High Cruise	15.3	14.0	14.6	18.3	10.3	14.3
	Deceleration	7.8	6.6	7.2	7.1	7.1	7.1
	Dumping				7.0	8.7	7.9
CO (%)	Idle	3.5	2.3	2.9	2.6	1.9	2.3
	Low Acceleration	10.8	9.3	10.0	11.3	8.9	10.1
	Medium Acceleration	14.6	4.1	14.4	13.3	13.2	13.2
	High Acceleration	19.2	19.6	19.4	17.9	16.8	17.4
	Low Cruise	10.4	11.0	10.7	10.2	8.8	9.5
	Medium Cruise	15.6	12.7	14.1	13.2	11.8	12.5
	High Cruise	17.1	20.1	18.6	16.4	17.3	16.9
	Deceleration	8.8	10.9	9.8	7.3	9.8	8.6
	Dumping				7.6	11.5	9.6
CO_2 (%)	Idle	1.4	0.9	1.1	0.9	0.7	0.8
	Low Acceleration	7.5	8.1	7.8	7.9	8.3	8.1
	Medium Acceleration	16.3	18.6	17.4	18.5	19.1	18.8
	High Acceleration	24.9	25.3	25.1	20.5	21.0	20.8
	Low Cruise	6.9	6.8	6.9	6.6	6.4	6.5
	Medium Cruise	13.7	13.5	13.6	15.4	13.2	14.3
	High Cruise	19.7	17.0	18.3	18.2	17.0	17.6
	Deceleration	9.7	9.8	9.7	7.7	8.3	8.0
	Dumping				4.3	5.9	5.1
PM (%)	Idle	1.7	1.4	1.6	1.3	0.9	1.1
	Low Acceleration	7.1	9.5	8.3	10.2	8.3	9.2
	Medium Acceleration	17.6	19.7	18.6	22.8	19.1	20.9
	High Acceleration	32.4	29.0	30.7	25.7	23.4	24.6
	Low Cruise	7.4	6.6	7.0	6.6	5.3	5.9
	Medium Cruise	11.6	9.6	10.6	13.4	12.2	12.8
	High Cruise	16.6	14.2	15.4	13.2	13.3	13.3
	Deceleration	5.6	9.9	7.8	6.0	7.5	6.8
	Dumping				0.9	10.0	5.4

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S= speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

Table A-10. Distribution of Total Fuel Consumption and Emission by Driving Mode and Load for Tier 2 Single Axle Dump Trucks (Soy Based B20)

		Unloaded			**Loaded**		
	Driving Mode[a]	Vehicle Number		Avg[b]	Vehicle Number		Avg[b]
		6117	**6123**		**6117**	**6123**	
Time (%)	Idle	32.8	29.1	30.9	26.7	5.2	16.0
	Low Acceleration	3.8	3.9	3.8	6.6	8.4	7.5
	Medium Acceleration	11.0	7.5	9.3	14.1	16.1	15.1
	High Acceleration	8.1	2.9	5.5	3.1	2.8	3.0
	Low Cruise	6.2	9.9	8.1	9.6	16.7	13.1
	Medium Cruise	11.8	4.5	8.2	15.1	14.2	14.7
	High Cruise	7.2	34.6	20.9	3.7	10.8	7.2
	Deceleration	19.0	7.7	13.4	18.9	23.8	21.4
	Dumping				2.3	1.9	2.1
Distance (%)	Idle						
	Low Acceleration	1.6	1.4	1.5	2.9	2.9	2.9
	Medium Acceleration	16.8	10.5	13.6	23.9	22.5	23.2
	High Acceleration	15.2	3.7	9.4	6.2	4.0	5.1
	Low Cruise	3.6	4.2	3.9	5.4	7.4	6.4
	Medium Cruise	21.0	7.3	14.1	30.9	23.6	27.3
	High Cruise	17.7	67.0	42.3	9.7	19.9	14.8
	Deceleration	24.1	6.0	15.1	21.1	19.8	20.4
	Dumping						
Fuel (%)	Idle	2.2	1.4	1.8	1.8	1.1	1.5
	Low Acceleration	10.3	5.6	8.0	8.4	7.0	7.7
	Medium Acceleration	17.3	17.9	17.6	16.8	17.2	17.0
	High Acceleration	21.5	22.4	22.0	21.9	18.9	20.4
	Low Cruise	8.5	8.3	8.4	8.9	8.4	8.7
	Medium Cruise	13.4	18.0	15.7	13.7	18.4	16.1
	High Cruise	18.4	19.4	18.9	16.0	18.5	17.2
	Deceleration	8.3	6.8	7.6	6.8	6.3	6.6
	Dumping				5.7	4.2	4.9
NO_x (%)	Idle	2.9	1.9	2.4	2.2	1.2	1.7
	Low Acceleration	13.1	7.9	10.5	11.0	9.0	10.0
	Medium Acceleration	18.6	20.4	19.5	20.8	22.0	21.4
	High Acceleration	24.4	29.5	27.0	19.5	23.9	21.7
	Low Cruise	8.5	5.9	7.2	7.1	8.1	7.6
	Medium Cruise	12.0	15.1	13.5	15.2	13.6	14.4
	High Cruise	14.4	14.3	14.3	12.5	13.5	13.0
	Deceleration	6.1	5.0	5.6	5.2	5.2	5.2
	Dumping				6.6	3.5	5.0

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S= speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

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Table A-10. Continued

	Driving Mode[a]	Unloaded: Vehicle Number 6117	Unloaded: Vehicle Number 6123	Unloaded: Avg[b]	Loaded: Vehicle Number 6117	Loaded: Vehicle Number 6123	Loaded: Avg[b]
HC (%)	Idle	5.5	7.9	6.7	4.7	6.4	5.6
	Low Acceleration	11.1	10.6	10.8	10.8	8.6	9.7
	Medium Acceleration	14.5	13.2	13.8	12.3	12.6	12.5
	High Acceleration	16.8	20.6	18.7	16.7	19.0	17.8
	Low Cruise	13.9	10.0	12.0	13.2	9.3	11.3
	Medium Cruise	11.3	12.9	12.1	10.3	11.1	10.7
	High Cruise	17.8	17.0	17.4	17.7	14.7	16.2
	Deceleration	9.0	7.8	8.4	8.9	7.0	8.0
	Dumping				5.3	11.3	8.3
CO (%)	Idle	5.8	5.2	5.5	4.2	4.1	4.2
	Low Acceleration	11.1	8.2	9.6	9.5	9.4	9.5
	Medium Acceleration	16.4	15.7	16.0	13.2	13.3	13.2
	High Acceleration	18.7	19.2	19.0	15.5	16.7	16.1
	Low Cruise	13.8	8.5	11.2	12.3	7.1	9.7
	Medium Cruise	11.4	15.3	13.3	9.7	14.1	11.9
	High Cruise	14.6	19.4	17.0	13.4	17.8	15.6
	Deceleration	8.3	8.3	8.3	8.3	8.5	8.4
	Dumping				14.0	9.2	11.6
CO_2 (%)	Idle	2.2	1.4	1.8	1.8	1.1	1.5
	Low Acceleration	10.3	5.8	8.0	8.6	7.1	7.9
	Medium Acceleration	17.3	18.5	17.9	17.2	17.5	17.3
	High Acceleration	21.6	23.2	22.4	20.9	20.4	20.6
	Low Cruise	8.5	8.3	8.4	8.9	8.3	8.6
	Medium Cruise	13.4	18.7	16.0	14.0	18.7	16.3
	High Cruise	18.4	20.1	19.3	16.3	18.8	17.6
	Deceleration	8.3	7.1	7.7	6.9	6.5	6.7
	Dumping				5.8	4.2	5.0
PM (%)	Idle	1.7	1.5	1.6	1.5	1.3	1.4
	Low Acceleration	11.4	4.7	8.1	9.8	7.2	8.5
	Medium Acceleration	17.6	17.8	17.7	19.0	17.8	18.4
	High Acceleration	25.6	27.4	26.5	22.2	25.4	23.8
	Low Cruise	8.4	4.0	6.2	7.2	5.5	6.4
	Medium Cruise	11.1	15.9	13.5	12.9	14.3	13.6
	High Cruise	17.8	22.5	20.1	17.0	18.4	17.7
	Deceleration	6.2	6.3	6.2	5.7	5.5	5.6
	Dumping				4.7	4.5	4.6

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S= speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

Table A-11. Sample Size on a Time Basis by Driving Mode, Vehicle, and Fuel for Tier 1 Tandem Dump Trucks

		Unloaded					Loaded				
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]
		0507	**0578**	**0579**	**0580**		**0507**	**0578**	**0579**	**0580**	
B20	Idle	1,197	2,060	4,525	6,458	3,560	10,201	4,605	6,205	3,922	6,233
	Low Acceleration	184	202	267	392	261	553	397	698	66	429
	Medium Acceleration	687	344	289	616	484	1,334	432	815	128	677
	High Acceleration	348	242	277	242	277	273	226	626	24	287
	Low Cruise	472	242	580	965	565	1,108	700	1,217	133	790
	Medium Cruise	492	298	253	436	370	888	333	736	194	538
	High Cruise	1,355	452	602	1,206	904	847	878	1,082	103	728
	Deceleration	840	569	602	857	717	1,240	546	1,508	135	857
	Dumping						150	127	189	25	123
	Total	5,575	4,409	7,395	11,172	7,138	16,594	8,244	13,076	4,730	10,661
Petroleum Diesel	Idle	5,056	9,440	7,467	8,077	7,510	1,377	2,594	84	2,846	1,725
	Low Acceleration	356	364	270	525	379	750	570	34	580	484
	Medium Acceleration	927	883	509	555	719	1,417	863	159	349	697
	High Acceleration	794	502	221	140	414	364	284	33	78	190
	Low Cruise	531	546	638	1,197	728	1,193	829	31	1,613	917
	Medium Cruise	406	605	231	207	362	700	553	64	359	419
	High Cruise	1,781	1,388	1,075	42	1,072	1,194	1,307	124	36	665
	Deceleration	1,256	1,001	327	770	839	1,300	979	59	605	736
	Dumping						188	86	25	144	111
	Total	11,107	14,729	10,738	11,513	12,022	8,483	8,065	613	6,610	5,943

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes.

Table A-12. Sample Size on a Time Basis by Driving Mode, Vehicle, and Fuel for Tier 1 Single Axle Dump Trucks

		Unloaded					Loaded				
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**	
B20	Idle	1,046	4,548	7,504	2,445	3,886	2,112	1,517	3,722	5,315	3,167
	Low Acceleration	216	30	209	139	149	164	80	88	201	133
	Medium Acceleration	596	49	799	448	473	890	315	223	575	501
	High Acceleration	853	20	486	327	422	577	39	83	61	190
	Low Cruise	363	34	353	210	240	301	98	174	349	231
	Medium Cruise	178	28	697	276	295	490	226	113	444	318
	High Cruise	3,346	59	1,484	913	1,451	3,086	220	586	341	1,058
	Deceleration	1,172	65	1,070	686	748	1,142	166	294	523	531
	Dumping						51	21	12	42	32
	Total	7,770	4,833	12,602	5,444	7,662	8,813	2,682	5,295	7,851	6,160
Petroleum Diesel	Idle	6,014	3,011	14,383	5,975	7,346	2,831	1,307	206	4,058	2,101
	Low Acceleration	279	325	264	369	309	280	445	53	400	295
	Medium Acceleration	544	760	387	384	519	536	897	152	342	482
	High Acceleration	222	590	335	207	339	48	413	25	179	166
	Low Cruise	778	721	818	659	744	575	870	76	747	567
	Medium Cruise	907	437	345	208	474	1,085	332	128	144	422
	High Cruise	966	1,342	771	675	939	64	1,663	25	601	588
	Deceleration	779	1,265	655	567	817	536	1,227	195	432	598
	Dumping						11	99	24	14	37
	Total	10,489	8,451	17,958	9,044	11,486	5,966	7,253	884	6,917	5,255

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

Table A-13. Sample Size on a Time Basis by Driving Mode, Vehicle, and Fuel for Tier 2 Tandem Dump Trucks

		Unloaded			Loaded		
	Driving Mode[a]	Vehicle Number		Avg[b]	Vehicle Number		Avg[b]
		0125	**0126**		**0125**	**0126**	
B20	Idle	1,258	3,398	2,328	3,109	2,780	2,945
	Low Acceleration	335	209	272	537	431	484
	Medium Acceleration	490	270	380	672	636	654
	High Acceleration	338	374	356	347	468	408
	Low Cruise	580	450	515	844	762	803
	Medium Cruise	610	382	496	610	320	465
	High Cruise	4,017	4,404	4,211	3,676	4,446	4,061
	Deceleration	628	502	565	710	734	722
	Dumping				61	64	63
	Total	8,256	9,989	9,123	10,566	10,641	10,604
Petroleum Diesel	Idle	4,199	4,780	4,490	3,317	1,352	2,335
	Low Acceleration	427	307	367	543	378	461
	Medium Acceleration	845	327	586	876	624	750
	High Acceleration	192	1,057	625	217	1,002	610
	Low Cruise	734	808	771	1,199	742	971
	Medium Cruise	1,153	356	755	1,044	407	726
	High Cruise	614	3,480	2,047	1,620	3,620	2,620
	Deceleration	633	709	671	797	765	781
	Dumping				604	112	358
	Total	8,797	11,824	10,311	10,217	9,002	9,610

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

Table A-14. Sample Size on a Time Basis by Driving Mode, Vehicle, and Fuel for Tier 2 Single Axle Dump Trucks

		Unloaded			**Loaded**		
	Driving Mode[a]	Vehicle Number		Avg[b]	Vehicle Number		Avg[b]
		6117	**6123**		**6117**	**6123**	
B20	Idle	2,698	1,037	1,868	1,735	161	948
	Low Acceleration	312	138	225	427	259	343
	Medium Acceleration	907	267	587	917	495	706
	High Acceleration	666	103	385	202	86	144
	Low Cruise	511	353	432	622	512	567
	Medium Cruise	971	160	566	983	436	710
	High Cruise	595	1,235	915	242	330	286
	Deceleration	1,565	274	920	1,230	731	981
	Dumping				146	58	102
	Total	8,225	3,567	5,896	6,504	3,068	4,786
Petroleum Diesel	Idle	5,008	6,076	5,542	4,806	5,264	5,035
	Low Acceleration	215	177	196	372	415	394
	Medium Acceleration	812	640	726	835	449	642
	High Acceleration	928	546	737	246	179	213
	Low Cruise	385	426	406	747	827	787
	Medium Cruise	480	586	533	487	127	307
	High Cruise	963	2,297	1,630	613	378	496
	Deceleration	1,222	887	1,055	809	671	740
	Dumping				130	180	155
	Total	10,013	11,635	10,824	9,045	8,490	8,768

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

Table A-15. Average Speed on a Mile Per Hour Basis by Driving Mode, Vehicle, and Fuel for Tier 1 Tandem Dump Trucks

		Unloaded					**Loaded**				
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]
		0507	**0578**	**0579**	**0580**		**0507**	**0578**	**0579**	**0580**	
B20	Idle										
	Low Acceleration	8.91	13.0	11.0	7.38	10.1	8.80	11.3	12.4	10.2	10.7
	Medium Acceleration	34.0	32.0	29.3	35.5	32.7	33.5	31.8	30.6	33.7	32.4
	High Acceleration	41.6	39.5	41.9	42.2	41.3	39.5	48.3	41.5	47.9	44.3
	Low Cruise	10.4	13.4	10.7	7.50	10.5	9.99	11.2	11.4	13.2	11.4
	Medium Cruise	40.4	39.7	40.7	40.5	40.3	39.2	38.0	39.0	40.6	39.2
	High Cruise	54.9	49.9	56.2	50.8	53.0	49.1	61.1	55.0	51.5	54.2
	Deceleration	30.2	26.7	24.4	23.6	26.2	23.0	29.6	23.8	27.5	26.0
	Dumping										
	Equal Weight Avg[b]	31.5	30.6	30.6	29.6	30.6	29.0	33.0	30.5	32.1	31.2
	Empirical Weight Avg[c]	29.4	17.2	11.9	12.7	17.8	10.6	14.5	15.1	5.20	11.4
Petroleum Diesel	Idle										
	Low Acceleration	8.26	10.4	8.99	9.32	9.24	10.7	10.3	13.2	7.78	10.5
	Medium Acceleration	32.4	34.2	33.9	27.4	32.0	32.4	31.1	34.7	29.8	32.0
	High Acceleration	44.5	42.2	45.5	32.1	41.1	45.2	51.1	39.9	32.7	42.2
	Low Cruise	9.73	10.4	12.9	8.09	10.3	12.5	13.5	19.4	10.2	13.9
	Medium Cruise	39.2	39.7	38.7	39.1	39.2	39.2	38.7	39.4	36.3	38.4
	High Cruise	56.3	55.5	57.3	48.5	54.4	50.2	61.3	49.0	46.2	51.7
	Deceleration	29.3	29.5	28.1	14.7	25.4	24.2	24.3	34.3	14.2	24.2
	Dumping										
	Equal Weight Avg[b]	27.5	27.7	28.2	22.4	26.4	23.8	25.6	25.5	19.7	23.5
	Empirical Weight Avg[c]	20.4	13.0	11.0	4.84	12.3	24.1	22.8	30.2	8.65	21.4

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table A-16. Average Speeds on a Mile Per Hour by Driving Mode, Vehicle, and Fuel for Tier 1 Single Axle Dump Trucks

		Unloaded					Loaded				
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**	
B20	Idle										
	Low Acceleration	8.45	10.1	9.32	8.63	9.13	9.40	9.03	10.0	9.80	9.56
	Medium Acceleration	34.6	32.8	33.5	36.5	34.4	35.7	33.8	36.5	35.5	35.4
	High Acceleration	46.3	32.3	44.2	44.6	41.9	48.6	29.6	51.1	36.8	41.5
	Low Cruise	9.44	16.1	16.0	10.4	13.0	15.0	14.4	13.1	12.5	13.8
	Medium Cruise	38.7	42.3	38.3	39.7	39.8	39.8	39.8	40.3	39.0	39.7
	High Cruise	57.9	46.8	53.9	52.2	52.7	58.0	46.5	51.2	47.3	50.8
	Deceleration	32.6	26.1	31.8	32.2	30.7	34.4	24.0	33.0	25.4	29.2
	Dumping										
	Equal Weight Avg[b]	28.5	25.8	28.4	28.0	27.7	26.8	21.9	26.1	22.9	24.4
	Empirical Weight Avg[c]	39.2	1.81	15.6	21.1	19.4	34.5	14.8	11.3	9.65	11.3
Petroleum Diesel	Idle										
	Low Acceleration	8.33	6.99	7.39	10.0	8.18	8.66	7.92	8.58	8.37	8.38
	Medium Acceleration	33.4	36.0	32.0	26.3	31.9	31.4	34.8	30.8	26.2	30.8
	High Acceleration	35.5	43.2	47.4	44.6	42.7	29.4	43.1	36.6	45.3	38.6
	Low Cruise	11.5	8.13	9.01	10.5	9.79	11.5	8.46	9.33	8.05	9.34
	Medium Cruise	39.3	39.7	38.2	33.7	37.7	38.4	40.0	37.7	32.6	37.2
	High Cruise	50.0	54.3	56.8	57.7	54.7	45.8	51.2	51.6	58.1	51.7
	Deceleration	25.3	30.4	29.4	21.5	26.7	19.0	27.3	22.3	18.3	21.7
	Dumping										
	Equal Weight Avg[b]	25.4	27.3	27.5	25.5	26.5	20.5	23.6	21.9	21.9	22.0
	Empirical Weight Avg[c]	13.4	22.4	6.34	9.74	13.0	13.8	26.4	19.5	10.7	17.6

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table A-17. Average Speed on a Mile Per Hour Basis by Driving Mode, Vehicle, and Fuel for Tier 2 Tandem Dump Trucks

		Unloaded			**Loaded**		
	Driving Mode[a]	Vehicle Number		Avg[b]	Vehicle Number		Avg[b]
		0125	**0126**		**0125**	**0126**	
B20	Idle						
	Low Acceleration	10.0	8.00	9.00	9.29	8.48	8.89
	Medium Acceleration	32.2	31.3	31.8	31.0	32.4	31.7
	High Acceleration	45.7	45.7	45.7	48.8	49.0	48.9
	Low Cruise	14.2	13.8	14.0	11.6	11.1	11.4
	Medium Cruise	37.5	38.2	37.9	38.0	37.2	37.6
	High Cruise	53.6	54.6	54.1	54.2	54.2	54.2
	Deceleration	30.0	32.9	31.5	26.9	32.4	29.7
	Dumping						
	Equal Weight Avg[b]	27.9	28.1	28.0	24.4	25.0	24.7
	Empirical Weight Avg[c]	36.3	30.5	33.4	27.8	31.2	29.5
Petroleum Diesel	Idle						
	Low Acceleration	10.5	9.49	10.0	8.53	8.75	8.64
	Medium Acceleration	33.1	32.3	32.7	32.7	33.4	33.1
	High Acceleration	32.3	29.5	30.9	42.4	24.1	33.3
	Low Cruise	15.6	13.2	14.4	10.8	10.5	10.7
	Medium Cruise	40.0	41.0	40.5	38.7	38.0	38.4
	High Cruise	50.8	54.3	52.6	53.4	54.3	53.9
	Deceleration	21.2	28.9	25.1	21.5	30.0	25.8
	Dumping						
	Equal Weight Avg[b]	25.4	26.1	25.8	23.1	22.1	22.6
	Empirical Weight Avg[c]	16.0	23.6	19.8	19.5	32.3	25.9

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table A-18. Average Speeds on a Mile Per Hour Basis by Driving Mode, Vehicle, and Fuel for Tier 2 Single Axle Dump Trucks

		Unloaded			**Loaded**		
	Driving Mode[a]	Vehicle Number **6117**	Vehicle Number **6123**	Avg[b]	Vehicle Number **6117**	Vehicle Number **6123**	Avg[b]
B20	Idle						
	Low Acceleration	9.20	9.32	9.26	8.41	8.38	8.40
	Medium Acceleration	32.4	36.0	34.2	32.1	34.2	33.2
	High Acceleration	39.8	32.8	36.3	37.5	34.6	36.1
	Low Cruise	12.3	11.0	11.7	10.7	10.9	10.8
	Medium Cruise	37.8	41.5	39.7	38.9	40.8	39.9
	High Cruise	51.8	49.9	50.9	49.6	45.6	47.6
	Deceleration	27.0	20.2	23.6	21.1	20.4	20.8
	Dumping						
	Equal Weight Avg[b]	23.4	25.1	25.7	22.0	21.7	21.8
	Empirical Weight Avg[c]	21.3	25.8	23.5	19.0	24.6	21.8
Petroleum Diesel	Idle						
	Low Acceleration	8.48	7.38	7.93	7.76	6.97	7.37
	Medium Acceleration	35.6	33.7	34.7	34.0	33.6	33.8
	High Acceleration	40.1	42.9	41.5	37.0	45.1	41.1
	Low Cruise	14.2	8.74	11.5	10.5	6.59	8.55
	Medium Cruise	38.6	40.4	39.5	39.3	39.7	39.5
	High Cruise	50.4	53.0	51.7	48.7	50.0	49.4
	Deceleration	32.4	28.2	30.3	22.5	19.8	21.2
	Dumping						
	Equal Weight Avg[b]	27.5	26.8	27.1	22.2	22.4	22.3
	Empirical Weight Avg[c]	18.0	18.9	18.5	12.8	8.10	10.4

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45)

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table A-19. Standard Deviation on a Per Time Basis by Driving Mode, Vehicle, and Load for Tier 1 Tandem Dump Trucks (Petroleum Diesel)

		Unloaded					**Loaded**				
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]
		0507	**0578**	**0579**	**0580**		**0507**	**0578**	**0579**	**0580**	
Fuel (g/sec)	Idle	0.109	0.092	0.106	0.120	0.054	0.294	0.174	0.203	0.147	0.106
	Low Acceleration	1.83	1.47	1.56	2.64	0.965	2.50	1.91	1.60	2.79	1.12
	Medium Acceleration	2.58	2.26	1.82	3.49	1.30	2.67	2.45	2.01	3.29	1.32
	High Acceleration	2.62	2.25	1.81	3.42	1.30	2.86	2.13	1.86	2.81	1.23
	Low Cruise	2.06	1.45	1.43	2.53	0.961	2.79	2.39	2.03	2.04	1.17
	Medium Cruise	2.69	1.99	1.67	3.36	1.26	2.76	2.69	1.82	3.55	1.39
	High Cruise	2.20	1.74	1.53	3.63	1.21	3.28	2.27	1.84	4.74	1.62
	Deceleration	2.12	1.71	2.06	1.66	0.950	3.30	2.60	2.37	3.81	1.54
	Dumping						0.563	0.575	0.256	0.856	0.301
	SD of Avg[b]	0.768	0.616	0.565	1.00	0.379	0.853	0.698	0.573	1.00	0.399
NO_x (g/sec)	Idle	0.003	0.003	0.003	0.004	0.002	0.008	0.005	0.004	0.005	0.003
	Low Acceleration	0.038	0.032	0.039	0.053	0.021	0.093	0.043	0.048	0.063	0.032
	Medium Acceleration	0.104	0.059	0.060	0.076	0.308	0.148	0.094	0.078	0.071	0.051
	High Acceleration	0.108	0.067	0.086	0.077	0.043	0.182	0.101	0.058	0.064	0.056
	Low Cruise	0.045	0.037	0.043	0.052	0.022	0.112	0.057	0.039	0.046	0.035
	Medium Cruise	0.086	0.057	0.067	0.066	0.035	0.177	0.123	0.079	0.071	0.060
	High Cruise	0.124	0.097	0.095	0.084	0.051	0.233	0.125	0.073	0.076	0.071
	Deceleration	0.082	0.060	0.090	0.031	0.035	0.211	0.109	0.091	0.075	0.066
	Dumping						0.018	0.014	0.010	0.020	0.008
	SD of Avg[b]	0.029	0.020	0.024	0.022	0.012	0.051	0.029	0.020	0.020	0.016

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Standard deviation of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

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Table A-19. Continued

	Driving Mode[a]	Unloaded					Loaded				
		Vehicle Number				Avg[b]	Vehicle Number				Avg[b]
		0507	**0578**	**0579**	**0580**		**0507**	**0578**	**0579**	**0580**	
HC (mg/sec)	Idle	1.17	0.538	0.467	1.12	0.443	1.21	0.701	1.95	1.15	0.666
	Low Acceleration	5.97	2.36	2.24	3.74	1.94	6.06	3.37	9.67	5.76	3.31
	Medium Acceleration	5.44	2.82	2.19	4.25	1.94	6.16	3.80	11.2	7.79	3.87
	High Acceleration	4.95	2.59	1.77	5.59	2.02	5.41	3.97	8.84	9.41	3.64
	Low Cruise	6.31	2.46	2.29	3.22	1.96	5.36	3.40	6.87	3.74	2.52
	Medium Cruise	4.05	2.53	2.06	3.05	1.51	4.47	4.26	10.3	6.26	3.39
	High Cruise	3.95	2.25	1.37	4.14	1.58	4.67	3.10	6.54	9.15	3.14
	Deceleration	3.55	2.57	1.81	2.41	1.33	3.90	3.56	6.60	4.34	2.38
	Dumping						2.37	1.20	0.55	2.14	0.864
	SD of Avg[b]	1.66	0.836	0.659	1.29	0.589	1.56	1.09	2.59	2.06	0.953
CO (mg/sec)	Idle	11.6	1.03	1.16	2.93	3.01	13.3	2.18	1.22	1.71	3.41
	Low Acceleration	14.3	9.86	20.6	10.3	7.20	9.20	7.02	18.6	10.7	6.09
	Medium Acceleration	7.62	6.17	8.59	10.4	4.17	7.85	6.17	8.91	10.2	4.20
	High Acceleration	7.49	5.56	7.35	10.1	3.90	7.46	7.23	9.18	9.92	4.26
	Low Cruise	26.0	8.58	7.79	9.66	7.52	22.2	6.57	16.5	12.4	7.76
	Medium Cruise	5.12	5.57	5.19	6.11	2.76	6.62	5.59	6.87	8.10	3.43
	High Cruise	4.24	6.56	4.55	8.96	3.18	4.82	6.04	6.15	10.7	3.64
	Deceleration	28.7	6.88	6.37	6.16	7.70	23.4	6.20	20.6	9.16	8.27
	Dumping						8.36	5.32	3.32	6.18	3.04
	SD of Avg[b]	5.58	2.38	3.31	2.99	1.88	4.38	1.99	4.01	3.09	1.75

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Standard deviation of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

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Table A-19. Continued

	Driving Mode[a]	Unloaded					Loaded				
		Vehicle Number				Avg[b]	Vehicle Number				Avg[b]
		0507	**0578**	**0579**	**0580**		**0507**	**0578**	**0579**	**0580**	
CO_2 (g/sec)	Idle	0.342	0.290	0.334	0.372	0.168	0.928	0.550	0.639	0.454	0.333
	Low Acceleration	5.80	4.65	4.92	8.15	3.02	7.90	6.04	5.03	8.62	3.52
	Medium Acceleration	8.16	7.14	5.74	10.8	4.08	8.44	7.75	6.36	10.2	4.15
	High Acceleration	8.30	7.10	5.72	10.6	4.07	9.05	6.74	5.88	8.70	3.86
	Low Cruise	6.51	4.58	4.52	7.81	3.01	8.81	7.56	6.41	6.30	3.67
	Medium Cruise	8.52	6.29	5.27	10.4	3.94	8.74	8.51	5.74	11.0	4.35
	High Cruise	6.97	5.51	4.84	11.2	3.78	10.4	7.19	5.83	14.7	5.05
	Deceleration	6.71	5.40	6.53	5.14	2.99	10.3	8.22	7.48	11.8	4.82
	Dumping						1.78	1.82	0.809	2.65	0.941
	SD of Avg[b]	2.43	1.95	1.79	3.10	1.19	2.70	2.21	1.81	3.09	1.25
PM (mg/sec)	Idle	0.026	0.028	0.021	0.034	0.014	0.032	0.033	0.023	0.033	0.015
	Low Acceleration	0.270	0.270	0.348	0.468	0.174	0.352	0.319	0.399	0.490	0.198
	Medium Acceleration	0.381	0.401	0.400	0.709	0.246	0.415	0.362	0.513	0.627	0.245
	High Acceleration	0.371	0.399	0.443	0.818	0.270	0.392	0.352	0.696	0.612	0.267
	Low Cruise	0.210	0.231	0.319	0.350	0.142	0.367	0.378	0.427	0.186	0.176
	Medium Cruise	0.308	0.316	0.335	0.408	0.172	0.445	0.411	0.532	0.656	0.260
	High Cruise	0.303	0.234	0.242	0.556	0.179	0.359	0.312	0.553	0.666	0.247
	Deceleration	0.205	0.233	0.345	0.144	0.122	0.379	0.377	0.647	0.430	0.236
	Dumping						0.076	0.131	0.047	0.141	0.053
	SD of Avg[b]	0.099	0.101	0.117	0.177	0.064	0.114	0.107	0.161	0.162	0.069

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Standard deviation of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

Table A-20. Standard Deviation on a Per Time Basis by Driving Mode, Vehicle, and Load for Tier 1 Single Axle Dump Trucks (Petroleum Diesel)

		Unloaded					Loaded				
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**	
Fuel (g/sec)	Idle	0.078	0.030	0.035	0.028	0.024	0.058	0.050	0.148	0.028	0.042
	Low Acceleration	0.930	1.09	0.762	1.05	0.483	1.28	1.65	1.24	1.15	0.670
	Medium Acceleration	1.26	2.05	1.36	1.95	0.845	1.88	2.10	1.75	1.91	0.958
	High Acceleration	1.48	1.94	1.59	1.79	0.854	1.83	2.17	1.29	1.67	0.883
	Low Cruise	0.714	0.979	0.495	0.632	0.363	1.21	1.22	0.960	0.834	0.535
	Medium Cruise	0.916	1.49	1.00	1.17	0.583	1.62	2.31	1.46	2.50	1.01
	High Cruise	1.19	2.10	1.84	2.20	0.937	1.88	2.16	2.10	2.30	1.06
	Deceleration	1.01	1.65	2.17	1.54	0.822	1.52	1.68	0.920	2.08	0.803
	Dumping						0.385	0.750	0.371	0.475	0.259
	SD of Avg[b]	0.362	0.551	0.472	0.517	0.241	0.479	0.574	0.427	0.550	0.255
NO_x (g/sec)	Idle	0.002	0.004	0.002	0.001	0.001	0.002	0.005	0.005	0.001	0.002
	Low Acceleration	0.044	0.027	0.030	0.043	0.018	0.059	0.047	0.057	0.046	0.026
	Medium Acceleration	0.055	0.051	0.069	0.082	0.033	0.077	0.056	0.076	0.079	0.036
	High Acceleration	0.069	0.046	0.073	0.079	0.034	0.073	0.063	0.057	0.065	0.032
	Low Cruise	0.042	0.028	0.017	0.025	0.015	0.056	0.032	0.032	0.033	0.020
	Medium Cruise	0.040	0.036	0.038	0.045	0.020	0.069	0.062	0.059	0.090	0.035
	High Cruise	0.041	0.042	0.065	0.068	0.028	0.063	0.044	0.082	0.080	0.034
	Deceleration	0.036	0.035	0.058	0.042	0.022	0.068	0.036	0.035	0.063	0.026
	Dumping						0.028	0.024	0.016	0.022	0.011
	SD of Avg[b]	0.016	0.013	0.018	0.019	0.008	0.020	0.015	0.018	0.020	0.009

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Standard deviation of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

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Table A-20. Continued

	Driving Mode[a]	Unloaded					Loaded				
		Vehicle Number				Avg[b]	Vehicle Number				Avg[b]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**	
HC (mg/sec)	Idle	0.693	0.642	0.406	0.334	0.270	0.466	0.376	0.415	0.282	0.195
	Low Acceleration	1.13	1.42	0.742	1.02	0.553	1.02	1.75	1.08	0.988	0.625
	Medium Acceleration	1.30	2.91	1.35	1.99	0.999	1.89	2.57	2.21	1.44	1.03
	High Acceleration	1.51	3.04	1.66	2.64	1.15	1.85	2.56	1.89	1.86	1.03
	Low Cruise	0.897	1.63	0.692	0.734	0.529	1.07	1.76	0.953	0.747	0.597
	Medium Cruise	1.03	2.10	0.721	1.07	0.668	1.36	2.16	1.94	1.61	0.897
	High Cruise	1.21	2.74	1.42	2.94	1.11	1.96	2.09	0.745	1.83	0.870
	Deceleration	1.06	2.22	1.03	1.64	0.783	1.22	1.94	1.04	1.32	0.711
	Dumping						0.851	1.31	0.447	0.496	0.425
	SD of Avg[b]	0.399	0.787	0.382	0.626	0.287	0.462	0.647	0.449	0.232	0.253
CO (mg/sec)	Idle	1.96	0.674	0.670	0.665	0.570	0.601	1.10	2.98	1.01	0.847
	Low Acceleration	24.3	11.1	12.9	17.7	8.63	43.6	23.9	29.6	22.9	15.6
	Medium Acceleration	37.8	15.8	26.4	27.2	14.0	28.7	21.9	32.0	30.9	14.3
	High Acceleration	36.4	16.2	29.0	24.6	13.8	38.6	34.3	27.2	17.3	15.2
	Low Cruise	14.1	10.9	8.17	9.32	5.43	24.9	10.9	20.1	15.0	9.24
	Medium Cruise	11.5	7.62	13.9	12.5	5.80	10.0	8.77	16.7	16.8	6.79
	High Cruise	3.37	5.24	6.94	5.44	2.70	3.68	4.80	2.53	4.89	2.05
	Deceleration	9.88	6.90	7.06	9.47	4.22	18.5	7.87	12.4	9.10	6.33
	Dumping						9.66	12.0	5.67	8.00	4.57
	SD of Avg[b]	7.70	3.73	5.68	5.62	2.93	8.15	5.73	6.59	5.51	3.29

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Standard deviation of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

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Table A-20. Continued

	Driving Mode[a]	Unloaded 4743	Unloaded 4750	Unloaded 4869	Unloaded 4870	Unloaded Avg[b]	Loaded 4743	Loaded 4750	Loaded 4869	Loaded 4870	Loaded Avg[b]
CO_2 (g/sec)	Idle	0.245	0.093	0.110	0.090	0.074	0.183	0.158	0.464	0.088	0.133
	Low Acceleration	2.92	3.42	2.39	3.31	1.52	3.99	5.18	3.89	3.60	2.10
	Medium Acceleration	3.96	6.47	4.27	6.14	2.66	5.95	6.65	5.53	6.02	3.02
	High Acceleration	4.67	6.13	5.02	5.65	2.70	5.76	6.84	4.10	5.28	2.79
	Low Cruise	2.24	3.08	1.56	1.99	1.14	3.81	3.85	3.01	2.62	1.68
	Medium Cruise	2.89	4.71	3.15	3.70	1.84	5.12	7.29	4.59	7.92	3.19
	High Cruise	3.76	6.64	5.81	6.97	2.96	5.94	6.82	6.65	7.27	3.35
	Deceleration	3.17	5.21	6.86	4.88	2.60	4.80	5.31	2.90	6.58	2.54
	Dumping						1.21	2.35	1.17	1.50	0.814
	SD of Avg[b]	1.14	1.74	1.49	1.63	0.759	1.51	1.81	1.35	1.74	0.807
PM (mg/sec)	Idle	0.026	0.018	0.015	0.014	0.010	0.019	0.028	0.030	0.018	0.012
	Low Acceleration	0.341	0.201	0.240	0.342	0.144	0.375	0.326	0.312	0.387	0.175
	Medium Acceleration	0.447	0.314	0.319	0.503	0.202	0.609	0.354	0.414	0.471	0.236
	High Acceleration	0.587	0.359	0.345	0.463	0.225	0.582	0.381	0.280	0.378	0.210
	Low Cruise	0.213	0.159	0.171	0.229	0.098	0.362	0.206	0.286	0.301	0.147
	Medium Cruise	0.226	0.205	0.266	0.344	0.133	0.404	0.290	0.362	0.476	0.194
	High Cruise	0.225	0.301	0.303	0.345	0.148	0.285	0.287	0.386	0.355	0.165
	Deceleration	0.224	0.223	0.422	0.355	0.159	0.403	0.224	0.203	0.403	0.161
	Dumping						0.092	0.232	0.109	0.217	0.087
	SD of Avg[b]	0.116	0.086	0.101	0.125	0.054	0.131	0.092	0.097	0.120	0.056

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Standard deviation of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

Table A-21. Standard Deviation on a Per Time Basis by Driving Mode, Vehicle, and Load for Tier 1 Tandem Dump Trucks (Soy Based B20)

	Driving Mode[a]	Unloaded					Loaded				
		Vehicle Number				Avg[b]	Vehicle Number				Avg[b]
		0507	**0578**	**0579**	**0580**		**0507**	**0578**	**0579**	**0580**	
Fuel (g/sec)	Idle	0.091	0.221	0.147	0.120	0.076	0.065	0.192	0.190	0.353	0.112
	Low Acceleration	1.72	1.86	1.51	1.35	0.811	1.91	2.12	1.88	1.82	0.968
	Medium Acceleration	2.27	2.18	1.91	2.25	1.08	2.37	2.37	2.22	2.36	1.16
	High Acceleration	2.23	2.28	2.21	2.31	1.13	2.15	2.36	2.26	2.92	1.22
	Low Cruise	1.60	2.14	1.38	1.12	0.802	1.79	2.16	1.64	1.62	0.908
	Medium Cruise	2.13	1.97	1.55	1.81	0.939	2.62	2.57	2.11	1.73	1.14
	High Cruise	1.90	1.80	1.79	1.78	0.910	2.50	2.39	2.03	2.94	1.24
	Deceleration	1.58	1.68	1.64	1.67	0.822	1.66	2.44	1.86	2.86	1.13
	Dumping						0.445	0.973	0.739	0.526	0.351
	SD of Avg[b]	0.641	0.662	0.573	0.596	0.310	0.640	0.700	0.597	0.705	0.331
NO_x (g/sec)	Idle	0.003	0.009	0.003	0.003	0.003	0.003	0.006	0.005	0.008	0.003
	Low Acceleration	0.031	0.045	0.042	0.031	0.019	0.044	0.072	0.061	0.032	0.027
	Medium Acceleration	0.052	0.076	0.080	0.041	0.032	0.058	0.131	0.089	0.042	0.043
	High Acceleration	0.088	0.077	0.092	0.053	0.039	0.056	0.151	0.094	0.058	0.049
	Low Cruise	0.032	0.062	0.042	0.022	0.021	0.035	0.084	0.055	0.029	0.028
	Medium Cruise	0.047	0.067	0.052	0.036	0.026	0.071	0.134	0.085	0.043	0.045
	High Cruise	0.083	0.093	0.111	0.057	0.044	0.069	0.165	0.108	0.054	0.054
	Deceleration	0.044	0.064	0.076	0.048	0.030	0.045	0.147	0.073	0.066	0.046
	Dumping						0.010	0.030	0.031	0.013	0.012
	SD of Avg[b]	0.019	0.023	0.025	0.014	0.010	0.016	0.038	0.025	0.014	0.013

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Standard deviation of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

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Table A-21. Continued

	Driving Mode[a]	Unloaded 0507	Unloaded 0578	Unloaded 0579	Unloaded 0580	Unloaded Avg[b]	Loaded 0507	Loaded 0578	Loaded 0579	Loaded 0580	Loaded Avg[b]
HC (mg/sec)	Idle	0.633	1.51	0.793	0.668	0.485	0.599	0.751	0.855	0.574	0.352
	Low Acceleration	3.48	5.16	3.71	1.25	1.84	2.65	5.75	4.61	2.06	2.03
	Medium Acceleration	4.36	5.11	4.42	1.58	2.05	2.97	5.00	5.12	1.05	1.96
	High Acceleration	6.10	5.20	4.81	1.87	2.38	3.06	4.76	5.10	1.35	1.94
	Low Cruise	3.15	6.17	3.61	1.32	1.98	2.09	5.00	4.04	1.97	1.76
	Medium Cruise	3.16	4.82	4.05	1.29	1.79	2.72	4.51	4.54	0.754	1.75
	High Cruise	2.69	3.66	3.71	1.41	1.51	2.18	4.25	4.42	1.35	1.66
	Deceleration	2.43	4.14	3.93	1.44	1.59	1.68	4.72	3.78	1.74	1.63
	Dumping						1.30	4.29	5.63	0.606	1.80
	SD of Avg[b]	1.26	1.65	1.35	0.492	0.630	0.758	1.51	1.48	0.460	0.573
CO (mg/sec)	Idle	1.92	11.0	1.46	2.18	2.87	0.780	16.7	2.49	10.1	4.92
	Low Acceleration	19.9	10.9	22.0	58.1	16.5	15.5	12.0	16.0	18.2	7.79
	Medium Acceleration	17.5	9.35	13.6	17.5	7.44	7.19	11.8	11.2	9.85	5.08
	High Acceleration	7.82	8.76	11.2	10.9	4.89	5.95	37.9	10.2	7.75	10.1
	Low Cruise	27.4	17.8	11.5	25.7	10.8	16.2	22.8	11.3	29.3	10.5
	Medium Cruise	4.67	7.23	6.08	7.42	3.22	5.50	8.79	7.10	3.27	3.25
	High Cruise	3.85	9.23	5.36	3.82	2.99	4.92	8.02	6.33	6.44	3.26
	Deceleration	12.5	13.2	10.1	29.0	8.93	14.0	32.4	10.4	18.7	10.3
	Dumping						5.34	27.8	11.5	4.46	7.72
	SD of Avg[b]	5.17	4.02	4.14	9.17	3.00	3.28	7.44	3.43	4.80	2.51

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Standard deviation of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

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Table A-21. Continued

	Driving Mode[a]	Unloaded 0507	Unloaded 0578	Unloaded 0579	Unloaded 0580	Unloaded Avg[b]	Loaded 0507	Loaded 0578	Loaded 0579	Loaded 0580	Loaded Avg[b]
CO_2 (g/sec)	Idle	0.283	0.938	0.472	0.368	0.287	0.200	0.746	0.652	1.08	0.370
	Low Acceleration	5.30	9.50	7.66	4.16	3.48	5.90	10.9	9.67	5.63	4.18
	Medium Acceleration	7.02	11.2	9.81	6.96	4.47	7.33	12.2	11.4	7.29	4.91
	High Acceleration	6.92	11.6	11.4	7.15	4.77	6.66	12.3	11.7	9.04	5.08
	Low Cruise	4.94	10.8	6.96	3.47	3.55	5.53	11.2	8.54	4.99	3.97
	Medium Cruise	6.60	10.1	7.83	5.59	3.86	8.09	13.2	10.9	5.34	4.92
	High Cruise	5.89	9.25	9.17	5.51	3.83	7.73	12.4	10.4	9.08	5.03
	Deceleration	4.90	8.39	8.13	5.16	3.42	5.13	12.7	9.34	8.85	4.69
	Dumping						1.37	5.18	3.65	1.63	1.67
	SD of Avg[b]	1.98	3.37	2.92	1.84	1.30	1.98	3.62	3.07	2.18	1.40
PM (mg/sec)	Idle	0.020	0.130	0.066	0.019	0.037	0.018	0.150	0.078	0.063	0.045
	Low Acceleration	0.376	1.61	1.20	0.244	0.515	0.359	2.16	1.71	0.344	0.698
	Medium Acceleration	0.479	1.96	1.65	0.460	0.661	0.427	1.80	1.93	0.505	0.680
	High Acceleration	0.448	2.09	2.21	0.526	0.779	0.367	1.77	2.10	0.624	0.710
	Low Cruise	0.280	1.42	0.775	0.129	0.412	0.258	1.75	1.17	0.263	0.536
	Medium Cruise	0.365	1.63	0.853	0.279	0.474	0.443	1.87	1.68	0.265	0.643
	High Cruise	0.226	1.20	1.14	0.241	0.423	0.413	1.34	1.46	0.410	0.517
	Deceleration	0.182	1.04	0.954	0.182	0.358	0.228	1.44	1.07	0.401	0.464
	Dumping						0.070	0.604	0.627	0.045	0.219
	SD of Avg[b]	0.116	0.530	0.443	0.107	0.177	0.108	0.520	0.483	0.124	0.182

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Standard deviation of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

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Table A-22. Standard Deviation on a Per Time Basis by Driving Mode, Vehicle, and Load for Tier 1 Single Axle Dump Trucks (Soy Based B20)

	Driving Mode[a]	Unloaded Vehicle Number 4743	4750	4869	4870	Unloaded Avg[b]	Loaded Vehicle Number 4743	4750	4869	4870	Loaded Avg[b]
Fuel (g/sec)	Idle	0.160	0.015	0.106	0.119	0.056	0.144	0.035	0.022	0.066	0.041
	Low Acceleration	1.64	0.815	1.31	1.64	0.696	1.79	1.75	1.52	1.98	0.884
	Medium Acceleration	2.63	2.07	1.83	2.25	1.11	2.76	1.91	2.09	2.30	1.14
	High Acceleration	2.50	1.93	1.83	2.11	1.05	2.76	1.69	2.27	2.69	1.20
	Low Cruise	1.57	1.25	1.27	1.37	0.686	2.34	2.43	1.16	1.57	0.974
	Medium Cruise	2.50	2.28	1.48	2.34	1.09	3.03	1.99	2.22	2.30	1.21
	High Cruise	2.30	2.10	1.77	1.93	1.02	2.71	1.84	2.03	2.31	1.12
	Deceleration	2.57	1.87	1.89	1.70	1.02	3.34	2.10	2.66	1.89	1.28
	Dumping						1.41	0.735	0.884	0.781	0.495
	SD of Avg[b]	0.756	0.604	0.544	0.640	0.320	0.814	0.586	0.069	0.644	0.335
NO_x (g/sec)	Idle	0.005	0.001	0.002	0.004	0.002	0.005	0.002	0.000	0.002	0.001
	Low Acceleration	0.030	0.030	0.018	0.022	0.013	0.036	0.032	0.032	0.022	0.016
	Medium Acceleration	0.051	0.050	0.032	0.039	0.022	0.055	0.055	0.033	0.038	0.023
	High Acceleration	0.048	0.030	0.029	0.034	0.018	0.050	0.045	0.036	0.038	0.021
	Low Cruise	0.039	0.045	0.023	0.021	0.017	0.053	0.074	0.027	0.028	0.025
	Medium Cruise	0.052	0.061	0.025	0.042	0.023	0.072	0.061	0.039	0.052	0.029
	High Cruise	0.040	0.043	0.029	0.030	0.018	0.049	0.047	0.041	0.042	0.022
	Deceleration	0.044	0.047	0.026	0.023	0.018	0.066	0.060	0.044	0.038	0.027
	Dumping						0.054	0.022	0.025	0.021	0.017
	SD of Avg[b]	0.015	0.015	0.009	0.010	0.006	0.017	0.016	0.011	0.011	0.007

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Standard deviation of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

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Table A-22. Continued

	Driving Mode[a]	Unloaded 4743	Unloaded 4750	Unloaded 4869	Unloaded 4870	Unloaded Avg[b]	Loaded 4743	Loaded 4750	Loaded 4869	Loaded 4870	Loaded Avg[b]
HC (mg/sec)	Idle	0.474	0.404	0.438	0.462	0.223	0.540	0.341	0.455	0.379	0.218
	Low Acceleration	2.08	0.553	1.67	1.82	0.817	3.54	1.32	1.55	1.67	1.10
	Medium Acceleration	3.36	1.13	2.53	2.57	1.26	3.83	1.61	1.26	2.67	1.27
	High Acceleration	4.17	0.974	2.91	3.08	1.51	4.39	1.93	1.07	2.92	1.43
	Low Cruise	1.90	0.643	1.47	1.02	0.671	3.10	1.09	1.06	1.92	0.987
	Medium Cruise	2.33	0.911	1.77	1.59	0.863	3.46	1.67	1.06	2.21	1.14
	High Cruise	3.69	1.03	2.36	2.48	1.28	3.96	1.33	1.30	2.40	1.25
	Deceleration	3.64	0.644	1.85	1.55	1.10	4.82	1.50	0.933	1.44	1.33
	Dumping						4.13	0.739	0.428	0.679	1.07
	SD of Avg[b]	1.04	0.291	0.709	0.704	0.368	1.24	0.454	0.357	0.661	0.380
CO (mg/sec)	Idle	1.37	0.413	1.76	2.98	0.935	2.64	0.517	0.516	1.68	0.803
	Low Acceleration	20.2	19.9	23.3	17.1	10.1	44.5	17.9	32.3	27.4	16.0
	Medium Acceleration	23.7	11.3	24.9	14.6	9.75	28.5	11.1	19.8	18.2	10.2
	High Acceleration	21.1	9.48	20.6	10.6	8.19	17.2	12.8	4.61	24.2	8.17
	Low Cruise	20.9	17.4	31.7	14.6	11.1	27.1	11.4	20.4	18.7	10.1
	Medium Cruise	12.2	6.27	10.1	7.59	4.66	9.42	5.65	8.36	8.51	4.05
	High Cruise	6.04	5.10	4.06	3.91	2.43	6.65	3.92	3.35	3.76	2.30
	Deceleration	13.3	10.7	12.3	6.91	5.53	19.1	6.33	10.0	9.51	6.10
	Dumping						13.8	8.43	12.8	32.6	9.66
	SD of Avg[b]	5.89	4.14	6.69	3.87	2.64	7.47	3.33	5.23	6.35	2.90

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Standard deviation of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

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Table A-22. Continued

	Driving Mode[a]	Unloaded: Vehicle Number 4743	Unloaded: 4750	Unloaded: 4869	Unloaded: 4870	Unloaded: Avg[b]	Loaded: Vehicle Number 4743	Loaded: 4750	Loaded: 4869	Loaded: 4870	Loaded: Avg[b]
CO_2 (g/sec)	Idle	0.493	0.044	0.326	0.365	0.174	0.443	0.106	0.067	0.203	0.126
	Low Acceleration	5.06	2.51	4.02	5.05	2.14	5.49	5.40	4.67	6.10	2.72
	Medium Acceleration	8.14	6.40	5.66	6.97	3.43	8.55	5.90	6.47	7.11	3.54
	High Acceleration	7.73	5.98	5.67	6.54	3.26	8.54	5.24	7.02	8.31	3.70
	Low Cruise	4.85	3.86	3.91	4.21	2.11	7.22	7.52	3.56	4.83	3.01
	Medium Cruise	7.74	7.05	4.57	7.24	3.38	9.38	6.17	6.87	7.13	3.74
	High Cruise	7.12	6.50	5.48	5.98	3.15	8.39	5.68	6.27	7.14	3.47
	Deceleration	7.93	5.78	5.84	5.26	3.14	10.3	6.49	8.24	5.81	3.95
	Dumping						4.35	2.27	2.68	2.39	1.52
	SD of Avg[b]	2.33	1.87	1.68	1.98	0.990	2.51	1.81	1.88	1.99	1.03
PM (mg/sec)	Idle	0.027	0.007	0.022	0.020	0.010	0.022	0.016	0.014	0.015	0.009
	Low Acceleration	0.230	0.216	0.271	0.344	0.135	0.437	0.336	0.291	0.295	0.172
	Medium Acceleration	0.391	0.374	0.382	0.337	0.186	0.454	0.426	0.333	0.297	0.191
	High Acceleration	0.412	0.270	0.438	0.335	0.185	0.424	0.375	0.372	0.339	0.189
	Low Cruise	0.207	0.251	0.250	0.252	0.121	0.337	0.391	0.263	0.266	0.159
	Medium Cruise	0.258	0.398	0.235	0.370	0.161	0.584	0.261	0.282	0.298	0.190
	High Cruise	0.380	0.369	0.265	0.204	0.157	0.393	0.217	0.306	0.298	0.155
	Deceleration	0.337	0.267	0.277	0.229	0.140	0.438	0.252	0.372	0.223	0.166
	Dumping						0.237	0.155	0.255	0.131	0.101
	SD of Avg[b]	0.108	0.104	0.103	0.100	0.052	0.133	0.099	0.098	0.086	0.053

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Standard deviation of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

Table A-23. Standard Deviation on a Per Time Basis by Driving Mode, Vehicle, and Load for Tier 2 Tandem Dump Trucks (Petroleum Diesel)

		Unloaded			Loaded		
	Driving Mode[a]	Vehicle Number		Avg[b]	Vehicle Number		Avg[b]
		0125	**0126**		**0125**	**0126**	
Fuel (g/sec)	Idle	0.156	0.107	0.095	0.164	0.252	0.150
	Low Acceleration	1.36	2.20	1.29	2.46	3.14	1.99
	Medium Acceleration	2.61	3.97	2.38	4.60	4.74	3.30
	High Acceleration	3.07	4.14	2.58	4.04	4.85	3.16
	Low Cruise	2.10	2.17	1.51	2.77	2.75	1.95
	Medium Cruise	1.80	2.81	1.67	3.97	4.58	3.03
	High Cruise	2.40	2.21	1.63	3.07	4.08	2.55
	Deceleration	2.29	2.89	1.84	3.12	3.52	2.35
	Dumping				0.330	1.49	0.760
	SD of Avg[b]	0.759	1.00	0.626	1.03	1.19	0.789
NO_x (g/sec)	Idle	0.003	0.003	0.002	0.004	0.006	0.003
	Low Acceleration	0.020	0.034	0.020	0.041	0.050	0.032
	Medium Acceleration	0.040	0.054	0.034	0.070	0.065	0.048
	High Acceleration	0.043	0.058	0.036	0.058	0.067	0.044
	Low Cruise	0.031	0.027	0.021	0.043	0.039	0.029
	Medium Cruise	0.027	0.035	0.022	0.072	0.066	0.049
	High Cruise	0.023	0.022	0.016	0.034	0.045	0.028
	Deceleration	0.029	0.031	0.021	0.044	0.039	0.029
	Dumping				0.008	0.031	0.016
	SD of Avg[b]	0.010	0.013	0.008	0.016	0.016	0.011
HC (mg/sec)	Idle	0.809	1.27	0.753	1.03	1.95	1.10
	Low Acceleration	2.13	2.70	1.72	5.11	2.19	2.78
	Medium Acceleration	3.79	4.39	2.90	5.79	6.44	4.33
	High Acceleration	5.38	5.20	3.74	6.37	3.97	3.75
	Low Cruise	2.65	3.32	2.13	5.45	4.97	3.69
	Medium Cruise	3.35	3.12	2.29	9.89	5.76	5.72
	High Cruise	4.07	2.34	2.35	3.20	5.19	3.04
	Deceleration	2.60	3.10	2.02	6.87	3.76	3.92
	Dumping				1.22	4.74	2.45
	SD of Avg[b]	1.19	1.19	0.841	1.88	1.52	1.21

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Standard deviation of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

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Table A-23. Continued

	Driving Mode[a]	Unloaded			Loaded		
		Vehicle Number		Avg[b]	Vehicle Number		Avg[b]
		0125	**0126**		**0125**	**0126**	
CO (mg/sec)	Idle	2.14	1.38	1.27	1.64	1.23	1.03
	Low Acceleration	15.6	20.1	12.7	19.4	14.6	12.1
	Medium Acceleration	14.4	28.6	16.0	17.0	11.9	10.4
	High Acceleration	14.2	25.2	14.4	11.1	13.5	8.74
	Low Cruise	12.6	17.5	10.8	18.1	12.9	11.1
	Medium Cruise	7.11	18.1	9.71	11.7	8.37	7.17
	High Cruise	6.42	10.2	6.01	6.63	8.44	5.36
	Deceleration	12.0	16.8	10.3	14.2	16.1	10.7
	Dumping				2.85	8.94	4.69
	SD of Avg[b]	4.05	6.70	3.91	4.31	3.82	2.88
CO_2 (g/sec)	Idle	0.493	0.335	0.298	0.518	0.795	0.475
	Low Acceleration	4.30	6.95	4.08	7.76	9.91	6.30
	Medium Acceleration	8.27	12.6	7.51	14.6	15.0	10.4
	High Acceleration	9.72	13.1	8.15	12.8	15.4	10.0
	Low Cruise	6.64	6.86	4.78	8.76	8.68	6.17
	Medium Cruise	5.70	8.89	5.28	12.6	14.5	9.58
	High Cruise	7.60	6.98	5.16	9.72	12.9	8.07
	Deceleration	7.23	9.12	5.82	9.84	11.1	7.42
	Dumping				1.04	4.69	2.40
	SD of Avg[b]	2.40	3.15	1.98	3.26	3.78	2.50
PM (mg/sec)	Idle	0.027	0.024	0.018	0.022	0.020	0.015
	Low Acceleration	0.266	0.372	0.229	0.476	0.471	0.335
	Medium Acceleration	0.469	0.477	0.335	0.702	0.708	0.498
	High Acceleration	0.739	0.665	0.497	0.681	0.737	0.502
	Low Cruise	0.343	0.336	0.240	0.437	0.359	0.283
	Medium Cruise	0.272	0.334	0.216	0.547	0.652	0.425
	High Cruise	0.311	0.266	0.205	0.381	0.459	0.298
	Deceleration	0.293	0.422	0.257	0.416	0.451	0.307
	Dumping				0.087	0.281	0.147
	SD of Avg[b]	0.138	0.142	0.099	0.157	0.169	0.115

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Standard deviation of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

Table A-24. Standard Deviation on a Per Time Basis by Driving Mode, Vehicle, and Load for Tier 2 Single Axle Dump Trucks (Petroleum Diesel)

		Unloaded			Loaded		
	Driving Mode[a]	Vehicle Number		Avg[b]	Vehicle Number		Avg[b]
		6117	**6123**		**6117**	**6123**	
Fuel (g/sec)	Idle	0.036	0.058	0.034	0.036	0.092	0.049
	Low Acceleration	1.39	1.10	0.886	1.34	1.85	1.14
	Medium Acceleration	1.69	1.74	1.22	1.85	2.06	1.38
	High Acceleration	1.90	1.88	1.33	1.91	2.36	1.52
	Low Cruise	1.21	1.31	1.89	1.32	1.47	0.988
	Medium Cruise	1.31	1.48	0.987	2.00	1.94	1.39
	High Cruise	1.78	1.74	1.25	2.08	2.43	1.60
	Deceleration	1.44	1.87	1.18	1.76	2.18	1.40
	Dumping				0.657	0.423	0.391
	SD of Avg[b]	0.513	0.533	0.370	0.526	0.609	0.402
NO_x (g/sec)	Idle	0.001	0.002	0.001	0.001	0.004	0.002
	Low Acceleration	0.040	0.033	0.026	0.049	0.066	0.041
	Medium Acceleration	0.056	0.073	0.046	0.077	0.076	0.054
	High Acceleration	0.056	0.059	0.040	0.066	0.069	0.048
	Low Cruise	0.026	0.041	0.024	0.033	0.054	0.032
	Medium Cruise	0.039	0.056	0.034	0.093	0.104	0.070
	High Cruise	0.045	0.054	0.035	0.065	0.091	0.056
	Deceleration	0.032	0.051	0.030	0.071	0.081	0.054
	Dumping				0.015	0.014	0.010
	SD of Avg[b]	0.014	0.018	0.011	0.020	0.023	0.015
HC (mg/sec)	Idle	0.428	0.465	0.316	1.12	0.542	0.620
	Low Acceleration	1.51	1.15	0.949	2.19	2.02	1.49
	Medium Acceleration	2.13	1.72	1.37	3.02	2.56	1.98
	High Acceleration	2.41	1.90	1.54	2.77	1.89	1.68
	Low Cruise	1.62	1.09	0.977	1.90	1.46	1.20
	Medium Cruise	1.57	1.33	1.03	3.15	2.30	1.95
	High Cruise	1.94	1.84	1.34	2.01	2.17	1.48
	Deceleration	1.90	1.66	1.26	2.14	1.76	1.39
	Dumping				3.84	0.891	1.97
	SD of Avg[b]	0.629	0.518	0.407	0.859	0.614	0.528

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Standard deviation of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

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Table A-24. Continued

	Driving Mode[a]	Unloaded: Vehicle Number 6117	Unloaded: Vehicle Number 6123	Unloaded: Avg[b]	Loaded: Vehicle Number 6117	Loaded: Vehicle Number 6123	Loaded: Avg[b]
CO (mg/sec)	Idle	1.10	0.873	0.702	1.78	0.846	0.985
	Low Acceleration	16.2	22.7	13.4	17.5	10.0	10.1
	Medium Acceleration	9.13	7.94	6.05	7.37	7.86	5.39
	High Acceleration	7.82	5.45	4.77	6.89	4.55	4.13
	Low Cruise	7.00	7.90	5.28	8.81	7.15	5.67
	Medium Cruise	4.14	3.31	2.64	4.08	4.71	3.12
	High Cruise	3.69	3.07	2.40	2.63	2.88	1.95
	Deceleration	5.07	5.79	3.85	8.69	8.13	5.95
	Dumping				11.7	2.21	5.95
	SD of Avg[b]	2.83	3.36	2.20	2.29	2.04	1.81
CO_2 (g/sec)	Idle	0.115	0.182	0.108	0.115	0.293	0.157
	Low Acceleration	4.37	3.49	2.80	4.22	5.85	3.61
	Medium Acceleration	5.34	5.52	3.84	5.86	6.51	4.28
	High Acceleration	6.00	5.94	4.22	6.03	7.46	4.80
	Low Cruise	3.83	4.15	2.83	4.16	4.65	3.12
	Medium Cruise	4.15	4.67	3.12	6.32	6.15	4.41
	High Cruise	5.63	5.51	3.94	6.59	7.69	5.06
	Deceleration	4.57	5.89	3.73	5.55	6.90	4.43
	Dumping				2.07	1.34	1.23
	SD of Avg[b]	1.62	1.69	1.17	1.66	1.93	1.27
PM (mg/sec)	Idle	0.011	0.010	0.007	0.015	0.012	0.010
	Low Acceleration	0.372	0.127	0.197	0.345	0.253	0.214
	Medium Acceleration	0.498	0.264	0.282	0.413	0.338	0.267
	High Acceleration	0.483	0.320	0.290	0.354	0.308	0.235
	Low Cruise	0.366	0.144	0.197	0.318	0.187	0.184
	Medium Cruise	0.305	0.169	0.174	0.461	0.351	0.290
	High Cruise	0.387	0.288	0.241	0.395	0.325	0.256
	Deceleration	0.330	0.312	0.227	0.353	0.333	0.243
	Dumping				0.190	0.049	0.098
	SD of Avg[b]	0.131	0.081	0.077	0.114	0.090	0.072

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Standard deviation of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

Table A-25. Standard Deviation on a Per Time Basis by Driving Mode, Vehicle, and Load for Tier 2 Tandem Dump Trucks (Soy Based B20)

	Driving Mode[a]	Unloaded Vehicle Number 0125	Unloaded Vehicle Number 0126	Unloaded Avg[b]	Loaded Vehicle Number 0125	Loaded Vehicle Number 0126	Loaded Avg[b]
Fuel (g/sec)	Idle	0.181	0.089	0.101	0.142	0.157	0.106
	Low Acceleration	1.31	1.98	1.19	2.68	3.22	2.09
	Medium Acceleration	2.57	3.42	2.14	4.07	4.56	3.06
	High Acceleration	2.74	3.72	2.31	4.43	4.45	3.14
	Low Cruise	1.55	1.97	1.25	2.77	2.94	2.02
	Medium Cruise	2.13	2.08	1.49	3.31	4.92	2.97
	High Cruise	2.00	2.38	1.55	4.25	4.23	3.00
	Deceleration	2.43	3.02	1.94	3.48	4.17	2.72
	Dumping				0.962	1.12	0.738
	SD of Avg[b]	0.715	0.905	0.577	1.07	1.22	0.812
NO_x (g/sec)	Idle	0.003	0.005	0.003	0.003	0.004	0.003
	Low Acceleration	0.020	0.029	0.018	0.042	0.048	0.032
	Medium Acceleration	0.038	0.056	0.034	0.051	0.069	0.043
	High Acceleration	0.045	0.069	0.041	0.053	0.062	0.041
	Low Cruise	0.017	0.034	0.019	0.039	0.042	0.029
	Medium Cruise	0.033	0.028	0.022	0.047	0.071	0.042
	High Cruise	0.015	0.029	0.017	0.041	0.050	0.032
	Deceleration	0.020	0.031	0.019	0.033	0.047	0.029
	Dumping				0.018	0.024	0.015
	SD of Avg[b]	0.010	0.014	0.009	0.013	0.017	0.011
HC (mg/sec)	Idle	0.980	1.21	0.778	0.862	2.49	1.32
	Low Acceleration	3.20	3.92	2.53	5.62	6.72	4.38
	Medium Acceleration	5.71	3.70	3.40	8.25	3.79	4.54
	High Acceleration	6.71	5.23	4.25	9.62	3.03	5.04
	Low Cruise	2.61	2.80	1.92	4.11	6.27	3.75
	Medium Cruise	3.40	3.72	2.52	5.84	1.75	3.05
	High Cruise	3.68	3.18	2.43	7.54	6.24	4.89
	Deceleration	3.99	2.75	2.42	5.73	7.61	4.76
	Dumping				4.56	2.30	2.56
	SD of Avg[b]	1.46	1.23	0.956	2.09	1.65	1.33

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Standard deviation of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

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Table A-25. Continued

	Driving Mode[a]	Unloaded Vehicle Number 0125	Unloaded Vehicle Number 0126	Unloaded Avg[b]	Loaded Vehicle Number 0125	Loaded Vehicle Number 0126	Loaded Avg[b]
CO (mg/sec)	Idle	1.10	0.975	0.733	0.909	1.25	0.772
	Low Acceleration	18.6	9.09	10.4	25.1	13.9	14.3
	Medium Acceleration	17.4	13.3	10.9	14.5	12.3	9.51
	High Acceleration	11.9	14.3	9.29	10.8	13.0	8.47
	Low Cruise	10.1	7.91	6.41	20.2	12.8	12.0
	Medium Cruise	7.12	6.91	4.96	9.39	8.92	6.48
	High Cruise	5.92	9.34	5.53	8.17	14.4	8.30
	Deceleration	10.9	11.4	7.90	12.9	12.9	9.12
	Dumping				8.11	8.48	5.87
	SD of Avg[b]	4.14	3.52	2.72	4.66	3.86	3.02
CO_2 (g/sec)	Idle	0.561	0.275	0.313	0.439	0.484	0.327
	Low Acceleration	4.03	6.07	3.64	8.26	9.96	6.47
	Medium Acceleration	7.95	10.6	6.62	12.6	14.1	9.46
	High Acceleration	8.47	11.5	7.14	13.7	13.8	9.72
	Low Cruise	4.78	6.09	3.87	8.56	9.08	6.24
	Medium Cruise	6.58	6.43	4.60	10.2	15.2	9.17
	High Cruise	6.20	7.35	4.81	13.2	13.1	9.27
	Deceleration	7.50	9.33	5.98	10.8	12.9	8.39
	Dumping				2.96	3.46	2.28
	SD of Avg[b]	2.21	2.80	1.78	3.22	3.77	2.51
PM (mg/sec)	Idle	0.014	0.015	0.010	0.017	0.019	0.013
	Low Acceleration	0.288	0.280	0.201	0.531	0.394	0.331
	Medium Acceleration	0.481	0.503	0.348	0.771	0.580	0.482
	High Acceleration	0.740	0.518	0.452	0.839	0.573	0.508
	Low Cruise	0.282	0.238	0.185	0.446	0.311	0.272
	Medium Cruise	0.334	0.237	0.205	0.481	0.602	0.385
	High Cruise	0.276	0.270	0.193	0.548	0.446	0.353
	Deceleration	0.338	0.428	0.272	0.448	0.519	0.343
	Dumping				0.260	0.152	0.151
	SD of Avg[b]	0.139	0.123	0.093	0.178	0.148	0.116

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Standard deviation of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

Table A-26. Standard Deviation on a Per Time Basis by Driving Mode, Vehicle, and Load for Tier 2 Single Axle Dump Trucks (Soy Based B20)

		Unloaded			Loaded		
	Driving Mode[a]	Vehicle Number		Avg[b]	Vehicle Number		Avg[b]
		6117	**6123**		**6117**	**6123**	
Fuel (g/sec)	Idle	0.195	0.082	0.106	0.236	0.163	0.144
	Low Acceleration	1.25	0.801	0.744	1.39	1.47	1.01
	Medium Acceleration	1.43	1.97	1.22	1.71	2.17	1.38
	High Acceleration	1.57	1.82	1.20	1.71	1.96	1.30
	Low Cruise	1.10	0.725	0.657	1.34	1.50	1.01
	Medium Cruise	1.24	1.47	0.962	1.64	1.99	1.29
	High Cruise	1.45	1.73	1.13	1.67	2.27	1.41
	Deceleration	1.28	1.41	0.954	1.44	1.78	1.14
	Dumping				0.720	0.438	0.422
	SD of Avg[b]	0.443	0.493	0.332	0.467	0.561	0.365
NO_x (g/sec)	Idle	0.005	0.002	0.003	0.004	0.003	0.003
	Low Acceleration	0.030	0.028	0.021	0.034	0.059	0.034
	Medium Acceleration	0.037	0.079	0.044	0.054	0.102	0.058
	High Acceleration	0.035	0.056	0.033	0.040	0.067	0.039
	Low Cruise	0.028	0.031	0.021	0.037	0.085	0.047
	Medium Cruise	0.027	0.057	0.032	0.066	0.127	0.072
	High Cruise	0.030	0.055	0.031	0.044	0.106	0.058
	Deceleration	0.023	0.031	0.019	0.034	0.075	0.041
	Dumping				0.018	0.011	0.011
	SD of Avg[b]	0.010	0.017	0.010	0.014	0.027	0.015
HC (mg/sec)	Idle	0.406	0.497	0.321	0.882	0.479	0.502
	Low Acceleration	1.87	1.03	1.07	1.96	1.42	1.21
	Medium Acceleration	2.08	2.65	1.68	3.45	2.12	2.02
	High Acceleration	2.07	3.28	1.94	3.19	2.34	1.98
	Low Cruise	2.54	0.841	1.34	2.26	1.40	1.33
	Medium Cruise	1.98	2.73	1.69	3.32	2.06	1.95
	High Cruise	1.45	5.51	2.85	2.78	2.57	1.89
	Deceleration	1.53	1.54	1.08	2.03	1.39	1.23
	Dumping				1.03	2.21	1.22
	SD of Avg[b]	0.651	0.968	0.583	0.829	0.627	0.520

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Standard deviation of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

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Table A-26. Continued

	Driving Mode[a]	Unloaded Vehicle Number 6117	Unloaded Vehicle Number 6123	Unloaded Avg[b]	Loaded Vehicle Number 6117	Loaded Vehicle Number 6123	Loaded Avg[b]
CO (mg/sec)	Idle	4.39	0.770	2.23	5.06	1.02	2.58
	Low Acceleration	11.2	3.15	5.84	24.7	5.44	12.7
	Medium Acceleration	6.55	5.27	4.20	6.89	5.50	4.41
	High Acceleration	5.91	7.63	4.82	5.76	4.83	3.76
	Low Cruise	6.95	2.38	3.67	14.2	3.75	7.32
	Medium Cruise	3.73	3.65	2.61	3.63	3.14	2.40
	High Cruise	3.39	5.38	3.18	3.62	4.24	2.79
	Deceleration	7.26	4.75	4.34	12.2	3.94	6.43
	Dumping				31.0	2.86	15.6
	SD of Avg[b]	2.34	1.62	1.42	5.04	1.36	2.61
CO_2 (g/sec)	Idle	0.601	0.255	0.327	0.726	0.506	0.442
	Low Acceleration	3.87	2.48	2.30	4.29	4.53	3.12
	Medium Acceleration	4.43	6.09	3.77	5.30	6.71	4.28
	High Acceleration	4.85	5.64	3.72	5.30	6.05	4.02
	Low Cruise	3.38	2.24	2.04	4.14	4.64	3.11
	Medium Cruise	3.83	4.55	2.97	5.06	6.17	3.99
	High Cruise	4.47	5.37	3.50	5.16	7.03	4.36
	Deceleration	3.96	4.37	2.95	4.46	5.50	3.54
	Dumping				2.21	1.35	1.29
	SD of Avg[b]	1.37	1.53	1.03	1.44	1.73	1.13
PM (mg/sec)	Idle	0.024	0.012	0.013	0.036	0.020	0.021
	Low Acceleration	0.287	0.093	0.151	0.311	0.212	0.188
	Medium Acceleration	0.305	0.259	0.200	0.336	0.283	0.220
	High Acceleration	0.290	0.279	0.201	0.327	0.259	0.209
	Low Cruise	0.246	0.078	0.129	0.277	0.194	0.169
	Medium Cruise	0.236	0.185	0.150	0.309	0.223	0.191
	High Cruise	0.262	0.285	0.194	0.274	0.237	0.181
	Deceleration	0.236	0.181	0.149	0.249	0.199	0.159
	Dumping				0.152	0.067	0.083
	SD of Avg[b]	0.088	0.069	0.056	0.090	0.069	0.056

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Standard deviation of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

Table A-27. Relative Standard Error (RSE)[a] on a Per Time Basis by Driving Mode, Vehicle, and Load for Tier 1 Tandem Dump Trucks (Petroleum Diesel)

	Driving Mode[b]	Unloaded 0507	Unloaded 0578	Unloaded 0579	Unloaded 0580	Unloaded Avg[c]	Loaded 0507	Loaded 0578	Loaded 0579	Loaded 0580	Loaded Avg[c]
Fuel (%)	Idle	0.5	0.4	0.6	0.3	0.2	2.6	1.2	9.8	0.6	2.6
	Low Acceleration	3.8	3.1	3.3	3.3	1.7	2.7	2.5	6.3	3.0	2.0
	Medium Acceleration	1.6	1.7	2.4	2.5	1.0	1.1	1.6	2.8	2.5	1.0
	High Acceleration	1.6	2.0	2.8	4.4	1.5	2.2	2.1	5.4	4.2	1.9
	Low Cruise	4.9	3.2	2.6	2.7	1.7	2.9	2.9	8.9	1.5	2.5
	Medium Cruise	3.6	2.7	2.7	7.5	2.3	1.7	2.3	4.3	3.9	1.6
	High Cruise	1.1	1.3	1.2	16.0	4.0	1.7	1.3	3.3	14.0	3.6
	Deceleration	3.0	3.6	5.1	3.8	2.0	3.2	3.9	7.4	6.0	2.7
	Dumping						3.0	4.5	6.4	6.0	2.6
	RSE of Avg[c]	1.0	0.9	1.0	2.4	0.7	0.8	0.9	2.2	2.0	0.8
NO_x (%)	Idle	0.2	0.2	0.2	0.2	0.1	0.9	0.5	2.1	0.5	0.6
	Low Acceleration	2.0	2.2	2.8	2.2	1.2	2.2	1.7	5.6	2.2	1.7
	Medium Acceleration	1.7	1.4	1.9	1.8	0.9	1.3	1.6	3.1	2.1	1.1
	High Acceleration	1.5	1.7	2.9	2.9	1.2	2.7	2.4	3.8	2.5	1.4
	Low Cruise	3.1	1.9	2.6	4.2	1.5	2.7	1.6	6.9	2.0	2.0
	Medium Cruise	2.9	2.2	3.6	5.3	1.8	2.2	2.7	5.2	3.0	1.7
	High Cruise	1.2	2.1	1.5	10.7	2.8	2.0	1.1	3.2	7.0	2.0
	Deceleration	2.7	3.7	5.9	2.3	2.0	3.7	2.7	8.6	4.0	2.6
	Dumping						2.0	2.0	4.2	3.8	1.6
	RSE of Avg[c]	0.8	0.8	1.1	1.7	0.6	0.8	0.6	1.7	1.2	0.6

[a]: Relative Standard Error (RSE) is defined as the sample size divided by the mean and the square root of the sample size, and multiplied by 100 percent to convert to a percent basis.

[b]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
  - Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
  - Idle and dumping are not driven significant distance during these modes.

[c]: Relative Standard Error of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

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Table A-27. Continued

	Driving Mode[b]	Unloaded 0507	Unloaded 0578	Unloaded 0579	Unloaded 0580	Unloaded Avg[c]	Loaded 0507	Loaded 0578	Loaded 0579	Loaded 0580	Loaded Avg[c]
HC (%)	Idle	0.9	0.2	0.2	0.6	0.3	1.7	0.4	8.9	0.9	2.3
	Low Acceleration	4.2	2.0	3.9	2.2	1.6	2.2	2.1	12.9	2.9	3.4
	Medium Acceleration	2.0	1.2	2.1	1.7	0.9	1.5	1.5	6.3	3.4	1.9
	High Acceleration	1.8	1.4	1.9	4.0	1.3	2.6	2.3	9.4	8.7	3.3
	Low Cruise	5.1	1.7	2.2	2.4	1.6	2.1	1.2	15.8	2.3	4.0
	Medium Cruise	3.1	0.9	1.6	6.1	1.8	2.2	1.4	12.4	6.2	3.5
	High Cruise	1.3	0.5	0.8	14.1	3.6	1.7	0.6	6.7	27.8	7.2
	Deceleration	2.4	1.0	2.9	3.4	1.3	2.3	1.2	13.4	6.2	3.7
	Dumping						3.6	1.4	3.1	5.3	1.8
	RSE of Avg[c]	1.0	0.4	0.8	2.1	0.6	0.8	0.5	3.5	3.5	1.3
CO (%)	Idle	3.7	0.1	0.6	0.8	1.0	7.5	0.5	5.1	0.7	2.3
	Low Acceleration	6.7	3.6	11.9	2.4	3.6	1.9	1.8	17.6	2.1	4.5
	Medium Acceleration	1.4	1.3	2.3	1.9	0.9	1.0	1.2	3.7	1.9	1.1
	High Acceleration	1.4	1.3	3.1	2.7	1.1	1.9	1.9	8.3	3.3	2.3
	Low Cruise	10.9	3.0	2.9	2.4	3.0	4.5	1.3	20.9	1.9	5.4
	Medium Cruise	2.0	1.0	2.7	2.7	1.1	1.7	0.9	5.8	2.1	1.6
	High Cruise	0.8	0.7	1.1	11.1	2.8	0.9	0.6	3.1	9.4	2.5
	Deceleration	8.3	1.4	3.9	2.0	2.4	5.4	1.0	17.3	2.7	4.6
	Dumping						2.6	1.6	4.1	3.1	1.5
	RSE of Avg[c]	2.0	0.7	1.7	1.6	0.8	1.2	0.4	3.9	1.3	1.1

[b]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[c]: Relative Standard Error of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

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Table A-27. Continued

	Driving Mode[b]	Unloaded 0507	Unloaded 0578	Unloaded 0579	Unloaded 0580	Unloaded Avg[c]	Loaded 0507	Loaded 0578	Loaded 0579	Loaded 0580	Loaded Avg[c]
CO_2 (%)	Idle	0.5	0.3	0.6	0.3	0.2	2.5	1.2	9.6	0.6	2.5
	Low Acceleration	3.7	3.1	3.2	3.3	1.7	2.5	2.5	6.2	3.0	1.9
	Medium Acceleration	1.6	1.7	2.4	2.4	1.0	1.1	1.6	2.7	2.4	1.0
	High Acceleration	1.6	2.0	2.7	4.4	1.4	2.2	2.1	5.3	4.1	1.8
	Low Cruise	5.0	3.1	2.5	2.6	1.7	2.9	2.9	8.5	1.5	2.4
	Medium Cruise	3.7	2.7	2.6	7.4	2.3	1.7	2.3	4.3	3.8	1.6
	High Cruise	1.1	1.3	1.2	15.6	3.9	1.7	1.3	3.2	13.8	3.6
	Deceleration	3.0	3.6	5.1	3.7	2.0	3.2	3.9	7.3	5.8	2.7
	Dumping						2.9	4.5	6.3	5.9	2.5
	RSE of Avg[c]	1.0	0.9	1.0	2.4	0.7	0.8	0.9	2.1	1.9	0.8
PM (%)	Idle	0.3	0.1	0.1	0.4	0.1	0.8	0.3	0.8	0.5	0.3
	Low Acceleration	3.0	3.1	4.8	4.4	2.0	2.0	2.1	6.0	4.1	2.0
	Medium Acceleration	1.5	1.8	2.0	3.2	1.1	1.1	1.4	3.3	2.8	1.2
	High Acceleration	1.3	1.9	3.3	6.6	1.9	1.6	1.8	10.3	5.5	3.0
	Low Cruise	4.1	0.8	0.9	5.6	1.7	2.8	0.7	3.4	0.9	1.1
	Medium Cruise	3.5	0.7	1.0	4.8	1.5	2.3	0.6	1.9	3.5	1.1
	High Cruise	1.4	0.3	0.3	14.0	3.5	1.9	0.4	1.5	9.1	2.4
	Deceleration	2.6	1.0	1.7	2.2	1.0	3.1	0.8	6.1	3.2	1.9
	Dumping						3.1	1.6	0.6	5.0	1.5
	RSE of Avg[c]	0.9	0.5	0.8	2.3	0.7	0.7	0.4	1.6	1.5	0.6

[b]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[c]: Relative Standard Error of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

Table A-28. Relative Standard Error (RSE)[a] on a Per Time Basis by Driving Mode, Vehicle, and Load for Tier 1 Single Axle Dump Trucks (Petroleum Diesel)

		Unloaded					**Loaded**				
	Driving Mode[b]	Vehicle Number				Avg[c]	Vehicle Number				Avg[c]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**	
Fuel (%)	Idle	0.4	0.2	0.1	0.2	0.1	0.4	0.5	3.4	0.2	0.9
	Low Acceleration	4.4	3.9	4.0	4.1	2.1	3.8	4.1	8.4	3.0	2.6
	Medium Acceleration	2.0	1.6	2.2	2.7	1.1	2.2	1.3	3.2	2.2	1.2
	High Acceleration	3.0	1.5	1.8	2.3	1.1	7.0	1.7	4.6	2.1	2.2
	Low Cruise	3.2	3.2	2.3	3.2	1.5	3.7	3.3	7.3	2.8	2.3
	Medium Cruise	1.5	2.9	2.9	4.7	1.6	1.9	3.4	5.3	6.6	2.3
	High Cruise	1.3	1.2	1.5	1.8	0.7	7.0	1.1	8.5	1.6	2.8
	Deceleration	4.2	3.9	5.1	6.7	2.5	5.9	3.8	3.5	8.2	2.8
	Dumping						7.6	5.4	7.0	10.5	3.9
	RSE of Avg[c]	1.0	0.9	1.0	1.3	0.5	1.7	1.1	2.0	1.8	0.8
NO_x (%)	Idle	0.2	0.4	0.1	0.1	0.1	0.2	0.7	1.7	0.1	0.5
	Low Acceleration	3.7	3.0	3.3	4.1	1.8	3.4	3.3	8.0	3.1	2.4
	Medium Acceleration	1.8	1.7	2.6	3.1	1.2	1.9	1.3	3.0	2.4	1.1
	High Acceleration	2.6	1.3	2.2	2.9	1.2	5.8	2.0	4.5	2.3	2.0
	Low Cruise	3.1	2.3	1.7	2.7	1.2	3.1	2.2	6.0	2.5	1.9
	Medium Cruise	1.3	2.5	2.8	4.9	1.6	1.7	3.4	5.2	5.7	2.1
	High Cruise	1.3	1.1	1.8	2.2	0.8	7.1	0.9	11.4	1.8	3.4
	Deceleration	3.0	2.5	3.8	4.4	1.8	4.5	2.3	4.0	5.5	2.1
	Dumping						8.2	4.6	5.5	10.2	3.7
	RSE of Avg[c]	0.8	0.7	0.9	1.2	0.5	1.6	0.9	2.0	1.6	0.8

[a]: Relative Standard Error (RSE) is defined as the sample size divided by the mean and the square root of the sample size, and multiplied by 100 percent to convert to a percent basis.
[b]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
  - Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
  - Idle and dumping are not driven significant distance during these modes.

[c]: Relative Standard Error of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

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Table A-28. Continued

		Unloaded					Loaded				
	Driving Mode[b]	Vehicle Number				Avg[c]	Vehicle Number				Avg[c]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**	
HC (%)	Idle	0.6	1.0	0.4	0.6	0.4	0.6	0.8	3.7	0.6	1.0
	Low Acceleration	4.1	4.6	4.5	3.8	2.1	3.5	3.7	10.1	3.2	2.9
	Medium Acceleration	2.4	2.3	4.6	4.0	1.7	3.0	1.6	8.2	2.6	2.3
	High Acceleration	3.3	2.3	3.3	5.2	1.8	6.3	2.2	10.7	3.2	3.2
	Low Cruise	1.3	2.9	1.6	2.2	1.0	1.4	2.7	5.9	1.8	1.7
	Medium Cruise	0.7	2.8	2.5	2.9	1.2	0.6	2.8	7.9	4.5	2.4
	High Cruise	0.6	1.4	2.1	2.6	0.9	2.7	0.9	4.3	1.6	1.4
	Deceleration	0.9	2.3	2.6	4.0	1.3	0.9	1.9	3.5	3.0	1.3
	Dumping						3.5	6.0	20.5	7.3	5.7
	RSE of Avg[c]	0.8	0.9	1.1	1.2	0.5	1.0	1.0	3.2	1.2	0.9
CO (%)	Idle	0.5	0.3	0.1	0.2	0.1	0.2	0.7	4.4	0.3	1.1
	Low Acceleration	8.3	4.4	4.3	5.7	2.9	9.1	5.3	12.9	4.7	4.3
	Medium Acceleration	5.0	2.0	3.7	3.4	1.8	3.4	2.3	5.0	3.8	1.9
	High Acceleration	6.1	1.9	4.4	5.4	2.4	12.2	4.2	11.7	3.3	4.4
	Low Cruise	2.8	3.4	2.3	3.1	1.5	4.2	2.7	9.8	3.4	2.9
	Medium Cruise	1.6	2.0	4.2	3.5	1.5	1.1	2.5	5.2	5.2	2.0
	High Cruise	0.5	0.7	1.7	1.3	0.6	1.5	0.5	2.4	1.0	0.8
	Deceleration	2.5	1.8	2.8	3.7	1.4	4.7	1.7	6.0	3.8	2.2
	Dumping						11.8	6.3	9.5	15.5	5.6
	RSE of Avg[c]	1.5	0.8	1.2	1.3	0.6	2.3	1.1	2.7	2.1	1.1

[b]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[c]: Relative Standard Error of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

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Table A-28. Continued

		Unloaded					Loaded				
	Driving Mode[b]	Vehicle Number				Avg[c]	Vehicle Number				Avg[c]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**	
CO_2 (%)	Idle	0.4	0.2	0.1	0.2	0.1	0.4	0.5	3.4	0.2	0.9
	Low Acceleration	4.4	4.0	4.0	4.1	2.1	3.8	4.1	8.3	3.0	2.6
	Medium Acceleration	2.0	1.7	2.2	2.7	1.1	2.2	1.3	3.2	2.2	1.2
	High Acceleration	3.1	1.5	1.8	2.3	1.1	7.0	1.7	4.6	2.1	2.2
	Low Cruise	3.1	3.2	2.3	3.2	1.5	3.7	3.3	7.3	2.8	2.3
	Medium Cruise	1.5	2.9	2.9	4.8	1.6	1.9	3.4	5.3	6.6	2.3
	High Cruise	1.3	1.3	1.5	1.8	0.7	7.0	1.2	8.4	1.6	2.8
	Deceleration	4.2	3.9	5.1	6.7	2.6	6.0	3.8	3.5	8.3	2.9
	Dumping						7.6	5.4	7.0	10.5	3.9
	RSE of Avg[c]	1.0	0.9	1.0	1.3	0.5	1.7	1.1	2.0	1.8	0.8
PM (%)	Idle	0.4	0.6	0.3	0.3	0.2	0.4	1.1	4.1	0.4	1.1
	Low Acceleration	5.5	3.6	3.9	3.9	2.1	4.1	3.7	6.4	2.9	2.2
	Medium Acceleration	2.6	1.8	1.8	2.3	1.1	2.6	1.3	2.7	2.0	1.1
	High Acceleration	3.5	1.6	1.6	2.6	1.2	6.9	1.9	4.0	1.9	2.1
	Low Cruise	3.6	2.9	3.2	3.5	1.6	3.6	3.0	7.3	2.9	2.3
	Medium Cruise	1.6	2.8	2.3	3.9	1.4	1.8	2.9	4.6	4.3	1.8
	High Cruise	0.9	1.3	1.1	1.2	0.6	4.0	1.1	6.9	1.1	2.0
	Deceleration	2.6	2.8	4.1	4.6	1.8	4.2	2.7	3.5	5.2	2.0
	Dumping						6.2	5.7	7.0	14.3	4.5
	RSE of Avg[c]	1.1	0.8	0.9	1.1	0.5	1.4	1.0	1.8	1.8	0.8

[b]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
  - Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
  - Idle and dumping are not driven significant distance during these modes.

[c]: Relative Standard Error of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

Table A-29. Relative Standard Error (RSE)[a] on a Per Time Basis by Driving Mode, Vehicle, and Load for Tier 1 Tandem Dump Trucks (Soy Based B20)

		Unloaded					Loaded				
	Driving Mode[b]	Vehicle Number				Avg[c]	Vehicle Number				Avg[c]
		0507	0578	0579	0580		0507	0578	0579	0580	
Fuel (%)	Idle	0.9	1.2	0.5	0.4	0.4	0.2	0.7	0.5	1.5	0.4
	Low Acceleration	4.5	3.5	2.8	3.8	1.8	2.0	2.4	1.5	6.3	1.8
	Medium Acceleration	1.8	2.4	2.1	2.6	1.1	1.2	1.6	1.2	4.4	1.2
	High Acceleration	2.2	2.5	2.0	3.4	1.3	2.1	2.1	1.2	11.7	3.0
	Low Cruise	4.3	4.1	2.1	3.7	1.8	3.0	2.1	1.4	7.4	2.1
	Medium Cruise	3.3	2.9	2.2	2.7	1.4	2.3	2.6	1.5	2.7	1.2
	High Cruise	1.4	2.0	1.3	1.3	0.8	2.2	1.6	1.0	6.4	1.8
	Deceleration	4.0	6.0	2.8	3.9	2.2	2.7	5.1	1.7	9.6	2.8
	Dumping						2.4	3.7	2.5	8.7	2.5
	RSE of Avg[c]	1.1	1.2	0.7	1.1	0.5	0.7	0.9	0.5	2.4	0.7
NO_x (%)	Idle	0.4	1.0	0.2	0.3	0.3	0.1	0.4	0.3	0.8	0.2
	Low Acceleration	3.3	3.3	3.3	2.8	1.6	2.6	3.4	2.2	4.2	1.6
	Medium Acceleration	1.7	3.0	3.5	1.7	1.3	1.2	3.0	1.9	3.1	1.2
	High Acceleration	2.9	3.3	3.0	2.7	1.5	1.9	3.7	2.0	6.4	2.0
	Low Cruise	3.3	6.9	2.4	2.1	2.1	2.2	3.2	1.7	5.2	1.7
	Medium Cruise	2.6	3.9	3.0	2.2	1.5	2.4	3.6	2.2	2.7	1.4
	High Cruise	1.7	2.7	2.0	1.5	1.0	1.5	2.7	1.5	3.9	1.3
	Deceleration	3.5	4.6	4.4	3.7	2.0	2.3	7.0	2.2	8.1	2.8
	Dumping						2.0	4.9	3.0	6.3	2.2
	RSE of Avg[c]	0.9	1.4	1.0	0.8	0.5	0.6	1.3	0.7	1.7	0.6

[a]: Relative Standard Error(RSE) is defined as the sample size divided by the mean and the square root of the sample size, and multiplied by 100 percent to convert to a percent basis.
[b]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[c]: Relative Standard Error of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

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Table A-29. Continued

	Driving Mode[b]	Unloaded					Loaded				
		Vehicle Number				Avg[c]	Vehicle Number				Avg[c]
		0507	**0578**	**0579**	**0580**		**0507**	**0578**	**0579**	**0580**	
HC (%)	Idle	1.7	1.5	0.7	0.5	0.6	0.4	0.5	0.7	0.5	0.3
	Low Acceleration	6.4	6.7	5.0	2.5	2.7	2.5	4.9	3.3	6.5	2.3
	Medium Acceleration	3.1	3.6	4.5	1.7	1.7	1.3	2.8	2.9	1.9	1.2
	High Acceleration	5.8	4.5	4.6	2.6	2.3	2.8	3.4	3.0	5.0	1.8
	Low Cruise	4.4	6.8	4.5	1.8	2.3	1.7	2.9	2.6	4.2	1.5
	Medium Cruise	3.8	4.6	6.0	1.8	2.2	2.2	3.1	3.0	1.3	1.2
	High Cruise	1.8	2.5	3.0	1.1	1.1	1.7	1.7	2.0	3.1	1.1
	Deceleration	3.4	3.9	3.9	2.1	1.7	1.5	4.3	1.9	4.0	1.6
	Dumping						3.3	8.4	13.6	4.1	4.2
	RSE of Avg[c]	1.5	1.6	1.5	0.7	0.7	0.7	1.4	1.7	1.3	0.7
CO (%)	Idle	1.5	4.9	0.5	0.6	1.3	0.2	4.7	0.7	3.7	1.5
	Low Acceleration	8.7	3.0	5.3	16.5	4.9	3.4	2.1	2.1	8.9	2.5
	Medium Acceleration	3.7	1.8	2.9	3.6	1.5	0.9	1.9	1.4	3.7	1.1
	High Acceleration	2.4	2.0	2.6	3.6	1.4	1.8	7.1	1.4	6.9	2.5
	Low Cruise	14.3	8.3	4.3	7.7	4.7	4.1	5.3	2.3	14.7	4.1
	Medium Cruise	1.9	2.9	3.2	2.2	1.3	1.5	2.6	1.8	1.3	0.9
	High Cruise	0.8	2.5	1.5	0.9	0.8	1.0	1.2	1.1	3.2	0.9
	Deceleration	5.8	5.7	5.0	9.4	3.3	4.4	11.1	2.4	11.9	4.3
	Dumping						2.6	15.2	6.0	6.2	4.4
	RSE of Avg[c]	2.3	1.6	1.2	2.7	1.0	0.9	2.4	0.9	2.6	0.9

[b]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[c]: Relative Standard Error of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

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Table A-29. Continued

	Driving Mode[b]	Unloaded 0507	Unloaded 0578	Unloaded 0579	Unloaded 0580	Unloaded Avg[c]	Loaded 0507	Loaded 0578	Loaded 0579	Loaded 0580	Loaded Avg[c]
CO_2 (%)	Idle	0.9	1.5	0.5	0.4	0.5	0.2	0.8	0.6	1.5	0.4
	Low Acceleration	4.5	5.2	4.4	3.8	2.3	2.0	3.7	2.5	6.4	2.0
	Medium Acceleration	1.9	3.7	3.5	2.6	1.5	1.2	2.4	2.0	4.4	1.4
	High Acceleration	2.2	3.8	3.2	3.4	1.6	2.1	3.2	2.1	12.0	3.2
	Low Cruise	4.3	5.9	3.4	3.7	2.2	3.1	3.1	2.2	7.5	2.3
	Medium Cruise	3.3	4.3	3.6	2.7	1.7	2.3	3.9	2.4	2.8	1.5
	High Cruise	1.4	3.0	2.2	1.3	1.0	2.2	2.3	1.7	6.5	1.9
	Deceleration	4.1	8.8	4.4	3.9	2.8	2.9	7.7	2.7	9.7	3.2
	Dumping						2.5	5.6	3.9	8.8	2.9
	RSE of Avg[c]	1.1	1.8	1.2	1.1	0.7	0.7	1.4	0.8	2.4	0.8
PM (%)	Idle	1.0	2.4	0.9	0.4	0.7	0.2	1.8	0.9	1.4	0.6
	Low Acceleration	5.7	4.9	5.0	4.6	2.5	2.9	3.6	3.0	8.3	2.5
	Medium Acceleration	2.2	3.2	3.7	2.8	1.5	1.3	2.1	2.0	5.3	1.5
	High Acceleration	2.4	3.7	3.7	3.6	1.7	2.2	2.6	2.2	7.5	2.1
	Low Cruise	5.0	32.4	10.6	3.4	8.6	2.4	16.2	6.2	8.2	4.8
	Medium Cruise	4.4	21.3	7.5	3.4	5.8	2.7	13.4	8.0	3.4	4.1
	High Cruise	1.8	11.9	8.5	1.7	3.7	2.6	7.7	5.6	5.9	2.9
	Deceleration	3.8	17.5	10.2	3.9	5.2	3.8	16.6	5.3	9.6	5.1
	Dumping						3.1	20.7	38.1	6.8	11.0
	RSE of Avg[c]	1.3	5.6	2.5	1.1	1.6	0.8	3.9	4.5	2.2	1.6

[b]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[c]: Relative Standard Error of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

Table A-30. Relative Standard Error (RSE)[a] on a Per Time Basis by Driving Mode, Vehicle, and Load for Tier 1 Single Axle Dump Trucks (Soy Based B20)

		Unloaded					Loaded				
	Driving Mode[b]	Vehicle Number				Avg[c]	Vehicle Number				Avg[c]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**	
Fuel (%)	Idle	1.2	0.1	0.4	0.9	0.4	0.3	0.2	0.1	0.3	0.1
	Low Acceleration	4.6	9.3	5.6	8.6	3.6	2.5	3.4	2.8	11.5	3.2
	Medium Acceleration	2.2	8.5	2.1	2.6	2.3	1.3	2.1	1.7	3.8	1.2
	High Acceleration	1.5	10.4	1.9	2.5	2.7	2.6	2.3	1.9	11.2	3.0
	Low Cruise	5.4	11.2	4.7	7.8	3.9	2.5	3.2	2.0	8.5	2.4
	Medium Cruise	4.7	14.2	2.6	4.4	4.0	2.0	2.9	2.0	3.5	1.3
	High Cruise	0.7	6.8	1.2	1.8	1.8	1.5	1.4	1.4	5.8	1.6
	Deceleration	3.1	15.0	3.4	4.5	4.1	2.8	5.1	2.6	10.7	3.1
	Dumping						4.8	3.8	5.0	12.1	3.6
	RSE of Avg[c]	1.2	3.7	1.1	1.7	1.1	0.8	1.0	0.8	2.8	0.8
NO_x (%)	Idle	0.8	0.1	0.3	0.9	0.3	0.3	0.1	0.1	0.3	0.1
	Low Acceleration	3.0	7.0	3.5	5.4	2.5	1.8	1.8	2.3	6.3	1.8
	Medium Acceleration	1.8	6.1	1.9	2.6	1.8	1.1	1.8	1.4	3.3	1.0
	High Acceleration	1.4	4.9	1.8	2.3	1.5	2.3	1.8	1.8	8.7	2.3
	Low Cruise	3.8	9.6	4.2	5.9	3.2	2.2	2.7	2.5	6.8	2.0
	Medium Cruise	4.1	10.8	2.6	4.7	3.2	2.1	2.5	2.2	3.9	1.4
	High Cruise	0.7	5.0	1.4	2.1	1.4	1.2	1.3	1.9	6.2	1.7
	Deceleration	3.0	11.9	3.1	4.2	3.3	3.3	4.4	2.7	11.6	3.3
	Dumping						6.1	2.6	5.3	11.2	3.5
	RSE of Avg[c]	0.9	2.7	0.9	1.4	0.8	0.9	0.8	0.9	2.5	0.7

[a]: Relative Standard Error (RSE) is defined as the sample size divided by the mean and the square root of the sample size, and multiplied by 100 percent to convert to a percent basis.
[b]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[c]: Relative Standard Error of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

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Table A-30. Continued

		Unloaded					Loaded				
	Driving Mode[b]	Vehicle Number				Avg[c]	Vehicle Number				Avg[c]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**	
HC (%)	Idle	1.5	0.6	0.8	1.7	0.6	0.5	0.5	0.8	0.9	0.4
	Low Acceleration	8.4	9.8	13.4	15.7	6.1	7.3	4.3	4.8	16.5	4.8
	Medium Acceleration	5.7	8.4	4.6	6.3	3.2	3.2	3.3	2.1	8.9	2.6
	High Acceleration	4.3	10.7	6.2	6.2	3.6	6.5	3.3	1.4	21.2	5.6
	Low Cruise	5.9	9.4	6.1	7.8	3.7	4.7	2.7	2.1	8.9	2.6
	Medium Cruise	8.4	13.2	4.5	5.4	4.3	5.2	2.8	2.1	6.8	2.3
	High Cruise	2.0	10.7	2.3	3.6	2.9	3.4	1.4	1.1	9.1	2.5
	Deceleration	6.4	10.7	3.4	5.1	3.5	7.4	3.7	1.0	7.9	2.9
	Dumping						22.6	7.3	2.2	12.8	6.8
	RSE of Avg[c]	2.1	3.5	2.2	2.7	1.3	3.0	1.2	0.8	3.9	1.3
CO (%)	Idle	1.0	0.2	0.4	1.4	0.4	0.6	0.2	0.1	0.5	0.2
	Low Acceleration	5.6	24.2	11.2	9.7	7.2	6.5	4.0	5.8	18.1	5.1
	Medium Acceleration	3.2	7.7	3.9	4.3	2.5	2.4	2.2	2.6	7.9	2.2
	High Acceleration	2.2	8.5	4.0	3.5	2.6	2.6	2.8	0.6	23.1	5.9
	Low Cruise	11.0	23.5	18.1	12.9	8.5	4.2	3.0	4.4	19.1	5.1
	Medium Cruise	5.4	9.4	3.7	5.0	3.1	1.7	2.0	2.1	6.0	1.7
	High Cruise	0.6	2.9	0.5	1.1	0.8	1.2	0.5	0.4	2.4	0.7
	Deceleration	3.8	14.8	5.1	5.4	4.2	4.3	2.9	2.6	14.2	3.8
	Dumping						9.1	4.4	3.5	26.0	7.0
	RSE of Avg[c]	1.8	5.0	2.9	2.3	1.6	1.5	0.9	1.0	5.2	1.4

[b]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[c]: Relative Standard Error of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

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Table A-30. Continued

	Driving Mode[b]	Unloaded: Vehicle Number 4743	Unloaded: Vehicle Number 4750	Unloaded: Vehicle Number 4869	Unloaded: Vehicle Number 4870	Unloaded: Avg[c]	Loaded: Vehicle Number 4743	Loaded: Vehicle Number 4750	Loaded: Vehicle Number 4869	Loaded: Vehicle Number 4870	Loaded: Avg[c]
CO_2 (%)	Idle	1.2	0.1	0.4	1.0	0.4	0.3	0.2	0.1	0.3	0.1
	Low Acceleration	4.6	9.3	5.6	8.6	3.6	2.5	3.4	2.9	11.6	3.2
	Medium Acceleration	2.2	8.5	2.1	2.7	2.3	1.3	2.1	1.7	3.9	1.2
	High Acceleration	1.5	10.5	1.9	2.5	2.8	2.6	2.4	1.9	11.2	3.0
	Low Cruise	5.4	11.3	4.7	7.8	3.9	2.5	3.2	2.0	8.5	2.4
	Medium Cruise	4.7	14.2	2.6	4.4	4.0	2.0	2.9	2.0	3.5	1.3
	High Cruise	0.7	6.8	1.2	1.8	1.8	1.5	1.3	1.4	5.9	1.6
	Deceleration	3.1	15.0	3.4	4.5	4.1	2.8	5.1	2.6	10.7	3.1
	Dumping						4.8	3.8	4.9	12.0	3.6
	RSE of Avg[c]	1.2	3.7	1.1	1.7	1.1	0.8	1.0	0.8	2.8	0.8
PM (%)	Idle	1.2	0.3	0.3	0.5	0.3	0.3	0.6	0.2	0.3	0.2
	Low Acceleration	3.9	10.1	4.0	5.7	3.2	2.7	2.9	1.7	6.3	1.9
	Medium Acceleration	2.0	8.1	2.0	2.1	2.2	1.4	2.7	1.5	2.8	1.1
	High Acceleration	1.5	6.4	2.4	2.0	1.8	2.5	2.5	1.5	7.0	2.0
	Low Cruise	5.9	9.1	4.1	5.8	3.2	2.9	2.9	2.3	6.3	2.0
	Medium Cruise	4.5	13.8	2.3	4.2	3.8	3.5	2.4	1.7	3.5	1.4
	High Cruise	1.1	7.7	1.1	1.4	2.0	2.0	1.0	1.4	5.0	1.4
	Deceleration	4.2	12.1	2.9	3.9	3.4	4.1	3.5	2.4	7.2	2.3
	Dumping						5.8	3.2	3.7	7.7	2.7
	RSE of Avg[c]	1.2	3.3	0.9	1.3	1.0	1.1	0.9	0.7	1.9	0.6

[b]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[c]: Relative Standard Error of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

Table A-31. Relative Standard Error (RSE)[a] on a Per Time Basis by Driving Mode, Vehicle, and Load for Tier 2 Tandem Dump Trucks (Petroleum Diesel)

	Driving Mode[b]	Unloaded Vehicle Number 0125	Unloaded Vehicle Number 0126	Unloaded Avg[c]	Loaded Vehicle Number 0125	Loaded Vehicle Number 0126	Loaded Avg[c]
Fuel (%)	Idle	0.6	0.4	0.4	0.7	1.7	0.9
	Low Acceleration	3.1	4.0	2.5	3.7	3.7	2.6
	Medium Acceleration	1.9	4.1	2.3	2.4	2.5	1.7
	High Acceleration	3.4	1.9	2.0	3.2	2.1	1.9
	Low Cruise	3.3	2.8	2.2	3.0	3.3	2.2
	Medium Cruise	1.4	2.9	1.6	2.1	3.5	2.0
	High Cruise	1.7	0.7	0.9	1.4	0.8	0.8
	Deceleration	4.6	3.9	3.0	4.2	3.6	2.8
	Dumping				2.3	5.3	2.9
	RSE of Avg[c]	1.0	1.0	0.7	0.9	1.1	0.7
NO_x (%)	Idle	0.2	0.2	0.1	0.3	0.6	0.3
	Low Acceleration	1.9	2.8	1.7	2.7	2.7	1.9
	Medium Acceleration	1.7	2.4	1.5	1.8	1.7	1.2
	High Acceleration	2.3	1.6	1.4	2.5	1.6	1.5
	Low Cruise	3.0	1.8	1.7	2.0	2.3	1.5
	Medium Cruise	1.4	2.3	1.3	2.2	3.1	1.9
	High Cruise	1.6	0.6	0.9	1.2	0.7	0.7
	Deceleration	3.2	2.5	2.0	3.4	2.7	2.2
	Dumping				1.4	3.9	2.1
	RSE of Avg[c]	0.7	0.7	0.5	0.7	0.8	0.5
HC (%)	Idle	0.6	1.2	0.7	0.8	3.3	1.7
	Low Acceleration	2.6	3.3	2.1	4.2	1.6	2.2
	Medium Acceleration	2.5	3.7	2.2	2.1	3.4	2.0
	High Acceleration	6.0	2.8	3.3	3.7	1.3	1.9
	Low Cruise	2.8	2.6	1.9	3.2	3.8	2.5
	Medium Cruise	1.8	2.4	1.5	3.2	3.4	2.3
	High Cruise	2.3	0.6	1.2	0.7	1.1	0.7
	Deceleration	2.2	1.8	1.4	4.0	1.8	2.2
	Dumping				1.0	5.0	2.5
	RSE of Avg[c]	2.6	0.9	0.7	1.0	1.0	0.7

[a]: Relative Standard Error (RSE) is defined as the sample size divided by the mean and the square root of the sample size, and multiplied by 100 percent to convert to a percent basis .

[b]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[c]: Relative Standard Error of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

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Table A-31. Continued

		Unloaded			Loaded		
	Driving Mode[b]	Vehicle Number		Avg[c]	Vehicle Number		Avg[c]
		0125	**0126**		**0125**	**0126**	
CO (%)	Idle	0.7	0.5	0.4	0.6	0.7	0.5
	Low Acceleration	4.9	5.1	3.5	4.0	2.7	2.4
	Medium Acceleration	2.1	5.2	2.8	2.0	1.2	1.1
	High Acceleration	4.0	2.8	2.5	2.4	1.1	1.3
	Low Cruise	2.9	1.9	1.7	2.7	1.2	1.5
	Medium Cruise	0.9	3.0	1.6	1.2	1.1	0.8
	High Cruise	0.9	0.5	0.5	0.5	0.3	0.3
	Deceleration	2.9	2.9	2.1	2.6	2.1	1.7
	Dumping				0.7	3.8	1.9
	RSE of Avg[c]	1.0	1.1	0.8	0.7	0.6	0.5
CO_2 (%)	Idle	0.7	0.4	0.4	0.8	1.7	0.9
	Low Acceleration	3.1	4.0	2.5	3.7	3.7	2.6
	Medium Acceleration	1.9	4.1	2.3	2.0	2.5	1.7
	High Acceleration	3.5	1.9	2.0	3.2	2.1	1.9
	Low Cruise	3.3	2.8	2.2	3.0	3.3	2.2
	Medium Cruise	1.4	2.9	1.6	2.1	3.5	2.1
	High Cruise	1.7	0.7	0.9	1.4	0.8	0.8
	Deceleration	4.6	3.9	3.0	4.2	3.6	2.8
	Dumping				2.3	5.3	2.9
	RSE of Avg[c]	1.0	1.0	0.7	0.9	1.1	0.7
PM (%)	Idle	0.8	0.5	0.5	0.7	0.7	0.5
	Low Acceleration	4.1	4.2	3.0	4.1	3.4	2.6
	Medium Acceleration	2.1	2.5	1.6	1.9	1.9	1.3
	High Acceleration	4.4	1.9	2.4	2.7	1.9	1.7
	Low Cruise	4.6	3.5	2.9	3.0	3.3	2.2
	Medium Cruise	1.5	2.9	1.6	1.9	3.3	1.9
	High Cruise	1.6	0.7	0.9	0.9	0.7	0.6
	Deceleration	3.3	3.9	2.6	3.4	3.4	2.4
	Dumping				1.0	5.3	2.7
	RSE of Avg[c]	1.1	1.0	0.7	0.8	1.0	0.6

[b]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[c]: Relative Standard Error of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

Table A-32. Relative Standard Error (RSE)[a] on a Per Time Basis by Driving Mode, Vehicle, and Load for Tier 2 Single Axle Dump Trucks (Petroleum Diesel)

		Unloaded			Loaded		
	Driving Mode[b]	Vehicle Number		Avg[c]	Vehicle Number		Avg[c]
		6117	**6123**		**6117**	**6123**	
Fuel (%)	Idle	0.2	0.2	0.2	0.2	0.4	0.2
	Low Acceleration	5.2	5.5	3.8	3.6	4.7	3.0
	Medium Acceleration	1.8	2.1	1.4	1.5	2.3	1.4
	High Acceleration	1.5	2.1	1.3	2.4	4.2	2.4
	Low Cruise	5.1	5.2	3.6	3.4	3.6	2.5
	Medium Cruise	2.7	2.5	1.8	2.7	4.2	2.5
	High Cruise	1.7	1.0	1.0	2.3	2.8	1.8
	Deceleration	3.0	3.3	2.2	4.0	4.0	2.8
	Dumping				5.6	3.0	3.2
	RSE of Avg[c]	1.1	1.2	0.8	1.1	1.2	0.8
NO_x (%)	Idle	0.1	0.2	0.1	0.1	0.3	0.2
	Low Acceleration	4.4	3.8	2.9	3.5	3.8	2.6
	Medium Acceleration	1.8	2.2	1.4	1.7	1.9	1.3
	High Acceleration	1.2	1.7	1.0	2.2	3.1	1.9
	Low Cruise	4.0	4.6	3.0	2.9	3.9	2.4
	Medium Cruise	2.8	3.2	2.1	4.3	8.0	4.5
	High Cruise	1.9	1.1	1.1	2.5	3.1	2.0
	Deceleration	2.4	3.6	2.2	5.1	4.9	3.5
	Dumping				3.9	2.6	2.4
	RSE of Avg[c]	0.9	1.0	0.7	1.1	1.3	0.9
HC (%)	Idle	0.4	0.4	0.3	1.1	0.5	0.6
	Low Acceleration	5.0	5.0	3.5	4.6	3.6	2.9
	Medium Acceleration	2.1	2.0	1.4	2.7	2.3	1.8
	High Acceleration	2.0	2.1	1.4	4.1	2.5	2.4
	Low Cruise	4.2	3.0	2.6	2.8	2.2	1.8
	Medium Cruise	2.4	1.7	1.5	4.2	5.3	3.4
	High Cruise	1.7	1.2	1.0	2.0	2.3	1.5
	Deceleration	2.2	2.7	1.7	2.5	2.8	1.9
	Dumping				7.4	2.8	3.9
	RSE of Avg[c]	1.0	0.9	0.7	1.3	1.0	0.8

[a]: Relative Standard Error (RSE) is defined as the sample size divided by the mean and the square root of the sample size, and multiplied by 100 percent to convert to a percent basis .

[b]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[c]: Relative Standard Error of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

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Table A-32. Continued

	Driving Mode[b]	Unloaded: Vehicle Number 6117	Unloaded: Vehicle Number 6123	Unloaded: Avg[c]	Loaded: Vehicle Number 6117	Loaded: Vehicle Number 6123	Loaded: Avg[c]
CO (%)	Idle	0.2	0.2	0.2	0.4	0.2	0.2
	Low Acceleration	8.8	14.1	8.3	6.2	3.4	3.5
	Medium Acceleration	2.2	2.2	1.6	1.6	2.0	1.3
	High Acceleration	1.6	1.8	1.2	2.4	2.3	1.7
	Low Cruise	4.1	5.2	3.3	3.2	2.4	2.0
	Medium Cruise	2.1	1.2	1.2	1.6	3.1	1.7
	High Cruise	1.0	0.6	0.6	0.8	1.1	0.7
	Deceleration	1.9	2.8	1.7	3.3	3.6	2.4
	Dumping				5.9	1.9	3.1
	RSE of Avg[c]	1.3	1.9	1.2	1.1	0.8	0.7
CO_2 (%)	Idle	0.2	0.3	0.2	0.2	0.4	0.2
	Low Acceleration	5.2	5.5	3.8	3.6	4.8	3.0
	Medium Acceleration	1.8	2.1	1.4	1.6	2.3	1.4
	High Acceleration	1.4	2.2	1.3	2.3	4.2	2.4
	Low Cruise	5.1	5.2	3.6	3.2	3.9	2.5
	Medium Cruise	2.7	2.5	1.8	2.7	4.2	2.5
	High Cruise	1.7	1.0	1.0	2.3	2.8	1.8
	Deceleration	3.0	3.3	2.3	4.1	4.0	2.8
	Dumping				5.6	3.0	3.2
	RSE of Avg[c]	1.1	1.2	0.8	1.1	1.2	0.8
PM (%)	Idle	0.3	0.2	0.2	0.4	0.2	0.2
	Low Acceleration	7.6	4.1	4.3	4.5	2.2	2.5
	Medium Acceleration	2.3	1.9	1.5	1.8	1.9	1.3
	High Acceleration	1.7	1.6	1.2	1.9	2.3	1.5
	Low Cruise	6.4	4.0	3.8	3.3	3.0	2.2
	Medium Cruise	3.1	1.9	1.8	3.1	5.0	2.9
	High Cruise	1.7	0.8	1.0	2.1	2.0	1.4
	Deceleration	2.5	3.7	2.2	2.9	4.1	2.5
	Dumping				5.3	2.2	2.9
	RSE of Avg[c]	1.4	0.9	0.8	1.0	1.0	0.7

[b]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[c]: Relative Standard Error of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

Table A-33. Relative Standard Error (RSE)[a] on a Per Time Basis by Driving Mode, Vehicle, and Load for Tier 2 Tandem Dump Trucks (Soy Based B20)

	Driving Mode[b]	Unloaded			Loaded		
		Vehicle Number		Avg[c]	Vehicle Number		Avg[c]
		0125	0126		0125	0126	
Fuel (%)	Idle	1.3	0.5	0.7	0.6	0.9	0.5
	Low Acceleration	3.3	4.9	3.0	3.4	3.9	2.6
	Medium Acceleration	2.5	3.2	2.0	2.0	1.9	1.4
	High Acceleration	2.1	2.2	1.5	2.7	2.0	1.7
	Low Cruise	3.3	3.9	2.5	3.4	3.4	2.4
	Medium Cruise	2.2	2.3	1.6	2.0	4.3	2.4
	High Cruise	0.6	0.6	0.4	0.9	0.8	0.6
	Deceleration	3.5	4.0	2.7	4.0	3.8	2.7
	Dumping				6.7	4.9	4.1
	RSE of Avg[c]	0.9	1.1	0.7	1.1	1.1	0.8
NO_x (%)	Idle	0.4	0.4	0.3	0.2	0.3	0.2
	Low Acceleration	2.3	3.0	1.9	2.5	2.6	1.8
	Medium Acceleration	2.3	3.0	1.9	1.5	1.7	1.1
	High Acceleration	2.5	2.7	1.8	2.5	1.9	1.6
	Low Cruise	1.4	2.8	1.6	2.5	2.3	1.7
	Medium Cruise	2.2	2.0	1.5	2.1	3.7	2.1
	High Cruise	0.4	0.6	0.3	0.8	0.7	0.5
	Deceleration	2.2	2.7	1.8	2.9	2.8	2.0
	Dumping				5.4	3.2	3.2
	RSE of Avg[c]	0.7	0.8	0.5	0.9	0.8	0.6
HC (%)	Idle	1.3	1.4	0.9	0.7	2.7	1.4
	Low Acceleration	5.0	3.8	3.1	4.2	3.9	2.9
	Medium Acceleration	4.2	2.5	2.5	2.6	1.4	1.5
	High Acceleration	4.1	3.3	2.6	3.8	1.0	2.0
	Low Cruise	2.9	3.3	2.2	2.4	4.9	2.8
	Medium Cruise	3.3	4.9	3.0	3.5	1.7	1.9
	High Cruise	1.0	0.8	0.7	1.0	1.5	0.9
	Deceleration	5.5	4.4	3.5	4.5	6.4	3.9
	Dumping				12.1	5.4	6.6
	RSE of Avg[c]	1.3	1.2	0.9	1.7	1.2	1.0

[a]: Relative Standard Error (RSE) is defined as the sample size divided by the mean and the square root of the sample size, and multiplied by 100 percent to convert to a percent basis .

[b]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.

- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[c]: Relative Standard Error of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

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Table A-33. Continued

	Driving Mode[b]	Unloaded: Vehicle Number 0125	Unloaded: Vehicle Number 0126	Unloaded: Avg[c]	Loaded: Vehicle Number 0125	Loaded: Vehicle Number 0126	Loaded: Avg[c]
CO (%)	Idle	0.6	0.4	0.4	0.3	0.6	0.3
	Low Acceleration	6.2	4.1	3.7	4.5	3.6	2.9
	Medium Acceleration	3.5	3.5	2.5	2.0	1.8	1.3
	High Acceleration	2.2	2.3	1.6	1.5	1.7	1.1
	Low Cruise	2.6	2.1	1.7	3.2	2.5	2.0
	Medium Cruise	1.2	1.7	1.0	1.3	2.0	1.2
	High Cruise	0.4	0.4	0.3	0.4	0.6	0.4
	Deceleration	3.2	2.9	2.2	3.1	2.3	1.9
	Dumping				6.4	4.4	3.9
	RSE of Avg[c]	1.1	0.9	0.7	1.0	0.8	0.7
CO_2 (%)	Idle	1.3	0.5	0.7	0.6	0.9	0.5
	Low Acceleration	3.4	4.9	2.9	3.4	3.9	2.6
	Medium Acceleration	2.5	3.2	2.0	2.0	2.0	1.4
	High Acceleration	2.1	2.2	1.5	2.7	2.0	1.7
	Low Cruise	3.3	3.9	2.6	3.4	3.4	2.4
	Medium Cruise	2.2	2.3	1.6	2.0	4.3	2.4
	High Cruise	0.6	0.6	0.4	0.9	0.8	0.6
	Deceleration	3.5	4.0	2.7	4.0	3.8	2.8
	Dumping				6.7	4.9	4.1
	RSE of Avg[c]	0.9	1.1	0.7	1.1	1.1	0.8
PM (%)	Idle	0.5	0.4	0.3	0.4	0.6	0.4
	Low Acceleration	5.0	4.9	3.5	3.7	3.6	2.6
	Medium Acceleration	2.8	3.7	2.3	2.1	1.9	1.4
	High Acceleration	2.8	2.2	1.8	2.9	1.8	1.7
	Low Cruise	3.6	4.1	2.7	3.8	3.3	2.5
	Medium Cruise	2.6	3.0	2.0	2.4	4.3	2.5
	High Cruise	0.6	0.7	0.5	1.1	0.8	0.7
	Deceleration	5.4	4.6	3.6	4.6	4.0	3.0
	Dumping				6.4	3.0	3.5
	RSE of Avg[c]	1.2	1.2	0.8	1.2	1.0	0.8

[b]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[c]: Relative Standard Error of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

Table A-34. Relative Standard Error (RSE)[a] by Driving Mode, Vehicle, and Load for Tier 2 Single Axle Dump Trucks (Soy Based B20)

		Unloaded			Loaded		
	Driving Mode[b]	Vehicle Number		Avg[c]	Vehicle Number		Avg[c]
		6117	**6123**		**6117**	**6123**	
Fuel (%)	Idle	1.0	1.0	0.7	1.5	4.5	2.4
	Low Acceleration	4.3	6.8	4.0	3.8	5.1	3.2
	Medium Acceleration	1.7	3.8	2.1	1.6	2.2	1.4
	High Acceleration	1.7	4.5	2.4	2.6	4.4	2.6
	Low Cruise	3.5	2.6	2.2	2.9	3.1	2.1
	Medium Cruise	1.8	3.6	2.0	1.8	2.0	1.4
	High Cruise	2.0	1.4	1.2	3.2	2.7	2.1
	Deceleration	2.4	7.0	3.7	2.9	4.1	2.5
	Dumping				5.0	5.4	3.7
	RSE of Avg[c]	0.9	1.6	0.9	1.0	1.3	0.8
NO_x (%)	Idle	0.8	0.5	0.5	0.9	2.0	1.1
	Low Acceleration	3.3	4.7	2.8	2.8	3.9	2.4
	Medium Acceleration	1.6	3.6	2.0	1.6	2.0	1.3
	High Acceleration	1.4	2.9	1.6	2.7	2.9	2.0
	Low Cruise	3.6	4.3	2.8	3.9	4.5	3.0
	Medium Cruise	1.8	4.6	2.5	2.6	4.3	2.5
	High Cruise	2.1	1.7	1.4	4.2	4.2	3.0
	Deceleration	2.4	5.6	3.1	3.5	5.1	3.1
	Dumping				4.2	4.1	2.9
	RSE of Avg[c]	0.8	1.4	0.8	1.0	1.3	0.8
HC (%)	Idle	0.6	1.3	0.7	1.6	2.8	1.6
	Low Acceleration	4.3	5.3	3.4	3.2	4.9	3.0
	Medium Acceleration	2.2	7.9	4.1	3.4	3.7	2.5
	High Acceleration	2.2	10.1	5.2	5.0	6.4	4.0
	Low Cruise	3.7	2.9	2.3	2.5	3.2	2.0
	Medium Cruise	2.5	10.7	5.5	3.8	4.3	2.9
	High Cruise	1.5	5.9	3.1	3.7	4.6	3.0
	Deceleration	1.9	7.6	3.9	2.4	3.5	2.1
	Dumping				5.9	12.3	6.8
	RSE of Avg[c]	0.9	2.5	1.3	1.2	1.9	1.1

[a]: Relative Standard Error (RSE) is defined as the sample size divided by the mean and the square root of the sample size, and multiplied by 100 percent to convert to a percent basis .

[b]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[c]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes.

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Table A-34. Continued

	Driving Mode[b]	Unloaded Vehicle Number 6117	Unloaded Vehicle Number 6123	Unloaded Avg[c]	Loaded Vehicle Number 6117	Loaded Vehicle Number 6123	Loaded Avg[c]
CO (%)	Idle	1.9	0.7	1.0	2.7	2.1	1.7
	Low Acceleration	7.4	4.7	4.4	11.6	3.9	6.1
	Medium Acceleration	1.7	3.0	1.7	1.6	2.0	1.3
	High Acceleration	1.6	5.7	2.9	2.4	3.4	2.1
	Low Cruise	2.9	2.2	1.8	4.3	2.5	2.5
	Medium Cruise	1.4	2.7	1.5	1.1	1.2	0.8
	High Cruise	1.2	1.1	0.8	1.6	1.4	1.1
	Deceleration	2.8	5.0	2.9	3.9	1.9	2.2
	Dumping				17.0	4.4	8.8
	RSE of Avg[c]	1.1	1.3	0.9	2.4	0.9	1.3
CO_2 (%)	Idle	1.0	1.1	0.7	1.5	4.6	2.4
	Low Acceleration	4.3	6.8	4.0	3.8	5.1	3.2
	Medium Acceleration	1.7	3.8	2.1	1.6	2.2	1.4
	High Acceleration	1.7	4.5	2.4	2.8	4.2	2.5
	Low Cruise	3.5	2.6	2.2	3.0	4.7	2.1
	Medium Cruise	1.8	3.6	2.0	1.8	2.1	1.4
	High Cruise	2.0	1.4	1.2	3.2	2.7	2.1
	Deceleration	2.4	7.1	3.7	2.9	4.1	2.5
	Dumping				5.0	5.5	3.7
	RSE of Avg[c]	0.9	1.6	0.9	1.0	1.4	0.8
PM (%)	Idle	0.8	1.0	0.6	1.4	3.4	1.8
	Low Acceleration	4.3	6.5	3.9	3.7	5.1	3.1
	Medium Acceleration	1.7	3.5	1.9	1.4	2.0	1.2
	High Acceleration	1.3	3.9	2.1	2.5	3.1	2.0
	Low Cruise	3.9	4.1	2.8	3.6	4.3	2.8
	Medium Cruise	2.0	3.6	2.1	1.8	2.1	1.4
	High Cruise	1.8	1.4	1.1	2.5	2.0	1.6
	Deceleration	2.9	6.8	3.7	3.0	3.7	2.4
	Dumping				6.3	5.3	4.1
	RSE of Avg[c]	0.9	1.5	0.9	1.1	1.2	0.8

[b]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[c]: Relative Standard Error of average for modal average and vehicle average: For unloaded, it averaged to 8 modes and for loaded, it averaged to 9 modes.

Table A-35. Preliminary Average Fuel Consumption and Emission Rates on a Per Mile Basis by Driving Mode, Vehicle, and Load for Tier 1 Tandem Dump Trucks (Petroleum Diesel)

		Unloaded					**Loaded**					
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	Ratio[c]
		0507	**0578**	**0579**	**0580**		**0507**	**0578**	**0579**	**0580**		
Fuel (kg/mile)	Low Acceleration	1.12	0.851	1.15	1.33	1.11	1.13	1.10	1.19	1.76	1.30	1.16
	Medium Acceleration	0.604	0.467	0.356	0.792	0.555	0.730	0.614	0.593	0.866	0.701	1.26
	High Acceleration	0.473	0.430	0.342	0.739	0.496	0.542	0.431	0.540	0.842	0.589	1.19
	Low Cruise	0.673	0.675	0.600	0.956	0.726	0.808	0.768	0.757	1.18	0.879	1.21
	Medium Cruise	0.344	0.275	0.380	0.285	0.321	0.561	0.465	0.486	0.471	0.496	1.54
	High Cruise	0.299	0.228	0.236	0.259	0.255	0.393	0.288	0.372	0.440	0.373	1.46
	Deceleration	0.242	0.182	0.285	0.387	0.274	0.428	0.316	0.436	0.657	0.459	1.67
	Equal Weight Avg[b]	0.536	0.444	0.479	0.679	0.534	0.657	0.569	0.624	0.889	0.685	1.28
	Empirical Weight Avg[d]	0.441	0.373	0.423	0.802	0.510	0.645	0.531	0.554	1.07	0.700	1.37
NO_x (g/mile)	Low Acceleration	43.1	27.0	34.0	41.7	36.5	53.0	38.1	39.5	54.1	46.2	1.27
	Medium Acceleration	22.9	14.8	14.9	23.3	19.0	33.4	22.5	20.3	22.3	24.6	1.30
	High Acceleration	20.2	15.1	15.7	25.2	19.1	28.3	17.8	24.1	32.6	25.7	1.35
	Low Cruise	23.2	28.8	18.5	12.8	20.8	34.1	32.3	18.7	19.9	26.3	1.26
	Medium Cruise	13.8	9.56	11.5	7.98	10.7	28.4	18.0	17.3	12.6	19.1	1.78
	High Cruise	16.0	8.01	12.1	9.01	11.3	24.0	17.8	15.1	14.2	17.8	1.58
	Deceleration	10.4	6.20	10.8	11.7	9.76	23.8	18.9	14.5	19.2	19.1	1.96
	Equal Weight Avg[b]	21.4	15.6	16.8	18.8	18.2	32.2	23.6	21.4	25.0	25.5	1.40
	Empirical Weight Avg[d]	18.5	13.1	15.7	18.8	16.5	31.5	23.1	19.4	25.0	24.8	1.50

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not shown because no significant distance is driven during these modes

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-35. Continued

	Driving Mode[a]	Unloaded					Loaded					Ratio[c]
		Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	
		0507	**0578**	**0579**	**0580**		**0507**	**0578**	**0579**	**0580**		
HC (g/mile)	Low Acceleration	3.28	2.13	1.38	2.93	2.43	3.42	2.34	3.52	3.79	3.27	1.34
	Medium Acceleration	0.975	0.827	0.487	1.39	0.919	1.20	1.02	1.46	1.46	1.29	1.40
	High Acceleration	0.801	0.711	0.484	1.31	0.827	0.871	0.731	1.48	1.34	1.11	1.34
	Low Cruise	2.00	2.19	1.17	1.37	1.68	2.17	2.60	1.45	1.43	1.91	1.13
	Medium Cruise	0.588	1.03	0.797	0.318	0.683	0.703	1.21	0.950	0.532	0.849	1.24
	High Cruise	0.467	0.739	0.342	0.336	0.471	0.557	0.804	0.648	0.427	0.609	1.29
	Deceleration	0.523	0.949	0.443	0.622	0.634	0.696	1.41	0.674	0.720	0.875	1.38
	Equal Weight Avg[b]	1.23	1.23	0.730	1.18	1.09	1.37	1.45	1.45	1.39	1.41	1.29
	Empirical Weight Avg[d]	0.909	1.07	0.664	1.37	1.00	1.34	1.43	1.24	1.59	1.40	1.40
CO (g/mile)	Low Acceleration	4.92	4.92	4.22	7.34	5.35	5.84	5.80	4.94	9.99	6.64	1.24
	Medium Acceleration	2.01	1.72	1.73	3.09	2.14	2.27	2.07	1.96	3.46	2.44	1.14
	High Acceleration	1.55	1.58	1.25	3.54	1.98	1.66	1.61	1.73	3.73	2.18	1.10
	Low Cruise	3.85	4.29	2.93	4.11	3.80	4.10	4.67	2.64	5.79	4.30	1.13
	Medium Cruise	1.16	2.12	1.18	1.47	1.49	1.32	2.42	1.36	1.98	1.77	1.19
	High Cruise	0.823	1.61	0.817	0.926	1.04	1.10	1.60	1.32	1.48	1.38	1.32
	Deceleration	1.19	1.84	1.15	2.76	1.74	1.78	3.05	1.63	3.46	2.48	1.43
	Equal Weight Avg[b]	2.22	2.58	1.90	3.32	2.50	2.58	3.03	2.22	4.27	3.03	1.21
	Empirical Weight Avg[d]	1.71	2.23	1.74	3.92	2.40	2.55	2.94	1.91	5.38	3.20	1.33

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not shown because no significant distance is driven during these modes

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-35. Continued

	Driving Mode[a]	Unloaded: Vehicle Number 0507	Unloaded: 0578	Unloaded: 0579	Unloaded: 0580	Unloaded: Avg[b]	Loaded: Vehicle Number 0507	Loaded: 0578	Loaded: 0579	Loaded: 0580	Loaded: Avg[b]	Ratio[c]
CO_2 (kg/mile)	Low Acceleration	3.60	2.74	3.70	4.21	3.56	3.82	3.53	3.79	5.60	4.19	1.18
	Medium Acceleration	1.91	1.47	1.14	2.46	1.75	2.29	1.94	1.94	2.73	2.23	1.28
	High Acceleration	1.46	1.36	1.12	2.27	1.55	1.74	1.37	1.73	2.65	1.87	1.21
	Low Cruise	2.09	2.19	1.99	3.05	2.33	2.57	2.43	2.51	3.71	2.80	1.20
	Medium Cruise	1.05	0.866	1.27	0.904	1.02	1.79	1.47	1.53	1.51	1.57	1.54
	High Cruise	0.921	0.718	0.756	0.824	0.805	1.30	0.910	1.20	1.38	1.20	1.49
	Deceleration	0.764	0.572	0.900	1.23	0.866	1.35	0.994	1.40	2.08	1.46	1.68
	Equal Weight Avg[b]	1.68	1.42	1.55	2.13	1.70	2.12	1.81	2.01	2.81	2.19	1.29
	Empirical Weight Avg[d]	1.38	1.19	1.37	2.53	1.62	2.08	1.68	1.79	3.38	2.32	1.43
PM (g/mile)	Low Acceleration	0.207	0.156	0.178	0.179	0.180	0.218	0.219	0.312	0.230	0.245	1.36
	Medium Acceleration	0.095	0.081	0.096	0.122	0.098	0.116	0.104	0.127	0.147	0.123	1.25
	High Acceleration	0.080	0.080	0.070	0.118	0.087	0.100	0.082	0.106	0.139	0.107	1.23
	Low Cruise	0.083	0.453	0.375	0.065	0.244	0.111	0.480	0.423	0.174	0.297	1.22
	Medium Cruise	0.040	0.156	0.196	0.055	0.112	0.068	0.263	0.320	0.099	0.188	1.68
	High Cruise	0.032	0.117	0.158	0.046	0.088	0.039	0.142	0.251	0.095	0.132	1.49
	Deceleration	0.027	0.089	0.145	0.059	0.080	0.050	0.215	0.145	0.138	0.137	1.71
	Equal Weight Avg[b]	0.081	0.162	0.174	0.092	0.127	0.100	0.215	0.241	0.146	0.175	1.38
	Empirical Weight Avg[d]	0.062	0.144	0.188	0.091	0.121	0.095	0.218	0.213	0.165	0.173	1.42

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not shown because no significant distance is driven during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes
[c]: Loaded / Unloaded
[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table A-36. Preliminary Average Fuel Consumption and Emission Rates on a Per Mile Basis by Driving Mode, Vehicle, and Load for Tier 1 Single Axle Dump Trucks (Petroleum Diesel)

		Unloaded					**Loaded**					
	Driving Mode[a]	Vehicle Number 4743	4750	4869	4870	Avg[b]	Vehicle Number 4743	4750	4869	4870	Avg[b]	Ratio[c]
Fuel (kg/mile)	Low Acceleration	0.549	0.788	0.565	0.486	0.597	0.827	0.857	0.857	0.831	0.843	1.41
	Medium Acceleration	0.295	0.452	0.352	0.505	0.401	0.422	0.580	0.526	0.636	0.541	1.35
	High Acceleration	0.331	0.433	0.368	0.437	0.392	0.462	0.530	0.555	0.473	0.505	1.29
	Low Cruise	0.255	0.509	0.302	0.265	0.333	0.433	0.535	0.582	0.486	0.509	1.53
	Medium Cruise	0.185	0.226	0.175	0.183	0.192	0.241	0.332	0.231	0.351	0.289	1.50
	High Cruise	0.211	0.306	0.284	0.291	0.273	0.264	0.348	0.344	0.373	0.332	1.22
	Deceleration	0.122	0.141	0.204	0.162	0.157	0.210	0.166	0.305	0.239	0.230	1.46
	Equal Weight Avg[b]	0.278	0.408	0.322	0.333	0.335	0.408	0.478	0.486	0.484	0.464	1.39
	Empirical Weight Avg[d]	0.235	0.351	0.299	0.314	0.300	0.358	0.424	0.430	0.483	0.424	1.41
NO_x (g/mile)	Low Acceleration	31.1	25.2	26.8	19.4	25.6	43.6	30.0	41.1	32.7	36.9	1.44
	Medium Acceleration	14.1	11.1	15.1	18.8	14.8	19.9	14.8	23.8	24.6	20.8	1.41
	High Acceleration	18.1	12.0	13.8	15.3	14.8	22.3	12.7	24.5	16.8	19.1	1.29
	Low Cruise	15.2	19.6	14.6	12.6	15.5	23.6	21.4	23.6	21.5	22.5	1.45
	Medium Cruise	9.13	6.21	6.88	6.85	7.27	11.6	9.02	9.65	14.6	11.2	1.55
	High Cruise	7.35	7.05	8.31	7.58	7.57	8.78	8.16	10.0	11.4	9.60	1.27
	Deceleration	6.28	4.55	7.27	6.71	6.21	12.4	5.93	10.0	10.8	9.80	1.58
	Equal Weight Avg[b]	14.5	12.3	13.2	12.5	13.1	20.3	14.6	20.4	18.9	18.6	1.42
	Empirical Weight Avg[d]	11.7	10.3	12.0	11.8	11.5	18.4	12.7	17.8	19.1	17.0	1.48

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not shown because no significant distance is driven during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-36. Continued

		Unloaded					Loaded					
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	Ratio[c]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**		
HC (g/mile)	Low Acceleration	0.717	0.876	0.497	0.497	0.647	0.723	1.01	0.617	0.671	0.755	1.17
	Medium Acceleration	0.253	0.452	0.169	0.349	0.306	0.318	0.552	0.255	0.418	0.386	1.26
	High Acceleration	0.308	0.457	0.208	0.285	0.314	0.516	0.489	0.349	0.350	0.426	1.35
	Low Cruise	0.791	0.926	0.622	0.445	0.696	1.01	0.932	0.715	0.691	0.838	1.20
	Medium Cruise	0.470	0.320	0.145	0.274	0.302	0.617	0.385	0.208	0.327	0.384	1.27
	High Cruise	0.480	0.362	0.157	0.275	0.319	0.702	0.404	0.241	0.296	0.411	1.29
	Deceleration	0.618	0.315	0.189	0.290	0.353	1.15	0.395	0.344	0.420	0.576	1.63
	Equal Weight Avg[b]	0.520	0.530	0.284	0.345	0.420	0.719	0.595	0.390	0.453	0.539	1.29
	Empirical Weight Avg[d]	0.535	0.476	0.299	0.351	0.415	0.739	0.554	0.358	0.491	0.540	1.29
CO (g/mile)	Low Acceleration	7.61	7.26	9.01	5.81	7.42	11.9	9.73	13.2	10.5	11.3	1.52
	Medium Acceleration	3.50	2.88	4.12	5.67	4.04	4.18	3.32	6.08	6.02	4.90	1.21
	High Acceleration	4.09	2.93	2.71	2.53	3.07	5.60	3.37	4.57	3.14	4.17	1.36
	Low Cruise	5.70	5.29	4.89	3.97	4.96	7.65	5.90	9.07	7.22	7.46	1.50
	Medium Cruise	2.24	1.63	1.67	2.64	2.04	2.59	1.74	2.72	2.96	2.50	1.23
	High Cruise	1.72	1.39	0.939	1.00	1.26	2.39	1.67	1.48	1.21	1.69	1.33
	Deceleration	2.05	1.31	1.19	1.80	1.59	3.19	1.76	2.37	2.27	2.40	1.51
	Equal Weight Avg[b]	3.84	3.24	3.50	3.35	3.48	5.35	3.93	5.65	4.75	4.92	1.41
	Empirical Weight Avg[d]	3.27	2.63	3.07	3.16	3.03	4.77	3.31	5.01	5.03	4.53	1.49

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not shown because no significant distance is driven during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-36. Continued

		Unloaded					Loaded					
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	Ratio[c]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**		
CO_2 (kg/mile)	Low Acceleration	1.72	2.47	1.78	1.53	1.88	2.60	2.70	2.69	2.61	2.65	1.41
	Medium Acceleration	0.927	1.42	1.11	1.59	1.26	1.33	1.83	1.65	2.01	1.70	1.35
	High Acceleration	1.03	1.40	1.16	1.38	1.24	1.46	1.67	1.75	1.53	1.60	1.29
	Low Cruise	0.799	1.60	0.948	0.833	1.04	1.36	1.68	1.83	1.52	1.60	1.53
	Medium Cruise	0.582	0.711	0.552	0.574	0.605	0.759	1.05	0.725	1.11	0.909	1.50
	High Cruise	0.664	0.935	0.896	0.918	0.853	0.834	1.02	1.11	1.12	1.02	1.20
	Deceleration	0.383	0.444	0.644	0.510	0.495	0.660	0.522	0.966	0.753	0.725	1.46
	Equal Weight Avg[b]	0.870	1.28	1.01	1.05	1.05	1.29	1.50	1.53	1.52	1.46	1.38
	Empirical Weight Avg[d]	0.739	1.10	0.941	0.990	0.943	1.13	1.31	1.35	1.51	1.32	1.41
PM (g/mile)	Low Acceleration	0.160	0.160	0.187	0.166	0.168	0.229	0.189	0.274	0.285	0.244	1.45
	Medium Acceleration	0.080	0.065	0.103	0.151	0.099	0.115	0.092	0.145	0.179	0.132	1.33
	High Acceleration	0.116	0.079	0.087	0.102	0.096	0.149	0.084	0.139	0.117	0.122	1.28
	Low Cruise	0.067	0.092	0.075	0.086	0.080	0.130	0.100	0.174	0.172	0.144	1.80
	Medium Cruise	0.044	0.032	0.060	0.065	0.050	0.064	0.050	0.066	0.102	0.070	1.40
	High Cruise	0.057	0.040	0.062	0.068	0.057	0.069	0.044	0.078	0.078	0.067	1.19
	Deceleration	0.044	0.026	0.049	0.054	0.043	0.078	0.031	0.068	0.073	0.063	1.44
	Equal Weight Avg[b]	0.081	0.071	0.089	0.099	0.085	0.119	0.084	0.135	0.144	0.120	1.42
	Empirical Weight Avg[d]	0.066	0.058	0.078	0.093	0.074	0.103	0.071	0.118	0.147	0.110	1.48

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not shown because no significant distance is driven during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table A-37. Preliminary Average Fuel Consumption and Emission Rates on a Per Mile Basis by Driving Mode, Vehicle, and Load for Tier 1 Tandem Dump Trucks (Soy Based B20)

	Driving Mode[a]	**Unloaded**					**Loaded**					Ratio[c]
		Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	
		0507	**0578**	**0579**	**0580**		**0507**	**0578**	**0579**	**0580**		
Fuel (kg/mile)	Low Acceleration	1.13	1.05	1.10	0.868	1.04	1.70	1.38	1.35	1.25	1.42	1.37
	Medium Acceleration	0.497	0.546	0.645	0.353	0.510	0.585	0.821	0.753	0.512	0.668	1.31
	High Acceleration	0.479	0.533	0.577	0.370	0.490	0.579	0.555	0.633	0.383	0.537	1.10
	Low Cruise	0.589	0.900	0.925	0.471	0.721	0.641	1.23	1.07	0.515	0.865	1.20
	Medium Cruise	0.264	0.358	0.383	0.283	0.322	0.348	0.518	0.476	0.401	0.436	1.35
	High Cruise	0.235	0.312	0.348	0.283	0.295	0.285	0.302	0.402	0.315	0.326	1.11
	Deceleration	0.161	0.159	0.351	0.225	0.224	0.271	0.249	0.433	0.338	0.323	1.44
	Equal Weight Avg[b]	0.480	0.550	0.618	0.408	0.514	0.630	0.723	0.731	0.531	0.654	1.27
	Empirical Weight Avg[d]	0.360	0.461	0.590	0.373	0.446	0.557	0.703	0.702	0.487	0.612	1.37
NO_x (g/mile)	Low Acceleration	27.9	26.3	25.5	26.8	26.6	30.3	33.7	30.2	32.5	31.7	1.19
	Medium Acceleration	12.6	15.3	16.5	9.94	13.6	14.5	24.1	19.3	12.6	17.6	1.30
	High Acceleration	13.9	13.9	16.1	10.7	13.6	16.0	20.0	16.6	14.0	16.7	1.22
	Low Cruise	15.7	15.6	24.1	15.6	17.8	17.2	31.6	29.8	13.0	22.9	1.29
	Medium Cruise	7.21	9.12	9.59	7.13	8.26	9.28	19.6	13.1	10.4	13.1	1.58
	High Cruise	8.66	11.8	14.4	7.91	10.7	11.7	12.0	14.9	9.57	12.0	1.12
	Deceleration	5.20	7.79	10.4	6.76	7.53	8.86	10.9	12.9	9.14	10.4	1.39
	Equal Weight Avg[b]	13.0	14.3	16.6	12.1	14.0	15.4	21.7	19.5	14.5	17.8	1.27
	Empirical Weight Avg[d]	10.4	12.9	16.5	11.2	12.7	14.2	20.9	19.2	12.8	16.8	1.32

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not shown because no significant distance is driven during these modes

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes
[c]: Loaded / Unloaded
[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-37. Continued

	Driving Mode[a]	Unloaded 0507	Unloaded 0578	Unloaded 0579	Unloaded 0580	Unloaded Avg[b]	Loaded 0507	Loaded 0578	Loaded 0579	Loaded 0580	Loaded Avg[b]	Ratio[c]
HC (g/mile)	Low Acceleration	1.62	1.49	1.50	1.25	1.47	1.88	1.88	1.52	1.38	1.67	1.14
	Medium Acceleration	0.572	0.855	0.718	0.372	0.629	0.688	0.987	0.731	0.516	0.730	1.16
	High Acceleration	0.485	0.677	0.540	0.389	0.523	0.598	0.694	0.581	0.413	0.571	1.09
	Low Cruise	1.15	1.56	1.13	1.16	1.25	1.36	2.10	1.42	1.11	1.50	1.19
	Medium Cruise	0.330	0.550	0.376	0.300	0.389	0.376	0.761	0.518	0.380	0.509	1.31
	High Cruise	0.264	0.504	0.319	0.261	0.337	0.332	0.490	0.446	0.297	0.391	1.16
	Deceleration	0.293	0.607	0.608	0.354	0.466	0.507	0.567	0.757	0.491	0.581	1.25
	Equal Weight Avg[b]	0.675	0.893	0.742	0.585	0.724	0.820	1.07	0.854	0.656	0.849	1.17
	Empirical Weight Avg[d]	0.496	0.798	0.721	0.570	0.646	0.780	1.08	0.862	0.621	0.835	1.29
CO (g/mile)	Low Acceleration	6.81	7.07	8.26	8.68	7.70	7.98	9.10	8.39	8.86	8.58	1.11
	Medium Acceleration	1.93	3.21	3.36	2.01	2.63	2.38	3.41	3.41	2.52	2.93	1.12
	High Acceleration	1.50	2.60	2.23	1.68	2.00	1.81	2.64	2.46	1.74	2.16	1.08
	Low Cruise	3.07	3.69	3.71	5.19	3.92	4.32	5.21	4.43	4.70	4.67	1.19
	Medium Cruise	0.970	1.30	1.06	1.42	1.19	1.15	1.74	1.35	1.61	1.46	1.23
	High Cruise	0.865	1.28	0.927	0.849	0.979	1.28	1.31	1.18	1.38	1.29	1.31
	Deceleration	0.879	1.32	1.22	1.61	1.26	1.41	1.52	1.67	1.77	1.59	1.26
	Equal Weight Avg[b]	2.29	2.93	2.97	3.06	2.81	2.90	3.56	3.27	3.22	3.24	1.15
	Empirical Weight Avg[d]	1.58	2.46	2.61	2.77	2.36	2.68	3.38	3.05	2.90	3.00	1.27

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not shown because no significant distance is driven during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes
[c]: Loaded / Unloaded
[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-37. Continued

		Unloaded					Loaded					
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	Ratio[c]
		0507	**0578**	**0579**	**0580**		**0507**	**0578**	**0579**	**0580**		
CO_2 (kg/mile)	Low Acceleration	3.49	3.54	3.45	2.68	3.29	5.20	4.71	4.18	3.85	4.48	1.36
	Medium Acceleration	1.53	1.83	2.04	1.09	1.62	1.80	2.82	2.40	1.58	2.15	1.32
	High Acceleration	1.48	1.81	1.84	1.14	1.57	1.79	1.90	1.96	1.16	1.70	1.08
	Low Cruise	1.81	3.15	2.90	1.45	2.33	1.95	4.31	3.47	1.57	2.83	1.21
	Medium Cruise	0.814	1.25	1.22	0.873	1.04	1.07	1.74	1.52	1.21	1.39	1.33
	High Cruise	0.724	1.06	1.10	0.872	0.938	0.881	1.07	1.25	0.957	1.04	1.11
	Deceleration	0.497	0.541	1.11	0.693	0.711	0.797	0.854	1.34	1.03	1.01	1.41
	Equal Weight Avg[b]	1.48	1.88	1.95	1.26	1.64	1.93	2.49	2.30	1.62	2.08	1.27
	Empirical Weight Avg[d]	1.11	1.58	1.86	1.15	1.42	1.70	2.43	2.22	1.49	1.96	1.37
PM (g/mile)	Low Acceleration	0.197	0.637	0.482	0.132	0.362	0.218	0.965	0.618	0.180	0.495	1.37
	Medium Acceleration	0.088	0.375	0.321	0.067	0.213	0.097	0.467	0.391	0.091	0.261	1.23
	High Acceleration	0.085	0.335	0.312	0.081	0.203	0.092	0.338	0.334	0.127	0.223	1.10
	Low Cruise	0.090	0.076	0.102	0.058	0.081	0.115	0.132	0.171	0.075	0.123	1.52
	Medium Cruise	0.033	0.040	0.064	0.035	0.043	0.051	0.072	0.072	0.050	0.061	1.42
	High Cruise	0.022	0.034	0.035	0.029	0.030	0.040	0.035	0.052	0.048	0.044	1.45
	Deceleration	0.020	0.033	0.056	0.024	0.033	0.027	0.045	0.078	0.047	0.049	1.48
	Equal Weight Avg[b]	0.076	0.219	0.196	0.061	0.138	0.091	0.293	0.245	0.088	0.180	1.30
	Empirical Weight Avg[d]	0.053	0.172	0.153	0.051	0.107	0.083	0.237	0.209	0.074	0.150	1.41

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not shown because no significant distance is driven during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes
[c]: Loaded / Unloaded
[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table A-38. Preliminary Average Fuel Consumption and Emission Rates on a Per Mile Basis by Driving Mode, Vehicle, and Load for Tier 1 Single Axle Dump Trucks (Soy Based B20)

		Unloaded					**Loaded**					
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	Ratio[c]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**		
Fuel (kg/mile)	Low Acceleration	1.03	0.569	0.626	0.677	0.725	1.15	1.03	0.730	0.776	0.920	1.27
	Medium Acceleration	0.523	0.384	0.330	0.397	0.409	0.580	0.475	0.426	0.536	0.505	1.23
	High Acceleration	0.449	0.462	0.366	0.382	0.415	0.485	0.584	0.336	0.478	0.471	1.14
	Low Cruise	0.585	0.427	0.328	0.417	0.439	0.672	0.725	0.456	0.461	0.579	1.32
	Medium Cruise	0.372	0.258	0.204	0.294	0.282	0.466	0.345	0.362	0.432	0.401	1.42
	High Cruise	0.352	0.309	0.264	0.243	0.292	0.378	0.347	0.302	0.300	0.332	1.14
	Deceleration	0.269	0.213	0.195	0.163	0.210	0.356	0.264	0.286	0.214	0.280	1.33
	Equal Weight Avg[b]	0.511	0.375	0.330	0.368	0.396	0.584	0.539	0.414	0.457	0.498	1.26
	Empirical Weight Avg[d]	0.400	0.347	0.281	0.300	0.332	0.449	0.458	0.364	0.425	0.424	1.28
NO_x (g/mile)	Low Acceleration	28.5	27.8	13.9	14.2	21.1	33.3	34.7	18.7	15.8	25.6	1.21
	Medium Acceleration	11.9	13.0	6.34	7.10	9.56	13.6	15.7	7.99	10.2	11.9	1.24
	High Acceleration	9.33	15.2	6.03	6.46	9.24	9.85	19.7	5.50	8.80	11.0	1.19
	Low Cruise	21.0	18.0	6.48	8.63	13.5	17.7	25.7	8.54	10.1	15.5	1.15
	Medium Cruise	8.95	9.06	3.56	4.87	6.61	10.5	12.2	5.98	8.80	9.37	1.42
	High Cruise	6.24	8.71	3.62	3.36	5.48	8.56	9.70	4.56	5.07	6.97	1.27
	Deceleration	4.72	6.83	2.84	2.29	4.17	6.07	8.78	4.49	4.02	5.84	1.40
	Equal Weight Avg[b]	12.9	14.1	6.11	6.70	9.96	14.2	18.1	7.97	8.97	12.3	1.24
	Empirical Weight Avg[d]	8.45	12.6	4.72	5.02	7.70	10.1	15.2	6.43	8.36	10.0	1.30

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not shown because no significant distance is driven during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes
[c]: Loaded / Unloaded
[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-38. Continued

		Unloaded					Loaded					
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	Ratio[c]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**		
HC (g/mile)	Low Acceleration	0.716	0.367	0.335	0.408	0.457	0.785	0.610	0.439	0.459	0.573	1.26
	Medium Acceleration	0.252	0.211	0.210	0.190	0.215	0.328	0.252	0.203	0.268	0.263	1.22
	High Acceleration	0.259	0.226	0.173	0.221	0.220	0.302	0.478	0.219	0.275	0.319	1.45
	Low Cruise	0.642	0.262	0.290	0.311	0.376	0.480	0.387	0.399	0.541	0.452	1.20
	Medium Cruise	0.194	0.111	0.141	0.160	0.151	0.203	0.296	0.168	0.215	0.221	1.46
	High Cruise	0.197	0.096	0.178	0.159	0.158	0.247	0.245	0.256	0.197	0.236	1.50
	Deceleration	0.183	0.103	0.186	0.130	0.151	0.195	0.260	0.259	0.223	0.234	1.55
	Equal Weight Avg[b]	0.349	0.197	0.216	0.226	0.247	0.363	0.361	0.278	0.311	0.330	1.34
	Empirical Weight Avg[d]	0.248	0.176	0.194	0.186	0.201	0.274	0.305	0.267	0.293	0.285	1.42
CO (g/mile)	Low Acceleration	10.5	5.37	5.56	6.26	6.92	11.2	9.03	7.56	6.83	8.66	1.25
	Medium Acceleration	3.17	2.29	2.40	1.59	2.36	3.33	2.58	2.63	2.06	2.65	1.12
	High Acceleration	2.58	2.77	1.91	1.33	2.15	2.95	3.68	2.30	2.09	2.76	1.28
	Low Cruise	3.81	2.84	2.09	2.70	2.86	4.61	3.63	3.63	2.46	3.58	1.25
	Medium Cruise	1.58	1.07	0.983	0.829	1.12	1.69	1.39	1.30	0.941	1.33	1.19
	High Cruise	1.17	1.75	1.49	0.848	1.31	1.21	2.01	1.74	1.19	1.54	1.17
	Deceleration	1.12	1.24	0.836	0.55	0.940	1.32	1.40	1.08	0.817	1.15	1.23
	Equal Weight Avg[b]	3.42	2.48	2.18	2.01	2.52	3.76	3.39	2.89	2.34	3.10	1.23
	Empirical Weight Avg[d]	1.97	2.24	1.67	1.32	1.80	2.10	2.64	2.28	1.92	2.24	1.24

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not shown because no significant distance is driven during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-38. Continued

		Unloaded					Loaded					
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	Ratio[c]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**		
CO_2 (kg/mile)	Low Acceleration	3.17	1.75	1.92	2.08	2.23	3.52	3.18	2.24	2.39	2.83	1.27
	Medium Acceleration	1.61	1.18	1.02	1.23	1.26	1.79	1.47	1.32	1.66	1.56	1.24
	High Acceleration	1.39	1.42	1.13	1.18	1.28	1.50	1.80	1.04	1.48	1.45	1.14
	Low Cruise	1.80	1.31	1.01	1.28	1.35	2.07	2.24	1.42	1.42	1.79	1.32
	Medium Cruise	1.15	0.797	0.628	0.907	0.870	1.44	1.06	1.12	1.34	1.24	1.43
	High Cruise	1.08	0.954	0.816	0.750	0.901	1.17	1.12	0.934	0.903	1.03	1.14
	Deceleration	0.828	0.658	0.602	0.503	0.648	1.10	0.813	0.886	0.661	0.865	1.33
	Equal Weight Avg[b]	1.57	1.15	1.02	1.13	1.22	1.80	1.67	1.28	1.41	1.54	1.26
	Empirical Weight Avg[d]	1.23	1.07	0.865	0.925	1.02	1.39	1.42	1.13	1.31	1.31	1.28
PM (g/mile)	Low Acceleration	0.172	0.139	0.182	0.214	0.177	0.267	0.231	0.230	0.210	0.234	1.33
	Medium Acceleration	0.082	0.072	0.074	0.076	0.076	0.091	0.081	0.077	0.094	0.086	1.13
	High Acceleration	0.073	0.106	0.066	0.073	0.080	0.075	0.120	0.069	0.096	0.090	1.14
	Low Cruise	0.070	0.105	0.073	0.104	0.088	0.085	0.127	0.090	0.105	0.102	1.16
	Medium Cruise	0.040	0.046	0.036	0.048	0.043	0.050	0.053	0.053	0.057	0.053	1.25
	High Cruise	0.038	0.048	0.042	0.035	0.041	0.042	0.058	0.046	0.044	0.048	1.17
	Deceleration	0.026	0.038	0.033	0.025	0.031	0.032	0.047	0.044	0.038	0.040	1.31
	Equal Weight Avg[b]	0.071	0.079	0.072	0.082	0.076	0.092	0.102	0.087	0.092	0.093	1.22
	Empirical Weight Avg[d]	0.050	0.070	0.055	0.057	0.058	0.058	0.082	0.067	0.080	0.072	1.23

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not shown because no significant distance is driven during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes
[c]: Loaded / Unloaded
[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded.

Table A-39. Preliminary Average Fuel Consumption and Emission Rates on a Per Mile Basis by Driving Mode, Vehicle, and Load for Tier 2 Tandem Dump Trucks (Petroleum Diesel)

		Unloaded			**Loaded**			
	Driving Mode[a]	Vehicle Number **0125**	Vehicle Number **0126**	Avg[b]	Vehicle Number **0125**	Vehicle Number **0126**	Avg[b]	Ratio[c]
Fuel (kg/mile)	Low Acceleration	0.734	1.18	0.959	1.20	1.79	1.50	1.56
	Medium Acceleration	0.511	0.594	0.553	0.724	0.821	0.773	1.40
	High Acceleration	0.718	0.815	0.767	0.734	1.12	0.925	1.21
	Low Cruise	0.537	0.743	0.640	0.895	1.05	0.974	1.52
	Medium Cruise	0.345	0.451	0.398	0.551	0.608	0.580	1.46
	High Cruise	0.396	0.370	0.383	0.381	0.586	0.483	1.26
	Deceleration	0.338	0.348	0.343	0.440	0.425	0.432	1.26
	Equal Weight Avg[b]	0.511	0.644	0.577	0.704	0.914	0.809	1.40
	Empirical Weight Avg[d]	0.464	0.527	0.496	0.645	0.767	0.706	1.42
NO_x (g/mile)	Low Acceleration	17.8	26.6	22.2	27.0	38.7	32.8	1.48
	Medium Acceleration	8.90	13.7	11.3	14.8	16.8	15.8	1.40
	High Acceleration	14.8	13.9	14.4	13.4	19.9	16.6	1.16
	Low Cruise	8.78	14.3	11.6	21.0	20.9	20.9	1.81
	Medium Cruise	5.02	7.12	6.07	9.49	9.85	9.67	1.59
	High Cruise	4.02	4.47	4.30	4.87	7.23	6.07	1.42
	Deceleration	6.14	5.79	5.96	7.59	6.36	6.98	1.17
	Equal Weight Avg[b]	9.36	12.3	10.8	14.0	17.1	15.6	1.44
	Empirical Weight Avg[d]	7.96	8.71	8.33	12.6	12.7	12.7	1.52
HC (g/mile)	Low Acceleration	1.37	1.75	1.56	2.22	2.90	2.56	1.64
	Medium Acceleration	0.579	0.726	0.652	1.01	0.815	0.913	1.40
	High Acceleration	0.723	0.705	0.714	1.00	1.42	1.21	1.69
	Low Cruise	0.810	1.24	1.03	1.62	1.66	1.64	1.60
	Medium Cruise	0.482	0.612	0.547	0.899	0.807	0.853	1.56
	High Cruise	0.504	0.436	0.470	0.725	0.525	0.625	1.33
	Deceleration	0.804	0.800	0.802	1.01	0.910	0.962	1.20
	Equal Weight Avg[b]	0.754	0.896	0.825	1.21	1.29	1.25	1.52
	Empirical Weight Avg[d]	0.693	0.685	0.689	1.14	0.952	1.05	1.52

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not shown because no significant distance is driven during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-39. Continued

		Unloaded			Loaded			
	Driving Mode[a]	Vehicle Number 0125	Vehicle Number 0126	Avg[b]	Vehicle Number 0125	Vehicle Number 0126	Avg[b]	Ratio[c]
CO (g/mile)	Low Acceleration	5.28	8.57	6.92	8.68	11.3	9.98	1.44
	Medium Acceleration	2.51	3.38	2.94	3.23	4.38	3.80	1.29
	High Acceleration	2.84	3.34	3.09	2.63	5.62	4.12	1.33
	Low Cruise	3.69	9.02	6.36	6.51	13.1	9.82	1.54
	Medium Cruise	2.12	2.81	2.51	2.70	3.71	3.21	1.28
	High Cruise	2.01	2.34	2.17	2.17	2.69	2.43	1.12
	Deceleration	2.76	2.70	2.73	3.23	3.26	3.24	1.19
	Equal Weight Avg[b]	3.04	4.60	3.82	4.16	6.29	5.23	1.37
	Empirical Weight Avg[d]	2.86	3.64	3.25	3.94	4.79	4.37	1.34
CO_2 (kg/mile)	Low Acceleration	2.31	3.73	3.02	3.78	5.64	4.71	1.56
	Medium Acceleration	1.61	1.89	1.75	2.32	2.62	2.47	1.41
	High Acceleration	2.26	2.57	2.42	2.32	3.52	2.92	1.21
	Low Cruise	1.69	2.34	2.02	2.81	3.32	3.07	1.52
	Medium Cruise	1.09	1.42	1.26	1.74	1.92	1.83	1.46
	High Cruise	1.25	1.17	1.21	1.20	1.85	1.53	1.26
	Deceleration	1.07	1.10	1.08	1.39	1.34	1.36	1.26
	Equal Weight Avg[b]	1.61	2.03	1.82	2.22	2.89	2.55	1.40
	Empirical Weight Avg[d]	1.46	1.66	1.56	2.04	2.42	2.23	1.43
PM (g/mile)	Low Acceleration	0.107	0.190	0.148	0.212	0.297	0.255	1.72
	Medium Acceleration	0.085	0.120	0.103	0.141	0.164	0.152	1.48
	High Acceleration	0.135	0.132	0.134	0.144	0.182	0.163	1.22
	Low Cruise	0.063	0.093	0.078	0.141	0.137	0.139	1.78
	Medium Cruise	0.048	0.055	0.052	0.084	0.092	0.088	1.71
	High Cruise	0.055	0.044	0.049	0.069	0.070	0.070	1.41
	Deceleration	0.060	0.050	0.055	0.072	0.057	0.065	1.17
	Equal Weight Avg[b]	0.079	0.098	0.088	0.123	0.143	0.133	1.51
	Empirical Weight Avg[d]	0.069	0.074	0.072	0.111	0.111	0.111	1.54

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not shown because no significant distance is driven during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table A-40. Preliminary Average Fuel Consumption and Emission Rates on a Per Mile Basis by Driving Mode, Vehicle, and Load for Tier 2 Single Axle Dump Trucks (Petroleum Diesel)

		Unloaded			**Loaded**			
	Driving Mode[a]	Vehicle Number **6117**	Vehicle Number **6123**	Avg[b]	Vehicle Number **6117**	Vehicle Number **6123**	Avg[b]	Ratio[c]
Fuel (kg/mile)	Low Acceleration	0.768	0.733	0.751	0.898	0.992	0.945	1.26
	Medium Acceleration	0.332	0.349	0.341	0.440	0.462	0.451	1.32
	High Acceleration	0.382	0.315	0.349	0.498	0.337	0.418	1.20
	Low Cruise	0.310	0.504	0.407	0.483	0.781	0.632	1.55
	Medium Cruise	0.210	0.221	0.215	0.310	0.375	0.342	1.59
	High Cruise	0.236	0.256	0.246	0.265	0.323	0.294	1.20
	Deceleration	0.151	0.241	0.196	0.244	0.386	0.315	1.61
	Equal Weight Avg[b]	0.341	0.374	0.358	0.448	0.522	0.485	1.36
	Empirical Weight Avg[d]	0.284	0.300	0.292	0.413	0.576	0.494	1.69
NO_x (g/mile)	Low Acceleration	26.3	31.2	28.8	34.3	43.9	39.1	1.36
	Medium Acceleration	11.0	13.8	12.4	16.5	20.1	18.3	1.48
	High Acceleration	13.9	12.3	13.1	19.1	13.1	16.1	1.23
	Low Cruise	8.52	17.8	13.2	14.4	26.5	20.4	1.55
	Medium Cruise	6.01	6.43	6.22	8.97	10.5	9.72	1.56
	High Cruise	5.59	7.01	6.30	7.71	10.8	9.27	1.47
	Deceleration	4.18	6.07	5.12	7.79	11.6	9.69	1.89
	Equal Weight Avg[b]	10.8	13.5	12.2	15.5	19.5	17.5	1.44
	Empirical Weight Avg[d]	8.83	9.69	9.26	14.0	21.2	17.6	1.90
HC (g/mile)	Low Acceleration	0.870	0.849	0.860	1.15	1.43	1.29	1.50
	Medium Acceleration	0.361	0.366	0.364	0.411	0.559	0.485	1.33
	High Acceleration	0.357	0.325	0.341	0.416	0.443	0.430	1.26
	Low Cruise	0.499	0.725	0.612	0.838	1.26	1.05	1.71
	Medium Cruise	0.278	0.291	0.285	0.311	0.351	0.331	1.16
	High Cruise	0.261	0.216	0.239	0.305	0.349	0.327	1.37
	Deceleration	0.276	0.266	0.271	0.485	0.445	0.465	1.72
	Equal Weight Avg[b]	0.415	0.434	0.424	0.560	0.690	0.625	1.47
	Empirical Weight Avg[d]	0.345	0.319	0.332	0.543	0.800	0.672	2.02

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not shown because no significant distance is driven during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-40. Continued

		Unloaded			Loaded			
	Driving Mode[a]	Vehicle Number		Avg[b]	Vehicle Number		Avg[b]	Ratio[c]
		6117	**6123**		**6117**	**6123**		
CO (g/mile)	Low Acceleration	5.35	5.90	5.63	6.77	7.44	7.11	1.26
	Medium Acceleration	1.45	1.51	1.48	1.74	1.95	1.84	1.25
	High Acceleration	1.43	1.11	1.27	1.81	1.17	1.49	1.18
	Low Cruise	2.22	3.06	2.64	3.40	5.58	4.49	1.70
	Medium Cruise	0.834	0.983	0.909	1.08	1.22	1.15	1.27
	High Cruise	0.810	0.773	0.792	0.939	1.01	0.972	1.23
	Deceleration	0.868	0.881	0.874	1.46	1.60	1.53	1.76
	Equal Weight Avg[b]	1.85	2.03	1.94	2.46	2.85	2.66	1.37
	Empirical Weight Avg[d]	1.35	1.27	1.31	2.25	3.41	2.83	2.17
CO_2 (kg/mile)	Low Acceleration	2.42	2.31	2.37	2.83	3.12	2.97	1.26
	Medium Acceleration	1.04	1.10	1.07	1.37	1.46	1.41	1.32
	High Acceleration	1.24	0.990	1.11	1.62	1.05	1.34	1.20
	Low Cruise	0.976	1.59	1.28	1.63	2.29	1.96	1.53
	Medium Cruise	0.661	0.696	0.679	0.978	1.19	1.08	1.59
	High Cruise	0.744	0.807	0.776	0.838	1.02	0.929	1.20
	Deceleration	0.477	0.760	0.619	0.768	1.22	0.991	1.60
	Equal Weight Avg[b]	1.08	1.18	1.13	1.43	1.62	1.53	1.35
	Empirical Weight Avg[d]	0.901	0.947	0.924	1.32	1.77	1.54	1.67
PM (g/mile)	Low Acceleration	0.143	0.113	0.128	0.184	0.288	0.236	1.85
	Medium Acceleration	0.077	0.058	0.067	0.084	0.092	0.088	1.31
	High Acceleration	0.083	0.072	0.077	0.117	0.079	0.098	1.27
	Low Cruise	0.074	0.072	0.073	0.120	0.117	0.119	1.63
	Medium Cruise	0.043	0.032	0.037	0.061	0.057	0.059	1.58
	High Cruise	0.051	0.050	0.051	0.056	0.061	0.059	1.16
	Deceleration	0.042	0.036	0.039	0.068	0.057	0.062	1.60
	Equal Weight Avg[b]	0.073	0.062	0.067	0.099	0.107	0.103	1.53
	Empirical Weight Avg[d]	0.064	0.052	0.058	0.091	0.112	0.102	1.75

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not shown because no significant distance is driven during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded.

Table A-41. Preliminary Average Fuel Consumption and Emission Rates on a Per Mile Basis by Driving Mode, Vehicle, and Load for Tier 2 Tandem Dump Trucks (Soy Based B20)

		Unloaded			**Loaded**			
	Driving Mode[a]	Vehicle Number **0125**	Vehicle Number **0126**	Avg[b]	Vehicle Number **0125**	Vehicle Number **0126**	Avg[b]	Ratio[c]
Fuel (kg/mile)	Low Acceleration	0.768	1.27	1.02	1.31	1.70	1.50	1.48
	Medium Acceleration	0.519	0.741	0.630	0.916	1.03	0.974	1.55
	High Acceleration	0.557	0.692	0.625	0.648	0.749	0.699	1.12
	Low Cruise	0.501	0.618	0.560	0.879	1.02	0.948	1.69
	Medium Cruise	0.374	0.442	0.408	0.622	0.621	0.622	1.52
	High Cruise	0.377	0.388	0.383	0.516	0.548	0.532	1.39
	Deceleration	0.330	0.372	0.351	0.442	0.449	0.445	1.27
	Equal Weight Avg[b]	0.490	0.645	0.567	0.761	0.874	0.818	1.44
	Empirical Weight Avg[d]	0.420	0.465	0.443	0.659	0.703	0.681	1.54
NO_x (g/mile)	Low Acceleration	17.3	29.7	23.5	28.3	37.8	33.0	1.41
	Medium Acceleration	8.47	13.2	10.9	15.1	18.2	16.7	1.53
	High Acceleration	8.50	10.4	9.14	8.48	11.0	9.75	1.07
	Low Cruise	12.8	15.4	14.1	16.9	21.4	19.2	1.36
	Medium Cruise	5.77	6.78	6.27	8.58	10.3	9.37	1.50
	High Cruise	4.53	4.86	4.69	5.34	7.26	6.30	1.34
	Deceleration	4.41	5.62	5.02	5.57	7.00	6.29	1.25
	Equal Weight Avg[b]	8.74	12.3	10.5	12.6	16.1	14.4	1.37
	Empirical Weight Avg[d]	6.36	7.19	6.78	9.65	11.6	10.6	1.56
HC (g/mile)	Low Acceleration	1.27	3.24	2.26	2.22	3.53	2.87	1.27
	Medium Acceleration	0.681	1.05	0.864	1.40	1.21	1.30	1.51
	High Acceleration	0.695	0.653	0.674	0.997	0.999	1.00	1.48
	Low Cruise	0.939	1.04	0.992	1.81	1.49	1.65	1.67
	Medium Cruise	0.399	0.367	0.383	0.648	0.564	0.610	1.58
	High Cruise	0.379	0.394	0.386	0.832	0.417	0.621	1.62
	Deceleration	0.348	0.308	0.328	0.645	0.484	0.564	1.72
	Equal Weight Avg[b]	0.673	1.01	0.840	1.22	1.24	1.23	1.47
	Empirical Weight Avg[d]	0.503	0.562	0.532	1.07	0.806	0.938	1.76

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not shown because no significant distance is driven during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded.

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Table A-41. Continued

		Unloaded			Loaded			
	Driving Mode[a]	Vehicle Number		Avg[b]	Vehicle Number		Avg[b]	Ratio[c]
		0125	**0126**		**0125**	**0126**		
CO (g/mile)	Low Acceleration	5.95	6.88	6.42	9.42	7.91	8.66	1.35
	Medium Acceleration	2.52	2.66	2.59	3.31	3.08	3.19	1.23
	High Acceleration	2.33	2.53	2.43	2.83	2.60	2.72	1.12
	Low Cruise	4.06	4.71	4.38	6.77	6.01	6.39	1.46
	Medium Cruise	2.30	1.96	2.13	2.68	2.40	2.54	1.19
	High Cruise	1.77	2.17	1.97	2.34	2.42	2.38	1.21
	Deceleration	1.62	1.96	1.79	2.10	2.29	2.20	1.23
	Equal Weight Avg[b]	2.94	3.27	3.10	4.21	3.82	4.01	1.29
	Empirical Weight Avg[d]	2.27	2.51	2.39	3.48	3.13	3.30	1.38
CO_2 (kg/mile)	Low Acceleration	2.37	3.89	3.13	4.02	5.25	4.63	1.48
	Medium Acceleration	1.60	2.28	1.94	2.83	3.19	3.01	1.55
	High Acceleration	1.72	2.13	1.93	2.00	2.32	2.16	1.12
	Low Cruise	1.54	1.90	1.72	2.71	3.13	2.92	1.69
	Medium Cruise	1.15	1.36	1.26	1.92	1.92	1.92	1.53
	High Cruise	1.16	1.20	1.18	1.59	1.69	1.64	1.39
	Deceleration	1.02	1.15	1.08	1.36	1.39	1.37	1.27
	Equal Weight Avg[b]	1.51	1.99	1.75	2.35	2.70	2.52	1.44
	Empirical Weight Avg[d]	1.30	1.43	1.36	2.03	2.17	2.10	1.53
PM (g/mile)	Low Acceleration	0.114	0.177	0.146	0.241	0.224	0.232	1.59
	Medium Acceleration	0.087	0.094	0.091	0.161	0.135	0.148	1.63
	High Acceleration	0.113	0.095	0.104	0.116	0.109	0.113	1.08
	Low Cruise	0.083	0.072	0.077	0.125	0.109	0.117	1.51
	Medium Cruise	0.049	0.038	0.043	0.078	0.075	0.076	1.75
	High Cruise	0.050	0.039	0.044	0.054	0.056	0.055	1.24
	Deceleration	0.030	0.045	0.037	0.049	0.053	0.051	1.36
	Equal Weight Avg[b]	0.075	0.080	0.078	0.118	0.109	0.113	1.46
	Empirical Weight Avg[d]	0.059	0.051	0.055	0.090	0.081	0.085	1.55

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not shown because no significant distance is driven during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded.

Table A-42. Preliminary Average Fuel Consumption and Emission Rates on a Per Mile Basis by Driving Mode, Vehicle, and Load for Tier 2 Single Axle Dump Trucks (Soy Based B20)

		Unloaded			Loaded			
	Driving Mode[a]	Vehicle Number		Avg[b]	Vehicle Number		Avg[b]	Ratio[c]
		6117	**6123**		**6117**	**6123**		
Fuel (kg/mile)	Low Acceleration	0.653	0.386	0.519	0.756	0.770	0.763	1.47
	Medium Acceleration	0.311	0.318	0.315	0.395	0.460	0.427	1.36
	High Acceleration	0.316	0.437	0.376	0.440	0.499	0.470	1.25
	Low Cruise	0.405	0.484	0.445	0.629	0.703	0.666	1.50
	Medium Cruise	0.207	0.278	0.242	0.265	0.414	0.339	1.40
	High Cruise	0.208	0.248	0.228	0.243	0.371	0.307	1.35
	Deceleration	0.181	0.216	0.198	0.242	0.285	0.263	1.33
	Equal Weight Avg[b]	0.326	0.338	0.332	0.424	0.500	0.462	1.39
	Empirical Weight Avg[d]	0.273	0.302	0.288	0.385	0.471	0.428	1.49
NO_x (g/mile)	Low Acceleration	20.3	20.1	20.2	25.3	40.4	32.8	1.62
	Medium Acceleration	8.22	13.4	10.8	12.6	24.1	18.3	1.70
	High Acceleration	8.77	21.3	15.0	10.1	25.8	17.9	1.19
	Low Cruise	9.88	12.7	11.3	12.8	27.8	20.3	1.80
	Medium Cruise	4.54	8.61	6.57	7.55	12.4	10.0	1.52
	High Cruise	3.99	6.76	5.37	4.88	11.0	7.96	1.48
	Deceleration	3.23	5.91	4.57	4.74	9.53	7.14	1.56
	Equal Weight Avg[b]	8.43	12.7	10.6	11.1	21.6	16.4	1.55
	Empirical Weight Avg[d]	6.61	9.64	8.12	10.1	19.3	14.7	1.81
HC (g/mile)	Low Acceleration	0.955	0.637	0.796	1.25	0.769	1.01	1.27
	Medium Acceleration	0.354	0.206	0.280	0.376	0.275	0.331	1.16
	High Acceleration	0.336	0.351	0.343	0.435	0.410	0.422	1.23
	Low Cruise	0.896	0.510	0.703	1.21	0.641	0.924	1.32
	Medium Cruise	0.238	0.175	0.206	0.259	0.203	0.231	1.12
	High Cruise	0.273	0.191	0.232	0.349	0.241	0.295	1.27
	Deceleration	0.266	0.218	0.242	0.414	0.257	0.336	1.39
	Equal Weight Avg[b]	0.474	0.327	0.400	0.614	0.399	0.507	1.27
	Empirical Weight Avg[d]	0.382	0.270	0.326	0.556	0.370	0.463	1.42

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not shown because no significant distance is driven during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded.

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Table A-42. Continued

	Driving Mode[a]	Unloaded: 6117	Unloaded: 6123	Unloaded: Avg[b]	Loaded: 6117	Loaded: 6123	Loaded: Avg[b]	Ratio[c]
CO (g/mile)	Low Acceleration	3.37	2.19	2.78	4.41	3.73	4.07	1.46
	Medium Acceleration	1.41	1.08	1.25	1.59	1.29	1.44	1.16
	High Acceleration	1.31	1.46	1.39	1.60	1.60	1.60	1.16
	Low Cruise	3.13	1.93	2.53	4.48	2.15	3.31	1.31
	Medium Cruise	0.840	0.918	0.879	0.965	1.15	1.06	1.20
	High Cruise	0.787	0.969	0.878	1.05	1.30	1.17	1.34
	Deceleration	0.863	1.03	0.945	1.53	1.38	1.45	1.54
	Equal Weight Avg[b]	1.67	1.37	1.52	2.23	1.80	2.02	1.33
	Empirical Weight Avg[d]	1.35	1.20	1.28	2.06	1.68	1.87	1.39
CO_2 (kg/mile)	Low Acceleration	2.01	1.19	1.60	2.33	2.37	2.35	1.47
	Medium Acceleration	0.960	0.982	0.971	1.22	1.42	1.32	1.36
	High Acceleration	0.975	1.35	1.16	1.27	1.63	1.45	1.25
	Low Cruise	1.25	1.49	1.37	1.89	2.18	2.04	1.49
	Medium Cruise	0.638	0.859	0.749	0.817	1.27	1.04	1.39
	High Cruise	0.641	0.765	0.704	0.747	1.15	0.947	1.35
	Deceleration	0.557	0.667	0.612	0.746	0.879	0.812	1.33
	Equal Weight Avg[b]	1.00	1.04	1.04	1.29	1.56	1.42	1.39
	Empirical Weight Avg[d]	0.843	0.932	0.887	1.18	1.46	1.32	1.48
PM (g/mile)	Low Acceleration	0.149	0.047	0.098	0.176	0.111	0.144	1.47
	Medium Acceleration	0.065	0.046	0.055	0.089	0.067	0.078	1.42
	High Acceleration	0.077	0.077	0.077	0.090	0.095	0.093	1.20
	Low Cruise	0.082	0.033	0.058	0.103	0.066	0.084	1.46
	Medium Cruise	0.035	0.035	0.035	0.050	0.045	0.048	1.36
	High Cruise	0.041	0.042	0.041	0.052	0.052	0.052	1.26
	Deceleration	0.028	0.029	0.028	0.041	0.035	0.038	1.35
	Equal Weight Avg[b]	0.068	0.044	0.056	0.086	0.067	0.077	1.37
	Empirical Weight Avg[d]	0.054	0.041	0.048	0.076	0.058	0.067	1.41

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not shown because no significant distance is driven during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded.

Table A-43. Preliminary Average Emission Rates on a Per Gallon Basis by Driving Mode, Vehicle, and Load for Tier 1 Tandem Dump Trucks (Petroleum Diesel)

		Unloaded					**Loaded**					
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	Ratio[c]
		0507	**0578**	**0579**	**0580**		**0507**	**0578**	**0579**	**0580**		
NO_x (kg/gallon)	Idle	0.266	0.244	0.243	0.128	0.220	0.254	0.235	0.272	0.125	0.222	1.01
	Low Acceleration	0.123	0.101	0.094	0.100	0.104	0.149	0.110	0.106	0.098	0.115	1.11
	Medium Acceleration	0.120	0.101	0.133	0.093	0.112	0.146	0.116	0.109	0.082	0.113	1.01
	High Acceleration	0.136	0.112	0.146	0.109	0.126	0.166	0.131	0.142	0.123	0.141	1.12
	Low Cruise	0.110	0.135	0.098	0.042	0.096	0.134	0.134	0.079	0.054	0.100	1.04
	Medium Cruise	0.127	0.111	0.096	0.089	0.106	0.161	0.123	0.113	0.085	0.121	1.14
	High Cruise	0.170	0.112	0.164	0.111	0.139	0.194	0.197	0.129	0.102	0.156	1.12
	Deceleration	0.137	0.108	0.120	0.096	0.115	0.177	0.190	0.106	0.093	0.141	1.23
	Dumping						0.152	0.170	0.195	0.117	0.158	
	Equal Weight Avg[b]	0.149	0.128	0.137	0.096	0.127	0.170	0.156	0.139	0.098	0.141	1.11
	Empirical Weight Avg[d]	0.197	0.196	0.209	0.113	0.179	0.176	0.180	0.139	0.098	0.148	0.83
HC (g/gallon)	Idle	20.7	38.0	33.8	15.7	27.0	20.0	38.1	33.8	16.6	27.1	1.00
	Low Acceleration	9.35	7.97	3.81	6.98	7.03	9.60	6.74	9.43	6.84	8.15	1.16
	Medium Acceleration	5.13	5.64	4.36	5.56	5.17	5.23	5.31	7.84	5.37	5.93	1.15
	High Acceleration	5.38	5.26	4.51	5.65	5.20	5.12	5.39	8.72	5.07	6.08	1.17
	Low Cruise	9.44	10.3	6.21	4.57	7.63	8.52	10.8	6.08	3.83	7.30	0.96
	Medium Cruise	5.43	11.9	6.68	3.54	6.89	3.99	8.29	6.22	3.59	5.52	0.80
	High Cruise	4.97	10.3	4.62	4.12	6.01	4.51	8.88	5.53	3.08	5.50	0.92
	Deceleration	6.86	16.6	4.94	5.11	8.38	5.17	14.2	4.92	3.49	6.95	0.83
	Dumping						11.0	20.7	14.2	9.05	13.7	
	Equal Weight Avg[b]	8.41	13.2	8.61	6.40	9.17	8.12	13.1	10.7	6.33	9.59	1.05
	Empirical Weight Avg[d]	12.8	28.0	25.0	12.6	19.6	8.39	18.5	10.8	9.77	11.9	0.61

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes
[c]: Loaded / Unloaded
[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-43. Continued

	Driving Mode[a]	Unloaded 0507	Unloaded 0578	Unloaded 0579	Unloaded 0580	Unloaded Avg[b]	Loaded 0507	Loaded 0578	Loaded 0579	Loaded 0580	Loaded Avg[b]	Ratio[c]
CO (g/gallon)	Idle	49.7	103	32.4	30.7	53.9	49.5	97.4	36.8	31.4	53.8	1.00
	Low Acceleration	14.0	18.4	11.6	17.5	15.4	16.4	16.7	13.2	18.0	16.1	1.05
	Medium Acceleration	10.6	11.7	15.5	12.4	12.5	9.90	10.7	10.5	12.7	11.0	0.87
	High Acceleration	10.4	11.7	11.6	15.2	12.2	9.77	11.8	10.2	14.1	11.5	0.94
	Low Cruise	18.2	20.2	15.5	13.7	16.9	16.1	19.3	11.1	15.6	15.5	0.92
	Medium Cruise	10.7	24.6	9.90	16.4	15.4	7.48	16.6	8.90	13.4	11.6	0.75
	High Cruise	8.75	22.4	11.0	11.4	13.4	8.94	17.7	11.2	10.7	12.1	0.91
	Deceleration	15.7	32.1	12.8	22.7	20.8	13.2	30.8	11.9	16.8	18.1	0.87
	Dumping						53.5	85.0	64.6	44.3	61.8	
	Equal Weight Avg[b]	17.2	30.5	15.1	17.5	20.1	20.5	34.0	19.8	19.7	23.5	1.17
	Empirical Weight Avg[d]	29.1	73.6	26.4	26.4	38.9	18.9	44.7	16.6	23.0	25.8	0.66
CO_2 (kg/gallon)	Idle	9.92	10.3	10.0	9.91	10.0	10.3	10.1	10.3	10.0	10.2	1.02
	Low Acceleration	10.3	10.2	10.2	10.0	10.2	10.7	10.2	10.2	10.1	10.3	1.01
	Medium Acceleration	10.1	10.0	10.2	9.86	10.0	9.97	10.1	10.4	10.0	10.1	1.01
	High Acceleration	9.84	10.0	10.5	9.75	10.0	10.2	10.1	10.2	10.0	10.1	1.01
	Low Cruise	9.85	10.3	10.5	10.1	10.2	10.1	10.0	10.5	10.0	10.2	1.00
	Medium Cruise	9.67	10.0	10.6	10.1	10.1	10.2	10.0	10.0	10.2	10.1	1.00
	High Cruise	9.80	10.0	10.2	10.1	10.0	10.5	10.1	10.2	9.96	10.2	1.02
	Deceleration	10.0	10.0	10.0	10.1	10.0	10.0	10.0	10.2	10.1	10.1	1.01
	Dumping						10.2	10.0	10.2	10.0	10.1	
	Equal Weight Avg[b]	9.93	10.1	10.3	10.0	10.1	10.2	10.1	10.2	10.0	10.1	1.01
	Empirical Weight Avg[d]	9.92	10.2	10.1	10.0	10.0	10.2	10.1	10.3	10.0	10.1	1.01

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes
[c]: Loaded / Unloaded
[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-43. Continued

	Driving Mode[a]	Unloaded 0507	Unloaded 0578	Unloaded 0579	Unloaded 0580	Unloaded Avg[b]	Loaded 0507	Loaded 0578	Loaded 0579	Loaded 0580	Loaded Avg[b]	Ratio[c]
	Idle	1.17	2.66	4.51	0.731	2.27	1.10	2.56	4.42	0.931	2.25	0.99
PM (g/gallon)	Low Acceleration	0.591	0.585	0.490	0.428	0.523	0.612	0.630	0.838	0.416	0.623	1.19
	Medium Acceleration	0.500	0.552	0.858	0.488	0.600	0.503	0.538	0.678	0.541	0.565	0.94
	High Acceleration	0.537	0.589	0.656	0.506	0.572	0.585	0.603	0.627	0.524	0.585	1.02
	Low Cruise	0.393	2.14	1.99	0.215	1.18	0.438	1.99	1.78	0.468	1.17	0.99
	Medium Cruise	0.369	1.81	1.64	0.609	1.11	0.387	1.80	2.10	0.671	1.24	1.12
	High Cruise	0.339	1.64	2.14	0.559	1.17	0.318	1.57	2.14	0.684	1.18	1.01
	Deceleration	0.359	1.56	1.61	0.483	1.00	0.373	2.16	1.06	0.666	1.07	1.06
	Dumping						0.410	2.10	6.51	0.633	2.41	
	Equal Weight Avg[b]	0.533	1.44	1.74	0.502	1.05	0.525	1.55	2.24	0.614	1.23	1.17
	Empirical Weight Avg[d]	0.761	2.19	3.62	0.629	1.80	0.546	1.81	1.97	0.699	1.26	0.70

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table A-44. Preliminary Average Emission Rates on a Per Gallon Basis by Driving Mode, Vehicle, and Load for Tier 1 Single Axle Dump Trucks (Petroleum Diesel)

		Unloaded					**Loaded**					
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	Ratio[c]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**		
NO_x (kg/gallon)	Idle	0.214	0.208	0.234	0.216	0.218	0.231	0.198	0.215	0.220	0.216	0.99
	Low Acceleration	0.180	0.102	0.151	0.127	0.140	0.168	0.111	0.153	0.125	0.139	0.99
	Medium Acceleration	0.152	0.078	0.136	0.118	0.121	0.150	0.081	0.144	0.123	0.125	1.03
	High Acceleration	0.174	0.088	0.120	0.112	0.123	0.154	0.076	0.140	0.113	0.121	0.98
	Low Cruise	0.190	0.123	0.153	0.151	0.154	0.173	0.127	0.129	0.141	0.143	0.92
	Medium Cruise	0.157	0.087	0.125	0.119	0.122	0.154	0.086	0.133	0.133	0.126	1.04
	High Cruise	0.111	0.073	0.093	0.083	0.090	0.106	0.074	0.093	0.097	0.093	1.03
	Deceleration	0.164	0.102	0.113	0.132	0.128	0.188	0.114	0.104	0.144	0.138	1.08
	Dumping						0.211	0.119	0.178	0.150	0.165	
	Equal Weight Avg[b]	0.168	0.108	0.141	0.132	0.137	0.170	0.110	0.143	0.138	0.140	1.02
	Empirical Weight Avg[d]	0.189	0.133	0.213	0.184	0.180	0.195	0.114	0.149	0.181	0.160	0.89
HC (g/gallon)	Idle	16.9	13.2	9.43	9.14	12.2	18.6	13.0	8.17	9.30	12.3	1.01
	Low Acceleration	4.16	3.53	2.80	3.25	3.43	2.78	3.75	2.29	2.57	2.85	0.83
	Medium Acceleration	2.73	3.18	1.52	2.20	2.41	2.39	3.03	1.54	2.09	2.26	0.94
	High Acceleration	2.97	3.35	1.80	2.07	2.55	3.55	2.93	2.00	2.36	2.71	1.06
	Low Cruise	9.88	5.78	6.54	5.33	6.88	7.44	5.54	3.91	4.52	5.35	0.78
	Medium Cruise	8.08	4.51	2.63	4.76	5.00	8.14	3.69	2.87	2.96	4.42	0.88
	High Cruise	7.25	3.77	1.76	3.01	3.95	8.41	3.69	2.23	2.53	4.22	1.07
	Deceleration	16.1	7.09	2.94	5.68	7.96	17.4	7.58	3.58	5.59	8.53	1.07
	Dumping						15.2	5.07	1.30	4.79	6.58	
	Equal Weight Avg[b]	8.51	5.55	3.68	4.43	5.54	9.31	5.36	3.10	4.08	5.46	0.99
	Empirical Weight Avg[d]	13.3	7.74	8.19	7.39	9.16	13.1	6.14	4.00	6.90	7.53	0.82

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes
[c]: Loaded / Unloaded
[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-44. Continued

	Driving Mode[a]	Unloaded 4743	Unloaded 4750	Unloaded 4869	Unloaded 4870	Unloaded Avg[b]	Loaded 4743	Loaded 4750	Loaded 4869	Loaded 4870	Loaded Avg[b]	Ratio[c]
CO (g/gallon)	Idle	66.6	49.1	54.1	59.4	57.3	69.0	47.8	48.6	62.8	57.0	1.00
	Low Acceleration	44.1	29.3	50.7	38.0	40.5	45.5	36.1	49.0	40.0	42.7	1.05
	Medium Acceleration	37.7	20.3	37.2	35.7	32.7	31.5	18.2	36.7	30.1	29.1	0.89
	High Acceleration	39.3	21.5	23.5	18.5	25.7	38.5	20.2	26.2	21.1	26.5	1.03
	Low Cruise	71.1	33.1	51.5	47.6	50.8	56.2	35.1	49.6	47.2	47.0	0.93
	Medium Cruise	38.5	23.0	30.2	45.8	34.4	34.2	16.7	37.6	26.8	28.8	0.84
	High Cruise	26.0	14.4	10.5	11.0	15.5	28.7	15.2	13.7	10.3	17.0	1.10
	Deceleration	53.3	29.4	18.5	35.3	34.1	48.4	33.7	24.7	30.2	34.2	1.00
	Dumping						51.1	44.2	35.8	36.2	41.8	
	Equal Weight Avg[b]	47.1	27.5	34.5	36.4	36.4	44.8	29.7	35.8	33.9	36.0	0.99
	Empirical Weight Avg[d]	57.1	32.6	49.4	50.3	47.3	54.4	29.0	37.8	49.7	42.7	0.90
CO_2 (kg/gallon)	Idle	9.95	9.95	9.95	9.93	9.95	10.1	9.96	9.95	9.96	9.98	1.00
	Low Acceleration	9.99	9.98	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	1.00
	Medium Acceleration	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	1.00
	High Acceleration	9.90	10.3	10.0	10.1	10.1	10.0	10.0	10.0	10.3	10.1	1.00
	Low Cruise	9.98	10.0	9.97	9.98	9.98	9.98	10.0	9.98	9.98	9.98	1.00
	Medium Cruise	10.0	10.0	10.0	9.98	10.0	10.0	10.0	10.0	10.0	10.0	1.00
	High Cruise	10.0	9.73	10.0	10.0	9.96	10.0	9.31	10.3	9.52	9.78	0.98
	Deceleration	9.99	10.0	10.0	9.99	10.0	10.0	10.0	10.1	10.0	10.0	1.00
	Dumping						10.0	9.98	10.0	10.0	10.0	
	Equal Weight Avg[b]	9.99	9.99	10.0	10.0	9.99	10.0	9.31	10.0	9.98	9.99	1.00
	Empirical Weight Avg[d]	9.97	9.79	10.0	9.96	9.96	10.0	9.84	10.0	9.94	9.95	1.00

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-44. Continued

	Driving Mode[a]	Unloaded					Loaded					
		Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	Ratio[c]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**		
PM (g/gallon)	Idle	1.17	0.671	0.600	0.949	0.846	1.21	0.750	0.519	0.946	0.856	1.01
	Low Acceleration	0.926	0.646	1.05	1.08	0.927	0.879	0.700	1.02	1.09	0.922	0.99
	Medium Acceleration	0.859	0.454	0.932	0.948	0.798	0.864	0.502	0.876	0.893	0.784	0.98
	High Acceleration	1.11	0.579	0.756	0.741	0.797	1.03	0.506	0.795	0.786	0.779	0.98
	Low Cruise	0.841	0.575	0.791	1.03	0.810	0.953	0.593	0.952	1.13	0.906	1.12
	Medium Cruise	0.753	0.450	1.08	1.12	0.853	0.845	0.475	0.909	0.920	0.788	0.92
	High Cruise	0.860	0.421	0.693	0.741	0.678	0.834	0.402	0.720	0.666	0.655	0.97
	Deceleration	1.15	0.588	0.761	1.06	0.891	1.19	0.598	0.706	0.973	0.865	0.97
	Dumping						0.923	0.942	0.928	1.07	0.965	
	Equal Weight Avg[b]	0.959	0.548	0.834	0.960	0.825	0.969	0.608	0.825	0.941	0.836	1.01
	Empirical Weight Avg[d]	1.05	0.572	0.645	0.951	0.805	1.06	0.568	0.770	0.944	0.836	1.04

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded.

Table A-45. Preliminary Average Emission Rates on a Per Gallon Basis by Driving Mode, Vehicle, and Load for Tier 1 Tandem Dump Trucks (Soy Based B20)

		Unloaded					Loaded					
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	Ratio[c]
		0507	0578	0579	0580		0507	0578	0579	0580		
NO_x (kg/gallon)	Idle	0.180	0.148	0.166	0.157	0.163	0.202	0.146	0.165	0.134	0.162	0.99
	Low Acceleration	0.079	0.081	0.075	0.099	0.084	0.057	0.078	0.072	0.083	0.073	0.87
	Medium Acceleration	0.082	0.090	0.082	0.091	0.086	0.080	0.095	0.083	0.079	0.084	0.97
	High Acceleration	0.093	0.084	0.090	0.093	0.090	0.089	0.116	0.084	0.117	0.102	1.13
	Low Cruise	0.086	0.056	0.084	0.107	0.083	0.086	0.083	0.090	0.081	0.085	1.02
	Medium Cruise	0.088	0.082	0.081	0.081	0.083	0.086	0.122	0.089	0.083	0.095	1.14
	High Cruise	0.119	0.122	0.133	0.090	0.116	0.132	0.127	0.119	0.098	0.119	1.03
	Deceleration	0.104	0.158	0.095	0.097	0.113	0.105	0.141	0.096	0.087	0.107	0.95
	Dumping						0.089	0.076	0.111	0.106	0.095	
	Equal Weight Avg[b]	0.104	0.103	0.101	0.102	0.102	0.103	0.109	0.101	0.097	0.102	1.00
	Empirical Weight Avg[d]	0.117	0.126	0.139	0.131	0.128	0.160	0.130	0.127	0.126	0.136	1.06
HC (g/gallon)	Idle	11.6	17.7	11.8	16.9	14.5	15.9	18.0	12.0	15.0	15.2	1.05
	Low Acceleration	4.61	4.60	4.40	4.65	4.57	3.56	4.37	3.64	3.56	3.78	0.83
	Medium Acceleration	3.71	5.05	3.58	3.39	3.93	3.79	3.87	3.12	3.25	3.51	0.89
	High Acceleration	3.26	4.09	3.01	3.38	3.44	3.33	4.03	2.96	3.47	3.44	1.00
	Low Cruise	6.31	5.59	3.94	7.96	5.95	6.82	5.47	4.29	6.95	5.88	0.99
	Medium Cruise	4.03	4.94	3.16	3.41	3.89	3.48	4.73	3.50	3.06	3.69	0.95
	High Cruise	3.63	5.21	2.95	2.97	3.69	3.74	5.22	3.57	3.04	3.89	1.06
	Deceleration	5.84	12.3	5.58	5.07	7.20	6.02	7.32	5.64	4.68	5.92	0.82
	Dumping						6.87	6.18	4.47	7.84	6.34	
	Equal Weight Avg[b]	5.37	7.44	4.81	5.97	5.90	5.95	6.57	4.79	5.65	5.74	0.97
	Empirical Weight Avg[d]	5.95	11.9	8.76	11.7	9.58	11.6	12.4	7.81	13.2	11.2	1.17

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-45. Continued

	Driving Mode[a]	Unloaded: Vehicle Number 0507	0578	0579	0580	Unloaded: Avg[b]	Loaded: Vehicle Number 0507	0578	0579	0580	Loaded: Avg[b]	Ratio[c]
CO (g/gallon)	Idle	37.4	38.8	30.9	41.3	37.1	41.7	41.2	31.4	36.6	37.7	1.02
	Low Acceleration	19.3	21.8	24.3	32.2	24.4	15.1	21.2	20.0	22.8	19.8	0.81
	Medium Acceleration	12.5	19.0	16.8	18.3	16.6	13.1	13.4	14.6	15.9	14.2	0.86
	High Acceleration	10.1	15.7	12.4	14.6	13.2	10.1	15.3	12.5	14.6	13.1	0.99
	Low Cruise	16.8	13.2	12.9	35.5	19.6	21.7	13.6	13.4	29.4	19.5	1.00
	Medium Cruise	11.8	11.7	8.94	16.2	12.2	10.6	10.8	9.11	12.9	10.9	0.89
	High Cruise	11.9	13.2	8.57	9.64	10.8	14.4	13.9	9.45	14.1	13.0	1.20
	Deceleration	17.5	26.8	11.2	23.1	19.6	16.8	19.6	12.4	16.8	16.4	0.84
	Dumping						37.2	22.3	20.8	38.1	29.6	
	Equal Weight Avg[b]	17.2	20.0	15.7	23.8	19.2	20.1	19.0	16.0	22.4	19.4	1.01
	Empirical Weight Avg[d]	18.8	27.8	23.8	32.8	25.8	31.7	29.9	21.7	33.5	29.2	1.13
CO_2 (kg/gallon)	Idle	9.89	11.1	10.1	9.85	10.2	9.86	11.2	10.3	9.70	10.3	1.00
	Low Acceleration	9.92	10.9	10.1	9.93	10.2	9.85	10.9	10.0	9.89	10.2	0.99
	Medium Acceleration	9.94	10.8	10.2	9.90	10.2	9.93	11.1	10.2	9.95	10.3	1.01
	High Acceleration	9.94	10.9	10.3	9.93	10.3	9.94	11.0	10.0	9.72	10.2	0.99
	Low Cruise	9.91	11.3	10.1	9.89	10.3	9.81	11.3	10.5	9.78	10.3	1.00
	Medium Cruise	9.94	11.2	10.3	9.93	10.3	9.88	10.8	10.3	9.76	10.2	0.99
	High Cruise	9.95	11.0	10.1	9.90	10.2	9.94	11.4	10.0	9.79	10.3	1.01
	Deceleration	9.92	10.9	10.2	9.92	10.2	9.47	11.0	10.0	9.85	10.1	0.98
	Dumping						9.89	11.2	10.0	9.89	10.2	
	Equal Weight Avg[b]	9.93	11.0	10.2	9.91	10.3	9.84	11.1	10.1	9.82	10.2	1.00
	Empirical Weight Avg[d]	9.93	11.0	10.1	9.88	10.2	9.84	11.2	10.2	9.72	10.2	1.00

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-45. Continued

	Driving Mode[a]	Unloaded 0507	Unloaded 0578	Unloaded 0579	Unloaded 0580	Unloaded Avg[b]	Loaded 0507	Loaded 0578	Loaded 0579	Loaded 0580	Loaded Avg[b]	Ratio[c]
PM (g/gallon)	Idle	0.633	0.933	0.772	0.599	0.734	0.756	0.948	0.789	0.589	0.770	1.05
	Low Acceleration	0.559	1.96	1.41	0.488	1.11	0.414	2.25	1.47	0.463	1.15	1.04
	Medium Acceleration	0.568	2.21	1.60	0.614	1.25	0.534	1.83	1.67	0.571	1.15	0.92
	High Acceleration	0.570	2.02	1.74	0.702	1.26	0.513	1.96	1.70	1.07	1.31	1.04
	Low Cruise	0.490	0.271	0.355	0.396	0.378	0.578	0.344	0.516	0.471	0.477	1.26
	Medium Cruise	0.409	0.361	0.535	0.400	0.426	0.474	0.450	0.484	0.401	0.452	1.06
	High Cruise	0.305	0.355	0.326	0.329	0.329	0.453	0.371	0.415	0.489	0.432	1.31
	Deceleration	0.390	0.678	0.518	0.350	0.484	0.320	0.583	0.583	0.451	0.484	1.00
	Dumping						0.398	0.355	0.177	0.350	0.320	
	Equal Weight Avg[b]	0.490	1.10	0.908	0.485	0.746	0.493	1.01	0.868	0.539	0.728	0.98
	Empirical Weight Avg[d]	0.470	0.973	0.766	0.524	0.684	0.645	0.918	0.818	0.571	0.738	1.08

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table A-46. Preliminary Average Emission Rates on a Per Gallon Basis by Driving Mode, Vehicle, and Load for Tier 1 Single Axle Dump Trucks (Soy Based B20)

		Unloaded					Loaded					
	Driving Mode[a]	Vehicle Number 4743	4750	4869	4870	Avg[b]	Vehicle Number 4743	4750	4869	4870	Avg[b]	Ratio[c]
NO_x (kg/gallon)	Idle	0.132	0.251	0.097	0.102	0.145	0.130	0.267	0.091	0.093	0.145	1.00
	Low Acceleration	0.089	0.157	0.072	0.067	0.096	0.094	0.108	0.083	0.066	0.087	0.91
	Medium Acceleration	0.073	0.109	0.062	0.058	0.075	0.076	0.106	0.060	0.061	0.076	1.01
	High Acceleration	0.067	0.106	0.056	0.054	0.071	0.065	0.109	0.050	0.059	0.071	1.00
	Low Cruise	0.115	0.136	0.064	0.067	0.095	0.085	0.114	0.060	0.070	0.082	0.86
	Medium Cruise	0.078	0.113	0.056	0.053	0.075	0.072	0.114	0.053	0.066	0.076	1.02
	High Cruise	0.057	0.091	0.044	0.045	0.059	0.073	0.090	0.049	0.054	0.067	1.12
	Deceleration	0.057	0.103	0.047	0.045	0.063	0.055	0.107	0.050	0.060	0.068	1.08
	Dumping						0.098	0.141	0.084	0.091	0.103	
	Equal Weight Avg[b]	0.083	0.133	0.062	0.061	0.085	0.083	0.129	0.065	0.069	0.086	1.01
	Empirical Weight Avg[d]	0.073	0.242	0.079	0.074	0.117	0.085	0.197	0.080	0.084	0.110	0.95
HC (g/gallon)	Idle	7.32	11.7	7.69	7.21	8.49	7.90	11.7	7.73	6.78	8.53	1.01
	Low Acceleration	2.24	2.08	1.72	1.94	2.00	2.20	1.90	1.94	1.91	1.99	1.00
	Medium Acceleration	1.55	1.77	2.04	1.54	1.72	1.82	1.71	1.53	1.61	1.67	0.97
	High Acceleration	1.85	1.58	1.53	1.87	1.71	2.01	2.64	2.10	1.85	2.15	1.26
	Low Cruise	3.53	1.97	2.85	2.40	2.69	2.30	1.72	2.82	3.78	2.65	0.99
	Medium Cruise	1.68	1.39	2.23	1.75	1.76	1.40	2.77	1.49	1.60	1.82	1.03
	High Cruise	1.81	1.00	2.17	2.11	1.77	2.10	2.27	2.72	2.12	2.31	1.30
	Deceleration	2.20	1.55	3.08	2.57	2.35	1.76	3.17	2.91	3.35	2.80	1.19
	Dumping						2.00	1.70	3.51	2.63	2.46	
	Equal Weight Avg[b]	2.77	2.88	2.91	2.67	2.81	2.61	3.29	2.97	2.85	2.93	1.04
	Empirical Weight Avg[d]	2.68	11.1	5.52	4.39	5.93	3.38	7.62	6.16	5.36	5.63	0.95

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-46. Continued

	Driving Mode[a]	Unloaded 4743	Unloaded 4750	Unloaded 4869	Unloaded 4870	Unloaded Avg[b]	Loaded 4743	Loaded 4750	Loaded 4869	Loaded 4870	Loaded Avg[b]	Ratio[c]
CO (g/gallon)	Idle	30.9	40.9	56.6	55.9	46.1	31.4	41.0	59.0	52.1	45.9	1.00
	Low Acceleration	32.8	30.4	28.6	29.7	30.4	31.5	28.1	33.4	28.4	30.4	1.00
	Medium Acceleration	19.6	19.3	23.4	12.9	18.8	18.4	17.5	19.9	12.4	17.0	0.91
	High Acceleration	18.5	19.3	16.8	11.2	16.5	19.6	20.3	22.1	14.1	19.0	1.16
	Low Cruise	21.0	21.4	20.5	20.8	20.9	22.1	16.1	25.6	17.2	20.2	0.97
	Medium Cruise	13.7	13.4	15.5	9.09	12.9	11.7	13.0	11.5	7.01	10.8	0.84
	High Cruise	10.7	18.2	18.2	11.3	14.6	10.3	18.6	18.5	12.8	15.1	1.03
	Deceleration	13.4	18.7	13.8	10.8	14.2	11.9	17.1	12.2	12.3	13.4	0.94
	Dumping						16.7	32.3	67.2	62.3	44.6	
	Equal Weight Avg[b]	20.1	22.7	24.2	20.2	21.8	19.3	22.7	29.9	24.3	24.0	1.10
	Empirical Weight Avg[d]	16.6	39.7	41.1	32.1	32.4	17.9	30.9	47.2	39.9	34.0	1.05
CO_2 (kg/gallon)	Idle	9.87	9.87	9.85	9.86	9.87	9.88	9.88	9.85	9.86	9.87	1.00
	Low Acceleration	9.90	9.93	9.89	9.91	9.91	9.88	9.91	9.88	9.91	9.90	1.00
	Medium Acceleration	9.92	9.93	9.93	9.94	9.93	9.92	9.93	9.95	9.94	9.94	1.00
	High Acceleration	9.93	9.94	9.93	9.95	9.93	9.93	9.93	9.96	9.95	9.94	1.00
	Low Cruise	9.89	9.90	9.88	9.91	9.90	9.91	9.94	10.0	9.91	9.95	1.01
	Medium Cruise	9.93	9.94	9.94	9.95	9.94	9.94	9.94	9.96	9.95	9.95	1.00
	High Cruise	9.93	9.95	9.95	9.95	9.95	9.93	10.4	9.96	9.70	9.99	1.00
	Deceleration	9.92	9.93	9.94	9.94	9.93	9.93	9.93	9.96	9.94	9.94	1.00
	Dumping						9.89	9.92	9.98	9.86	9.91	
	Equal Weight Avg[b]	9.91	9.92	9.91	9.93	9.92	9.91	10.0	9.95	9.89	9.93	1.00
	Empirical Weight Avg[d]	9.92	9.88	9.89	9.91	9.90	9.92	9.94	9.88	9.88	9.90	1.00

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-46. Continued

		Unloaded					Loaded					
	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	Ratio[c]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**		
PM (g/gallon)	Idle	0.546	0.507	0.853	0.994	0.725	0.569	0.516	0.837	0.828	0.687	0.95
	Low Acceleration	0.537	0.789	0.934	1.02	0.819	0.748	0.721	1.02	0.872	0.839	1.02
	Medium Acceleration	0.505	0.607	0.724	0.612	0.612	0.503	0.547	0.583	0.562	0.549	0.90
	High Acceleration	0.524	0.736	0.583	0.618	0.615	0.499	0.663	0.665	0.649	0.619	1.01
	Low Cruise	0.385	0.793	0.720	0.802	0.675	0.409	0.563	0.637	0.735	0.586	0.87
	Medium Cruise	0.344	0.578	0.575	0.526	0.506	0.348	0.494	0.473	0.425	0.435	0.86
	High Cruise	0.349	0.500	0.515	0.460	0.456	0.360	0.540	0.496	0.476	0.468	1.03
	Deceleration	0.312	0.572	0.551	0.495	0.482	0.290	0.571	0.490	0.569	0.480	0.99
	Dumping						0.445	0.800	1.26	0.845	0.836	
	Equal Weight Avg[b]	0.438	0.635	0.682	0.691	0.611	0.463	0.602	0.717	0.662	0.611	1.00
	Empirical Weight Avg[d]	0.408	0.514	0.751	0.757	0.608	0.433	0.535	0.756	0.749	0.618	1.02

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table A-47. Preliminary Average Emission Rates on a Per Gallon Basis by Driving Mode, Vehicle, and Load for Tier 2 Tandem Dump Trucks (Petroleum Diesel)

	Driving Mode[a]	Unloaded			Loaded			Ratio[c]
		Vehicle Number		Avg[b]	Vehicle Number		Avg[b]	
		0125	**0126**		**0125**	**0126**		
NO_x (kg/gallon)	Idle	0.152	0.201	0.177	0.155	0.210	0.182	1.03
	Low Acceleration	0.077	0.071	0.074	0.072	0.069	0.070	0.94
	Medium Acceleration	0.055	0.073	0.064	0.065	0.065	0.065	1.01
	High Acceleration	0.066	0.054	0.060	0.058	0.057	0.057	0.96
	Low Cruise	0.052	0.061	0.057	0.075	0.063	0.069	1.21
	Medium Cruise	0.046	0.050	0.048	0.055	0.051	0.053	1.10
	High Cruise	0.032	0.039	0.036	0.041	0.039	0.040	1.13
	Deceleration	0.058	0.053	0.055	0.055	0.048	0.051	0.93
	Dumping				0.117	0.089	0.103	
	Equal Weight Avg[b]	0.067	0.075	0.071	0.077	0.077	0.077	1.07
	Empirical Weight Avg[d]	0.100	0.110	0.105	0.093	0.074	0.083	0.79
HC (g/gallon)	Idle	16.9	12.7	14.8	17.4	13.0	15.2	1.03
	Low Acceleration	5.96	4.71	5.33	5.87	5.16	5.52	1.03
	Medium Acceleration	3.60	3.88	3.74	4.44	3.15	3.80	1.01
	High Acceleration	3.20	2.75	2.98	4.34	4.03	4.19	1.41
	Low Cruise	4.80	5.31	5.06	5.76	5.00	5.38	1.06
	Medium Cruise	4.44	4.32	4.38	5.19	4.22	4.70	1.07
	High Cruise	4.05	3.74	3.90	6.06	2.85	4.45	1.14
	Deceleration	7.57	7.30	7.43	7.34	6.81	7.07	0.95
	Dumping				28.4	10.8	19.6	
	Equal Weight Avg[b]	6.31	5.59	5.95	9.43	6.12	7.77	1.31
	Empirical Weight Avg[d]	10.6	7.66	9.12	10.9	5.31	8.08	0.89
CO (g/gallon)	Idle	37.2	34.6	35.9	36.4	36.9	36.7	1.02
	Low Acceleration	22.9	23.0	23.0	23.0	20.0	21.5	0.94
	Medium Acceleration	15.6	18.1	16.9	14.2	16.9	15.6	0.92
	High Acceleration	12.6	13.0	12.8	11.4	16.0	13.7	1.07
	Low Cruise	21.9	38.6	30.2	23.1	39.7	31.4	1.04
	Medium Cruise	20.2	19.8	20.0	15.6	19.4	17.5	0.87
	High Cruise	16.1	20.1	18.1	18.1	14.6	16.3	0.90
	Dumping	26.0	24.7	25.3	23.4	24.4	23.9	0.94
	Deceleration				89.9	27.0	58.5	
	Equal Weight Avg[b]	21.6	24.0	22.8	28.3	23.9	26.1	1.15
	Empirical Weight Avg[d]	28.1	26.9	27.5	28.8	21.8	25.3	0.92

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-47. Continued

	Driving Mode[a]	Unloaded Vehicle Number 0125	Unloaded Vehicle Number 0126	Unloaded Avg[b]	Loaded Vehicle Number 0125	Loaded Vehicle Number 0126	Loaded Avg[b]	Ratio[c]
CO_2 (kg/gallon)	Idle	9.30	9.97	9.64	9.15	10.2	9.68	1.00
	Low Acceleration	10.0	10.0	10.0	10.0	10.0	10.0	1.00
	Medium Acceleration	10.0	10.1	10.1	10.2	10.1	10.2	1.01
	High Acceleration	10.0	10.0	10.0	10.0	10.0	10.0	1.00
	Low Cruise	10.0	10.0	10.0	10.0	10.0	10.0	1.00
	Medium Cruise	10.0	10.0	10.0	10.0	10.0	10.0	1.00
	High Cruise	10.0	10.0	10.0	10.0	10.0	10.0	1.00
	Deceleration	10.0	10.0	10.0	10.0	10.0	10.0	1.00
	Dumping				9.85	10.0	9.92	
	Equal Weight Avg[b]	9.93	10.0	10.0	9.92	10.1	10.0	1.00
	Empirical Weight Avg[d]	9.68	10.0	9.84	9.74	10.1	9.91	1.01
PM (g/gallon)	Idle	0.406	0.625	0.516	0.419	0.634	0.527	1.02
	Low Acceleration	0.464	0.510	0.487	0.562	0.528	0.545	1.12
	Medium Acceleration	0.532	0.641	0.586	0.618	0.634	0.626	1.07
	High Acceleration	0.597	0.517	0.557	0.625	0.519	0.572	1.03
	Low Cruise	0.372	0.399	0.385	0.501	0.415	0.458	1.19
	Medium Cruise	0.446	0.385	0.416	0.484	0.481	0.483	1.16
	High Cruise	0.438	0.380	0.409	0.580	0.380	0.480	1.17
	Deceleration	0.567	0.458	0.513	0.525	0.428	0.476	0.93
	Dumping				1.87	0.604	1.24	
	Equal Weight Avg[b]	0.478	0.489	0.483	0.688	0.514	0.601	1.24
	Empirical Weight Avg[d]	0.441	0.508	0.475	0.584	0.472	0.528	1.11

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table A-48. Preliminary Average Emission Rates on a Per Gallon Basis by Driving Mode, Vehicle, and Load for Tier 2 Single Axle Dump Trucks (Petroleum Diesel)

	Driving Mode[a]	**Unloaded** Vehicle Number **6117**	**Unloaded** Vehicle Number **6123**	**Unloaded** Avg[ab]	**Loaded** Vehicle Number **6117**	**Loaded** Vehicle Number **6123**	**Loaded** Avg[b]	Ratio[c]
NO_x (kg/gallon)	Idle	0.141	0.155	0.148	0.152	0.148	0.150	1.01
	Low Acceleration	0.109	0.135	0.122	0.122	0.141	0.131	1.07
	Medium Acceleration	0.106	0.125	0.116	0.119	0.139	0.129	1.12
	High Acceleration	0.116	0.124	0.120	0.122	0.124	0.123	1.02
	Low Cruise	0.087	0.112	0.100	0.094	0.108	0.101	1.01
	Medium Cruise	0.091	0.093	0.092	0.092	0.089	0.090	0.98
	High Cruise	0.075	0.087	0.081	0.093	0.107	0.100	1.22
	Deceleration	0.088	0.080	0.084	0.101	0.095	0.098	1.17
	Dumping				0.101	0.122	0.112	
	Equal Weight Avg[b]	0.102	0.114	0.108	0.112	0.119	0.115	1.07
	Empirical Weight Avg[d]	0.118	0.128	0.123	0.130	0.135	0.132	1.07
HC (g/gallon)	Idle	17.7	16.6	17.2	17.8	15.0	16.4	0.96
	Low Acceleration	3.60	3.68	3.64	4.09	4.57	4.33	1.19
	Medium Acceleration	3.46	3.34	3.40	2.97	3.85	3.41	1.00
	High Acceleration	2.97	3.28	3.13	2.66	4.18	3.42	1.09
	Low Cruise	5.12	4.58	4.85	5.51	5.12	5.32	1.10
	Medium Cruise	4.22	4.20	4.21	3.19	2.97	3.08	0.73
	High Cruise	3.52	2.69	3.11	3.65	3.44	3.54	1.14
	Deceleration	5.79	3.51	4.65	6.31	3.67	4.99	1.07
	Dumping				14.1	7.19	10.7	
	Equal Weight Avg[b]	5.80	5.23	5.52	6.70	5.56	6.13	1.11
	Empirical Weight Avg[d]	10.9	10.2	10.6	11.6	11.0	11.3	1.07
CO (g/gallon)	Idle	78.0	55.7	66.8	79.5	51.5	65.5	0.98
	Low Acceleration	22.1	25.6	23.9	24.0	23.9	23.9	1.00
	Medium Acceleration	13.9	13.7	13.8	12.5	13.4	13.0	0.94
	High Acceleration	11.9	11.2	11.5	11.6	11.1	11.3	0.98
	Low Cruise	22.8	19.3	21.1	22.4	22.7	22.6	1.07
	Medium Cruise	12.7	14.2	13.4	11.1	10.4	10.7	0.80
	High Cruise	10.9	9.62	10.3	11.3	9.90	10.6	1.03
	Dumping	18.2	11.6	14.9	19.0	13.2	16.1	1.08
	Deceleration				53.8	27.4	40.6	
	Equal Weight Avg[b]	23.8	20.1	22.0	27.2	20.4	23.8	1.08
	Empirical Weight Avg[d]	46.5	35.0	40.7	50.4	38.5	44.4	1.09

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-48. Continued

	Driving Mode[a]	Unloaded 6117	Unloaded 6123	Unloaded Avg[b]	Loaded 6117	Loaded 6123	Loaded Avg[b]	Ratio[c]
CO_2 (kg/gallon)	Idle	9.89	9.93	9.91	9.90	9.95	9.93	1.00
	Low Acceleration	10.0	10.0	10.0	10.0	10.0	10.0	1.00
	Medium Acceleration	10.0	10.0	10.0	9.92	10.0	10.0	1.00
	High Acceleration	10.3	10.0	10.2	10.4	9.95	10.2	1.00
	Low Cruise	10.0	10.0	10.0	10.7	9.31	10.0	1.00
	Medium Cruise	10.0	10.0	10.0	10.0	10.0	10.0	1.00
	High Cruise	10.0	10.0	10.0	10.0	10.0	10.0	1.00
	Deceleration	10.0	10.0	10.0	10.0	10.0	10.0	1.00
	Dumping				9.94	10.0	9.97	
	Equal Weight Avg[b]	10.0	10.0	10.0	10.1	9.93	10.0	1.00
	Empirical Weight Avg[d]	10.0	10.0	10.0	10.0	9.91	10.0	1.00
PM (g/gallon)	Idle	0.574	0.689	0.632	0.624	0.657	0.641	1.01
	Low Acceleration	0.590	0.489	0.540	0.652	0.924	0.788	1.46
	Medium Acceleration	0.735	0.526	0.631	0.606	0.637	0.621	0.99
	High Acceleration	0.688	0.724	0.706	0.745	0.747	0.746	1.06
	Low Cruise	0.761	0.454	0.607	0.792	0.477	0.634	1.04
	Medium Cruise	0.645	0.465	0.555	0.624	0.483	0.554	1.00
	High Cruise	0.694	0.618	0.656	0.673	0.603	0.638	0.97
	Deceleration	0.872	0.477	0.674	0.879	0.468	0.674	1.00
	Dumping				0.972	0.511	0.742	
	Equal Weight Avg[b]	0.695	0.555	0.625	0.730	0.612	0.671	1.07
	Empirical Weight Avg[d]	0.656	0.629	0.643	0.672	0.631	0.651	1.01

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table A-49. Preliminary Average Emission Rates on a Per Gallon Basis by Driving Mode, Vehicle, and Load for Tier 2 Tandem Dump Trucks (Soy Based B20)

		Unloaded			**Loaded**			
	Driving Mode[a]	Vehicle Number		Avg[b]	Vehicle Number		Avg [b]	Ratio[c]
		0125	**0126**		**0125**	**0126**		
NO_x (kg/gallon)	Idle	0.172	0.226	0.199	0.162	0.238	0.200	1.00
	Low Acceleration	0.072	0.076	0.074	0.070	0.071	0.071	0.95
	Medium Acceleration	0.053	0.058	0.055	0.053	0.057	0.055	1.00
	High Acceleration	0.046	0.048	0.047	0.042	0.047	0.045	0.95
	Low Cruise	0.082	0.080	0.081	0.062	0.068	0.065	0.80
	Medium Cruise	0.050	0.049	0.050	0.044	0.053	0.049	0.99
	High Cruise	0.039	0.040	0.039	0.033	0.043	0.038	0.96
	Deceleration	0.043	0.049	0.046	0.041	0.050	0.045	0.99
	Dumping				0.074	0.105	0.090	
	Equal Weight Avg[b]	0.070	0.078	0.074	0.065	0.081	0.073	0.99
	Empirical Weight Avg[d]	0.066	0.108	0.087	0.078	0.099	0.088	1.02
HC (g/gallon)	Idle	17.6	15.1	16.5	17.8	16.5	17.1	1.04
	Low Acceleration	5.32	8.26	6.99	5.48	6.67	6.08	0.87
	Medium Acceleration	4.22	4.55	4.41	4.91	3.78	4.34	0.98
	High Acceleration	4.01	3.04	3.47	4.96	4.29	4.63	1.33
	Low Cruise	6.03	5.39	5.68	6.62	4.72	5.67	1.00
	Medium Cruise	3.44	2.67	3.02	3.36	2.92	3.14	1.04
	High Cruise	3.23	3.27	3.25	5.19	2.45	3.82	1.17
	Deceleration	3.39	2.67	2.99	4.71	3.47	4.09	1.37
	Dumping				8.38	5.99	7.18	
	Equal Weight Avg[b]	5.91	5.62	5.79	6.82	5.64	6.23	1.08
	Empirical Weight Avg[d]	5.82	7.48	6.65	8.87	6.72	7.80	1.17
CO (g/gallon)	Idle	44.6	37.9	41.2	44.8	37.7	41.3	1.00
	Low Acceleration	25.0	17.5	21.2	23.2	15.0	19.1	0.90
	Medium Acceleration	15.6	11.6	13.6	11.6	9.60	10.6	0.78
	High Acceleration	13.5	11.8	12.6	14.1	11.2	12.6	1.00
	Low Cruise	26.1	24.5	25.3	24.8	19.0	21.9	0.87
	Medium Cruise	19.8	14.3	17.0	13.9	12.4	13.2	0.77
	High Cruise	15.1	18.0	16.6	14.6	14.2	14.4	0.87
	Dumping	15.8	16.9	16.3	15.3	16.4	15.9	0.97
	Deceleration				28.4	27.2	27.8	
	Equal Weight Avg[b]	21.9	19.1	20.5	21.2	18.1	19.6	0.96
	Empirical Weight Avg[d]	21.1	24.5	22.8	24.6	20.5	22.6	0.99

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-49. Continued

	Driving Mode[a]	Unloaded Vehicle Number 0125	Unloaded Vehicle Number 0126	Unloaded Avg[b]	Loaded Vehicle Number 0125	Loaded Vehicle Number 0126	Loaded Avg[b]	Ratio[c]
CO_2 (kg/gallon)	Idle	9.85	9.86	9.85	9.67	10.2	9.96	1.01
	Low Acceleration	9.91	9.91	9.91	9.92	9.93	9.93	1.00
	Medium Acceleration	9.93	9.93	9.93	9.94	9.94	9.94	1.00
	High Acceleration	9.94	9.93	9.94	9.94	9.95	9.94	1.00
	Low Cruise	9.91	9.91	9.91	9.92	9.92	9.92	1.00
	Medium Cruise	9.92	9.93	9.93	9.94	9.94	9.94	1.00
	High Cruise	9.93	9.93	9.93	9.94	9.94	9.94	1.00
	Deceleration	9.92	9.92	9.92	9.93	9.93	9.93	1.00
	Dumping				9.89	9.89	9.89	
	Equal Weight Avg[b]	9.91	9.92	9.92	9.90	9.97	9.93	1.00
	Empirical Weight Avg[d]	9.91	9.91	9.91	9.85	10.0	9.94	1.00
PM (g/gallon)	Idle	0.628	0.580	0.604	0.612	0.572	0.592	0.98
	Low Acceleration	0.478	0.451	0.465	0.595	0.423	0.509	1.09
	Medium Acceleration	0.541	0.410	0.475	0.567	0.420	0.494	1.04
	High Acceleration	0.655	0.442	0.549	0.576	0.470	0.523	0.95
	Low Cruise	0.533	0.374	0.453	0.459	0.346	0.402	0.89
	Medium Cruise	0.424	0.275	0.349	0.402	0.389	0.395	1.13
	High Cruise	0.423	0.324	0.373	0.334	0.331	0.332	0.89
	Deceleration	0.291	0.390	0.340	0.358	0.381	0.369	1.08
	Dumping				0.091	0.716	0.404	
	Equal Weight Avg[b]	0.497	0.406	0.451	0.444	0.450	0.447	0.99
	Empirical Weight Avg[d]	0.471	0.424	0.447	0.466	0.418	0.442	0.99

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table A-50. Preliminary Average Emission Rates on a Per Gallon Basis by Driving Mode, Vehicle, and Load for Tier 2 Single Axle Dump Trucks (Soy Based B20)

		Unloaded			**Loaded**			
	Driving Mode[a]	Vehicle Number		Avg[b]	Vehicle Number		Avg[b]	Ratio[c]
		6117	**6123**		**6117**	**6123**		
NO_x (kg/gallon)	Idle	0.104	0.163	0.134	0.103	0.144	0.124	0.92
	Low Acceleration	0.100	0.168	0.134	0.108	0.169	0.138	1.03
	Medium Acceleration	0.085	0.136	0.110	0.102	0.169	0.136	1.23
	High Acceleration	0.089	0.157	0.123	0.074	0.166	0.120	0.98
	Low Cruise	0.078	0.085	0.082	0.065	0.127	0.096	1.18
	Medium Cruise	0.071	0.100	0.085	0.092	0.097	0.094	1.11
	High Cruise	0.062	0.088	0.075	0.065	0.096	0.080	1.07
	Deceleration	0.058	0.088	0.073	0.063	0.108	0.086	1.18
	Dumping				0.096	0.110	0.103	
	Equal Weight Avg[b]	0.081	0.123	0.102	0.085	0.132	0.109	1.07
	Empirical Weight Avg[d]	0.083	0.119	0.101	0.088	0.127	0.107	1.06
HC (g/gallon)	Idle	10.8	16.1	13.4	11.1	14.9	13.0	0.97
	Low Acceleration	4.71	5.32	5.01	5.34	3.21	4.28	0.85
	Medium Acceleration	3.67	2.08	2.87	3.06	1.92	2.49	0.87
	High Acceleration	3.42	2.59	3.00	3.18	2.64	2.91	0.97
	Low Cruise	7.11	3.39	5.25	6.18	2.93	4.56	0.87
	Medium Cruise	3.70	2.02	2.86	3.16	1.58	2.37	0.83
	High Cruise	4.23	2.47	3.35	4.62	2.09	3.36	1.00
	Deceleration	4.74	3.24	3.99	5.52	2.91	4.22	1.06
	Dumping				3.91	7.15	5.53	
	Equal Weight Avg[b]	5.30	4.65	4.97	5.12	4.38	4.75	0.96
	Empirical Weight Avg[d]	6.49	6.64	6.57	6.21	3.21	4.71	0.72
CO (g/gallon)	Idle	39.9	47.4	43.7	39.1	42.8	40.9	0.94
	Low Acceleration	16.6	18.3	17.4	18.8	15.6	17.2	0.99
	Medium Acceleration	14.6	11.0	12.8	13.0	9.07	11.0	0.86
	High Acceleration	13.4	10.7	12.1	11.7	10.3	11.0	0.92
	Low Cruise	24.9	12.8	18.8	22.9	9.85	16.4	0.87
	Medium Cruise	13.1	10.6	11.9	11.7	8.93	10.3	0.87
	High Cruise	12.2	12.6	12.4	13.9	11.2	12.6	1.02
	Dumping	15.4	15.3	15.3	20.3	15.6	18.0	1.17
	Deceleration				41.1	25.8	33.5	
	Equal Weight Avg[b]	18.8	17.9	18.4	21.4	16.6	19.5	1.06
	Empirical Weight Avg[d]	23.3	22.9	23.1	23.1	13.7	18.4	0.80

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-50. Continued

	Driving Mode[a]	Unloaded: Vehicle Number 6117	Unloaded: Vehicle Number 6123	Unloaded: Avg[b]	Loaded: Vehicle Number 6117	Loaded: Vehicle Number 6123	Loaded: Avg[b]	Ratio[c]
CO_2 (kg/gallon)	Idle	9.87	9.85	9.86	9.97	9.81	9.89	1.00
	Low Acceleration	9.91	9.93	9.92	9.91	9.90	9.90	1.00
	Medium Acceleration	9.93	9.94	9.94	9.94	9.95	9.95	1.00
	High Acceleration	9.94	9.95	9.94	9.28	10.5	9.90	1.00
	Low Cruise	9.91	9.92	9.91	9.68	9.98	9.83	0.99
	Medium Cruise	9.94	9.95	9.94	9.95	9.89	9.92	1.00
	High Cruise	9.94	9.95	9.94	9.89	9.95	9.92	1.00
	Deceleration	9.93	9.93	9.93	9.94	9.95	9.94	1.00
	Dumping				9.89	9.91	9.90	
	Equal Weight Avg[b]	9.92	9.93	9.92	9.80	9.98	9.91	1.00
	Empirical Weight Avg[d]	9.91	9.92	9.91	9.90	9.95	9.92	1.00
PM (g/gallon)	Idle	0.521	0.499	0.510	0.538	0.539	0.538	1.06
	Low Acceleration	0.733	0.390	0.562	0.751	0.463	0.607	1.08
	Medium Acceleration	0.675	0.461	0.568	0.730	0.472	0.601	1.06
	High Acceleration	0.785	0.567	0.676	0.658	0.614	0.636	0.94
	Low Cruise	0.653	0.221	0.437	0.525	0.302	0.413	0.95
	Medium Cruise	0.550	0.408	0.479	0.610	0.354	0.482	1.01
	High Cruise	0.638	0.538	0.588	0.687	0.452	0.570	0.97
	Deceleration	0.491	0.426	0.458	0.545	0.395	0.470	1.02
	Dumping				0.541	0.499	0.520	
	Equal Weight Avg[b]	0.631	0.439	0.535	0.621	0.454	0.537	1.01
	Empirical Weight Avg[d]	0.582	0.470	0.526	0.599	0.414	0.506	0.96

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table A-51. Summary of Average Fuel Consumption and Emission Rates on a Per Mile Basis by Driving Mode, Vehicle Type, and Load for Petroleum Diesel

		Unloaded				**Loaded**				**Ratio**[b]			
	Driving Mode[a]	Single Axle		Tandem		Single Axle		Tandem		Single Axle		Tandem	
		Tier1	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**
Fuel (kg/mile)	Low Acceleration	0.597	0.751	1.11	0.959	0.843	0.945	1.30	1.50	1.41	1.26	1.16	1.56
	Medium Acceleration	0.401	0.341	0.555	0.553	0.541	0.451	0.701	0.773	1.35	1.32	1.26	1.40
	High Acceleration	0.392	0.349	0.496	0.767	0.505	0.418	0.589	0.925	1.29	1.20	1.19	1.21
	Low Cruise	0.333	0.407	0.726	0.640	0.509	0.632	0.879	0.974	1.53	1.55	1.21	1.52
	Medium Cruise	0.192	0.215	0.321	0.398	0.289	0.342	0.496	0.580	1.50	1.59	1.54	1.46
	High Cruise	0.273	0.246	0.255	0.383	0.332	0.294	0.373	0.483	1.22	1.20	1.46	1.26
	Deceleration	0.157	0.196	0.274	0.343	0.230	0.315	0.459	0.432	1.46	1.61	1.67	1.26
	Equal Weight Avg[c]	0.335	0.358	0.534	0.577	0.464	0.485	0.685	0.809	1.39	1.36	1.28	1.40
	Empirical Weight Avg[d]	0.300	0.292	0.510	0.496	0.424	0.494	0.700	0.706	1.41	1.69	1.37	1.42
NO_x (g/mile)	Low Acceleration	25.6	28.8	36.5	22.2	36.9	39.1	46.2	32.8	1.44	1.36	1.27	1.48
	Medium Acceleration	14.8	12.4	19.0	11.3	20.8	18.3	24.6	15.8	1.41	1.48	1.30	1.40
	High Acceleration	14.8	13.1	19.1	14.4	19.1	16.1	25.7	16.6	1.29	1.23	1.35	1.16
	Low Cruise	15.5	13.2	20.8	11.6	22.5	20.4	26.3	20.9	1.45	1.55	1.26	1.81
	Medium Cruise	7.27	6.22	10.7	6.07	11.2	9.72	19.1	9.67	1.55	1.56	1.78	1.59
	High Cruise	7.57	6.30	11.3	4.30	9.60	9.27	17.8	6.07	1.27	1.47	1.58	1.42
	Deceleration	6.21	5.12	9.76	5.96	9.80	9.69	19.1	6.98	1.58	1.89	1.96	1.17
	Equal Weight Avg[c]	13.1	12.2	18.2	10.8	18.6	17.5	25.5	15.6	1.42	1.44	1.40	1.44
	Empirical Weight Avg[d]	11.5	9.26	16.5	8.33	17.0	17.6	24.8	12.7	1.48	1.90	1.50	1.52

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Loaded / Unloaded
[c]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes
[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-51. Continued

		Unloaded				**Loaded**				**Ratio**[b]			
	Driving Mode[a]	Single Axle		Tandem		Single Axle		Tandem		Single Axle		Tandem	
		Tier1	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**
HC (g/mile)	Low Acceleration	0.647	0.860	2.43	1.56	0.755	1.29	3.27	2.56	1.17	1.50	1.34	1.64
	Medium Acceleration	0.306	0.364	0.919	0.652	0.386	0.485	1.29	0.913	1.26	1.33	1.40	1.40
	High Acceleration	0.314	0.341	0.827	0.714	0.426	0.430	1.11	1.21	1.35	1.26	1.34	1.69
	Low Cruise	0.696	0.612	1.68	1.03	0.838	1.05	1.91	1.64	1.20	1.71	1.13	1.60
	Medium Cruise	0.302	0.285	0.683	0.547	0.384	0.331	0.849	0.853	1.27	1.16	1.24	1.56
	High Cruise	0.319	0.239	0.471	0.470	0.411	0.327	0.609	0.625	1.29	1.37	1.29	1.33
	Deceleration	0.353	0.271	0.634	0.802	0.576	0.465	0.875	0.962	1.63	1.72	1.38	1.20
	Equal Weight Avg[c]	0.420	0.424	1.09	0.825	0.539	0.625	1.41	1.25	1.29	1.47	1.29	1.52
	Empirical Weight Avg[d]	0.415	0.332	1.00	0.689	0.540	0.672	1.40	1.05	1.29	2.02	1.40	1.52
CO (g/mile)	Low Acceleration	7.42	5.63	5.35	6.92	11.3	7.11	6.64	9.98	1.52	1.26	1.24	1.44
	Medium Acceleration	4.04	1.48	2.14	2.94	4.90	1.84	2.44	3.80	1.21	1.25	1.14	1.29
	High Acceleration	3.07	1.27	1.98	3.09	4.17	1.49	2.18	4.12	1.36	1.18	1.10	1.33
	Low Cruise	4.96	2.64	3.80	6.36	7.46	4.49	4.30	9.82	1.50	1.70	1.13	1.54
	Medium Cruise	2.04	0.909	1.49	2.51	2.50	1.15	1.77	3.21	1.23	1.27	1.19	1.28
	High Cruise	1.26	0.792	1.04	2.17	1.69	0.972	1.38	2.43	1.33	1.23	1.32	1.12
	Deceleration	1.59	0.874	1.74	2.73	2.40	1.53	2.48	3.24	1.51	1.76	1.43	1.19
	Equal Weight Avg[c]	3.48	1.94	2.50	3.82	4.92	2.66	3.03	5.23	1.41	1.37	1.21	1.37
	Empirical Weight Avg[d]	3.03	1.31	2.40	3.25	4.53	2.83	3.20	4.37	1.49	2.17	1.33	1.34

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Loaded / Unloaded
[c]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes
[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-51. Continued

		Unloaded				Loaded				Ratio[b]			
	Driving Mode[a]	Single Axle		Tandem		Single Axle		Tandem		Single Axle		Tandem	
		Tier1	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**
CO_2 (kg/mile)	Low Acceleration	1.88	2.37	3.56	3.02	2.65	2.97	4.19	4.71	1.41	1.26	1.18	1.56
	Medium Acceleration	1.26	1.07	1.75	1.75	1.70	1.41	2.23	2.47	1.35	1.32	1.28	1.41
	High Acceleration	1.24	1.11	1.55	2.42	1.60	1.34	1.87	2.92	1.29	1.20	1.21	1.21
	Low Cruise	1.04	1.28	2.33	2.02	1.60	1.96	2.80	3.07	1.53	1.53	1.20	1.52
	Medium Cruise	0.605	0.679	1.02	1.26	0.909	1.08	1.57	1.83	1.50	1.59	1.54	1.46
	High Cruise	0.853	0.776	0.805	1.21	1.01	0.929	1.20	1.53	1.20	1.20	1.49	1.26
	Deceleration	0.495	0.619	0.866	1.08	0.725	0.991	1.46	1.36	1.46	1.60	1.68	1.26
	Equal Weight Avg[c]	1.05	1.13	1.70	1.82	1.46	1.53	2.19	2.55	1.38	1.35	1.29	1.40
	Empirical Weight Avg[d]	0.943	0.924	1.62	1.56	1.32	1.54	2.32	2.23	1.41	1.67	1.43	1.43
PM (g/mile)	Low Acceleration	0.168	0.128	0.180	0.148	0.244	0.236	0.245	0.255	1.45	1.85	1.36	1.72
	Medium Acceleration	0.099	0.067	0.098	0.103	0.132	0.088	0.123	0.152	1.33	1.31	1.25	1.48
	High Acceleration	0.096	0.077	0.087	0.134	0.122	0.098	0.107	0.163	1.28	1.27	1.23	1.22
	Low Cruise	0.080	0.073	0.244	0.078	0.144	0.119	0.297	0.139	1.80	1.63	1.22	1.78
	Medium Cruise	0.050	0.037	0.112	0.052	0.070	0.059	0.188	0.088	1.40	1.58	1.68	1.71
	High Cruise	0.057	0.051	0.088	0.049	0.067	0.059	0.132	0.070	1.19	1.16	1.49	1.41
	Deceleration	0.043	0.039	0.080	0.055	0.063	0.062	0.137	0.065	1.44	1.60	1.71	1.17
	Equal Weight Avg[c]	0.085	0.067	0.127	0.088	0.120	0.103	0.175	0.133	1.42	1.53	1.38	1.51
	Empirical Weight Avg[d]	0.074	0.058	0.121	0.072	0.110	0.102	0.173	0.111	1.48	1.75	1.42	1.54

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Loaded / Unloaded

[c]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table A-52. Summary of Fuel Consumption and Emission Rates on a Per Mile Basis by Driving Mode, Vehicle Type, and Load for Soy-Based B20

		Unloaded				**Loaded**				**Ratio**[b]			
	Driving Mode[a]	Single Axle		Tandem		Single Axle		Tandem		Single Axle		Tandem	
		Tier1	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**
Fuel (kg/mile)	Low Acceleration	0.725	0.519	1.04	1.02	0.920	0.763	1.42	1.50	1.27	1.47	1.37	1.48
	Medium Acceleration	0.409	0.315	0.510	0.630	0.505	0.427	0.668	0.974	1.23	1.36	1.31	1.55
	High Acceleration	0.415	0.376	0.490	0.625	0.471	0.470	0.537	0.699	1.13	1.25	1.10	1.12
	Low Cruise	0.439	0.445	0.721	0.560	0.579	0.666	0.865	0.948	1.32	1.50	1.20	1.69
	Medium Cruise	0.282	0.242	0.322	0.408	0.401	0.339	0.436	0.622	1.42	1.40	1.35	1.52
	High Cruise	0.292	0.228	0.295	0.383	0.332	0.307	0.326	0.532	1.14	1.35	1.11	1.39
	Deceleration	0.210	0.198	0.224	0.351	0.280	0.263	0.323	0.445	1.33	1.33	1.44	1.27
	Equal Weight Avg[c]	0.396	0.332	0.514	0.567	0.498	0.462	0.654	0.818	1.26	1.39	1.27	1.44
	Empirical Weight Avg[d]	0.332	0.288	0.446	0.443	0.424	0.428	0.612	0.681	1.28	1.49	1.37	1.54
NO_x (g/mile)	Low Acceleration	21.1	20.2	26.6	23.5	25.6	32.8	31.7	33.0	1.21	1.62	1.19	1.41
	Medium Acceleration	9.56	10.8	13.6	10.9	11.9	18.3	17.6	16.7	1.24	1.70	1.30	1.53
	High Acceleration	9.24	15.0	13.6	9.14	11.0	17.9	16.7	9.75	1.19	1.19	1.22	1.07
	Low Cruise	13.5	11.3	17.8	14.1	15.5	20.3	22.9	19.2	1.15	1.80	1.29	1.36
	Medium Cruise	6.61	6.57	8.26	6.27	9.37	10.0	13.1	9.37	1.42	1.52	1.58	1.50
	High Cruise	5.48	5.37	10.7	4.69	6.97	7.96	12.0	6.30	1.27	1.48	1.12	1.34
	Deceleration	4.17	4.57	7.53	5.02	5.84	7.14	10.4	6.29	1.40	1.56	1.39	1.25
	Equal Weight Avg[c]	9.96	10.6	14.0	10.5	12.3	16.4	17.8	14.4	1.24	1.55	1.27	1.37
	Empirical Weight Avg[d]	7.70	8.12	12.7	6.78	10.0	14.7	16.8	10.6	1.30	1.81	1.32	1.56

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Loaded / Unloaded

[c]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-52. Continued

	Driving Mode[a]	Unloaded				Loaded				Ratio[b]			
		Single Axle		Tandem		Single Axle		Tandem		Single Axle		Tandem	
		Tier1	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**
HC (g/mile)	Low Acceleration	0.457	0.796	1.47	2.26	0.573	1.01	1.67	2.87	1.26	1.27	1.14	1.27
	Medium Acceleration	0.215	0.280	0.629	0.864	0.263	0.331	0.730	1.30	1.22	1.16	1.16	1.51
	High Acceleration	0.220	0.343	0.523	0.674	0.319	0.422	0.571	1.00	1.45	1.23	1.09	1.48
	Low Cruise	0.376	0.703	1.25	0.992	0.452	0.924	1.50	1.65	1.20	1.32	1.19	1.67
	Medium Cruise	0.151	0.206	0.389	0.383	0.221	0.231	0.509	0.610	1.46	1.12	1.31	1.58
	High Cruise	0.158	0.232	0.337	0.386	0.236	0.295	0.391	0.621	1.50	1.27	1.16	1.62
	Deceleration	0.151	0.242	0.466	0.328	0.234	0.336	0.581	0.564	1.55	1.39	1.25	1.72
	Equal Weight Avg[c]	0.247	0.400	0.724	0.840	0.330	0.507	0.849	1.23	1.34	1.27	1.17	1.47
	Empirical Weight Avg[d]	0.201	0.326	0.646	0.532	0.285	0.463	0.835	0.938	1.42	1.42	1.29	1.76
CO (g/mile)	Low Acceleration	6.92	2.78	7.70	6.42	8.66	4.07	8.58	8.66	1.25	1.46	1.11	1.35
	Medium Acceleration	2.36	1.25	2.63	2.59	2.65	1.44	2.93	3.19	1.12	1.16	1.12	1.23
	High Acceleration	2.15	1.39	2.00	2.43	2.76	1.60	2.16	2.72	1.28	1.16	1.08	1.12
	Low Cruise	2.86	2.53	3.92	4.38	3.58	3.31	4.67	6.39	1.25	1.31	1.19	1.46
	Medium Cruise	1.12	0.879	1.19	2.13	1.33	1.06	1.46	2.54	1.19	1.20	1.23	1.19
	High Cruise	1.31	0.878	0.979	1.97	1.54	1.17	1.29	2.38	1.17	1.34	1.31	1.21
	Deceleration	0.940	0.945	1.26	1.79	1.15	1.45	1.59	2.20	1.23	1.54	1.26	1.23
	Equal Weight Avg[c]	2.52	1.52	2.81	3.10	3.10	2.02	3.24	4.01	1.23	1.33	1.15	1.29
	Empirical Weight Avg[d]	1.80	1.28	2.36	2.39	2.24	1.87	3.00	3.30	1.24	1.39	1.27	1.38

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Loaded / Unloaded
[c]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes
[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-52. Continued

	Driving Mode[a]	Unloaded				Loaded				Ratio[b]			
		Single Axle		Tandem		Single Axle		Tandem		Single Axle		Tandem	
		Tier1	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**
CO_2 (kg/mile)	Low Acceleration	2.23	1.60	3.29	3.13	2.83	2.35	4.48	4.63	1.27	1.47	1.36	1.48
	Medium Acceleration	1.26	0.971	1.62	1.94	1.56	1.32	2.15	3.01	1.24	1.36	1.32	1.55
	High Acceleration	1.28	1.16	1.57	1.93	1.45	1.45	1.70	2.16	1.14	1.25	1.08	1.12
	Low Cruise	1.35	1.37	2.33	1.72	1.79	1.63	2.83	2.92	1.32	1.49	1.21	1.69
	Medium Cruise	0.870	0.749	1.04	1.26	1.24	2.04	1.39	1.92	1.43	1.39	1.33	1.53
	High Cruise	0.901	0.704	0.938	1.18	1.03	1.04	1.04	1.64	1.14	1.35	1.11	1.39
	Deceleration	0.648	0.612	0.711	1.08	0.865	0.947	1.01	1.37	1.33	1.33	1.41	1.27
	Equal Weight Avg[c]	1.22	1.04	1.64	1.75	1.54	1.42	2.08	2.52	1.26	1.39	1.27	1.44
	Empirical Weight Avg[d]	1.02	0.887	1.42	1.36	1.31	1.32	1.96	2.10	1.28	1.48	1.37	1.53
PM (g/mile)	Low Acceleration	0.177	0.098	0.362	0.146	0.234	0.144	0.495	0.232	1.33	1.47	1.37	1.59
	Medium Acceleration	0.076	0.055	0.213	0.091	0.086	0.078	0.261	0.148	1.13	1.42	1.23	1.63
	High Acceleration	0.080	0.077	0.203	0.104	0.090	0.093	0.223	0.113	1.14	1.20	1.10	1.08
	Low Cruise	0.088	0.058	0.081	0.077	0.102	0.084	0.123	0.117	1.16	1.46	1.52	1.51
	Medium Cruise	0.043	0.035	0.043	0.043	0.053	0.048	0.061	0.076	1.25	1.36	1.42	1.75
	High Cruise	0.041	0.041	0.030	0.044	0.048	0.052	0.044	0.055	1.17	1.26	1.45	1.24
	Deceleration	0.031	0.028	0.033	0.037	0.040	0.038	0.049	0.051	1.31	1.35	1.48	1.36
	Equal Weight Avg[c]	0.076	0.056	0.138	0.078	0.093	0.077	0.180	0.113	1.22	1.37	1.30	1.46
	Empirical Weight Avg[d]	0.058	0.048	0.107	0.055	0.072	0.067	0.150	0.085	1.23	1.41	1.41	1.55

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Loaded / Unloaded

[c]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table A-53. Summary of Average Emission Rates on a Per Gallon Basis by Driving Mode, Vehicle Type, and Load for Petroleum Diesel

		Unloaded				**Loaded**				**Ratio**[b]			
	Driving Mode[a]	Single Axle		Tandem		Single Axle		Tandem		Single Axle		Tandem	
		Tier1	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**
NO_x (kg/gallon)	Idle	0.218	0.148	0.220	0.177	0.216	0.150	0.222	0.182	0.99	1.01	1.01	1.03
	Low Acceleration	0.140	0.122	0.104	0.074	0.139	0.131	0.115	0.070	0.99	1.07	1.11	0.94
	Medium Acceleration	0.121	0.116	0.112	0.064	0.125	0.129	0.113	0.065	1.03	1.12	1.01	1.01
	High Acceleration	0.123	0.120	0.126	0.060	0.121	0.123	0.141	0.057	0.98	1.02	1.12	0.96
	Low Cruise	0.154	0.100	0.096	0.057	0.143	0.101	0.100	0.069	0.92	1.01	1.04	1.21
	Medium Cruise	0.122	0.092	0.106	0.048	0.126	0.090	0.121	0.053	1.04	0.98	1.14	1.10
	High Cruise	0.090	0.081	0.139	0.036	0.093	0.100	0.156	0.040	1.03	1.22	1.12	1.13
	Deceleration	0.128	0.084	0.115	0.055	0.138	0.098	0.141	0.051	1.08	1.17	1.23	0.93
	Dumping					0.165	0.112	0.158	0.103				
	Equal Weight Avg[c]	0.137	0.108	0.127	0.071	0.140	0.115	0.141	0.077	1.02	1.07	1.11	1.07
	Empirical Weight Avg[d]	0.180	0.123	0.179	0.105	0.160	0.132	0.148	0.083	0.89	1.07	0.83	0.79
HC (g/gallon)	Idle	12.2	17.2	27.0	14.8	12.3	16.4	27.1	15.2	1.01	0.96	1.00	1.03
	Low Acceleration	3.43	3.64	7.03	5.33	2.85	4.33	8.15	5.52	0.83	1.19	1.16	1.03
	Medium Acceleration	2.41	3.40	5.17	3.74	2.26	3.41	5.93	3.80	0.94	1.00	1.15	1.01
	High Acceleration	2.55	3.13	5.20	2.98	2.71	3.42	6.08	4.19	1.06	1.09	1.17	1.41
	Low Cruise	6.88	4.85	7.63	5.06	5.35	5.32	7.30	5.38	0.78	1.10	0.96	1.06
	Medium Cruise	5.00	4.21	6.89	4.38	4.42	3.08	5.52	4.70	0.88	0.73	0.80	1.07
	High Cruise	3.95	3.11	6.01	3.90	4.22	3.54	5.50	4.45	1.07	1.14	0.92	1.14
	Deceleration	7.96	4.65	8.38	7.43	8.53	4.99	6.95	7.07	1.07	1.07	0.83	0.95
	Dumping					6.58	10.7	13.7	19.6				
	Equal Weight Avg[c]	5.54	5.52	9.17	5.95	5.46	6.13	9.59	7.77	0.99	1.11	1.05	1.31
	Empirical Weight Avg[d]	9.16	10.6	19.6	9.12	7.53	11.3	11.9	8.08	0.82	1.07	0.61	0.89

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Loaded / Unloaded

[c]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-53. Continued

	Driving Mode[a]	Unloaded Single Axle Tier1	Unloaded Single Axle Tier2	Unloaded Tandem Tier1	Unloaded Tandem Tier2	Loaded Single Axle Tier1	Loaded Single Axle Tier2	Loaded Tandem Tier1	Loaded Tandem Tier2	Ratio[b] Single Axle Tier1	Ratio[b] Single Axle Tier2	Ratio[b] Tandem Tier1	Ratio[b] Tandem Tier2
CO (g/gallon)	Idle	57.3	66.8	53.9	35.9	57.0	65.5	53.8	36.7	0.99	0.98	1.00	1.02
	Low Acceleration	40.5	23.9	15.4	23.0	42.7	23.9	16.1	21.5	1.05	1.00	1.05	0.94
	Medium Acceleration	32.7	13.8	12.5	16.9	29.1	13.0	11.0	15.6	0.89	0.94	0.87	0.92
	High Acceleration	25.7	11.5	12.2	12.8	26.5	11.3	11.5	13.7	1.03	0.98	0.94	1.07
	Low Cruise	50.8	21.1	16.9	30.2	47.0	22.6	15.5	31.4	0.93	1.07	0.92	1.04
	Medium Cruise	34.4	13.4	15.4	20.0	28.8	10.7	11.6	17.5	0.84	0.80	0.75	0.87
	High Cruise	15.5	10.3	13.4	18.1	17.0	10.6	12.1	16.3	1.10	1.03	0.91	0.90
	Deceleration	34.1	14.9	20.8	25.3	34.2	16.1	18.1	23.9	1.00	1.08	0.87	0.94
	Dumping					41.8	40.6	61.8	58.5				
	Equal Weight Avg[c]	36.4	22.0	20.1	22.8	36.0	23.8	23.5	26.1	0.99	1.08	1.17	1.15
	Empirical Weight Avg[d]	47.3	40.7	38.9	27.5	42.7	44.4	25.8	25.3	0.90	1.09	0.66	0.92
CO_2 (kg/gallon)	Idle	9.95	9.91	10.0	9.64	9.98	9.93	10.2	9.68	1.00	1.00	1.02	1.00
	Low Acceleration	10.0	10.0	10.2	10.0	10.0	10.0	10.3	10.0	1.00	1.00	1.01	1.00
	Medium Acceleration	10.0	10.0	10.0	10.1	10.0	10.0	10.1	10.2	1.00	1.00	1.01	1.01
	High Acceleration	10.1	10.2	10.0	10.0	10.1	10.2	10.1	10.0	1.00	1.00	1.01	1.00
	Low Cruise	9.98	10.0	10.2	10.0	9.98	10.0	10.2	10.0	1.00	1.00	1.00	1.00
	Medium Cruise	10.0	10.0	10.1	10.0	10.0	10.0	10.1	10.0	1.00	1.00	1.00	1.00
	High Cruise	9.96	10.0	10.0	10.0	9.78	10.0	10.2	10.0	0.98	1.00	1.02	1.00
	Deceleration	10.0	10.0	10.0	10.0	10.0	10.0	10.1	10.0	1.00	1.00	1.01	1.00
	Dumping					10.0	9.97	10.1	9.92				
	Equal Weight Avg[c]	9.99	10.0	10.1	10.0	9.99	10.0	10.1	10.2	1.00	1.00	1.01	1.00
	Empirical Weight Avg[d]	9.96	10.0	10.0	9.84	9.95	10.0	10.1	9.91	1.00	1.00	1.01	1.01

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Loaded / Unloaded

[c]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-53. Continued

		Unloaded				Loaded				Ratio[b]			
	Driving Mode[a]	Single Axle		Tandem		Single Axle		Tandem		Single Axle		Tandem	
		Tier1	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**
PM (g/gallon)	Idle	0.846	0.632	2.27	0.516	0.856	0.641	2.25	0.527	1.01	1.01	0.99	1.02
	Low Acceleration	0.927	0.540	0.523	0.487	0.922	0.788	0.623	0.545	0.99	1.46	1.19	1.12
	Medium Acceleration	0.798	0.631	0.600	0.586	0.784	0.621	0.565	0.626	0.98	0.99	0.94	1.07
	High Acceleration	0.797	0.706	0.572	0.557	0.779	0.746	0.585	0.572	0.98	1.06	1.02	1.03
	Low Cruise	0.810	0.607	1.18	0.385	0.906	0.634	1.17	0.458	1.12	1.04	0.99	1.19
	Medium Cruise	0.853	0.555	1.11	0.416	0.788	0.554	1.24	0.483	0.92	1.00	1.12	1.16
	High Cruise	0.678	0.656	1.17	0.409	0.655	0.638	1.18	0.480	0.97	0.97	1.01	1.17
	Deceleration	0.891	0.674	1.00	0.513	0.865	0.674	1.07	0.476	0.97	1.00	1.06	0.93
	Dumping					0.965	0.742	2.41	1.24				
	Equal Weight Avg[c]	0.825	0.625	1.05	0.483	0.836	0.671	1.23	0.601	1.01	1.07	1.17	1.24
	Empirical Weight Avg[d]	0.805	0.643	1.80	0.475	0.836	0.651	1.26	0.528	1.04	1.01	0.70	1.11

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Loaded / Unloaded

[c]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table A-54. Summary of Average Emission Rates on a Per Gallon Basis by Driving Mode, Vehicle Type, and Load for Soy-Based B20

		Unloaded				Loaded				Ratio[b]			
	Driving Mode[a]	Single Axle		Tandem		Single Axle		Tandem		Single Axle		Tandem	
		Tier1	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**
NO_x (kg/gallon)	Idle	0.145	0.134	0.163	0.199	0.145	0.124	0.162	0.200	1.00	0.92	0.99	1.00
	Low Acceleration	0.096	0.134	0.084	0.074	0.087	0.138	0.073	0.071	0.91	1.03	0.87	0.95
	Medium Acceleration	0.075	0.110	0.086	0.055	0.076	0.136	0.084	0.055	1.01	1.23	0.97	1.00
	High Acceleration	0.071	0.123	0.090	0.047	0.071	0.120	0.102	0.045	1.00	0.98	1.13	0.95
	Low Cruise	0.095	0.082	0.083	0.081	0.082	0.096	0.085	0.065	0.86	1.18	1.02	0.80
	Medium Cruise	0.075	0.085	0.083	0.050	0.076	0.094	0.095	0.049	1.02	1.11	1.14	0.99
	High Cruise	0.059	0.075	0.116	0.039	0.067	0.080	0.119	0.038	1.12	1.07	1.03	0.96
	Deceleration	0.063	0.073	0.113	0.046	0.068	0.086	0.107	0.045	1.08	1.18	0.95	0.99
	Dumping					0.103	0.103	0.095	0.090				
	Equal Weight Avg[c]	0.085	0.102	0.102	0.074	0.086	0.109	0.102	0.073	1.01	1.07	1.00	0.99
	Empirical Weight Avg[d]	0.117	0.101	0.128	0.087	0.110	0.107	0.136	0.088	0.95	1.06	1.06	1.02
HC (g/gallon)	Idle	8.49	13.4	14.5	16.5	8.53	13.0	15.2	17.1	1.01	0.97	1.05	1.04
	Low Acceleration	2.00	5.01	4.57	6.99	1.99	4.28	3.78	6.08	1.00	0.85	0.83	0.87
	Medium Acceleration	1.72	2.87	3.93	4.41	1.67	2.49	3.51	4.34	0.97	0.87	0.89	0.98
	High Acceleration	1.71	3.00	3.44	3.47	2.15	2.91	3.44	4.63	1.26	0.97	1.00	1.33
	Low Cruise	2.69	5.25	5.95	5.68	2.65	4.56	5.88	5.67	0.99	0.87	0.99	1.00
	Medium Cruise	1.76	2.86	3.89	3.02	1.82	2.37	3.69	3.14	1.03	0.83	0.95	1.04
	High Cruise	1.77	3.35	3.69	3.25	2.31	3.36	3.89	3.82	1.30	1.00	1.06	1.18
	Deceleration	2.35	3.99	7.20	2.99	2.80	4.22	5.92	4.09	1.19	1.06	0.82	1.37
	Dumping					2.46	5.53	6.34	7.18				
	Equal Weight Avg[c]	2.81	4.97	5.90	5.79	2.93	4.75	5.74	6.23	1.04	0.96	0.97	1.08
	Empirical Weight Avg[d]	5.93	6.57	9.58	6.65	5.63	4.71	11.2	7.80	0.95	0.72	1.17	1.17

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Loaded / Unloaded
[c]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes
[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-54. Continued

	Driving Mode[a]	Unloaded				Loaded				Ratio[b]			
		Single Axle		Tandem		Single Axle		Tandem		Single Axle		Tandem	
		Tier1	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**
CO (g/gallon)	Idle	46.1	43.7	37.1	41.2	45.9	40.9	37.7	41.3	1.00	0.94	1.02	1.00
	Low Acceleration	30.4	17.4	24.4	21.2	30.4	17.2	19.8	19.1	1.00	0.99	0.81	0.90
	Medium Acceleration	18.8	12.8	16.6	13.6	17.0	11.0	14.2	10.6	0.90	0.86	0.86	0.78
	High Acceleration	16.5	12.1	13.2	12.6	19.0	11.0	13.1	12.6	1.16	0.92	0.99	1.00
	Low Cruise	20.9	18.8	19.6	25.3	20.2	16.4	19.5	21.9	0.97	0.87	1.00	0.87
	Medium Cruise	12.9	11.9	12.2	17.0	10.8	10.3	10.9	13.2	0.84	0.87	0.89	0.78
	High Cruise	14.6	12.4	10.8	16.6	15.1	12.6	13.0	14.4	1.03	1.02	1.20	0.87
	Deceleration	14.2	15.3	19.6	16.3	13.4	18.0	16.4	15.9	0.94	1.17	0.84	0.97
	Dumping					44.6	33.5	29.6	27.8				
	Equal Weight Avg[c]	21.8	18.4	19.2	20.5	24.0	19.5	19.4	19.6	1.10	1.06	1.01	0.96
	Empirical Weight Avg[d]	32.4	23.1	25.8	22.8	34.0	18.4	29.2	22.6	1.05	0.80	1.13	0.99
CO_2 (kg/gallon)	Idle	9.87	9.86	10.2	9.85	9.87	9.89	10.3	9.96	1.00	1.00	1.00	1.01
	Low Acceleration	9.91	9.92	10.2	9.91	9.90	9.90	10.2	9.93	1.00	1.00	0.99	1.00
	Medium Acceleration	9.93	9.94	10.2	9.93	9.94	9.95	10.3	9.94	1.00	1.00	1.01	1.00
	High Acceleration	9.93	9.94	10.3	9.94	9.94	9.90	10.2	9.94	1.00	1.00	0.99	1.00
	Low Cruise	9.90	9.91	10.3	9.91	9.95	9.83	10.3	9.92	1.01	1.01	1.00	1.00
	Medium Cruise	9.94	9.94	10.3	9.93	9.95	9.92	10.2	9.94	1.00	1.00	0.99	1.00
	High Cruise	9.95	9.94	10.2	9.93	9.99	9.92	10.3	9.94	1.00	1.00	1.01	1.00
	Deceleration	9.93	9.93	10.2	9.92	9.94	9.94	10.1	9.93	1.00	1.00	0.98	1.00
	Dumping					9.91	9.90	10.2	9.89				
	Equal Weight Avg[c]	9.92	9.92	10.3	9.92	9.93	9.91	10.2	9.93	1.00	1.00	1.00	1.00
	Empirical Weight Avg[d]	9.90	9.91	10.2	9.91	9.90	9.92	10.2	9.94	1.00	1.00	1.00	1.00

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Loaded / Unloaded
[c]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes
[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

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Table A-54. Continued

	Driving Mode[a]	Unloaded				Loaded				Ratio[b]			
		Single Axle		Tandem		Single Axle		Tandem		Single Axle		Tandem	
		Tier1	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**	**Tier1**	**Tier2**
PM (g/gallon)	Idle	0.725	0.510	0.734	0.604	0.687	0.538	0.770	0.592	0.95	1.06	1.05	0.98
	Low Acceleration	0.819	0.562	1.11	0.465	0.839	0.607	1.15	0.509	1.02	1.08	1.04	1.09
	Medium Acceleration	0.612	0.568	1.25	0.475	0.549	0.601	1.15	0.494	0.90	1.06	0.92	1.04
	High Acceleration	0.615	0.676	1.26	0.549	0.619	0.636	1.31	0.523	1.01	0.94	1.04	0.95
	Low Cruise	0.675	0.437	0.378	0.453	0.586	0.413	0.477	0.402	0.87	0.95	1.26	0.89
	Medium Cruise	0.506	0.479	0.426	0.349	0.435	0.482	0.452	0.395	0.86	1.01	1.06	1.13
	High Cruise	0.456	0.588	0.329	0.373	0.468	0.570	0.432	0.332	1.03	0.97	1.31	0.89
	Deceleration	0.482	0.458	0.484	0.340	0.480	0.470	0.484	0.369	0.99	1.02	1.00	1.09
	Dumping					0.836	0.520	0.320	0.404				
	Equal Weight Avg[c]	0.611	0.535	0.746	0.451	0.611	0.537	0.728	0.447	1.00	1.00	0.98	0.99
	Empirical Weight Avg[d]	0.608	0.526	0.684	0.447	0.618	0.506	0.738	0.442	1.02	0.96	1.08	0.99

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not driven significant distance during these modes.

[b]: Loaded / Unloaded

[c]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded

Table A-55. The Ratio of B20 to Petroleum Diesel by Driving Mode and individual Vehicles for Tier 1 Tandem Dump Trucks

NO_x (kg/gallon)	Driving Mode[a]	Unloaded					Loaded					
		Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	Ratio[c]
		0507	0578	0579	0580		0507	0578	0579	0580		
B20 Biodiesel	Idle	0.180	0.148	0.166	0.157	0.163	0.202	0.146	0.165	0.134	0.162	0.99
	Low Acceleration	0.079	0.081	0.075	0.099	0.084	0.057	0.078	0.072	0.083	0.073	0.87
	Medium Acceleration	0.082	0.090	0.082	0.091	0.086	0.080	0.095	0.083	0.079	0.084	0.97
	High Acceleration	0.093	0.084	0.090	0.093	0.090	0.089	0.116	0.084	0.117	0.102	1.13
	Low Cruise	0.086	0.056	0.084	0.107	0.083	0.086	0.083	0.090	0.081	0.085	1.02
	Medium Cruise	0.088	0.082	0.081	0.081	0.083	0.086	0.122	0.089	0.083	0.095	1.14
	High Cruise	0.119	0.122	0.133	0.090	0.116	0.132	0.127	0.119	0.098	0.119	1.03
	Deceleration	0.104	0.158	0.095	0.097	0.113	0.105	0.141	0.096	0.087	0.107	0.95
	Dumping						0.089	0.076	0.111	0.106	0.095	
	Equal Weight Avg[b]	0.104	0.103	0.101	0.102	0.102	0.103	0.109	0.101	0.097	0.102	1.00
	Empirical Weight Avg[d]	0.117	0.126	0.139	0.131	0.128	0.160	0.130	0.127	0.126	0.136	1.06
Petroleum Diesel	Idle	0.266	0.244	0.243	0.128	0.220	0.254	0.235	0.272	0.125	0.222	1.01
	Low Acceleration	0.123	0.101	0.094	0.100	0.104	0.149	0.110	0.106	0.098	0.115	1.11
	Medium Acceleration	0.120	0.101	0.133	0.093	0.112	0.146	0.116	0.109	0.082	0.113	1.01
	High Acceleration	0.136	0.112	0.146	0.109	0.126	0.166	0.131	0.142	0.123	0.141	1.12
	Low Cruise	0.110	0.135	0.098	0.042	0.096	0.134	0.134	0.079	0.054	0.100	1.04
	Medium Cruise	0.127	0.111	0.096	0.089	0.106	0.161	0.123	0.113	0.085	0.121	1.14
	High Cruise	0.170	0.112	0.164	0.111	0.139	0.194	0.197	0.129	0.102	0.156	1.12
	Deceleration	0.137	0.108	0.120	0.096	0.115	0.177	0.190	0.106	0.093	0.141	1.23
	Dumping						0.152	0.170	0.195	0.117	0.158	
	Equal Weight Avg[b]	0.149	0.128	0.137	0.096	0.127	0.170	0.156	0.139	0.098	0.141	1.11
	Empirical Weight Avg[d]	0.197	0.196	0.209	0.113	0.179	0.176	0.180	0.139	0.098	0.148	0.83
B20/PD Ratio	Idle	0.677	0.607	0.683	1.23	0.741	0.795	0.621	0.607	1.07	0.730	
	Low Acceleration	0.642	0.802	0.798	0.990	0.808	0.383	0.709	0.679	0.847	0.635	
	Medium Acceleration	0.683	0.891	0.617	0.978	0.768	0.548	0.819	0.761	0.963	0.743	
	High Acceleration	0.684	0.750	0.616	0.853	0.714	0.536	0.885	0.592	0.951	0.723	
	Low Cruise	0.782	0.415	0.857	2.55	0.865	0.642	0.619	1.14	1.50	0.850	
	Medium Cruise	0.693	0.739	0.844	0.910	0.783	0.534	0.992	0.788	0.976	0.785	
	High Cruise	0.700	1.09	0.811	0.811	0.835	0.680	0.645	0.922	0.961	0.763	
	Deceleration	0.759	1.46	0.792	1.01	0.983	0.593	0.742	0.906	0.935	0.759	
	Dumping						0.586	0.447	0.569	0.906	0.601	
	Equal Weight Avg[b]	0.698	0.805	0.737	1.06	0.803	0.606	0.699	0.727	0.990	0.723	
	Empirical Weight Avg[d]	0.594	0.643	0.665	1.16	0.715	0.909	0.722	0.914	1.29	0.919	

Table A-55. Continued

HC (g/gallon)	Driving Mode[a]	Unloaded					Loaded					Ratio[c]
		Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	
		0507	**0578**	**0579**	**0580**		**0507**	**0578**	**0579**	**0580**		
B20 Biodiesel	Idle	11.6	17.7	11.8	16.9	14.5	15.9	18.0	12.0	15.0	15.2	1.05
	Low Acceleration	4.61	4.60	4.40	4.65	4.57	3.56	4.37	3.64	3.56	3.78	0.83
	Medium Acceleration	3.71	5.05	3.58	3.39	3.93	3.79	3.87	3.12	3.25	3.51	0.89
	High Acceleration	3.26	4.09	3.01	3.38	3.44	3.33	4.03	2.96	3.47	3.44	1.00
	Low Cruise	6.31	5.59	3.94	7.96	5.95	6.82	5.47	4.29	6.95	5.88	0.99
	Medium Cruise	4.03	4.94	3.16	3.41	3.89	3.48	4.73	3.50	3.06	3.69	0.95
	High Cruise	3.63	5.21	2.95	2.97	3.69	3.74	5.22	3.57	3.04	3.89	1.06
	Deceleration	5.84	12.3	5.58	5.07	7.20	6.02	7.32	5.64	4.68	5.92	0.82
	Dumping						6.87	6.18	4.47	7.84	6.34	
	Equal Weight Avg[b]	5.37	7.44	4.81	5.97	5.90	5.95	6.57	4.79	5.65	5.74	0.97
	Empirical Weight Avg[d]	5.95	11.9	8.76	11.7	9.58	11.6	12.4	7.81	13.2	11.2	1.17
Petroleum Diesel	Idle	20.7	38.0	33.8	15.7	27.0	20.0	38.1	33.8	16.6	27.1	1.00
	Low Acceleration	9.35	7.97	3.81	6.98	7.03	9.60	6.74	9.43	6.84	8.15	1.16
	Medium Acceleration	5.13	5.64	4.36	5.56	5.17	5.23	5.31	7.84	5.37	5.93	1.15
	High Acceleration	5.38	5.26	4.51	5.65	5.20	5.12	5.39	8.72	5.07	6.08	1.17
	Low Cruise	9.44	10.3	6.21	4.57	7.63	8.52	10.8	6.08	3.83	7.30	0.96
	Medium Cruise	5.43	11.9	6.68	3.54	6.89	3.99	8.29	6.22	3.59	5.52	0.80
	High Cruise	4.97	10.3	4.62	4.12	6.01	4.51	8.88	5.53	3.08	5.50	0.92
	Deceleration	6.86	16.6	4.94	5.11	8.38	5.17	14.2	4.92	3.49	6.95	0.83
	Dumping						11.0	20.7	14.2	9.05	13.7	
	Equal Weight Avg[b]	8.41	13.2	8.61	6.40	9.17	8.12	13.1	10.7	6.33	9.59	1.05
	Empirical Weight Avg[d]	12.8	28.0	25.0	12.6	19.6	8.39	18.5	10.8	9.77	11.9	0.61
B20/PD Ratio	Idle	0.560	0.466	0.349	1.08	0.537	0.795	0.472	0.355	0.902	0.561	
	Low Acceleration	0.493	0.577	1.15	0.666	0.650	0.371	0.648	0.386	0.520	0.464	
	Medium Acceleration	0.723	0.895	0.821	0.610	0.760	0.725	0.729	0.398	0.605	0.592	
	High Acceleration	0.606	0.778	0.667	0.598	0.662	0.650	0.748	0.339	0.684	0.566	
	Low Cruise	0.671	0.543	0.634	1.74	0.780	0.800	0.506	0.706	1.81	0.805	
	Medium Cruise	0.742	0.415	0.473	0.963	0.565	0.872	0.571	0.563	0.852	0.668	
	High Cruise	0.730	0.506	0.639	0.721	0.614	0.829	0.588	0.646	0.987	0.707	
	Deceleration	0.851	0.741	1.13	0.992	0.859	1.16	0.515	1.15	1.34	0.852	
	Dumping						0.625	0.299	0.315	0.866	0.463	
	Equal Weight Avg[b]	0.639	0.564	0.559	0.933	0.643	0.733	0.502	0.448	0.893	0.599	
	Empirical Weight Avg[d]	0.465	0.425	0.350	0.929	0.489	1.38	0.670	0.723	1.35	0.941	

Table A-55. Continued

CO (g/gallon)	Driving Mode[a]	Unloaded 0507	Unloaded 0578	Unloaded 0579	Unloaded 0580	Unloaded Avg[b]	Loaded 0507	Loaded 0578	Loaded 0579	Loaded 0580	Loaded Avg[b]	Ratio[c]
B20 Biodiesel	Idle	37.4	38.8	30.9	41.3	37.1	41.7	41.2	31.4	36.6	37.7	1.02
	Low Acceleration	19.3	21.8	24.3	32.2	24.4	15.1	21.2	20.0	22.8	19.8	0.81
	Medium Acceleration	12.5	19.0	16.8	18.3	16.6	13.1	13.4	14.6	15.9	14.2	0.86
	High Acceleration	10.1	15.7	12.4	14.6	13.2	10.1	15.3	12.5	14.6	13.1	0.99
	Low Cruise	16.8	13.2	12.9	35.5	19.6	21.7	13.6	13.4	29.4	19.5	1.00
	Medium Cruise	11.8	11.7	8.94	16.2	12.2	10.6	10.8	9.11	12.9	10.9	0.89
	High Cruise	11.9	13.2	8.57	9.64	10.8	14.4	13.9	9.45	14.1	13.0	1.20
	Deceleration	17.5	26.8	11.2	23.1	19.6	16.8	19.6	12.4	16.8	16.4	0.84
	Dumping						37.2	22.3	20.8	38.1	29.6	
	Equal Weight Avg[b]	17.2	20.0	15.7	23.8	19.2	20.1	19.0	16.0	22.4	19.4	1.01
	Empirical Weight Avg[d]	18.8	27.8	23.8	32.8	25.8	31.7	29.9	21.7	33.5	29.2	1.13
Petroleum Diesel	Idle	49.7	103	32.4	30.7	53.9	49.5	97.4	36.8	31.4	53.8	1.00
	Low Acceleration	14.0	18.4	11.6	17.5	15.4	16.4	16.7	13.2	18.0	16.1	1.05
	Medium Acceleration	10.6	11.7	15.5	12.4	12.5	9.90	10.7	10.5	12.7	11.0	0.87
	High Acceleration	10.4	11.7	11.6	15.2	12.2	9.77	11.8	10.2	14.1	11.5	0.94
	Low Cruise	18.2	20.2	15.5	13.7	16.9	16.1	19.3	11.1	15.6	15.5	0.92
	Medium Cruise	10.7	24.6	9.90	16.4	15.4	7.48	16.6	8.90	13.4	11.6	0.75
	High Cruise	8.75	22.4	11.0	11.4	13.4	8.94	17.7	11.2	10.7	12.1	0.91
	Deceleration	15.7	32.1	12.8	22.7	20.8	13.2	30.8	11.9	16.8	18.1	0.87
	Dumping						53.5	85.0	64.6	44.3	61.8	
	Equal Weight Avg[b]	17.2	30.5	15.1	17.5	20.1	20.5	34.0	19.8	19.7	23.5	1.17
	Empirical Weight Avg[d]	29.1	73.6	26.4	26.4	38.9	18.9	44.7	16.6	23.0	25.8	0.66
B20/PD Ratio	Idle	0.753	0.377	0.954	1.35	0.688	0.842	0.423	0.853	1.17	0.701	
	Low Acceleration	1.38	1.18	2.09	1.84	1.58	0.921	1.27	1.52	1.27	1.23	
	Medium Acceleration	1.18	1.62	1.08	1.48	1.33	1.32	1.25	1.39	1.25	1.29	
	High Acceleration	0.971	1.34	1.07	0.961	1.08	1.03	1.30	1.23	1.04	1.14	
	Low Cruise	0.923	0.653	0.832	2.59	1.16	1.35	0.705	1.21	1.88	1.26	
	Medium Cruise	1.10	0.476	0.903	0.988	0.792	1.42	0.651	1.02	0.963	0.940	
	High Cruise	1.36	0.589	0.779	0.846	0.806	1.61	0.785	0.844	1.32	1.07	
	Deceleration	1.11	0.835	0.875	1.02	0.942	1.27	0.636	1.04	1.00	0.906	
	Dumping						0.695	0.262	0.322	0.860	0.479	
	Equal Weight Avg[b]	1.00	0.656	1.04	1.36	0.955	0.980	0.559	0.808	1.14	0.826	
	Empirical Weight Avg[d]	0.646	0.378	0.902	1.24	0.663	1.68	0.669	1.31	1.46	1.13	

Table A-55. Continued

CO_2 (kg/gallon)	Driving Mode[a]	Unloaded 0507	Unloaded 0578	Unloaded 0579	Unloaded 0580	Unloaded Avg[b]	Loaded 0507	Loaded 0578	Loaded 0579	Loaded 0580	Loaded Avg[b]	Ratio[c]
B20 Biodiesel	Idle	9.89	11.1	10.1	9.85	10.2	9.86	11.2	10.3	9.70	10.3	1.00
	Low Acceleration	9.92	10.9	10.1	9.93	10.2	9.85	10.9	10.0	9.89	10.2	0.99
	Medium Acceleration	9.94	10.8	10.2	9.90	10.2	9.93	11.1	10.2	9.95	10.3	1.01
	High Acceleration	9.94	10.9	10.3	9.93	10.3	9.94	11.0	10.0	9.72	10.2	0.99
	Low Cruise	9.91	11.3	10.1	9.89	10.3	9.81	11.3	10.5	9.78	10.3	1.00
	Medium Cruise	9.94	11.2	10.3	9.93	10.3	9.88	10.8	10.3	9.76	10.2	0.99
	High Cruise	9.95	11.0	10.1	9.90	10.2	9.94	11.4	10.0	9.79	10.3	1.01
	Deceleration	9.92	10.9	10.2	9.92	10.2	9.47	11.0	10.0	9.85	10.1	0.98
	Dumping						9.89	11.2	10.0	9.89	10.2	
	Equal Weight Avg[b]	9.93	11.0	10.2	9.91	10.3	9.84	11.1	10.1	9.82	10.2	1.00
	Empirical Weight Avg[d]	9.93	11.0	10.1	9.88	10.2	9.84	11.2	10.2	9.72	10.2	1.00
Petroleum Diesel	Idle	9.92	10.3	10.0	9.91	10.0	10.3	10.1	10.3	10.0	10.2	1.02
	Low Acceleration	10.3	10.2	10.2	10.0	10.2	10.7	10.2	10.2	10.1	10.3	1.01
	Medium Acceleration	10.1	10.0	10.2	9.86	10.0	9.97	10.1	10.4	10.0	10.1	1.01
	High Acceleration	9.84	10.0	10.5	9.75	10.0	10.2	10.1	10.2	10.0	10.1	1.01
	Low Cruise	9.85	10.3	10.5	10.1	10.2	10.1	10.0	10.5	10.0	10.2	1.00
	Medium Cruise	9.67	10.0	10.6	10.1	10.1	10.2	10.0	10.0	10.2	10.1	1.00
	High Cruise	9.80	10.0	10.2	10.1	10.0	10.5	10.1	10.2	9.96	10.2	1.02
	Deceleration	10.0	10.0	10.0	10.1	10.0	10.0	10.0	10.2	10.1	10.1	1.01
	Dumping						10.2	10.0	10.2	10.0	10.1	
	Equal Weight Avg[b]	9.93	10.1	10.3	10.0	10.1	10.2	10.1	10.2	10.0	10.1	1.01
	Empirical Weight Avg[d]	9.92	10.2	10.1	10.0	10.0	10.2	10.1	10.3	10.0	10.1	1.01
B20/PD Ratio	Idle	0.997	1.08	1.01	0.995	1.02	0.957	1.11	1.00	0.970	1.01	
	Low Acceleration	0.963	1.07	0.990	0.993	1.00	0.921	1.07	0.980	0.979	0.990	
	Medium Acceleration	0.984	1.08	1.00	1.00	1.02	1.00	1.10	0.981	1.00	1.02	
	High Acceleration	1.01	1.09	0.981	1.02	1.03	0.975	1.09	0.980	0.972	1.01	
	Low Cruise	1.01	1.10	0.962	0.979	1.01	0.971	1.13	1.00	0.978	1.01	
	Medium Cruise	1.03	1.12	0.972	0.983	1.02	0.969	1.08	1.03	0.957	1.01	
	High Cruise	1.02	1.10	0.990	0.980	1.02	0.947	1.13	0.980	0.983	1.01	
	Deceleration	0.992	1.09	1.02	0.982	1.02	0.947	1.10	0.980	0.975	1.00	
	Dumping						0.970	1.12	0.980	0.989	1.01	
	Equal Weight Avg[b]	1.00	1.09	0.990	0.991	1.02	0.965	1.10	0.990	0.982	1.01	
	Empirical Weight Avg[d]	1.00	1.08	1.00	0.988	1.02	0.965	1.11	0.990	0.972	1.01	

Table A-55. Continued

PM (g/gallon)	Driving Mode[a]	Unloaded 0507	Unloaded 0578	Unloaded 0579	Unloaded 0580	Unloaded Avg[b]	Loaded 0507	Loaded 0578	Loaded 0579	Loaded 0580	Loaded Avg[b]	Ratio[c]
B20 Biodiesel	Idle	0.633	0.933	0.772	0.599	0.734	0.756	0.948	0.789	0.589	0.770	1.05
	Low Acceleration	0.559	1.96	1.41	0.488	1.11	0.414	2.25	1.47	0.463	1.15	1.04
	Medium Acceleration	0.568	2.21	1.60	0.614	1.25	0.534	1.83	1.67	0.571	1.15	0.92
	High Acceleration	0.570	2.02	1.74	0.702	1.26	0.513	1.96	1.70	1.07	1.31	1.04
	Low Cruise	0.490	0.271	0.355	0.396	0.378	0.578	0.344	0.516	0.471	0.477	1.26
	Medium Cruise	0.409	0.361	0.535	0.400	0.426	0.474	0.450	0.484	0.401	0.452	1.06
	High Cruise	0.305	0.355	0.326	0.329	0.329	0.453	0.371	0.415	0.489	0.432	1.31
	Deceleration	0.390	0.678	0.518	0.350	0.484	0.320	0.583	0.583	0.451	0.484	1.00
	Dumping						0.398	0.355	0.177	0.350	0.320	
	Equal Weight Avg[b]	0.490	1.10	0.908	0.485	0.746	0.493	1.01	0.868	0.539	0.728	0.98
	Empirical Weight Avg[d]	0.470	0.973	0.766	0.524	0.684	0.645	0.918	0.818	0.571	0.738	1.08
Petroleum Diesel	Idle	1.17	2.66	4.51	0.731	2.27	1.10	2.56	4.42	0.931	2.25	0.99
	Low Acceleration	0.591	0.585	0.490	0.428	0.523	0.612	0.630	0.838	0.416	0.623	1.19
	Medium Acceleration	0.500	0.552	0.858	0.488	0.600	0.503	0.538	0.678	0.541	0.565	0.94
	High Acceleration	0.537	0.589	0.656	0.506	0.572	0.585	0.603	0.627	0.524	0.585	1.02
	Low Cruise	0.393	2.14	1.99	0.215	1.18	0.438	1.99	1.78	0.468	1.17	0.99
	Medium Cruise	0.369	1.81	1.64	0.609	1.11	0.387	1.80	2.10	0.671	1.24	1.12
	High Cruise	0.339	1.64	2.14	0.559	1.17	0.318	1.57	2.14	0.684	1.18	1.01
	Deceleration	0.359	1.56	1.61	0.483	1.00	0.373	2.16	1.06	0.666	1.07	1.06
	Dumping						0.410	2.10	6.51	0.633	2.41	
	Equal Weight Avg[b]	0.533	1.44	1.74	0.502	1.05	0.525	1.55	2.24	0.614	1.23	1.17
	Empirical Weight Avg[d]	0.761	2.19	3.62	0.629	1.80	0.546	1.81	1.97	0.699	1.26	0.70
B20/PD Ratio	Idle	0.541	0.351	0.171	0.819	0.323	0.687	0.370	0.179	0.633	0.342	
	Low Acceleration	0.946	3.35	2.88	1.14	2.12	0.676	3.57	1.75	1.11	1.85	
	Medium Acceleration	1.14	4.00	1.86	1.26	2.08	1.06	3.40	2.46	1.06	2.04	
	High Acceleration	1.06	3.43	2.65	1.39	2.20	0.877	3.25	2.71	2.04	2.24	
	Low Cruise	1.25	0.127	0.178	1.84	0.320	1.32	0.173	0.290	1.01	0.408	
	Medium Cruise	1.11	0.199	0.326	0.657	0.384	1.22	0.250	0.230	0.598	0.365	
	High Cruise	0.900	0.216	0.152	0.589	0.281	1.42	0.236	0.194	0.715	0.366	
	Deceleration	1.09	0.435	0.322	0.725	0.484	0.858	0.270	0.550	0.677	0.452	
	Dumping						0.971	0.169	0.027	0.553	0.133	
	Equal Weight Avg[b]	0.919	0.764	0.522	0.966	0.710	0.939	0.652	0.388	0.878	0.592	
	Empirical Weight Avg[d]	0.618	0.444	0.212	0.833	0.380	1.18	0.507	0.415	0.817	0.586	

Table A-56. The Ratio of B20 to Petroleum Diesel by Driving Mode and individual Vehicles for Tier 1 Single Axle Dump Trucks

NO_x (kg/gallon)	Driving Mode[a]	Unloaded Vehicle Number 4743	Unloaded 4750	Unloaded 4869	Unloaded 4870	Unloaded Avg[b]	Loaded Vehicle Number 4743	Loaded 4750	Loaded 4869	Loaded 4870	Loaded Avg[b]	Ratio[c]
B20 Biodiesel	Idle	0.132	0.251	0.097	0.102	0.145	0.130	0.267	0.091	0.093	0.145	1.00
	Low Acceleration	0.089	0.157	0.072	0.067	0.096	0.094	0.108	0.083	0.066	0.087	0.91
	Medium Acceleration	0.073	0.109	0.062	0.058	0.075	0.076	0.106	0.060	0.061	0.076	1.01
	High Acceleration	0.067	0.106	0.056	0.054	0.071	0.065	0.109	0.050	0.059	0.071	1.00
	Low Cruise	0.115	0.136	0.064	0.067	0.095	0.085	0.114	0.060	0.070	0.082	0.86
	Medium Cruise	0.078	0.113	0.056	0.053	0.075	0.072	0.114	0.053	0.066	0.076	1.02
	High Cruise	0.057	0.091	0.044	0.045	0.059	0.073	0.090	0.049	0.054	0.067	1.12
	Deceleration	0.057	0.103	0.047	0.045	0.063	0.055	0.107	0.050	0.060	0.068	1.08
	Dumping						0.098	0.141	0.084	0.091	0.103	
	Equal Weight Avg[b]	0.083	0.133	0.062	0.061	0.085	0.083	0.129	0.065	0.069	0.086	1.01
	Empirical Weight Avg[d]	0.073	0.242	0.079	0.074	0.117	0.085	0.197	0.080	0.084	0.110	0.95
Petroleum Diesel	Idle	0.214	0.208	0.234	0.216	0.218	0.231	0.198	0.215	0.220	0.216	0.99
	Low Acceleration	0.180	0.102	0.151	0.127	0.140	0.168	0.111	0.153	0.125	0.139	0.99
	Medium Acceleration	0.152	0.078	0.136	0.118	0.121	0.150	0.081	0.144	0.123	0.125	1.03
	High Acceleration	0.174	0.088	0.120	0.112	0.123	0.154	0.076	0.140	0.113	0.121	0.98
	Low Cruise	0.190	0.123	0.153	0.151	0.154	0.173	0.127	0.129	0.141	0.143	0.92
	Medium Cruise	0.157	0.087	0.125	0.119	0.122	0.154	0.086	0.133	0.133	0.126	1.04
	High Cruise	0.111	0.073	0.093	0.083	0.090	0.106	0.074	0.093	0.097	0.093	1.03
	Deceleration	0.164	0.102	0.113	0.132	0.128	0.188	0.114	0.104	0.144	0.138	1.08
	Dumping						0.211	0.119	0.178	0.150	0.165	
	Equal Weight Avg[b]	0.168	0.108	0.141	0.132	0.137	0.170	0.110	0.143	0.138	0.140	1.02
	Empirical Weight Avg[d]	0.189	0.133	0.213	0.184	0.180	0.195	0.114	0.149	0.181	0.160	0.89
B20/PD Ratio	Idle	0.617	1.21	0.415	0.472	0.665	0.563	1.35	0.423	0.423	0.671	
	Low Acceleration	0.494	1.54	0.477	0.528	0.686	0.560	0.973	0.542	0.528	0.626	
	Medium Acceleration	0.480	1.40	0.456	0.492	0.620	0.507	1.31	0.417	0.496	0.608	
	High Acceleration	0.385	1.20	0.467	0.482	0.577	0.422	1.43	0.357	0.522	0.587	
	Low Cruise	0.605	1.11	0.418	0.444	0.617	0.491	0.898	0.465	0.496	0.573	
	Medium Cruise	0.497	1.30	0.448	0.445	0.615	0.468	1.33	0.398	0.496	0.603	
	High Cruise	0.514	1.25	0.473	0.542	0.656	0.689	1.22	0.527	0.557	0.720	
	Deceleration	0.348	1.01	0.416	0.341	0.492	0.293	0.939	0.481	0.417	0.493	
	Dumping						0.464	1.18	0.472	0.607	0.624	
	Equal Weight Avg[b]	0.494	1.23	0.440	0.462	0.620	0.488	1.17	0.455	0.500	0.614	
	Empirical Weight Avg[d]	0.386	1.82	0.371	0.402	0.650	0.436	1.73	0.537	0.464	0.688	

Table A-56. Continued

HC (g/gallon)	Driving Mode[a]	Unloaded 4743	Unloaded 4750	Unloaded 4869	Unloaded 4870	Unloaded Avg[b]	Loaded 4743	Loaded 4750	Loaded 4869	Loaded 4870	Loaded Avg[b]	Ratio[c]
B20 Biodiesel	Idle	7.32	11.7	7.69	7.21	8.49	7.90	11.7	7.73	6.78	8.53	1.01
	Low Acceleration	2.24	2.08	1.72	1.94	2.00	2.20	1.90	1.94	1.91	1.99	1.00
	Medium Acceleration	1.55	1.77	2.04	1.54	1.72	1.82	1.71	1.53	1.61	1.67	0.97
	High Acceleration	1.85	1.58	1.53	1.87	1.71	2.01	2.64	2.10	1.85	2.15	1.26
	Low Cruise	3.53	1.97	2.85	2.40	2.69	2.30	1.72	2.82	3.78	2.65	0.99
	Medium Cruise	1.68	1.39	2.23	1.75	1.76	1.40	2.77	1.49	1.60	1.82	1.03
	High Cruise	1.81	1.00	2.17	2.11	1.77	2.10	2.27	2.72	2.12	2.31	1.30
	Deceleration	2.20	1.55	3.08	2.57	2.35	1.76	3.17	2.91	3.35	2.80	1.19
	Dumping						2.00	1.70	3.51	2.63	2.46	
	Equal Weight Avg[b]	2.77	2.88	2.91	2.67	2.81	2.61	3.29	2.97	2.85	2.93	1.04
	Empirical Weight Avg[d]	2.68	11.1	5.52	4.39	5.93	3.38	7.62	6.16	5.36	5.63	0.95
Petroleum Diesel	Idle	16.9	13.2	9.43	9.14	12.2	18.6	13.0	8.17	9.30	12.3	1.01
	Low Acceleration	4.16	3.53	2.80	3.25	3.43	2.78	3.75	2.29	2.57	2.85	0.83
	Medium Acceleration	2.73	3.18	1.52	2.20	2.41	2.39	3.03	1.54	2.09	2.26	0.94
	High Acceleration	2.97	3.35	1.80	2.07	2.55	3.55	2.93	2.00	2.36	2.71	1.06
	Low Cruise	9.88	5.78	6.54	5.33	6.88	7.44	5.54	3.91	4.52	5.35	0.78
	Medium Cruise	8.08	4.51	2.63	4.76	5.00	8.14	3.69	2.87	2.96	4.42	0.88
	High Cruise	7.25	3.77	1.76	3.01	3.95	8.41	3.69	2.23	2.53	4.22	1.07
	Deceleration	16.1	7.09	2.94	5.68	7.96	17.4	7.58	3.58	5.59	8.53	1.07
	Dumping						15.2	5.07	1.30	4.79	6.58	
	Equal Weight Avg[b]	8.51	5.55	3.68	4.43	5.54	9.31	5.36	3.10	4.08	5.46	0.99
	Empirical Weight Avg[d]	13.3	7.74	8.19	7.39	9.16	13.1	6.14	4.00	6.90	7.53	0.82
B20/PD Ratio	Idle	0.433	0.886	0.815	0.789	0.696	0.425	0.900	0.946	0.729	0.693	
	Low Acceleration	0.538	0.589	0.614	0.597	0.583	0.791	0.507	0.847	0.743	0.698	
	Medium Acceleration	0.568	0.557	1.34	0.700	0.714	0.762	0.564	0.994	0.770	0.739	
	High Acceleration	0.623	0.472	0.850	0.903	0.671	0.566	0.901	1.05	0.784	0.793	
	Low Cruise	0.357	0.341	0.436	0.450	0.391	0.309	0.310	0.721	0.836	0.495	
	Medium Cruise	0.208	0.308	0.848	0.368	0.352	0.172	0.751	0.519	0.541	0.412	
	High Cruise	0.250	0.265	1.23	0.701	0.448	0.250	0.615	1.22	0.838	0.547	
	Deceleration	0.137	0.219	1.05	0.452	0.295	0.101	0.418	0.813	0.599	0.328	
	Dumping						0.132	0.335	2.70	0.549	0.374	
	Equal Weight Avg[b]	0.325	0.519	0.791	0.603	0.507	0.280	0.614	0.958	0.699	0.537	
	Empirical Weight Avg[d]	0.202	1.43	0.674	0.594	0.647	0.258	1.24	1.54	0.777	0.748	

Table A-56. Continued

CO (g/gallon)	Driving Mode[a]	Unloaded 4743	Unloaded 4750	Unloaded 4869	Unloaded 4870	Unloaded Avg[b]	Loaded 4743	Loaded 4750	Loaded 4869	Loaded 4870	Loaded Avg[b]	Ratio[c]
B20 Biodiesel	Idle	30.9	40.9	56.6	55.9	46.1	31.4	41.0	59.0	52.1	45.9	1.00
	Low Acceleration	32.8	30.4	28.6	29.7	30.4	31.5	28.1	33.4	28.4	30.4	1.00
	Medium Acceleration	19.6	19.3	23.4	12.9	18.8	18.4	17.5	19.9	12.4	17.0	0.91
	High Acceleration	18.5	19.3	16.8	11.2	16.5	19.6	20.3	22.1	14.1	19.0	1.16
	Low Cruise	21.0	21.4	20.5	20.8	20.9	22.1	16.1	25.6	17.2	20.2	0.97
	Medium Cruise	13.7	13.4	15.5	9.09	12.9	11.7	13.0	11.5	7.01	10.8	0.84
	High Cruise	10.7	18.2	18.2	11.3	14.6	10.3	18.6	18.5	12.8	15.1	1.03
	Deceleration	13.4	18.7	13.8	10.8	14.2	11.9	17.1	12.2	12.3	13.4	0.94
	Dumping						16.7	32.3	67.2	62.3	44.6	
	Equal Weight Avg[b]	20.1	22.7	24.2	20.2	21.8	19.3	22.7	29.9	24.3	24.0	1.10
	Empirical Weight Avg[d]	16.6	39.7	41.1	32.1	32.4	17.9	30.9	47.2	39.9	34.0	1.05
Petroleum Diesel	Idle	66.6	49.1	54.1	59.4	57.3	69.0	47.8	48.6	62.8	57.0	1.00
	Low Acceleration	44.1	29.3	50.7	38.0	40.5	45.5	36.1	49.0	40.0	42.7	1.05
	Medium Acceleration	37.7	20.3	37.2	35.7	32.7	31.5	18.2	36.7	30.1	29.1	0.89
	High Acceleration	39.3	21.5	23.5	18.5	25.7	38.5	20.2	26.2	21.1	26.5	1.03
	Low Cruise	71.1	33.1	51.5	47.6	50.8	56.2	35.1	49.6	47.2	47.0	0.93
	Medium Cruise	38.5	23.0	30.2	45.8	34.4	34.2	16.7	37.6	26.8	28.8	0.84
	High Cruise	26.0	14.4	10.5	11.0	15.5	28.7	15.2	13.7	10.3	17.0	1.10
	Deceleration	53.3	29.4	18.5	35.3	34.1	48.4	33.7	24.7	30.2	34.2	1.00
	Dumping						51.1	44.2	35.8	36.2	41.8	
	Equal Weight Avg[b]	47.1	27.5	34.5	36.4	36.4	44.8	29.7	35.8	33.9	36.0	0.99
	Empirical Weight Avg[d]	57.1	32.6	49.4	50.3	47.3	54.4	29.0	37.8	49.7	42.7	0.90
B20/PD Ratio	Idle	0.464	0.833	1.05	0.941	0.805	0.455	0.858	1.21	0.830	0.805	
	Low Acceleration	0.744	1.04	0.564	0.782	0.751	0.692	0.778	0.682	0.710	0.712	
	Medium Acceleration	0.520	0.951	0.629	0.361	0.575	0.584	0.962	0.542	0.412	0.584	
	High Acceleration	0.471	0.898	0.715	0.611	0.642	0.509	1.00	0.844	0.668	0.717	
	Low Cruise	0.295	0.647	0.398	0.437	0.411	0.393	0.459	0.516	0.364	0.430	
	Medium Cruise	0.356	0.583	0.513	0.198	0.375	0.342	0.778	0.306	0.262	0.375	
	High Cruise	0.412	1.26	1.73	1.03	0.942	0.359	1.22	1.35	1.24	0.888	
	Deceleration	0.251	0.636	0.746	0.306	0.416	0.246	0.507	0.494	0.407	0.392	
	Dumping						0.327	0.731	1.88	1.72	1.07	
	Equal Weight Avg[b]	0.427	0.825	0.701	0.555	0.599	0.431	0.764	0.835	0.717	0.667	
	Empirical Weight Avg[d]	0.291	1.22	0.832	0.638	0.685	0.329	1.07	1.25	0.803	0.796	

Table A-56. Continued

CO_2 (kg/gallon)	Driving Mode[a]	Unloaded 4743	Unloaded 4750	Unloaded 4869	Unloaded 4870	Unloaded Avg[b]	Loaded 4743	Loaded 4750	Loaded 4869	Loaded 4870	Loaded Avg[b]	Ratio[c]
B20 Biodiesel	Idle	9.87	9.87	9.85	9.86	9.87	9.88	9.88	9.85	9.86	9.87	1.00
	Low Acceleration	9.90	9.93	9.89	9.91	9.91	9.88	9.91	9.88	9.91	9.90	1.00
	Medium Acceleration	9.92	9.93	9.93	9.94	9.93	9.92	9.93	9.95	9.94	9.94	1.00
	High Acceleration	9.93	9.94	9.93	9.95	9.93	9.93	9.93	9.96	9.95	9.94	1.00
	Low Cruise	9.89	9.90	9.88	9.91	9.90	9.91	9.94	10.0	9.91	9.95	1.01
	Medium Cruise	9.93	9.94	9.94	9.95	9.94	9.94	9.94	9.96	9.95	9.95	1.00
	High Cruise	9.93	9.95	9.95	9.95	9.95	9.93	10.4	9.96	9.70	9.99	1.00
	Deceleration	9.92	9.93	9.94	9.94	9.93	9.93	9.93	9.96	9.94	9.94	1.00
	Dumping						9.89	9.92	9.98	9.86	9.91	
	Equal Weight Avg[b]	9.91	9.92	9.91	9.93	9.92	9.91	10.0	9.95	9.89	9.93	1.00
	Empirical Weight Avg[d]	9.92	9.88	9.89	9.91	9.90	9.92	9.94	9.88	9.88	9.90	1.00
Petroleum Diesel	Idle	9.95	9.95	9.95	9.93	9.95	10.1	9.96	9.95	9.96	9.98	1.00
	Low Acceleration	9.99	9.98	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	1.00
	Medium Acceleration	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	1.00
	High Acceleration	9.90	10.3	10.0	10.1	10.1	10.0	10.0	10.0	10.3	10.1	1.00
	Low Cruise	9.98	10.0	9.97	9.98	9.98	9.98	10.0	9.98	9.98	9.98	1.00
	Medium Cruise	10.0	10.0	10.0	9.98	10.0	10.0	10.0	10.0	10.0	10.0	1.00
	High Cruise	10.0	9.73	10.0	10.04	9.69	10.0	9.31	10.3	9.52	9.78	0.98
	Deceleration	9.99	10.0	10.0	9.99	10.0	10.0	10.0	10.1	10.0	10.0	1.00
	Dumping						10.0	9.98	10.0	10.0	10.0	
	Equal Weight Avg[b]	9.99	9.99	10.0	10.0	9.99	10.0	9.92	10.0	9.98	9.97	1.00
	Empirical Weight Avg[d]	9.97	9.79	10.0	9.96	9.96	10.0	9.84	10.0	9.94	9.95	1.00
B20/PD Ratio	Idle	0.992	0.992	0.990	0.993	0.992	0.978	0.992	0.990	0.990	0.989	
	Low Acceleration	0.991	0.995	0.989	0.991	0.991	0.988	0.991	0.988	0.991	0.990	
	Medium Acceleration	0.992	0.993	0.993	0.994	0.993	0.992	0.993	0.995	0.994	0.994	
	High Acceleration	1.00	0.965	0.993	0.985	0.983	0.993	0.990	0.996	0.966	0.984	
	Low Cruise	0.991	0.990	0.991	0.993	0.992	0.993	0.994	1.00	0.993	0.997	
	Medium Cruise	0.993	1.02	0.994	0.997	0.994	0.994	0.994	0.996	0.995	0.995	
	High Cruise	0.993	1.15	0.995	0.991	1.03	0.993	1.12	0.967	1.02	1.02	
	Deceleration	0.993	0.993	0.994	0.995	0.993	0.993	0.993	0.986	0.994	0.994	
	Dumping						0.989	0.994	0.998	0.986	0.991	
	Equal Weight Avg[b]	0.992	0.993	0.991	0.993	0.993	0.991	0.992	0.995	0.991	0.996	
	Empirical Weight Avg[d]	0.995	1.01	0.989	0.995	0.994	0.992	1.01	0.988	0.994	0.995	

Table A-56. Continued

PM (g/gallon)	Driving Mode[a]	Unloaded 4743	Unloaded 4750	Unloaded 4869	Unloaded 4870	Unloaded Avg[b]	Loaded 4743	Loaded 4750	Loaded 4869	Loaded 4870	Loaded Avg[b]	Ratio[c]
B20 Biodiesel	Idle	0.546	0.507	0.853	0.994	0.725	0.569	0.516	0.837	0.828	0.687	0.95
	Low Acceleration	0.537	0.789	0.934	1.02	0.819	0.748	0.721	1.02	0.872	0.839	1.02
	Medium Acceleration	0.505	0.607	0.724	0.612	0.612	0.503	0.547	0.583	0.562	0.549	0.90
	High Acceleration	0.524	0.736	0.583	0.618	0.615	0.499	0.663	0.665	0.649	0.619	1.01
	Low Cruise	0.385	0.793	0.720	0.802	0.675	0.409	0.563	0.637	0.735	0.586	0.87
	Medium Cruise	0.344	0.578	0.575	0.526	0.506	0.348	0.494	0.473	0.425	0.435	0.86
	High Cruise	0.349	0.500	0.515	0.460	0.456	0.360	0.540	0.496	0.476	0.468	1.03
	Deceleration	0.312	0.572	0.551	0.495	0.482	0.290	0.571	0.490	0.569	0.480	0.99
	Dumping						0.445	0.800	1.26	0.845	0.836	
	Equal Weight Avg[b]	0.438	0.635	0.682	0.691	0.611	0.463	0.602	0.717	0.662	0.611	1.00
	Empirical Weight Avg[d]	0.408	0.514	0.751	0.757	0.608	0.433	0.535	0.756	0.749	0.618	1.02
***Petroleum* Diesel**	Idle	1.17	0.671	0.600	0.949	0.846	1.21	0.750	0.519	0.946	0.856	1.01
	Low Acceleration	0.926	0.646	1.05	1.08	0.927	0.879	0.700	1.02	1.09	0.922	0.99
	Medium Acceleration	0.859	0.454	0.932	0.948	0.798	0.864	0.502	0.876	0.893	0.784	0.98
	High Acceleration	1.11	0.579	0.756	0.741	0.797	1.03	0.506	0.795	0.786	0.779	0.98
	Low Cruise	0.841	0.575	0.791	1.03	0.810	0.953	0.593	0.952	1.13	0.906	1.12
	Medium Cruise	0.753	0.450	1.08	1.12	0.853	0.845	0.475	0.909	0.920	0.788	0.92
	High Cruise	0.860	0.421	0.693	0.741	0.678	0.834	0.402	0.720	0.666	0.655	0.97
	Deceleration	1.15	0.588	0.761	1.06	0.891	1.19	0.598	0.706	0.973	0.865	0.97
	Dumping						0.923	0.942	0.928	1.07	0.965	
	Equal Weight Avg[b]	0.959	0.548	0.834	0.960	0.825	0.969	0.608	0.825	0.941	0.836	1.01
	Empirical Weight Avg[d]	1.05	0.572	0.645	0.951	0.805	1.06	0.568	0.770	0.944	0.836	1.04
B20/PD Ratio	Idle	0.467	0.756	1.42	1.05	0.857	0.470	0.688	1.61	0.875	0.803	
	Low Acceleration	0.580	1.22	0.890	0.944	0.883	0.852	1.03	1.00	0.800	0.910	
	Medium Acceleration	0.588	1.34	0.777	0.646	0.767	0.585	1.09	0.666	0.629	0.700	
	High Acceleration	0.472	1.27	0.771	0.834	0.772	0.484	1.31	0.836	0.826	0.795	
	Low Cruise	0.458	1.38	0.910	0.779	0.833	0.429	0.949	0.669	0.650	0.647	
	Medium Cruise	0.457	1.28	0.532	0.470	0.593	0.412	1.04	0.520	0.462	0.552	
	High Cruise	0.406	1.19	0.743	0.621	0.673	0.432	1.34	0.689	0.715	0.715	
	Deceleration	0.271	0.973	0.724	0.467	0.541	0.244	0.955	0.694	0.585	0.555	
	Dumping						0.483	0.849	1.36	0.790	0.866	
	Equal Weight Avg[b]	0.457	1.16	0.818	0.720	0.741	0.478	0.990	0.869	0.704	0.731	
	Empirical Weight Avg[d]	0.389	0.899	1.16	0.796	0.755	0.408	0.942	0.982	0.793	0.739	

Table A-57. The Ratio of B20 to Petroleum Diesel by Driving Mode and individual Vehicles for Tier 2 Tandem Dump Trucks

NO_x (kg/gallon)	Driving Mode[a]	Unloaded			Loaded			
		Vehicle Number		Avg[b]	Vehicle Number		Avg[b]	Ratio[c]
		0125	0126		0125	0126		
B20 Biodiesel	Idle	0.172	0.226	0.199	0.162	0.238	0.200	1.00
	Low Acceleration	0.072	0.076	0.074	0.070	0.071	0.071	0.95
	Medium Acceleration	0.053	0.058	0.055	0.053	0.057	0.055	1.00
	High Acceleration	0.046	0.048	0.047	0.042	0.047	0.045	0.95
	Low Cruise	0.082	0.080	0.081	0.062	0.068	0.065	0.80
	Medium Cruise	0.050	0.049	0.050	0.044	0.053	0.049	0.99
	High Cruise	0.039	0.040	0.039	0.033	0.043	0.038	0.96
	Deceleration	0.043	0.049	0.046	0.041	0.050	0.045	0.99
	Dumping				0.074	0.105	0.090	
	Equal Weight Avg[b]	0.070	0.078	0.074	0.065	0.081	0.073	0.99
	Empirical Weight Avg[d]	0.066	0.108	0.087	0.078	0.099	0.088	1.01
***Petroleum* Diesel**	Idle	0.152	0.201	0.177	0.155	0.210	0.182	1.03
	Low Acceleration	0.077	0.071	0.074	0.072	0.069	0.070	0.94
	Medium Acceleration	0.055	0.073	0.064	0.065	0.065	0.065	1.01
	High Acceleration	0.066	0.054	0.060	0.058	0.057	0.057	0.96
	Low Cruise	0.052	0.061	0.057	0.075	0.063	0.069	1.21
	Medium Cruise	0.046	0.050	0.048	0.055	0.051	0.053	1.10
	High Cruise	0.032	0.039	0.036	0.041	0.039	0.040	1.13
	Deceleration	0.058	0.053	0.055	0.055	0.048	0.051	0.93
	Dumping				0.117	0.089	0.103	
	Equal Weight Avg[b]	0.067	0.075	0.071	0.077	0.077	0.077	1.07
	Empirical Weight Avg[d]	0.100	0.110	0.105	0.093	0.074	0.083	0.79
***B20/PD* Ratio**	Idle	1.13	1.12	1.12	1.05	1.13	1.10	
	Low Acceleration	0.935	1.07	1.00	0.972	1.03	1.01	
	Medium Acceleration	0.964	0.795	0.859	0.815	0.877	0.846	
	High Acceleration	0.697	0.889	0.783	0.724	0.825	0.789	
	Low Cruise	1.58	1.31	1.42	0.827	1.08	0.942	
	Medium Cruise	1.09	0.980	1.04	0.800	1.04	0.925	
	High Cruise	1.22	1.03	1.08	0.805	1.10	0.950	
	Dumping	0.741	0.925	0.836	0.745	1.04	0.882	
	Deceleration						0.874	
	Equal Weight Avg[b]	1.04	1.04	1.04	0.844	1.05	0.948	
	Empirical Weight Avg[d]	0.660	0.982	0.829	0.839	1.34	1.06	

Table A-57. Continued

HC (g/gallon)	Driving Mode[a]	Unloaded Vehicle Number 0125	Unloaded Vehicle Number 0126	Unloaded Avg[b]	Loaded Vehicle Number 0125	Loaded Vehicle Number 0126	Loaded Avg[b]	Ratio[c]
B20 Biodiesel	Idle	17.6	15.1	16.5	17.8	16.5	17.1	1.04
	Low Acceleration	5.32	8.26	6.99	5.48	6.67	6.08	0.87
	Medium Acceleration	4.22	4.55	4.41	4.91	3.78	4.34	0.98
	High Acceleration	4.01	3.04	3.47	4.96	4.29	4.63	1.33
	Low Cruise	6.03	5.39	5.68	6.62	4.72	5.67	1.00
	Medium Cruise	3.44	2.67	3.02	3.36	2.92	3.14	1.04
	High Cruise	3.23	3.27	3.25	5.19	2.45	3.82	1.17
	Deceleration	3.39	2.67	2.99	4.71	3.47	4.09	1.37
	Dumping				8.38	5.99	7.18	
	Equal Weight Avg[b]	5.91	5.62	5.79	6.82	5.64	6.23	1.08
	Empirical Weight Avg[d]	5.82	7.48	6.65	8.87	6.72	7.80	1.17
Petroleum Diesel	Idle	16.9	12.7	14.8	17.4	13.0	15.2	1.03
	Low Acceleration	5.96	4.71	5.33	5.87	5.16	5.52	1.03
	Medium Acceleration	3.60	3.88	3.74	4.44	3.15	3.80	1.01
	High Acceleration	3.20	2.75	2.98	4.34	4.03	4.19	1.41
	Low Cruise	4.80	5.31	5.06	5.76	5.00	5.38	1.06
	Medium Cruise	4.44	4.32	4.38	5.19	4.22	4.70	1.07
	High Cruise	4.05	3.74	3.90	6.06	2.85	4.45	1.14
	Deceleration	7.57	7.30	7.43	7.34	6.81	7.07	0.95
	Dumping				28.4	10.8	19.6	
	Equal Weight Avg[b]	6.31	5.59	5.95	9.43	6.12	7.77	1.31
	Empirical Weight Avg[d]	10.6	7.66	9.12	10.9	5.31	8.09	0.89
B20/PD Ratio	Idle	1.04	1.19	1.11	1.02	1.27	1.13	
	Low Acceleration	0.893	1.75	1.31	0.934	1.29	1.10	
	Medium Acceleration	1.17	1.17	1.18	1.11	1.20	1.14	
	High Acceleration	1.25	1.11	1.16	1.14	1.06	1.11	
	Low Cruise	1.26	1.02	1.12	1.15	0.944	1.05	
	Medium Cruise	0.775	0.618	0.689	0.647	0.692	0.668	
	High Cruise	0.798	0.874	0.833	0.856	0.860	0.858	
	Dumping	0.448	0.366	0.402	0.642	0.510	0.579	
	Deceleration						0.366	
	Equal Weight Avg[b]	0.937	1.01	0.973	0.723	0.922	0.802	
	Empirical Weight Avg[d]	0.549	0.977	0.729	0.814	1.27	0.964	

Table A-57. Continued

CO (g/gallon)	Driving Mode[a]	Unloaded Vehicle Number 0125	Unloaded Vehicle Number 0126	Unloaded Avg[b]	Loaded Vehicle Number 0125	Loaded Vehicle Number 0126	Loaded Avg[b]	Ratio[c]
B20 Biodiesel	Idle	44.6	37.9	41.2	44.8	37.7	41.3	1.00
	Low Acceleration	25.0	17.5	21.2	23.2	15.0	19.1	0.90
	Medium Acceleration	15.6	11.6	13.6	11.6	9.60	10.6	0.78
	High Acceleration	13.5	11.8	12.6	14.1	11.2	12.6	1.00
	Low Cruise	26.1	24.5	25.3	24.8	19.0	21.9	0.87
	Medium Cruise	19.8	14.3	17.0	13.9	12.4	13.2	0.77
	High Cruise	15.1	18.0	16.6	14.6	14.2	14.4	0.87
	Deceleration	15.8	16.9	16.3	15.3	16.4	15.9	0.97
	Dumping				28.4	27.2	27.8	
	Equal Weight Avg[b]	21.9	19.1	20.5	21.2	18.1	19.6	0.96
	Empirical Weight Avg[d]	21.1	24.5	22.8	24.6	20.5	22.6	0.99
Petroleum Diesel	Idle	37.2	34.6	35.9	36.4	36.9	36.7	1.02
	Low Acceleration	22.9	23.0	23.0	23.0	20.0	21.5	0.94
	Medium Acceleration	15.6	18.1	16.9	14.2	16.9	15.6	0.92
	High Acceleration	12.6	13.0	12.8	11.4	16.0	13.7	1.07
	Low Cruise	21.9	38.6	30.2	23.1	39.7	31.4	1.04
	Medium Cruise	20.2	19.8	20.0	15.6	19.4	17.5	0.87
	High Cruise	16.1	20.1	18.1	18.1	14.6	16.3	0.90
	Deceleration	26.0	24.7	25.3	23.4	24.4	23.9	0.94
	Dumping				89.9	27.0	58.5	
	Equal Weight Avg[b]	21.6	24.0	22.8	28.3	23.9	26.1	1.15
	Empirical Weight Avg[d]	28.1	26.9	27.5	28.8	21.8	25.3	0.92
B20/PD Ratio	Idle	1.20	1.10	1.15	1.23	1.02	1.13	
	Low Acceleration	1.09	0.761	0.922	1.01	0.750	0.888	
	Medium Acceleration	1.00	0.641	0.805	0.817	0.568	0.679	
	High Acceleration	1.07	0.908	0.984	1.24	0.700	0.920	
	Low Cruise	1.19	0.635	0.838	1.07	0.479	0.697	
	Medium Cruise	0.980	0.722	0.850	0.891	0.639	0.754	
	High Cruise	0.938	0.896	0.917	0.807	0.973	0.883	
	Dumping	0.608	0.684	0.644	0.654	0.672	0.665	
	Deceleration						0.475	
	Equal Weight Avg[b]	1.01	0.796	0.899	0.749	0.757	0.751	
	Empirical Weight Avg[d]	0.751	0.911	0.829	0.854	0.940	0.893	

Table A-57. Continued

CO_2 (kg/gallon)	Driving Mode[a]	Unloaded Vehicle Number 0125	Unloaded Vehicle Number 0126	Unloaded Avg[b]	Loaded Vehicle Number 0125	Loaded Vehicle Number 0126	Loaded Avg[b]	Ratio[c]
B20 Biodiesel	Idle	9.85	9.86	9.85	9.67	10.2	9.96	1.01
	Low Acceleration	9.91	9.91	9.91	9.92	9.93	9.93	1.00
	Medium Acceleration	9.93	9.93	9.93	9.94	9.94	9.94	1.00
	High Acceleration	9.94	9.93	9.94	9.94	9.95	9.94	1.00
	Low Cruise	9.91	9.91	9.91	9.92	9.92	9.92	1.00
	Medium Cruise	9.92	9.93	9.93	9.94	9.94	9.94	1.00
	High Cruise	9.93	9.93	9.93	9.94	9.94	9.94	1.00
	Deceleration	9.92	9.92	9.92	9.93	9.93	9.93	1.00
	Dumping				9.89	9.89	9.89	
	Equal Weight Avg[b]	9.91	9.92	9.92	9.90	9.97	9.93	1.00
	Empirical Weight Avg[d]	9.91	9.91	9.91	9.85	10.0	9.94	1.00
Petroleum Diesel	Idle	9.30	9.97	9.64	9.15	10.2	9.68	1.00
	Low Acceleration	10.0	10.0	10.0	10.0	10.0	10.0	1.00
	Medium Acceleration	10.0	10.1	10.1	10.2	10.1	10.1	1.00
	High Acceleration	10.0	10.0	10.0	10.0	10.0	10.0	1.00
	Low Cruise	10.0	10.0	10.0	10.0	10.0	10.0	1.00
	Medium Cruise	10.0	10.0	10.0	10.0	10.0	10.0	1.00
	High Cruise	10.0	10.0	10.0	10.0	10.0	10.0	1.00
	Deceleration	10.0	10.0	10.0	10.0	10.0	10.0	1.00
	Dumping				9.85	10.0	9.92	
	Equal Weight Avg[b]	9.93	10.0	10.0	9.92	10.1	10.2	1.00
	Empirical Weight Avg[d]	9.68	10.0	9.84	9.74	10.1	10.1	1.02
B20/PD Ratio	Idle	1.06	0.989	1.02	1.06	1.00	1.03	
	Low Acceleration	0.991	0.991	0.991	0.992	0.993	0.993	
	Medium Acceleration	0.993	0.983	0.983	0.975	0.984	0.984	
	High Acceleration	0.994	0.993	0.994	0.994	0.995	0.994	
	Low Cruise	0.991	0.991	0.991	0.992	0.992	0.992	
	Medium Cruise	0.992	0.993	0.993	0.994	0.994	0.994	
	High Cruise	0.993	0.993	0.993	0.994	0.994	0.994	
	Dumping	0.992	0.992	0.992	0.993	0.993	0.993	
	Deceleration						0.997	
	Equal Weight Avg[b]	0.998	0.992	0.992	0.998	0.987	0.974	
	Empirical Weight Avg[d]	1.02	0.991	1.01	1.01	0.990	0.984	

Table A-57. Continued

PM (g/gallon)	Driving Mode[a]	Unloaded Vehicle Number 0125	Unloaded Vehicle Number 0126	Unloaded Avg[b]	Loaded Vehicle Number 0125	Loaded Vehicle Number 0126	Loaded Avg[b]	Ratio[c]
B20 Biodiesel	Idle	0.628	0.580	0.604	0.612	0.572	0.592	0.98
	Low Acceleration	0.478	0.451	0.465	0.595	0.423	0.509	1.09
	Medium Acceleration	0.541	0.410	0.475	0.567	0.420	0.494	1.04
	High Acceleration	0.655	0.442	0.549	0.576	0.470	0.523	0.95
	Low Cruise	0.533	0.374	0.453	0.459	0.346	0.402	0.89
	Medium Cruise	0.424	0.275	0.349	0.402	0.389	0.395	1.13
	High Cruise	0.423	0.324	0.373	0.334	0.331	0.332	0.89
	Deceleration	0.291	0.390	0.340	0.358	0.381	0.369	1.08
	Dumping				0.091	0.716	0.404	
	Equal Weight Avg[b]	0.497	0.406	0.451	0.444	0.450	0.447	0.99
	Empirical Weight Avg[d]	0.471	0.424	0.447	0.466	0.418	0.442	0.99
Petroleum Diesel	Idle	0.406	0.625	0.516	0.419	0.634	0.527	1.02
	Low Acceleration	0.464	0.510	0.487	0.562	0.528	0.545	1.12
	Medium Acceleration	0.532	0.641	0.586	0.618	0.634	0.626	1.07
	High Acceleration	0.597	0.517	0.557	0.625	0.519	0.572	1.03
	Low Cruise	0.372	0.399	0.385	0.501	0.415	0.458	1.19
	Medium Cruise	0.446	0.385	0.416	0.484	0.481	0.483	1.16
	High Cruise	0.438	0.380	0.409	0.580	0.380	0.480	1.17
	Deceleration	0.567	0.458	0.513	0.525	0.428	0.476	0.93
	Dumping				1.87	0.604	1.24	
	Equal Weight Avg[b]	0.478	0.489	0.483	0.688	0.514	0.601	1.24
	Empirical Weight Avg[d]	0.441	0.508	0.475	0.584	0.472	0.528	1.11
B20/PD Ratio	Idle	1.55	0.928	1.17	1.46	0.902	1.12	
	Low Acceleration	1.03	0.884	0.955	1.06	0.801	0.934	
	Medium Acceleration	1.02	0.640	0.811	0.917	0.662	0.789	
	High Acceleration	1.10	0.855	0.986	0.922	0.906	0.914	
	Low Cruise	1.43	0.937	1.18	0.916	0.834	0.878	
	Medium Cruise	0.951	0.714	0.839	0.831	0.809	0.818	
	High Cruise	0.966	0.853	0.912	0.576	0.871	0.692	
	Dumping	0.513	0.852	0.663	0.682	0.890	0.775	
	Deceleration						0.326	
	Equal Weight Avg[b]	1.04	0.830	0.934	0.645	0.875	0.744	
	Empirical Weight Avg[d]	1.07	0.835	0.941	0.798	0.886	0.837	

Table A-58. The Ratio of B20 to Petroleum Diesel by Driving Mode and individual Vehicles for Tier 2 Single Axle Dump Trucks

NO_x (kg/gallon)	Driving Mode[a]	Unloaded			Loaded			
		Vehicle Number		Avg[b]	Vehicle Number		Avg[b]	Ratio[c]
		6117	**6123**		**6117**	**6123**		
B20 Biodiesel	Idle	0.104	0.163	0.134	0.103	0.144	0.124	0.92
	Low Acceleration	0.100	0.168	0.134	0.108	0.169	0.138	1.03
	Medium Acceleration	0.085	0.136	0.110	0.102	0.169	0.136	1.23
	High Acceleration	0.089	0.157	0.123	0.074	0.166	0.120	0.98
	Low Cruise	0.078	0.085	0.082	0.065	0.127	0.096	1.18
	Medium Cruise	0.071	0.100	0.085	0.092	0.097	0.094	1.11
	High Cruise	0.062	0.088	0.075	0.065	0.096	0.080	1.07
	Deceleration	0.058	0.088	0.073	0.063	0.108	0.086	1.18
	Dumping				0.096	0.110	0.103	
	Equal Weight Avg[b]	0.081	0.123	0.102	0.085	0.132	0.109	1.07
	Empirical Weight Avg[d]	0.083	0.119	0.101	0.088	0.127	0.107	1.06
Petroleum Diesel	Idle	0.141	0.155	0.148	0.152	0.148	0.150	1.01
	Low Acceleration	0.109	0.135	0.122	0.122	0.141	0.131	1.07
	Medium Acceleration	0.106	0.125	0.116	0.119	0.139	0.129	1.12
	High Acceleration	0.116	0.124	0.120	0.122	0.124	0.123	1.02
	Low Cruise	0.087	0.112	0.100	0.094	0.108	0.101	1.01
	Medium Cruise	0.091	0.093	0.092	0.092	0.089	0.090	0.98
	High Cruise	0.075	0.087	0.081	0.093	0.107	0.100	1.22
	Deceleration	0.088	0.080	0.084	0.101	0.095	0.098	1.17
	Dumping				0.101	0.122	0.112	
	Equal Weight Avg[b]	0.102	0.114	0.108	0.112	0.119	0.115	1.07
	Empirical Weight Avg[d]	0.118	0.128	0.123	0.130	0.135	0.132	1.07
B20/PD Ratio	Idle	0.738	1.05	0.905	0.678	0.973	0.827	
	Low Acceleration	0.917	1.24	1.10	0.885	1.20	1.05	
	Medium Acceleration	0.802	1.09	0.948	0.857	1.22	1.05	
	High Acceleration	0.767	1.27	1.03	0.607	1.34	0.976	
	Low Cruise	0.897	0.759	0.820	0.691	1.18	0.950	
	Medium Cruise	0.780	1.08	0.924	1.00	1.09	1.04	
	High Cruise	0.827	1.01	0.926	0.699	0.897	0.800	
	Dumping	0.659	1.10	0.869	0.624	1.14	0.878	
	Deceleration						0.920	
	Equal Weight Avg[b]	0.794	1.08	0.944	0.759	1.11	0.948	
	Empirical Weight Avg[d]	0.703	0.930	0.821	0.677	0.941	0.811	

Table A-58. Continued

HC (g/gallon)	Driving Mode[a]	Unloaded: Vehicle Number 6117	Unloaded: Vehicle Number 6123	Unloaded: Avg[b]	Loaded: Vehicle Number 6117	Loaded: Vehicle Number 6123	Loaded: Avg[b]	Ratio[c]
B20 Biodiesel	Idle	10.8	16.1	13.4	11.1	14.9	13.0	0.97
	Low Acceleration	4.71	5.32	5.01	5.34	3.21	4.28	0.85
	Medium Acceleration	3.67	2.08	2.87	3.06	1.92	2.49	0.87
	High Acceleration	3.42	2.59	3.00	3.18	2.64	2.91	0.97
	Low Cruise	7.11	3.39	5.25	6.18	2.93	4.56	0.87
	Medium Cruise	3.70	2.02	2.86	3.16	1.58	2.37	0.83
	High Cruise	4.23	2.47	3.35	4.62	2.09	3.36	1.00
	Deceleration	4.74	3.24	3.99	5.52	2.91	4.22	1.06
	Dumping				3.91	7.15	5.53	
	Equal Weight Avg[b]	5.30	4.65	4.97	5.12	4.38	4.75	0.96
	Empirical Weight Avg[d]	6.49	6.64	6.57	6.21	3.21	4.71	0.72
Petroleum Diesel	Idle	17.7	16.6	17.2	17.8	15.0	16.4	0.96
	Low Acceleration	3.60	3.68	3.64	4.09	4.57	4.33	1.19
	Medium Acceleration	3.46	3.34	3.40	2.97	3.85	3.41	1.00
	High Acceleration	2.97	3.28	3.13	2.66	4.18	3.42	1.09
	Low Cruise	5.12	4.58	4.85	5.51	5.12	5.32	1.10
	Medium Cruise	4.22	4.20	4.21	3.19	2.97	3.08	0.73
	High Cruise	3.52	2.69	3.11	3.65	3.44	3.54	1.14
	Deceleration	5.79	3.51	4.65	6.31	3.67	4.99	1.07
	Dumping				14.1	7.19	10.7	
	Equal Weight Avg[b]	5.80	5.23	5.52	6.70	5.56	6.13	1.11
	Empirical Weight Avg[d]	10.9	10.2	10.6	11.6	11.0	11.3	1.07
B20/PD Ratio	Idle	0.610	0.970	0.779	0.624	0.993	0.793	
	Low Acceleration	1.31	1.45	1.38	1.31	0.702	0.988	
	Medium Acceleration	1.06	0.623	0.844	1.03	0.499	0.730	
	High Acceleration	1.15	0.790	0.958	1.20	0.632	0.851	
	Low Cruise	1.39	0.740	1.08	1.12	0.572	0.857	
	Medium Cruise	0.877	0.481	0.679	0.991	0.532	0.769	
	High Cruise	1.20	0.918	1.08	1.27	0.608	0.949	
	Dumping	0.819	0.923	0.858	0.875	0.793	0.846	
	Deceleration						0.517	
	Equal Weight Avg[b]	0.914	0.889	0.900	0.764	0.788	0.775	
	Empirical Weight Avg[d]	0.595	0.651	0.620	0.535	0.292	0.417	

Table A-58. Continued

CO (g/gallon)	Driving Mode[a]	Unloaded Vehicle Number 6117	Unloaded Vehicle Number 6123	Unloaded Avg[b]	Loaded Vehicle Number 6117	Loaded Vehicle Number 6123	Loaded Avg[b]	Ratio[c]
B20 Biodiesel	Idle	39.9	47.4	43.7	39.1	42.8	40.9	0.94
	Low Acceleration	16.6	18.3	17.4	18.8	15.6	17.2	0.99
	Medium Acceleration	14.6	11.0	12.8	13.0	9.07	11.0	0.86
	High Acceleration	13.4	10.7	12.1	11.7	10.3	11.0	0.92
	Low Cruise	24.9	12.8	18.8	22.9	9.85	16.4	0.87
	Medium Cruise	13.1	10.6	11.9	11.7	8.93	10.3	0.87
	High Cruise	12.2	12.6	12.4	13.9	11.2	12.6	1.02
	Deceleration	15.4	15.3	15.3	20.3	15.6	18.0	1.17
	Dumping				41.1	25.8	33.5	
	Equal Weight Avg[b]	18.8	17.9	18.4	21.4	16.6	19.5	1.06
	Empirical Weight Avg[d]	23.3	22.9	23.1	23.1	13.7	18.4	0.80
Petroleum Diesel	Idle	78.0	55.7	66.8	79.5	51.5	65.5	0.98
	Low Acceleration	22.1	25.6	23.9	24.0	23.9	23.9	1.00
	Medium Acceleration	13.9	13.7	13.8	12.5	13.4	13.0	0.94
	High Acceleration	11.9	11.2	11.5	11.6	11.1	11.3	0.98
	Low Cruise	22.8	19.3	21.1	22.4	22.7	22.6	1.07
	Medium Cruise	12.7	14.2	13.4	11.1	10.4	10.7	0.80
	High Cruise	10.9	9.62	10.3	11.3	9.90	10.6	1.03
	Deceleration	18.2	11.6	14.9	19.0	13.2	16.1	1.08
	Dumping				53.8	27.4	40.6	
	Equal Weight Avg[b]	23.8	20.1	22.0	27.2	20.4	23.8	1.08
	Empirical Weight Avg[d]	46.5	35.0	40.7	50.4	38.5	44.4	1.09
B20/PD Ratio	Idle	0.512	0.851	0.654	0.492	0.831	0.624	
	Low Acceleration	0.751	0.715	0.728	0.783	0.653	0.720	
	Medium Acceleration	1.05	0.803	0.928	1.04	0.677	0.846	
	High Acceleration	1.13	0.955	1.05	1.01	0.928	0.973	
	Low Cruise	1.09	0.663	0.891	1.02	0.436	0.726	
	Medium Cruise	1.03	0.746	0.888	1.05	0.859	0.960	
	High Cruise	1.12	1.31	1.20	1.23	1.13	1.19	
	Dumping	0.846	1.32	1.03	1.07	1.18	1.12	
	Deceleration						0.825	
	Equal Weight Avg[b]	0.790	0.891	0.836	0.787	0.814	0.819	
	Empirical Weight Avg[d]	0.501	0.654	0.568	0.458	0.356	0.414	

Table A-58. Continued

CO_2 (kg/gallon)	Driving Mode[a]	Unloaded 6117	Unloaded 6123	Unloaded Avg[b]	Loaded 6117	Loaded 6123	Loaded Avg[b]	Ratio[c]
B20 Biodiesel	Idle	9.87	9.85	9.86	9.97	9.81	9.89	1.00
	Low Acceleration	9.91	9.93	9.92	9.91	9.90	9.90	1.00
	Medium Acceleration	9.93	9.94	9.94	9.94	9.95	9.95	1.00
	High Acceleration	9.94	9.95	9.94	9.28	10.5	9.90	1.00
	Low Cruise	9.91	9.92	9.91	9.68	9.98	9.83	0.99
	Medium Cruise	9.94	9.95	9.94	9.95	9.89	9.92	1.00
	High Cruise	9.94	9.95	9.94	9.89	9.95	9.92	1.00
	Deceleration	9.93	9.93	9.93	9.94	9.95	9.94	1.00
	Dumping				9.89	9.91	9.90	
	Equal Weight Avg[b]	9.92	9.93	9.92	9.80	9.98	9.91	1.00
	Empirical Weight Avg[d]	9.91	9.92	9.91	9.90	9.95	9.92	1.00
Petroleum Diesel	Idle	9.89	9.93	9.91	9.90	9.95	9.93	1.00
	Low Acceleration	10.0	10.0	10.0	10.0	10.0	10.0	1.00
	Medium Acceleration	10.0	10.0	10.0	9.92	10.0	10.0	1.00
	High Acceleration	10.3	10.0	10.2	10.4	9.95	10.2	1.00
	Low Cruise	10.0	10.0	10.0	10.7	9.31	10.0	1.00
	Medium Cruise	10.0	10.0	10.0	10.0	10.0	10.0	1.00
	High Cruise	10.0	10.0	10.0	10.0	10.0	10.0	1.00
	Deceleration	10.0	10.0	10.0	10.0	10.0	10.0	1.00
	Dumping				9.94	10.0	9.97	
	Equal Weight Avg[b]	10.0	10.0	10.0	10.1	9.93	10.0	1.00
	Empirical Weight Avg[d]	10.0	10.0	10.0	10.0	9.91	10.0	1.00
B20/PD Ratio	Idle	0.998	0.992	0.995	1.01	0.986	0.996	
	Low Acceleration	0.991	0.993	0.992	0.990	0.990	0.990	
	Medium Acceleration	0.993	0.994	0.994	1.00	0.995	0.995	
	High Acceleration	0.965	0.995	0.975	0.894	1.06	0.971	
	Low Cruise	0.991	0.992	0.991	0.905	1.07	0.983	
	Medium Cruise	0.994	0.995	0.994	0.995	0.989	0.992	
	High Cruise	0.994	0.995	0.994	0.989	0.995	0.992	
	Dumping	0.993	0.993	0.993	0.994	0.995	0.994	
	Deceleration				0.995	0.991	0.993	
	Equal Weight Avg[b]	0.992	0.993	0.992	0.970	1.01	0.991	
	Empirical Weight Avg[d]	0.991	0.992	0.991	0.990	1.00	0.992	

Table A-58. Continued

PM (g/gallon)	Driving Mode[a]	Unloaded 6117	Unloaded 6123	Unloaded Avg[b]	Loaded 6117	Loaded 6123	Loaded Avg[b]	Ratio[c]
B20 Biodiesel	Idle	0.521	0.499	0.510	0.538	0.539	0.538	1.06
	Low Acceleration	0.733	0.390	0.562	0.751	0.463	0.607	1.08
	Medium Acceleration	0.675	0.461	0.568	0.730	0.472	0.601	1.06
	High Acceleration	0.785	0.567	0.676	0.658	0.614	0.636	0.94
	Low Cruise	0.653	0.221	0.437	0.525	0.302	0.413	0.95
	Medium Cruise	0.550	0.408	0.479	0.610	0.354	0.482	1.01
	High Cruise	0.638	0.538	0.588	0.687	0.452	0.570	0.97
	Deceleration	0.491	0.426	0.458	0.545	0.395	0.470	1.02
	Dumping				0.541	0.499	0.520	
	Equal Weight Avg[b]	0.631	0.439	0.535	0.621	0.454	0.537	1.01
	Empirical Weight Avg[d]	0.582	0.470	0.526	0.599	0.414	0.506	0.96
Petroleum Diesel	Idle	0.574	0.689	0.632	0.624	0.657	0.641	1.01
	Low Acceleration	0.590	0.489	0.540	0.652	0.924	0.788	1.46
	Medium Acceleration	0.735	0.526	0.631	0.606	0.637	0.621	0.99
	High Acceleration	0.688	0.724	0.706	0.745	0.747	0.746	1.06
	Low Cruise	0.761	0.454	0.607	0.792	0.477	0.634	1.04
	Medium Cruise	0.645	0.465	0.555	0.624	0.483	0.554	1.00
	High Cruise	0.694	0.618	0.656	0.673	0.603	0.638	0.97
	Deceleration	0.872	0.477	0.674	0.879	0.468	0.674	1.00
	Dumping				0.972	0.511	0.742	
	Equal Weight Avg[b]	0.695	0.555	0.625	0.730	0.612	0.671	1.07
	Empirical Weight Avg[d]	0.656	0.629	0.643	0.672	0.631	0.651	1.01
B20/PD Ratio	Idle	0.908	0.724	0.807	0.862	0.820	0.839	
	Low Acceleration	1.24	0.798	1.04	1.15	0.501	0.770	
	Medium Acceleration	0.918	0.876	0.900	1.20	0.741	0.968	
	High Acceleration	1.14	0.783	0.958	0.883	0.822	0.853	
	Low Cruise	0.858	0.487	0.720	0.663	0.633	0.651	
	Medium Cruise	0.853	0.877	0.863	0.978	0.733	0.870	
	High Cruise	0.919	0.871	0.896	1.02	0.750	0.893	
	Dumping	0.563	0.893	0.680	0.620	0.844	0.697	
	Deceleration						0.701	
	Equal Weight Avg[b]	0.908	0.791	0.856	0.851	0.742	0.800	
	Empirical Weight Avg[d]	0.887	0.747	0.818	0.891	0.656	0.777	

Table A-59. NO_x Emissions Corrected Ratio of B20 to Petroleum Diesel on a Per Time Basis by Driving Mode, Vehicle, and Load for Tier 1 Tandem Dump Trucks.

		Unloaded					**Loaded**					
NO_x (g/sec)	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	Ratio[c]
		0507	**0578**	**0579**	**0580**		**0507**	**0578**	**0579**	**0580**		
B20 Biodiesel	Idle	0.019	0.021	0.026	0.016	0.021	0.021	0.021	0.026	0.016	0.021	1.03
	Low Acceleration	0.076	0.105	0.090	0.056	0.082	0.092	0.129	0.120	0.073	0.103	1.27
	Medium Acceleration	0.131	0.151	0.154	0.099	0.134	0.149	0.236	0.189	0.119	0.173	1.29
	High Acceleration	0.176	0.169	0.215	0.126	0.172	0.194	0.299	0.220	0.188	0.225	1.31
	Low Cruise	0.050	0.064	0.083	0.033	0.058	0.053	0.109	0.108	0.048	0.080	1.38
	Medium Cruise	0.089	0.112	0.124	0.081	0.102	0.111	0.230	0.163	0.118	0.156	1.53
	High Cruise	0.145	0.182	0.258	0.113	0.174	0.175	0.225	0.262	0.138	0.200	1.15
	Deceleration	0.048	0.064	0.081	0.044	0.059	0.063	0.100	0.098	0.071	0.083	1.39
	Dumping						0.045	0.061	0.086	0.040	0.058	
	Equal Weight Avg[b]	0.092	0.109	0.129	0.071	0.100	0.100	0.157	0.141	0.090	0.122	1.22
	Empirical Weight Avg[d]	0.088	0.074	0.072	0.041	0.069	0.055	0.089	0.095	0.030	0.067	0.97
Petroleum Diesel	Idle	0.022	0.019	0.015	0.017	0.018	0.022	0.020	0.018	0.017	0.019	1.06
	Low Acceleration	0.091	0.074	0.082	0.104	0.088	0.145	0.104	0.139	0.112	0.125	1.43
	Medium Acceleration	0.190	0.134	0.134	0.170	0.157	0.277	0.184	0.188	0.178	0.207	1.32
	High Acceleration	0.230	0.168	0.191	0.216	0.201	0.327	0.240	0.256	0.284	0.277	1.38
	Low Cruise	0.058	0.079	0.064	0.034	0.059	0.109	0.115	0.097	0.054	0.094	1.60
	Medium Cruise	0.138	0.100	0.118	0.083	0.110	0.285	0.184	0.181	0.122	0.193	1.75
	High Cruise	0.230	0.117	0.185	0.117	0.162	0.307	0.288	0.198	0.175	0.242	1.49
	Deceleration	0.078	0.048	0.081	0.046	0.063	0.147	0.121	0.132	0.073	0.118	1.87
	Dumping						0.061	0.070	0.047	0.042	0.055	
	Equal Weight Avg[b]	0.129	0.093	0.109	0.098	0.107	0.187	0.147	0.140	0.117	0.148	1.38
	Empirical Weight Avg[d]	0.099	0.049	0.050	0.036	0.058	0.183	0.128	0.151	0.058	0.130	2.23
B20/PD Ratio	Idle	0.856	1.08	1.72	0.971	1.12	0.932	1.03	1.43	0.971	1.09	
	Low Acceleration	0.833	1.42	1.10	0.536	0.932	0.636	1.24	0.859	0.647	0.826	
	Medium Acceleration	0.691	1.13	1.15	0.583	0.852	0.536	1.28	1.00	0.671	0.838	
	High Acceleration	0.765	1.00	1.13	0.584	0.852	0.593	1.24	0.857	0.661	0.812	
	Low Cruise	0.857	0.816	1.30	0.971	0.980	0.485	0.946	1.11	0.896	0.849	
	Medium Cruise	0.645	1.12	1.05	0.976	0.923	0.390	1.25	0.900	0.967	0.807	
	High Cruise	0.633	1.55	1.39	0.966	1.08	0.569	0.782	1.33	0.791	0.828	
	Deceleration	0.620	1.33	0.999	0.957	0.941	0.427	0.825	0.739	0.973	0.700	
	Dumping						0.742	0.874	1.82	0.952	1.06	
	Equal Weight Avg[b]	0.708	1.17	1.18	0.723	0.933	0.537	1.06	1.01	0.769	0.826	
	Empirical Weight Avg[d]	0.895	1.50	1.43	1.16	1.18	0.299	0.691	0.626	0.519	0.515	

Table A-60. NO_x Emissions Corrected Ratio of B20 to Petroleum Diesel on a Per Mile Basis by Driving Mode, Vehicle, and Load for Tier 1 Tandem Dump Trucks.

NO_x (g/mile)	Driving Mode[a]	Unloaded					Loaded					Ratio[c]
		Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	
		0507	**0578**	**0579**	**0580**		**0507**	**057**	**0579**	**0580**		
B20 Biodiesel	Low Acceleration	30.7	29.2	29.3	27.1	29.1	33.3	37.4	34.7	32.8	34.6	1.19
	Medium Acceleration	13.9	17.0	19.0	10.0	15.0	16.0	26.8	22.2	12.7	19.4	1.30
	High Acceleration	15.3	15.4	18.5	10.8	15.0	17.6	22.2	19.1	14.1	18.3	1.22
	Low Cruise	17.3	17.3	27.7	15.8	19.5	18.9	35.1	34.3	13.1	25.3	1.30
	Medium Cruise	7.93	10.1	11.0	7.20	9.07	10.2	21.8	15.1	10.5	14.4	1.59
	High Cruise	9.53	13.1	16.6	7.99	11.8	12.9	13.3	17.1	9.67	13.2	1.12
	Deceleration	5.72	8.65	12.0	6.83	8.29	9.75	12.1	14.8	9.23	11.5	1.38
	Equal Weight Avg[b]	14.3	15.8	19.2	12.2	15.4	16.9	24.1	22.5	14.6	19.5	1.27
	Empirical Weight Avg[d]	11.5	14.3	19.0	11.3	14.0	15.6	23.2	22.1	13.0	18.5	1.32
Petroleum Diesel	Low Acceleration	39.7	25.7	32.6	40.0	34.5	48.8	36.2	37.9	51.9	43.7	1.27
	Medium Acceleration	21.1	14.1	14.3	22.4	18.0	30.7	21.4	19.5	21.4	23.2	1.30
	High Acceleration	18.6	14.3	15.1	24.2	18.0	26.0	16.9	23.1	31.3	24.3	1.35
	Low Cruise	21.3	27.4	17.8	12.3	19.7	31.4	30.7	18.0	19.1	24.8	1.26
	Medium Cruise	12.7	9.08	11.0	7.66	10.1	26.1	17.1	16.6	12.1	18.0	1.78
	High Cruise	14.7	7.61	11.6	8.65	10.6	22.1	16.9	14.5	13.6	16.8	1.58
	Deceleration	9.57	5.89	10.4	11.2	9.26	21.9	18.0	13.9	18.4	18.1	1.95
	Equal Weight Avg[b]	19.7	14.9	16.1	18.1	17.2	29.6	22.4	20.5	24.0	24.1	1.40
	Empirical Weight Avg[d]	17.0	12.5	15.0	18.1	15.7	28.9	22.0	18.6	24.0	23.4	1.49
B20/PD Ratio	Low Acceleration	0.774	1.14	0.898	0.676	0.843	0.684	1.03	0.916	0.632	0.791	
	Medium Acceleration	0.658	1.21	1.33	0.449	0.834	0.519	1.25	1.14	0.594	0.835	
	High Acceleration	0.823	1.08	1.23	0.447	0.832	0.676	1.31	0.825	0.452	0.750	
	Low Cruise	0.809	0.633	1.56	1.28	0.991	0.603	1.14	1.91	0.687	1.02	
	Medium Cruise	0.625	1.11	0.999	0.940	0.896	0.391	1.27	0.907	0.868	0.800	
	High Cruise	0.647	1.72	1.43	0.924	1.11	0.583	0.788	1.18	0.709	0.790	
	Deceleration	0.598	1.47	1.15	0.608	0.895	0.445	0.674	1.07	0.501	0.636	
	Equal Weight Avg[b]	0.729	1.07	1.19	0.678	0.896	0.573	1.07	1.10	0.609	0.809	
	Empirical Weight Avg[d]	0.674	1.15	1.26	0.625	0.895	0.540	1.06	1.19	0.541	0.791	

Table A-61. NO_x Emissions Corrected Ratio of B20 to Petroleum Diesel on a Per Gallon Basis by Driving Mode, Vehicle, and Load for Tier 1 Tandem Dump Trucks.

NO_x (kg/gallon)	Driving Mode[a]	Unloaded					Loaded					Ratio[c]
		Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	
		0507	**0578**	**0579**	**0580**		**0507**	**0578**	**0579**	**0580**		
B20 Biodiesel	Idle	0.198	0.164	0.191	0.159	0.178	0.223	0.163	0.189	0.135	0.177	1.00
	Low Acceleration	0.087	0.090	0.086	0.100	0.091	0.063	0.087	0.083	0.084	0.079	0.87
	Medium Acceleration	0.090	0.100	0.095	0.092	0.094	0.088	0.105	0.095	0.080	0.092	0.98
	High Acceleration	0.102	0.093	0.103	0.094	0.098	0.098	0.129	0.097	0.119	0.111	1.13
	Low Cruise	0.095	0.062	0.096	0.108	0.090	0.095	0.092	0.103	0.082	0.093	1.03
	Medium Cruise	0.097	0.091	0.093	0.082	0.091	0.095	0.135	0.102	0.084	0.104	1.15
	High Cruise	0.131	0.136	0.153	0.091	0.127	0.145	0.141	0.137	0.099	0.131	1.02
	Deceleration	0.114	0.175	0.110	0.098	0.124	0.116	0.156	0.110	0.088	0.118	0.95
	Dumping						0.097	0.084	0.128	0.107	0.104	
	Equal Weight Avg[b]	0.114	0.114	0.116	0.103	0.112	0.113	0.121	0.116	0.098	0.112	1.00
	Empirical Weight Avg[d]	0.128	0.140	0.159	0.132	0.140	0.176	0.144	0.146	0.127	0.148	1.06
Petroleum Diesel	Idle	0.245	0.232	0.234	0.123	0.208	0.234	0.224	0.261	0.120	0.210	1.01
	Low Acceleration	0.113	0.096	0.090	0.096	0.099	0.137	0.104	0.102	0.094	0.109	1.11
	Medium Acceleration	0.111	0.096	0.128	0.090	0.106	0.134	0.111	0.105	0.079	0.107	1.01
	High Acceleration	0.125	0.106	0.141	0.104	0.119	0.153	0.125	0.136	0.118	0.133	1.12
	Low Cruise	0.101	0.129	0.094	0.041	0.091	0.124	0.127	0.076	0.051	0.094	1.04
	Medium Cruise	0.117	0.105	0.092	0.085	0.100	0.148	0.117	0.108	0.082	0.114	1.14
	High Cruise	0.156	0.106	0.157	0.106	0.131	0.178	0.187	0.124	0.098	0.147	1.12
	Deceleration	0.126	0.103	0.115	0.092	0.109	0.163	0.181	0.101	0.089	0.134	1.23
	Dumping						0.140	0.161	0.187	0.112	0.150	
	Equal Weight Avg[b]	0.137	0.122	0.131	0.092	0.120	0.157	0.148	0.133	0.094	0.133	1.10
	Empirical Weight Avg[d]	0.181	0.186	0.200	0.109	0.169	0.162	0.171	0.133	0.094	0.140	0.83
B20/PD Ratio	Idle	0.811	0.709	0.816	1.29	0.855	0.952	0.727	0.726	1.12	0.846	
	Low Acceleration	0.770	0.937	0.957	1.05	0.922	0.462	0.836	0.814	0.899	0.727	
	Medium Acceleration	0.812	1.04	0.741	1.02	0.887	0.655	0.950	0.907	1.02	0.859	
	High Acceleration	0.819	0.875	0.734	0.898	0.824	0.643	1.03	0.711	1.00	0.832	
	Low Cruise	0.937	0.482	1.02	2.65	0.990	0.768	0.722	1.37	1.60	0.986	
	Medium Cruise	0.827	0.866	1.00	0.960	0.907	0.637	1.15	0.940	1.03	0.913	
	High Cruise	0.838	1.27	0.973	0.855	0.970	0.813	0.757	1.11	1.01	0.890	
	Deceleration	0.907	1.70	0.953	1.06	1.14	0.712	0.865	1.09	0.984	0.880	
	Dumping						0.696	0.520	0.684	0.954	0.693	
	Equal Weight Avg[b]	0.836	0.936	0.882	1.12	0.927	0.723	0.817	0.871	1.04	0.842	
	Empirical Weight Avg[d]	0.708	0.751	0.795	1.22	0.827	1.09	0.844	1.10	1.35	1.06	

Table A-62. NO_x Emissions Corrected Ratio of B20 to Petroleum Diesel on a Per Time Basis by Driving Mode, Vehicle, and Load for Tier 1 Single Axle Dump Trucks.

		Unloaded					**Loaded**					
NO_x (g/sec)	Driving Mode[a]	Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	Ratio[c]
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**		
B20 Biodiesel	Idle	0.019	0.019	0.009	0.009	0.014	0.019	0.020	0.009	0.010	0.014	1.05
	Low Acceleration	0.070	0.073	0.039	0.038	0.055	0.091	0.081	0.056	0.048	0.069	1.26
	Medium Acceleration	0.120	0.110	0.064	0.080	0.093	0.142	0.137	0.087	0.112	0.120	1.28
	High Acceleration	0.126	0.126	0.080	0.089	0.105	0.140	0.151	0.084	0.100	0.119	1.13
	Low Cruise	0.058	0.075	0.031	0.028	0.048	0.078	0.096	0.033	0.039	0.061	1.28
	Medium Cruise	0.101	0.099	0.041	0.060	0.075	0.122	0.126	0.072	0.105	0.106	1.42
	High Cruise	0.105	0.105	0.058	0.054	0.081	0.145	0.116	0.070	0.074	0.101	1.26
	Deceleration	0.045	0.047	0.027	0.022	0.035	0.061	0.055	0.044	0.031	0.048	1.36
	Dumping						0.077	0.070	0.037	0.040	0.056	
	Equal Weight Avg[b]	0.080	0.082	0.044	0.047	0.063	0.097	0.095	0.055	0.062	0.077	1.22
	Empirical Weight Avg[d]	0.085	0.023	0.025	0.033	0.041	0.098	0.060	0.025	0.030	0.053	1.29
Petroleum Diesel	Idle	0.017	0.019	0.018	0.016	0.017	0.019	0.020	0.020	0.017	0.019	1.09
	Low Acceleration	0.071	0.051	0.053	0.053	0.057	0.103	0.069	0.095	0.074	0.085	1.50
	Medium Acceleration	0.128	0.117	0.130	0.134	0.127	0.171	0.150	0.198	0.175	0.173	1.36
	High Acceleration	0.174	0.151	0.177	0.186	0.172	0.178	0.160	0.242	0.208	0.197	1.14
	Low Cruise	0.048	0.046	0.036	0.036	0.042	0.074	0.053	0.059	0.047	0.058	1.40
	Medium Cruise	0.098	0.071	0.071	0.063	0.076	0.122	0.105	0.098	0.130	0.114	1.50
	High Cruise	0.100	0.111	0.127	0.119	0.114	0.110	0.122	0.140	0.180	0.138	1.21
	Deceleration	0.043	0.040	0.057	0.039	0.045	0.065	0.047	0.060	0.054	0.056	1.26
	Dumping						0.100	0.055	0.059	0.056	0.067	
	Equal Weight Avg[b]	0.085	0.076	0.084	0.081	0.081	0.104	0.087	0.108	0.105	0.101	1.24
	Empirical Weight Avg[d]	0.046	0.061	0.032	0.038	0.044	0.067	0.083	0.089	0.055	0.074	1.66
B20/PD Ratio	Idle	1.13	0.984	0.469	0.566	0.790	1.02	1.03	0.424	0.600	0.767	
	Low Acceleration	1.00	1.41	0.729	0.713	0.962	0.888	1.17	0.591	0.641	0.808	
	Medium Acceleration	0.932	0.942	0.490	0.595	0.733	0.831	0.910	0.442	0.639	0.689	
	High Acceleration	0.722	0.837	0.453	0.477	0.612	0.783	0.944	0.349	0.481	0.603	
	Low Cruise	1.20	1.63	0.873	0.765	1.15	1.06	1.82	0.566	0.826	1.06	
	Medium Cruise	1.03	1.38	0.580	0.956	0.992	1.00	1.20	0.739	0.809	0.935	
	High Cruise	1.05	0.944	0.459	0.459	0.706	1.32	0.954	0.503	0.412	0.736	
	Deceleration	1.05	1.17	0.472	0.566	0.785	0.942	1.16	0.736	0.577	0.846	
	Dumping						0.767	1.28	0.621	0.715	0.827	
	Equal Weight Avg[b]	0.948	1.08	0.521	0.588	0.778	0.930	1.09	0.508	0.594	0.765	
	Empirical Weight Avg[d]	1.83	0.370	0.784	0.868	0.932	1.47	0.718	0.279	0.548	0.724	

Table A-63. NO_x Emissions Corrected Ratio of B20 to Petroleum Diesel on a Per Mile Basis by Driving Mode, Vehicle, and Load for Tier 1 Single Axle Dump Trucks.

NO_x (g/mile)	Driving Mode[a]	Unloaded					Loaded					Ratio[c]
		Vehicle Number				Avg[b]	Vehicle Number				Avg[b]	
		4743	**4750**	**4869**	**4870**		**4743**	**4750**	**4869**	**4870**		
B20 Biodiesel	Low Acceleration	29.9	25.9	15.0	15.8	21.6	35.0	32.3	20.2	17.5	26.2	1.21
	Medium Acceleration	12.5	12.1	6.85	7.88	9.83	14.3	14.6	8.63	11.3	12.2	1.24
	High Acceleration	9.80	14.1	6.51	7.17	9.49	10.3	18.3	5.94	9.77	11.1	1.18
	Low Cruise	22.1	16.7	7.00	9.58	13.8	18.6	23.9	9.22	11.2	15.7	1.14
	Medium Cruise	9.40	8.43	3.84	5.41	6.77	11.0	11.3	6.46	9.77	9.65	1.43
	High Cruise	6.55	8.10	3.91	3.73	5.57	8.99	9.02	4.92	5.63	7.14	1.28
	Deceleration	4.96	6.35	3.07	2.54	4.23	6.37	8.17	4.85	4.46	5.96	1.41
	Equal Weight Avg[b]	13.6	13.1	6.60	7.44	10.2	14.9	16.8	8.60	9.96	12.6	1.23
	Empirical Weight Avg[d]	8.88	11.7	5.13	5.57	7.83	10.6	14.1	6.93	9.28	10.2	1.31
Petroleum Diesel	Low Acceleration	30.5	26.5	26.0	19.0	25.5	42.7	31.5	39.9	32.0	36.5	1.43
	Medium Acceleration	13.8	11.7	14.6	18.4	14.6	19.5	15.5	23.1	24.1	20.6	1.40
	High Acceleration	17.7	12.6	13.4	15.0	14.7	21.9	13.3	23.8	16.5	18.9	1.28
	Low Cruise	14.9	20.6	14.2	12.3	15.5	23.1	22.5	22.9	21.1	22.4	1.44
	Medium Cruise	8.95	6.52	6.67	6.71	7.21	11.4	9.47	9.36	14.3	11.1	1.54
	High Cruise	7.20	7.40	8.06	7.43	7.52	8.60	8.57	9.70	11.2	9.51	1.26
	Deceleration	6.15	4.78	7.05	6.58	6.14	12.2	6.23	9.70	10.6	9.67	1.57
	Equal Weight Avg[b]	14.2	12.9	12.9	12.2	13.0	19.9	15.3	19.8	18.5	18.4	1.41
	Empirical Weight Avg[d]	11.5	10.8	11.7	11.6	11.4	18.0	13.3	17.3	18.7	16.8	1.48
B20/PD Ratio	Low Acceleration	0.982	0.977	0.577	0.829	0.849	0.818	1.02	0.507	0.547	0.718	
	Medium Acceleration	0.904	1.04	0.467	0.428	0.672	0.732	0.940	0.374	0.470	0.594	
	High Acceleration	0.552	1.12	0.487	0.478	0.641	0.473	1.37	0.250	0.593	0.588	
	Low Cruise	1.48	0.813	0.494	0.776	0.893	0.804	1.06	0.403	0.532	0.703	
	Medium Cruise	1.05	1.29	0.576	0.805	0.938	0.970	1.20	0.690	0.683	0.867	
	High Cruise	0.910	1.09	0.485	0.502	0.741	1.04	1.05	0.508	0.504	0.751	
	Deceleration	0.805	1.33	0.435	0.387	0.689	0.524	1.31	0.500	0.422	0.617	
	Equal Weight Avg[b]	0.959	1.02	0.513	0.609	0.782	0.750	1.10	0.435	0.537	0.684	
	Empirical Weight Avg[d]	0.772	1.09	0.440	0.482	0.689	0.589	1.06	0.401	0.497	0.608	

Table A-64. NO_x Emissions Corrected Ratio of B20 to Petroleum Diesel on a Per Gallon Basis by Driving Mode, Vehicle, and Load for Tier 1 Single Axle Dump Trucks.

NO_x (kg/gallon)	Driving Mode[a]	Unloaded 4743	Unloaded 4750	Unloaded 4869	Unloaded 4870	Unloaded Avg[b]	Loaded 4743	Loaded 4750	Loaded 4869	Loaded 4870	Loaded Avg[b]	Ratio[c]
B20 Biodiesel	Idle	0.139	0.233	0.105	0.113	0.148	0.137	0.248	0.098	0.103	0.147	0.99
	Low Acceleration	0.093	0.146	0.078	0.074	0.098	0.099	0.100	0.090	0.073	0.091	0.92
	Medium Acceleration	0.077	0.101	0.067	0.064	0.077	0.080	0.099	0.065	0.068	0.078	1.00
	High Acceleration	0.070	0.099	0.060	0.060	0.072	0.068	0.101	0.054	0.065	0.072	1.00
	Low Cruise	0.121	0.126	0.069	0.074	0.098	0.089	0.106	0.065	0.078	0.084	0.86
	Medium Cruise	0.082	0.105	0.060	0.059	0.077	0.076	0.106	0.057	0.073	0.078	1.02
	High Cruise	0.060	0.085	0.048	0.050	0.060	0.077	0.084	0.053	0.060	0.068	1.13
	Deceleration	0.060	0.096	0.051	0.050	0.064	0.058	0.100	0.054	0.067	0.069	1.08
	Dumping						0.103	0.131	0.091	0.101	0.106	
	Equal Weight Avg[b]	0.088	0.124	0.067	0.068	0.087	0.087	0.119	0.070	0.076	0.088	1.02
	Empirical Weight Avg[d]	0.077	0.226	0.085	0.082	0.118	0.089	0.183	0.087	0.092	0.113	0.96
Petroleum Diesel	Idle	0.210	0.218	0.227	0.212	0.217	0.226	0.208	0.209	0.216	0.215	0.99
	Low Acceleration	0.176	0.107	0.146	0.124	0.139	0.165	0.117	0.148	0.123	0.138	1.00
	Medium Acceleration	0.149	0.082	0.132	0.116	0.120	0.147	0.085	0.140	0.121	0.123	1.03
	High Acceleration	0.171	0.092	0.116	0.110	0.122	0.151	0.080	0.136	0.111	0.119	0.98
	Low Cruise	0.186	0.129	0.148	0.148	0.153	0.170	0.133	0.125	0.138	0.142	0.93
	Medium Cruise	0.154	0.091	0.121	0.117	0.121	0.151	0.090	0.129	0.130	0.125	1.04
	High Cruise	0.109	0.077	0.090	0.081	0.089	0.104	0.078	0.090	0.095	0.092	1.03
	Deceleration	0.161	0.107	0.110	0.129	0.127	0.184	0.120	0.101	0.141	0.136	1.08
	Dumping						0.207	0.125	0.173	0.147	0.163	
	Equal Weight Avg[b]	0.164	0.113	0.136	0.130	0.136	0.167	0.115	0.139	0.136	0.139	1.02
	Empirical Weight Avg[d]	0.185	0.140	0.206	0.180	0.178	0.191	0.120	0.144	0.177	0.158	0.89
B20/PD Ratio	Idle	0.661	1.07	0.462	0.535	0.681	0.603	1.19	0.471	0.479	0.683	
	Low Acceleration	0.530	1.36	0.531	0.598	0.706	0.599	0.862	0.604	0.598	0.656	
	Medium Acceleration	0.515	1.24	0.508	0.557	0.647	0.543	1.16	0.464	0.562	0.632	
	High Acceleration	0.413	1.07	0.520	0.546	0.592	0.452	1.27	0.398	0.591	0.606	
	Low Cruise	0.648	0.979	0.466	0.503	0.639	0.526	0.795	0.518	0.562	0.597	
	Medium Cruise	0.532	1.15	0.499	0.504	0.634	0.501	1.17	0.444	0.562	0.624	
	High Cruise	0.550	1.10	0.527	0.614	0.678	0.738	1.08	0.587	0.631	0.745	
	Deceleration	0.372	0.894	0.463	0.386	0.506	0.313	0.831	0.535	0.472	0.509	
	Dumping						0.498	1.05	0.525	0.687	0.654	
	Equal Weight Avg[b]	0.533	1.10	0.493	0.526	0.638	0.522	1.04	0.501	0.564	0.634	
	Empirical Weight Avg[d]	0.416	1.62	0.415	0.457	0.662	0.466	1.53	0.600	0.521	0.714	

Table A-65. NO_x Emissions Corrected Ratio of B20 to Petroleum Diesel on a Per Time Basis by Driving Mode, Vehicle, and Load for Tier 2 Tandem Dump Trucks.

		Unloaded			**Loaded**			
NO_x (g/sec)	Driving Mode[a]	Vehicle Number **0125**	Vehicle Number **0126**	Avg[b]	Vehicle Number **0125**	Vehicle Number **0126**	Avg[b]	Ratio[c]
B20 Biodiesel	Idle	0.020	0.020	0.020	0.021	0.022	0.022	1.07
	Low Acceleration	0.049	0.057	0.053	0.074	0.077	0.076	1.43
	Medium Acceleration	0.078	0.100	0.089	0.133	0.143	0.138	1.55
	High Acceleration	0.102	0.115	0.108	0.117	0.131	0.124	1.14
	Low Cruise	0.052	0.051	0.052	0.055	0.057	0.056	1.09
	Medium Cruise	0.061	0.063	0.062	0.093	0.092	0.093	1.49
	High Cruise	0.068	0.064	0.066	0.082	0.095	0.088	1.33
	Deceleration	0.038	0.044	0.041	0.043	0.055	0.049	1.19
	Dumping				0.044	0.082	0.063	
	Equal Weight Avg[b]	0.059	0.064	0.061	0.074	0.084	0.079	1.28
	Empirical Weight Avg[d]	0.058	0.050	0.054	0.064	0.074	0.069	1.27
Petroleum Diesel	Idle	0.017	0.021	0.019	0.018	0.023	0.020	1.07
	Low Acceleration	0.047	0.062	0.054	0.058	0.083	0.070	1.29
	Medium Acceleration	0.074	0.108	0.091	0.121	0.137	0.129	1.42
	High Acceleration	0.120	0.100	0.110	0.142	0.117	0.130	1.18
	Low Cruise	0.034	0.046	0.040	0.057	0.054	0.055	1.38
	Medium Cruise	0.050	0.071	0.061	0.092	0.092	0.092	1.51
	High Cruise	0.051	0.061	0.056	0.066	0.096	0.081	1.44
	Deceleration	0.032	0.040	0.036	0.041	0.047	0.044	1.20
	Dumping				0.019	0.065	0.042	
	Equal Weight Avg[b]	0.053	0.064	0.058	0.068	0.079	0.074	1.26
	Empirical Weight Avg[d]	0.036	0.048	0.042	0.053	0.081	0.067	1.62
B20/PD Ratio	Idle	1.19	0.947	1.06	1.19	0.951	1.06	
	Low Acceleration	1.05	0.932	0.981	1.29	0.936	1.08	
	Medium Acceleration	1.05	0.924	0.975	1.10	1.04	1.07	
	High Acceleration	0.852	1.14	0.986	0.825	1.12	0.956	
	Low Cruise	1.52	1.12	1.29	0.971	1.07	1.02	
	Medium Cruise	1.21	0.879	1.02	1.01	1.01	1.01	
	High Cruise	1.33	1.06	1.18	1.24	0.989	1.09	
	Dumping	1.16	1.10	1.13	1.06	1.18	1.12	
	Deceleration				2.32	1.26	1.50	
	Equal Weight Avg[b]	1.10	1.01	1.05	1.08	1.06	1.07	
	Empirical Weight Avg[d]	1.64	1.06	1.30	1.20	0.908	1.02	

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not shown because no significant distance is driven during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded.

Table A-66. NO_x Emissions Corrected Ratio of B20 to Petroleum Diesel on a Per Mile Basis by Driving Mode, Vehicle, and Load for Tier 2 Tandem Dump Trucks.

		Unloaded			**Loaded**			
NO_x (g/mile)	Driving Mode[a]	Vehicle Number **0125**	Vehicle Number **0126**	Avg[b]	Vehicle Number **0125**	Vehicle Number **0126**	Avg[b]	Ratio[c]
B20 Biodiesel	Low Acceleration	17.6	25.8	21.7	28.9	32.9	30.9	1.42
	Medium Acceleration	8.67	11.5	10.1	15.4	15.8	15.6	1.55
	High Acceleration	8.06	9.05	8.55	8.65	9.57	9.11	1.07
	Low Cruise	13.1	13.4	13.2	17.2	18.6	17.9	1.36
	Medium Cruise	5.89	5.90	5.89	8.75	8.96	8.86	1.50
	High Cruise	4.62	4.23	4.42	5.45	6.32	5.88	1.33
	Deceleration	4.50	4.89	4.69	5.68	6.10	5.89	1.25
	Equal Weight Avg[b]	8.92	10.7	9.80	12.9	14.0	13.5	1.37
	Empirical Weight Avg[d]	6.49	6.28	6.39	9.82	10.0	9.93	1.56
Petroleum Diesel	Low Acceleration	16.0	23.4	19.7	24.3	34.1	29.2	1.48
	Medium Acceleration	8.01	12.1	10.0	13.3	14.8	14.1	1.40
	High Acceleration	13.3	12.2	12.8	12.1	17.5	14.8	1.16
	Low Cruise	7.90	12.6	10.2	18.9	18.4	18.6	1.82
	Medium Cruise	4.52	6.27	5.39	8.54	8.67	8.60	1.60
	High Cruise	3.62	3.93	3.78	4.38	6.36	5.37	1.42
	Deceleration	5.53	5.10	5.31	6.83	5.60	6.21	1.17
	Equal Weight Avg[b]	8.42	10.8	9.61	12.6	15.1	13.8	1.44
	Empirical Weight Avg[d]	7.15	7.63	7.39	11.4	11.2	11.3	1.52
B20/PD Ratio	Low Acceleration	1.10	1.10	1.10	1.19	0.966	1.06	
	Medium Acceleration	1.08	0.953	1.00	1.16	1.07	1.11	
	High Acceleration	0.605	0.740	0.669	0.717	0.546	0.616	
	Low Cruise	1.65	1.06	1.29	0.912	1.01	0.961	
	Medium Cruise	1.30	0.941	1.09	1.02	1.03	1.03	
	High Cruise	1.28	1.07	1.18	1.24	0.990	1.09	
	Deceleration	0.814	0.960	0.884	0.832	1.07	0.948	
	Equal Weight Avg[b]	1.06	0.990	1.02	1.02	0.933	0.972	
	Empirical Weight Avg[d]	0.907	0.823	0.864	0.864	0.901	0.882	

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not shown because no significant distance is driven during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded.

Table A-67. NO_x Emissions Corrected Ratio of B20 to Petroleum Diesel on a Per Gallon Basis by Driving Mode, Vehicle, and Load for Tier 2 Tandem Dump Trucks.

NO_x (kg/gallon)	Driving Mode[a]	Unloaded			Loaded			Ratio[c]
		Vehicle Number 0125	Vehicle Number 0126	Avg[b]	Vehicle Number 0125	Vehicle Number 0126	Avg[b]	
B20 Biodiesel	Idle	0.175	0.197	0.186	0.165	0.207	0.186	1.00
	Low Acceleration	0.073	0.066	0.070	0.071	0.062	0.067	0.95
	Medium Acceleration	0.054	0.050	0.052	0.054	0.050	0.052	0.99
	High Acceleration	0.047	0.042	0.044	0.043	0.041	0.042	0.94
	Low Cruise	0.084	0.070	0.077	0.063	0.059	0.061	0.80
	Medium Cruise	0.051	0.043	0.047	0.045	0.046	0.045	0.97
	High Cruise	0.040	0.035	0.037	0.034	0.037	0.036	0.95
	Deceleration	0.044	0.043	0.043	0.042	0.044	0.043	0.99
	Dumping				0.075	0.091	0.083	
	Equal Weight Avg[b]	0.071	0.068	0.070	0.066	0.071	0.068	0.98
	Empirical Weight Avg[d]	0.067	0.093	0.080	0.080	0.086	0.083	1.03
Petroleum Diesel	Idle	0.137	0.177	0.157	0.140	0.185	0.162	1.03
	Low Acceleration	0.069	0.062	0.066	0.065	0.061	0.063	0.95
	Medium Acceleration	0.050	0.064	0.057	0.059	0.057	0.058	1.02
	High Acceleration	0.059	0.048	0.053	0.052	0.050	0.051	0.96
	Low Cruise	0.047	0.054	0.050	0.068	0.055	0.061	1.22
	Medium Cruise	0.041	0.044	0.043	0.050	0.045	0.047	1.11
	High Cruise	0.029	0.034	0.032	0.037	0.034	0.036	1.13
	Deceleration	0.052	0.047	0.049	0.050	0.042	0.046	0.93
	Dumping				0.105	0.078	0.092	
	Equal Weight Avg[b]	0.061	0.066	0.063	0.069	0.068	0.068	1.08
	Empirical Weight Avg[d]	0.090	0.097	0.093	0.084	0.065	0.074	0.80
B20/PD Ratio	Idle	1.28	1.11	1.19	1.18	1.12	1.15	
	Low Acceleration	1.06	1.06	1.06	1.10	1.02	1.06	
	Medium Acceleration	1.09	0.785	0.919	0.924	0.867	0.896	
	High Acceleration	0.790	0.879	0.829	0.821	0.815	0.818	
	Low Cruise	1.79	1.30	1.53	0.937	1.07	0.996	
	Medium Cruise	1.23	0.969	1.10	0.907	1.03	0.964	
	High Cruise	1.38	1.01	1.18	0.912	1.09	0.998	
	Dumping	0.840	0.914	0.875	0.845	1.03	0.930	
	Deceleration				0.717	1.17	0.909	
	Equal Weight Avg[b]	1.17	1.03	1.10	0.950	1.05	0.998	
	Empirical Weight Avg[d]	0.748	0.963	0.860	0.951	1.33	1.12	

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not shown because no significant distance is driven during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded.

Table A-68. NO_x Emissions Corrected Ratio of B20 to Petroleum Diesel on a Per Time Basis by Driving Mode, Vehicle, and Load for Tier 2 Single Axle Dump Trucks.

NO_x (g/sec)	Driving Mode[a]	Unloaded Vehicle Number 6117	Unloaded Vehicle Number 6123	Unloaded Avg[b]	Loaded Vehicle Number 6117	Loaded Vehicle Number 6123	Loaded Avg[b]	Ratio[c]
B20 Biodiesel	Idle	0.013	0.011	0.012	0.013	0.012	0.012	1.04
	Low Acceleration	0.055	0.048	0.052	0.063	0.087	0.075	1.45
	Medium Acceleration	0.078	0.125	0.102	0.119	0.213	0.166	1.63
	High Acceleration	0.103	0.180	0.142	0.111	0.231	0.171	1.21
	Low Cruise	0.036	0.036	0.036	0.040	0.078	0.059	1.64
	Medium Cruise	0.051	0.092	0.071	0.087	0.131	0.109	1.53
	High Cruise	0.060	0.087	0.074	0.071	0.130	0.101	1.36
	Deceleration	0.025	0.031	0.028	0.030	0.050	0.040	1.42
	Dumping				0.037	0.033	0.035	
	Equal Weight Avg[b]	0.053	0.076	0.065	0.063	0.107	0.085	1.32
	Empirical Weight Avg[d]	0.041	0.060	0.050	0.054	0.107	0.080	1.60
Petroleum Diesel	Idle	0.012	0.015	0.013	0.013	0.016	0.014	1.08
	Low Acceleration	0.061	0.067	0.064	0.073	0.088	0.081	1.26
	Medium Acceleration	0.108	0.134	0.121	0.154	0.196	0.175	1.45
	High Acceleration	0.153	0.152	0.153	0.194	0.171	0.182	1.19
	Low Cruise	0.034	0.045	0.039	0.042	0.051	0.046	1.18
	Medium Cruise	0.063	0.075	0.069	0.097	0.121	0.109	1.57
	High Cruise	0.077	0.107	0.092	0.103	0.156	0.129	1.40
	Deceleration	0.038	0.050	0.044	0.049	0.067	0.058	1.31
	Dumping				0.033	0.042	0.037	
	Equal Weight Avg[b]	0.068	0.080	0.074	0.084	0.101	0.092	1.24
	Empirical Weight Avg[d]	0.047	0.053	0.050	0.050	0.048	0.049	0.98
B20/PD Ratio	Idle	1.07	0.766	0.903	0.988	0.775	0.871	
	Low Acceleration	0.898	0.727	0.809	0.854	0.989	0.928	
	Medium Acceleration	0.727	0.929	0.839	0.769	1.09	0.948	
	High Acceleration	0.670	1.19	0.928	0.574	1.35	0.938	
	Low Cruise	1.07	0.811	0.923	0.969	1.53	1.28	
	Medium Cruise	0.803	1.23	1.03	0.896	1.09	1.00	
	High Cruise	0.782	0.816	0.802	0.690	0.835	0.777	
	Dumping	0.676	0.615	0.641	0.612	0.755	0.694	
	Deceleration				1.14	0.805	0.950	
	Equal Weight Avg[b]	0.772	0.949	0.868	0.753	1.07	0.924	
	Empirical Weight Avg[d]	0.874	1.12	1.01	1.08	2.24	1.65	

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not shown because no significant distance is driven during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded.

Table A-69. NO_x Emissions Corrected Ratio of B20 to Petroleum Diesel on a Per Mile Basis by Driving Mode, Vehicle, and Load for Tier 2 Single Axle Dump Trucks.

NO_x (g/mile)	Driving Mode[a]	Unloaded			Loaded			Ratio[c]
		Vehicle Number		Avg[b]	Vehicle Number		Avg[b]	
		6117	6123		6117	6123		
B20 Biodiesel	Low Acceleration	21.5	18.7	20.1	26.8	37.6	32.2	1.60
	Medium Acceleration	8.71	12.5	10.6	13.4	22.4	17.9	1.69
	High Acceleration	9.30	19.8	14.6	10.7	24.0	17.4	1.19
	Low Cruise	10.5	11.8	11.1	13.6	25.9	19.7	1.77
	Medium Cruise	4.81	8.01	6.41	8.00	11.5	9.77	1.52
	High Cruise	4.23	6.29	5.26	5.17	10.2	7.70	1.46
	Deceleration	3.42	5.50	4.46	5.02	8.86	6.94	1.56
	Equal Weight Avg[b]	8.92	11.8	10.4	11.8	20.1	15.9	1.54
	Empirical Weight Avg[d]	7.00	8.96	7.98	10.7	17.9	14.3	1.79
Petroleum Diesel	Low Acceleration	26.0	32.4	29.2	34.0	45.7	39.8	1.36
	Medium Acceleration	10.9	14.4	12.6	16.3	20.9	18.6	1.48
	High Acceleration	13.8	12.8	13.3	18.9	13.6	16.3	1.23
	Low Cruise	8.43	18.5	13.5	14.3	27.6	20.9	1.55
	Medium Cruise	5.95	6.69	6.32	8.88	10.9	9.90	1.57
	High Cruise	5.53	7.29	6.41	7.63	11.2	9.43	1.47
	Deceleration	4.14	6.31	5.23	7.71	12.1	9.89	1.89
	Equal Weight Avg[b]	10.7	14.1	12.4	15.4	20.3	17.8	1.44
	Empirical Weight Avg[d]	8.73	10.1	9.41	13.8	22.1	18.0	1.91
B20/PD Ratio	Low Acceleration	0.826	0.576	0.688	0.790	0.823	0.809	
	Medium Acceleration	0.800	0.868	0.839	0.818	1.07	0.961	
	High Acceleration	0.676	1.55	1.10	0.566	1.76	1.07	
	Low Cruise	1.24	0.638	0.827	0.952	0.938	0.943	
	Medium Cruise	0.809	1.20	1.01	0.901	1.06	0.987	
	High Cruise	0.764	0.862	0.820	0.678	0.911	0.816	
	Deceleration	0.827	0.871	0.854	0.651	0.735	0.702	
	Equal Weight Avg[b]	0.836	0.839	0.838	0.768	0.989	0.894	
	Empirical Weight Avg[d]	0.802	0.888	0.848	0.776	0.810	0.797	

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not shown because no significant distance is driven during these modes.

[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded.

Table A-70. NO_x Emissions Corrected Ratio of B20 to Petroleum Diesel on a Per Gallon Basis by Driving Mode, Vehicle, and Load for Tier 2 Single Axle Dump Trucks.

NO_x (kg/gallon)	Driving Mode[a]	Unloaded			Loaded			Ratio[c]
		Vehicle Number		Avg[b]	Vehicle Number		Avg[b]	
		6117	**6123**		**6117**	**6123**		
B20 Biodiesel	Idle	0.110	0.152	0.131	0.109	0.134	0.122	0.93
	Low Acceleration	0.106	0.156	0.131	0.114	0.157	0.136	1.04
	Medium Acceleration	0.090	0.126	0.108	0.108	0.157	0.133	1.22
	High Acceleration	0.094	0.146	0.120	0.078	0.154	0.116	0.97
	Low Cruise	0.083	0.079	0.081	0.069	0.118	0.094	1.16
	Medium Cruise	0.075	0.093	0.084	0.098	0.090	0.094	1.12
	High Cruise	0.066	0.082	0.074	0.069	0.089	0.079	1.07
	Deceleration	0.061	0.082	0.072	0.067	0.100	0.084	1.17
	Dumping				0.102	0.102	0.102	
	Equal Weight Avg[b]	0.086	0.115	0.100	0.090	0.123	0.107	1.06
	Empirical Weight Avg[d]	0.088	0.110	0.099	0.093	0.118	0.106	1.06
Petroleum Diesel	Idle	0.140	0.161	0.150	0.150	0.154	0.152	1.01
	Low Acceleration	0.108	0.140	0.124	0.121	0.147	0.134	1.08
	Medium Acceleration	0.105	0.130	0.117	0.118	0.145	0.131	1.12
	High Acceleration	0.115	0.129	0.122	0.121	0.129	0.125	1.02
	Low Cruise	0.086	0.116	0.101	0.093	0.112	0.103	1.01
	Medium Cruise	0.090	0.097	0.093	0.091	0.093	0.092	0.98
	High Cruise	0.074	0.090	0.082	0.092	0.111	0.102	1.23
	Deceleration	0.087	0.083	0.085	0.100	0.099	0.099	1.17
	Dumping				0.100	0.127	0.113	
	Equal Weight Avg[b]	0.101	0.118	0.110	0.110	0.124	0.117	1.07
	Empirical Weight Avg[d]	0.117	0.133	0.125	0.128	0.141	0.135	1.08
B20/PD Ratio	Idle	0.790	0.940	0.870	0.726	0.870	0.799	
	Low Acceleration	0.982	1.11	1.06	0.948	1.07	1.02	
	Medium Acceleration	0.859	0.973	0.922	0.918	1.09	1.01	
	High Acceleration	0.821	1.13	0.986	0.649	1.20	0.932	
	Low Cruise	0.960	0.679	0.798	0.740	1.05	0.911	
	Medium Cruise	0.835	0.962	0.901	1.07	0.975	1.02	
	High Cruise	0.885	0.905	0.896	0.748	0.802	0.778	
	Dumping	0.706	0.984	0.841	0.668	1.02	0.841	
	Deceleration				1.02	0.806	0.899	
	Equal Weight Avg[b]	0.852	0.967	0.914	0.826	0.988	0.912	
	Empirical Weight Avg[d]	0.756	0.831	0.796	0.726	0.838	0.785	

[a]: Acceleration modes are defined by acceleration times speed. Cruise modes are defined by vehicle speed.
- Acceleration (Low: Pd= 20, Medium 20<Pd=50, High Pd>50), where Pd=S x A, S=speed (mph), A=acceleration (mph/sec)
- Cruise (Low: S<30, Medium 30=S<45, High S=45), where S=speed (mph)
- Idle and dumping are not shown because no significant distance is driven during these modes.

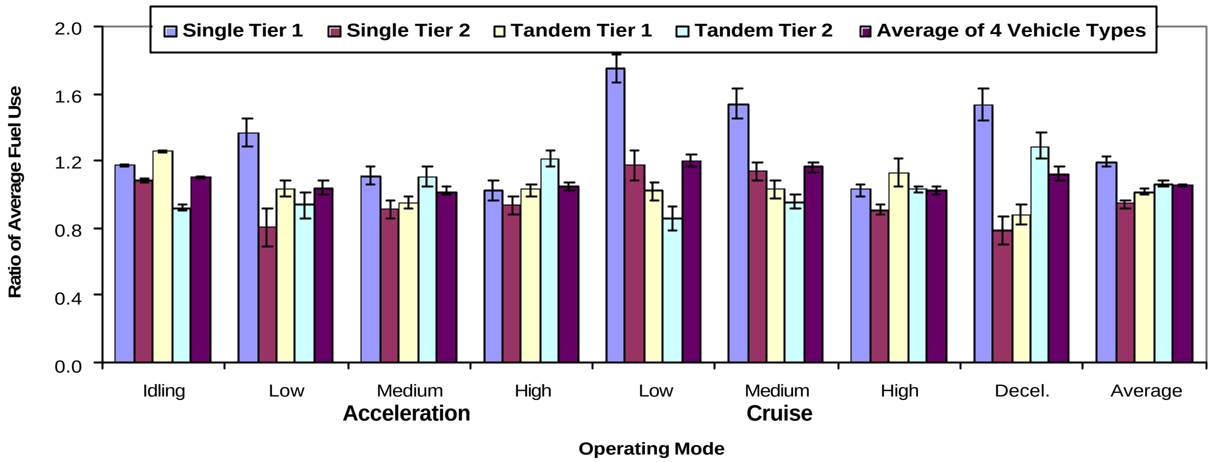
[b]: Arithmetic average of equal weights: For unloaded, equal weight averaged to 8 modes; for loaded, equal weights averaged to 9 modes

[c]: Loaded / Unloaded

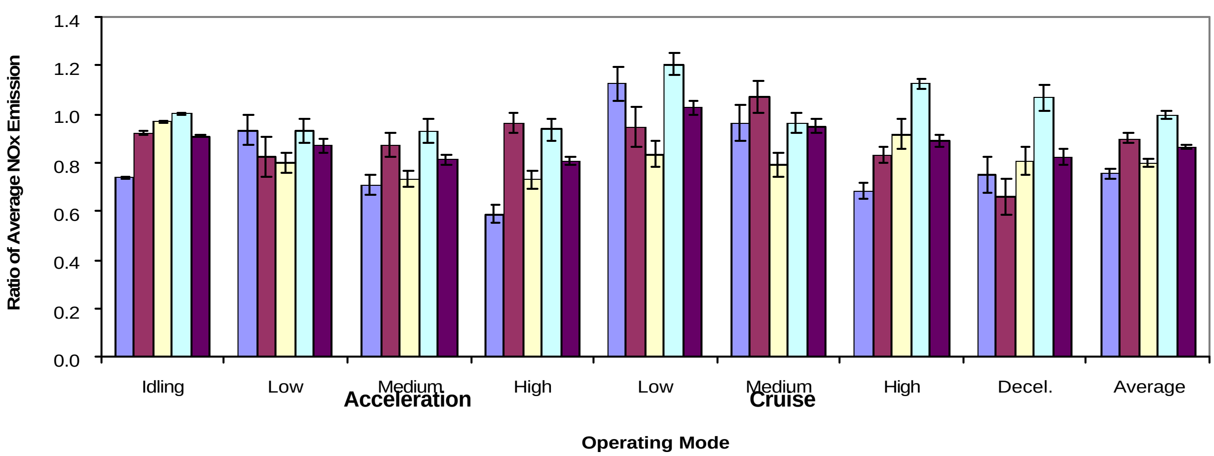
[d]: Empirical average of real world data based on actual modal weights, which vary between loaded and unloaded.

Appendix II

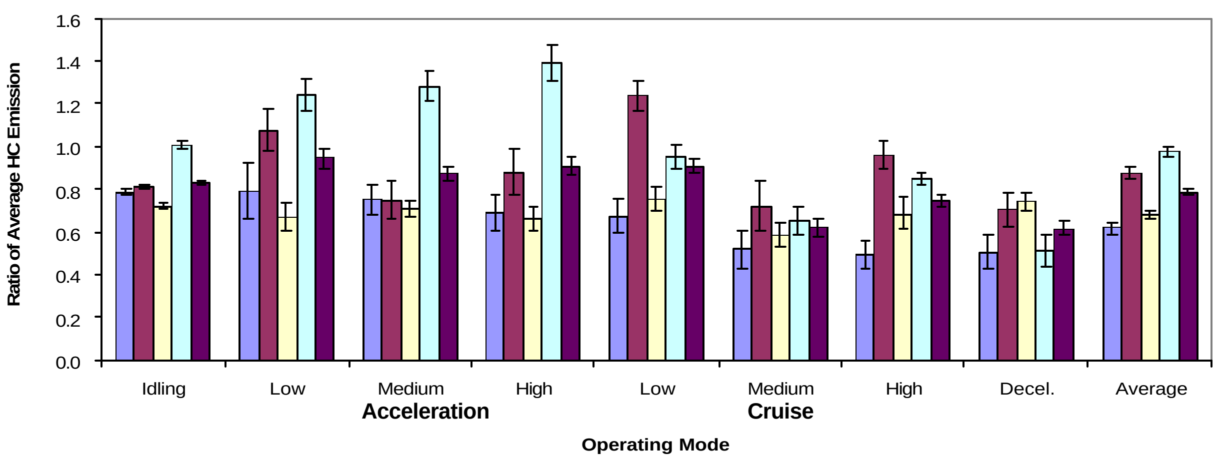
List of Figures



(a) Fuel Use

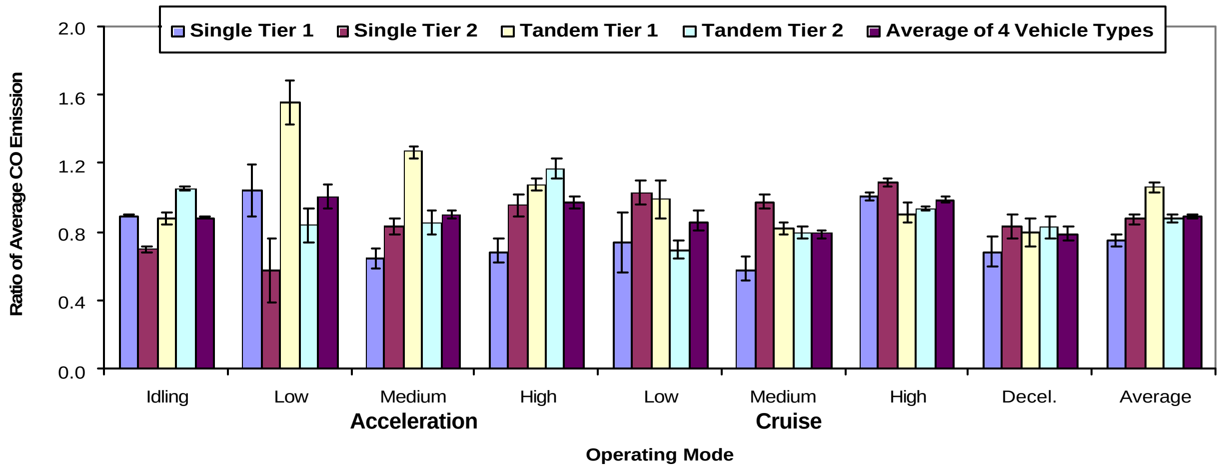


(b) NO_x Emission

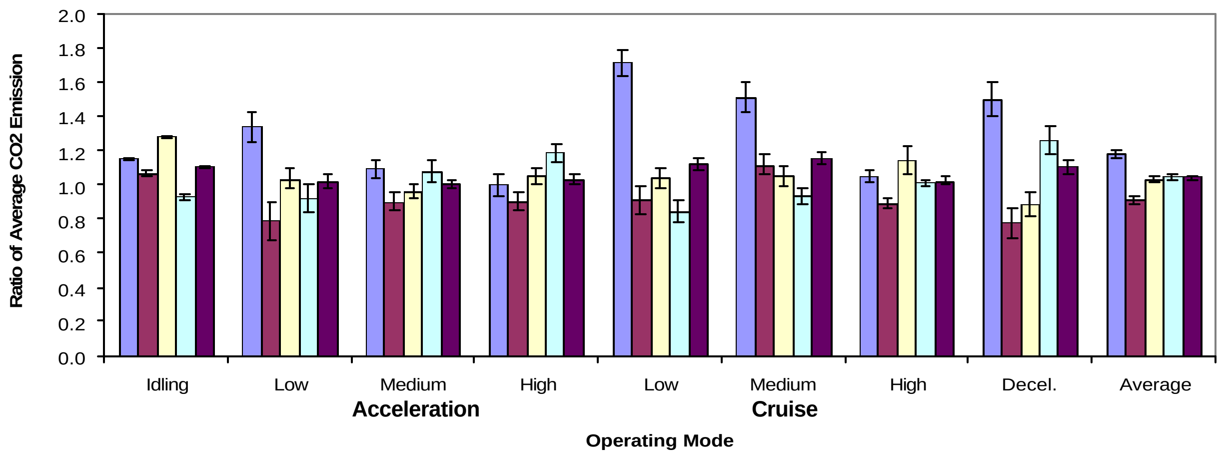


(c) HC Emission

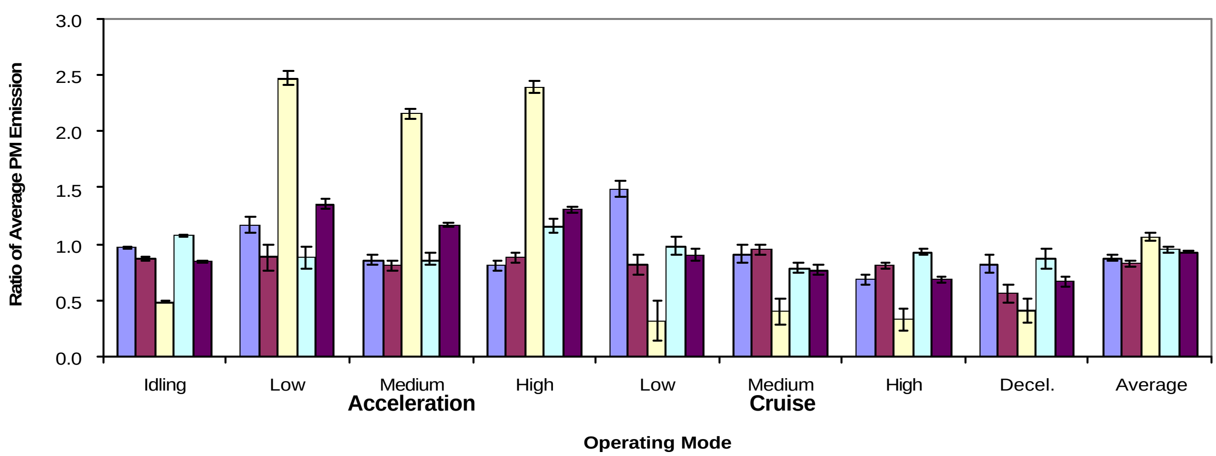
Figure B-1. Ratio of B20 to Petroleum diesel on Unloaded driving cycle by Driving Mode and Vehicle Type (g/sec basis)



(d) CO Emission

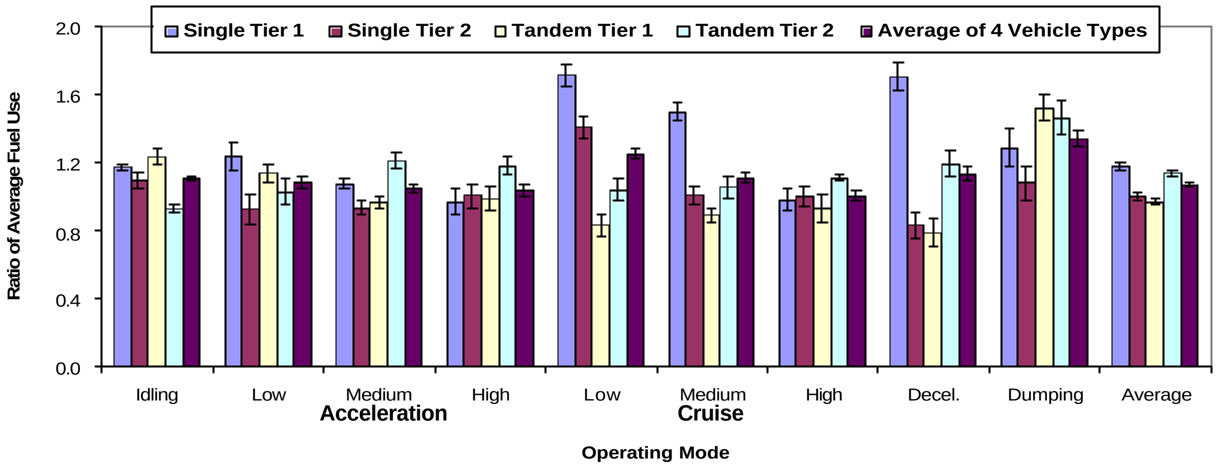


(e) CO_2 Emission

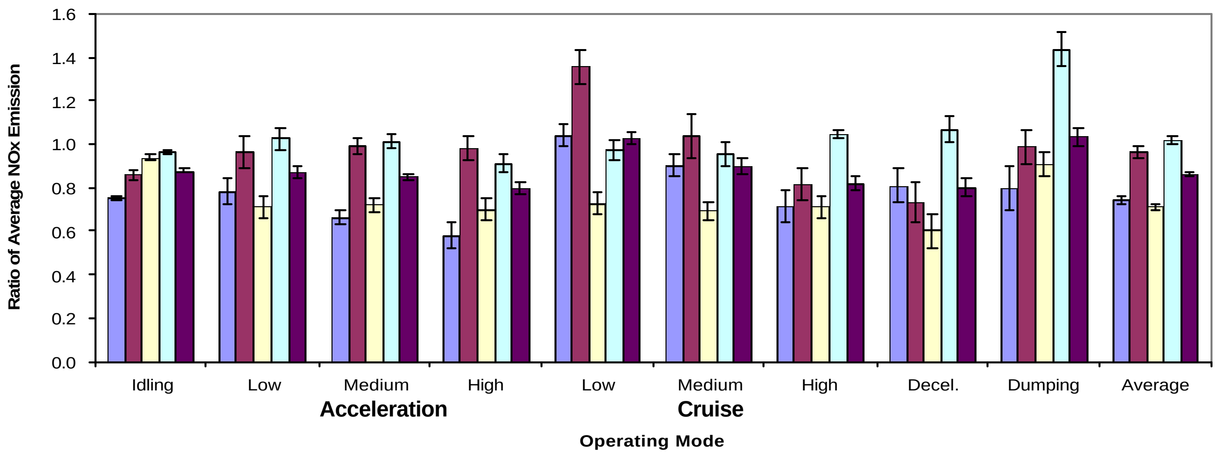


(f) PM Emission

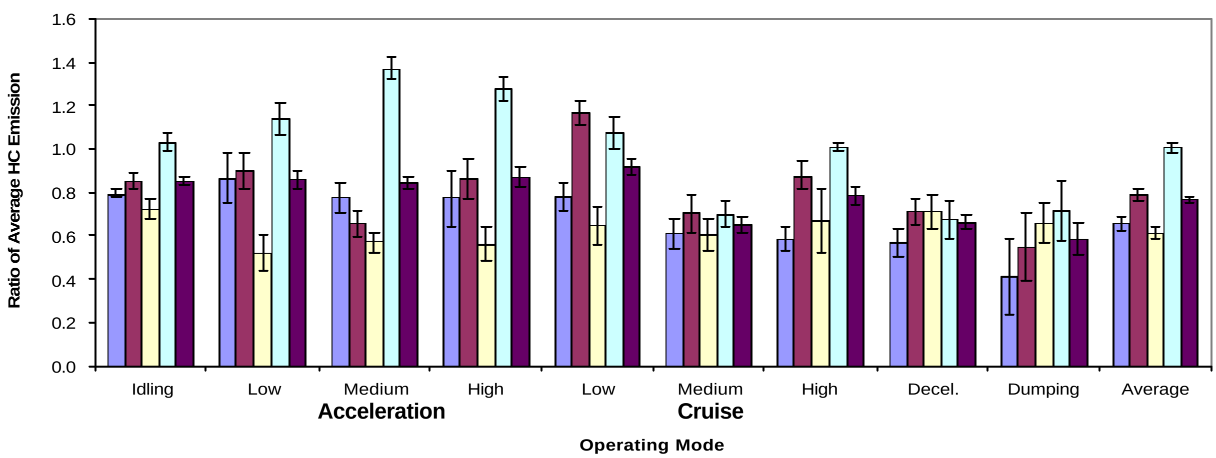
Figure B-1 Continued



(a) Fuel Use

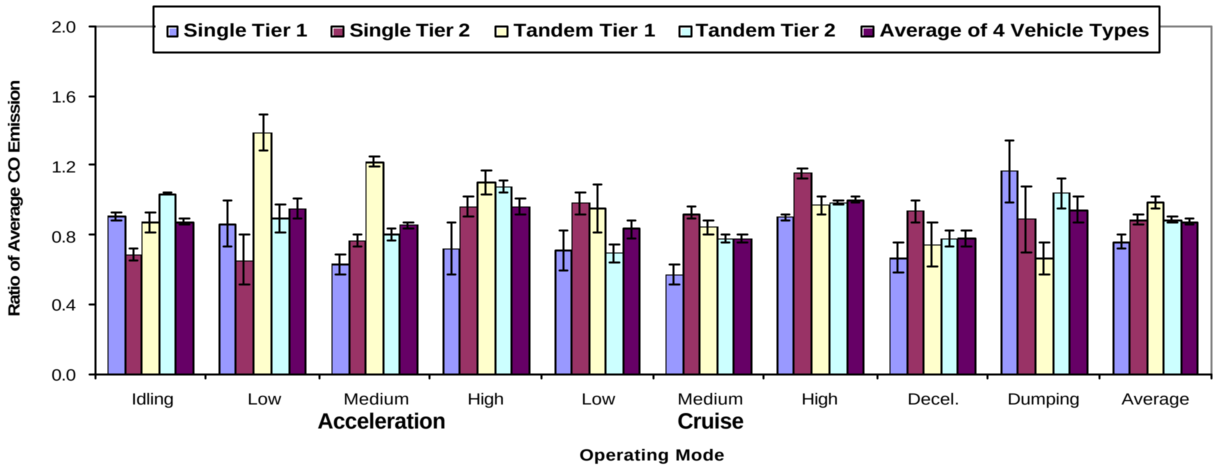


(b) NO_x Emission

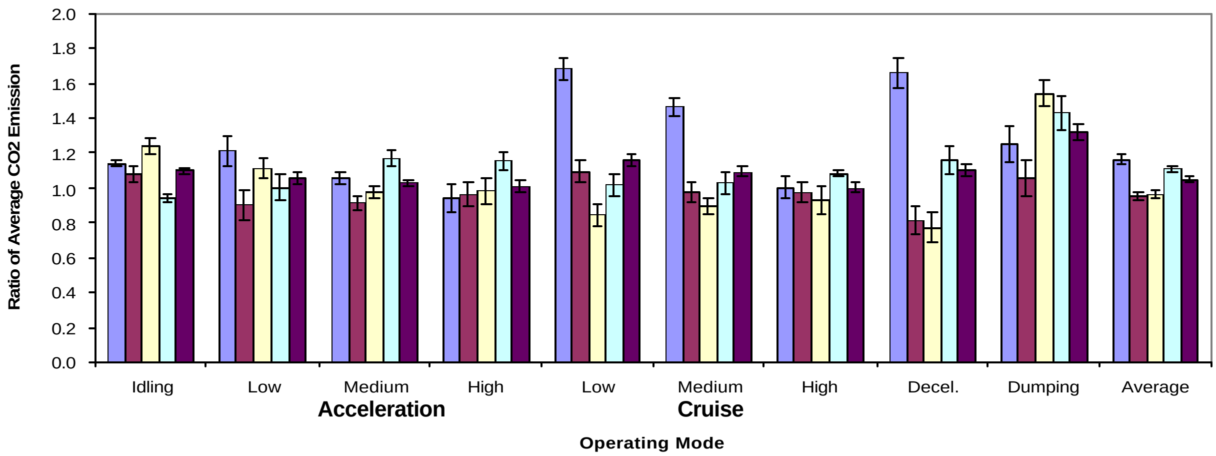


(c) HC Emission

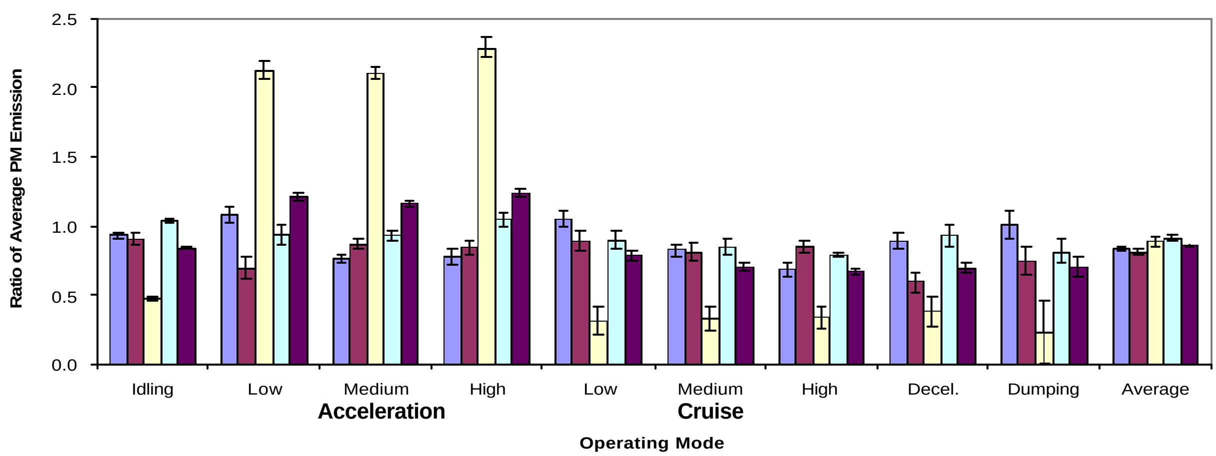
Figure B-2. Ratio of B20 to Petroleum diesel on Loaded driving cycle by Driving Mode and Vehicle Type (g/sec basis)



(d) CO Emission

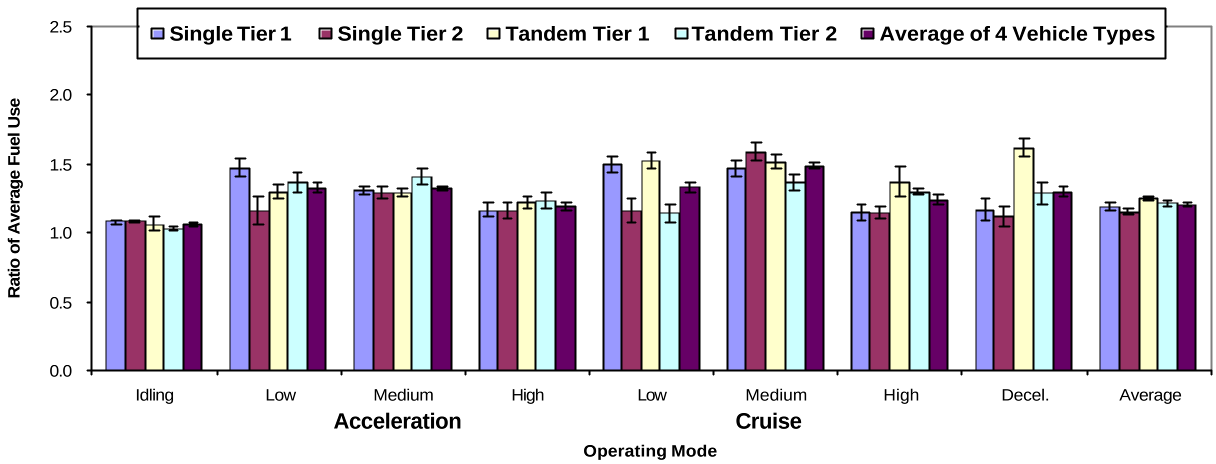


(e) CO_2 Emission

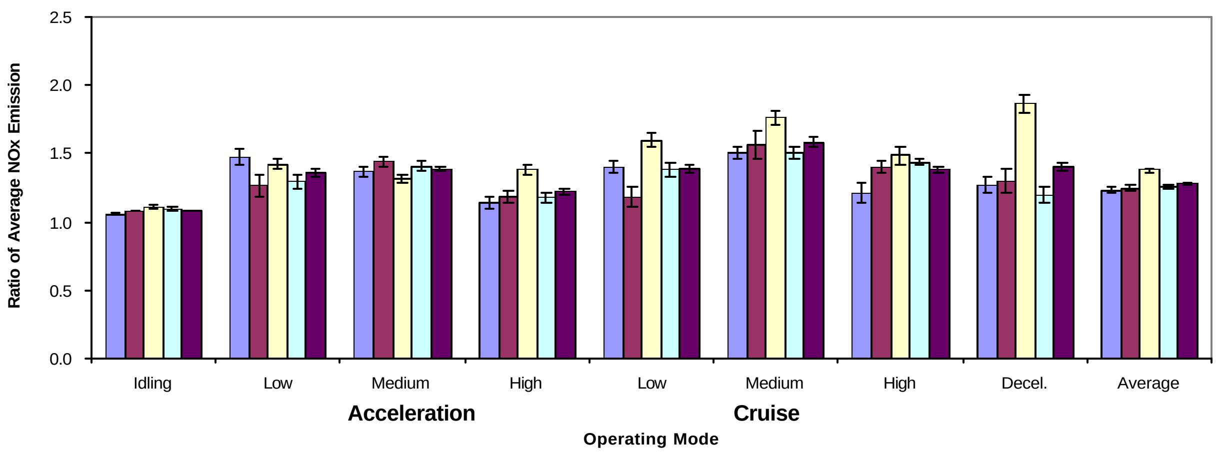


(f) PM Emission

Figure B-2. Continued



(a) Fuel Use



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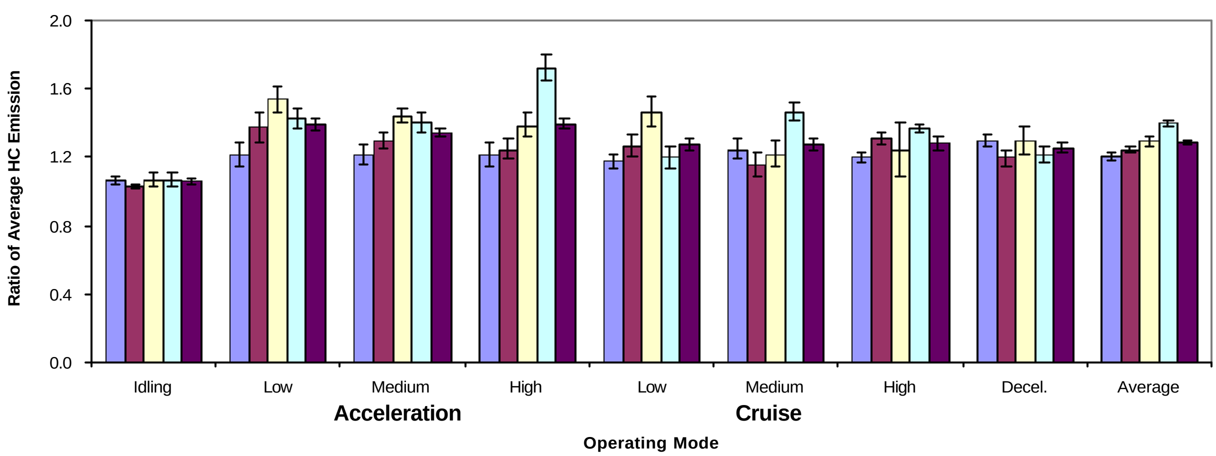
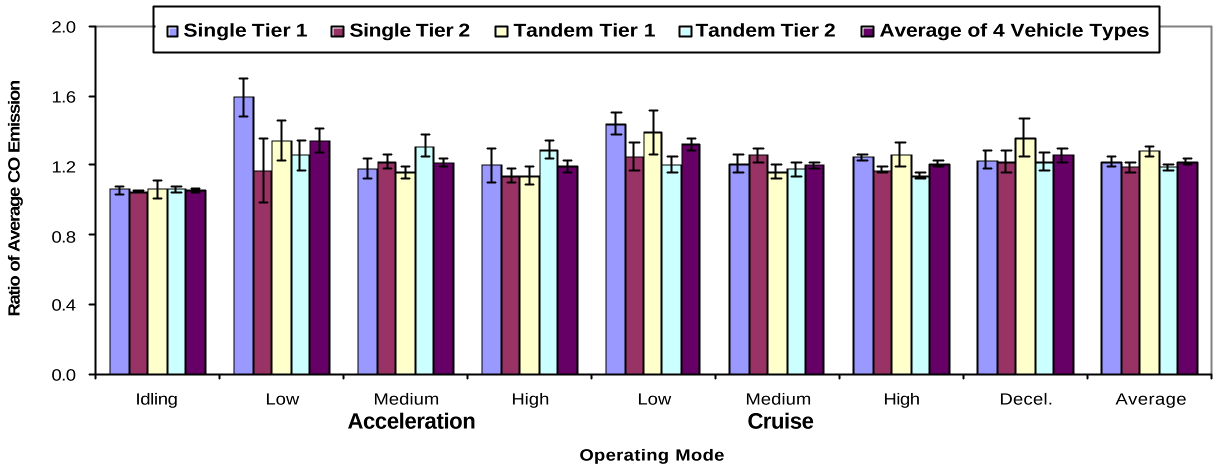
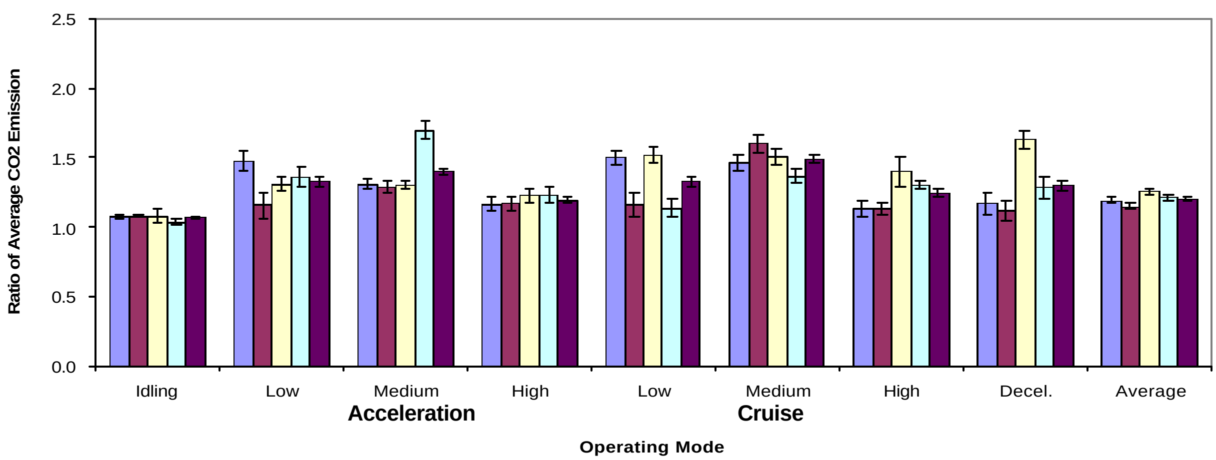


(c) HC Emission

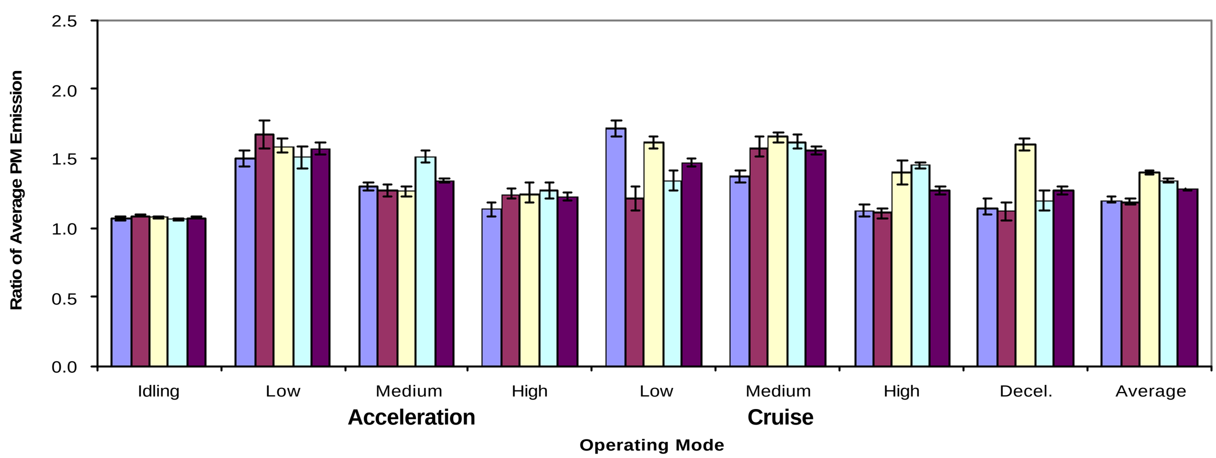
Figure B-3. Ratio of Loaded to Unloaded for Fuel Use, NO_x, HC, CO, CO_2, and PM emission fueled with Petroleum diesel by Driving Modes and Vehicle Types (g/sec basis)



(d) CO Emission

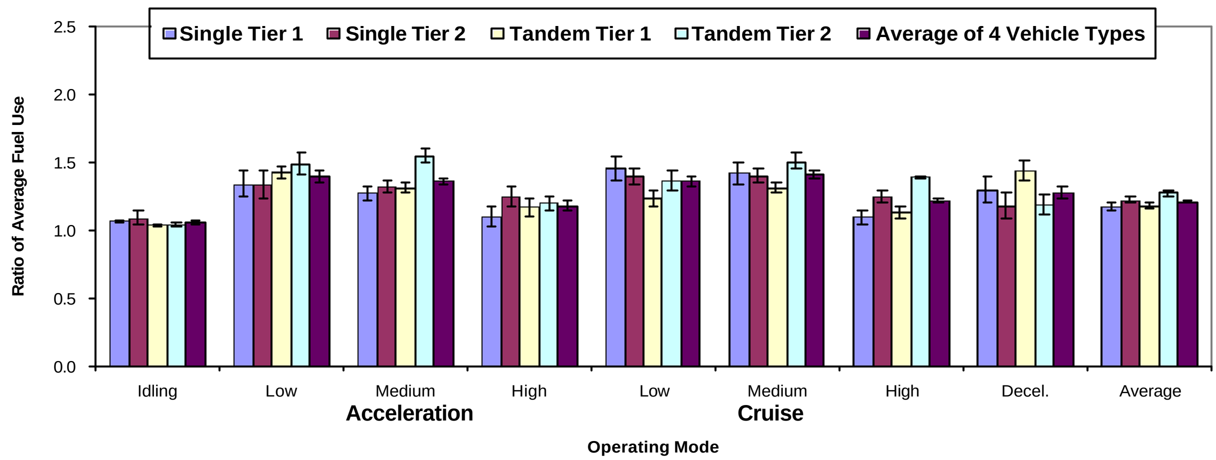


(e) CO_2 Emission

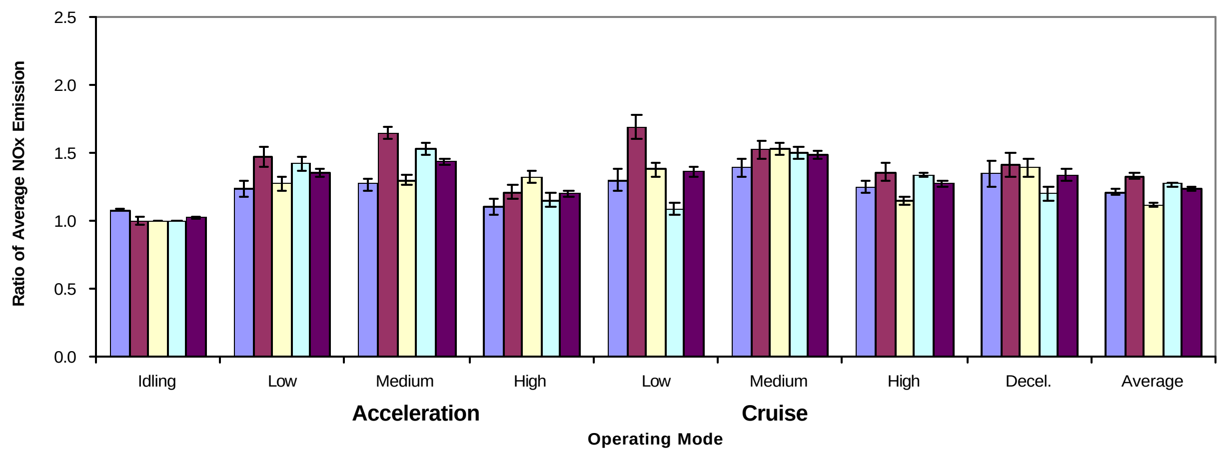


(f) PM Emission

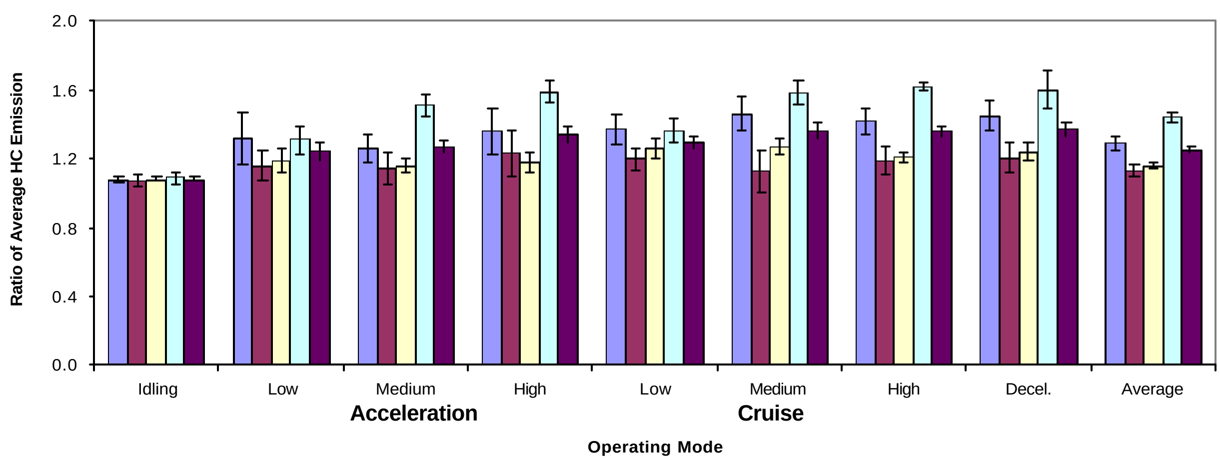
Figure B-3. Continued



(a) Fuel Use

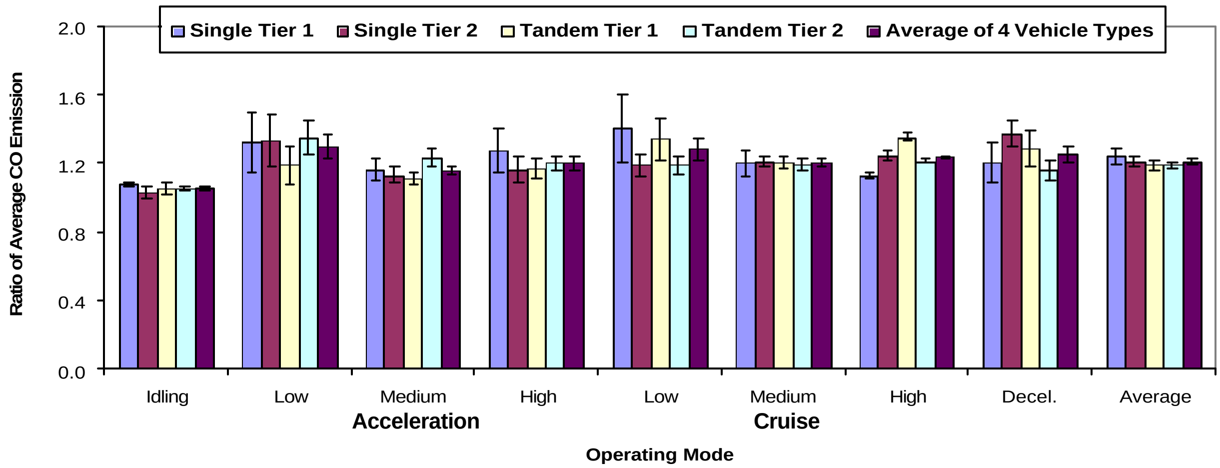


(b) NO_x Emission

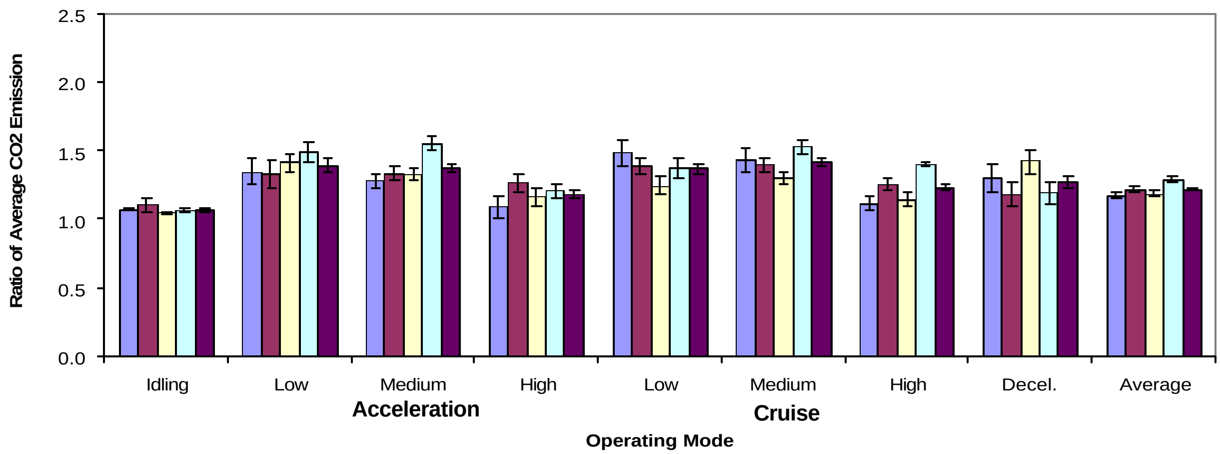


(c) HC Emission

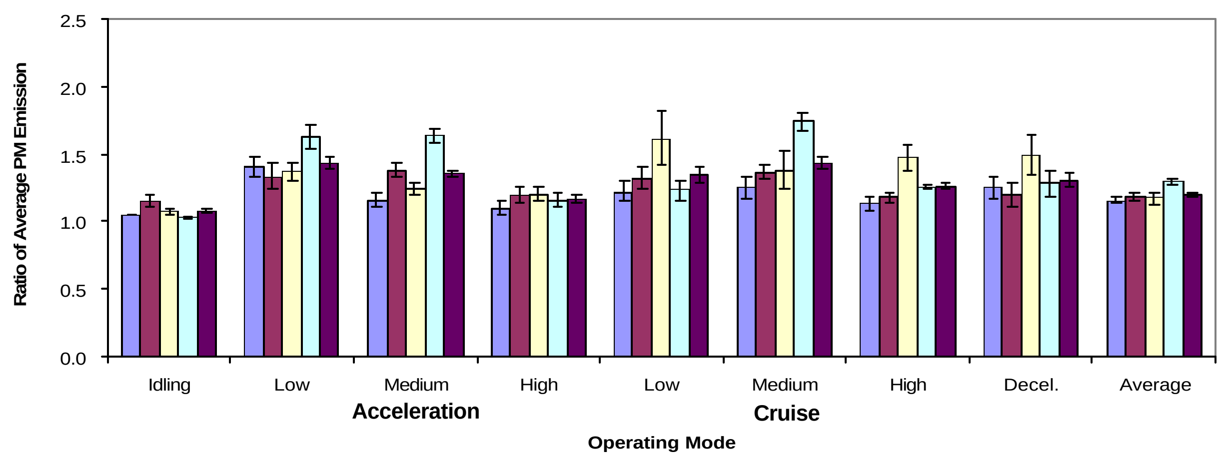
Figure B-4. Ratio of Loaded to Unloaded for Fuel Use, NO_x, HC, CO, CO_2, and PM emission fueled with Soy-based B20 by Driving Modes and Vehicle Types (g/sec basis)



(d) CO Emission

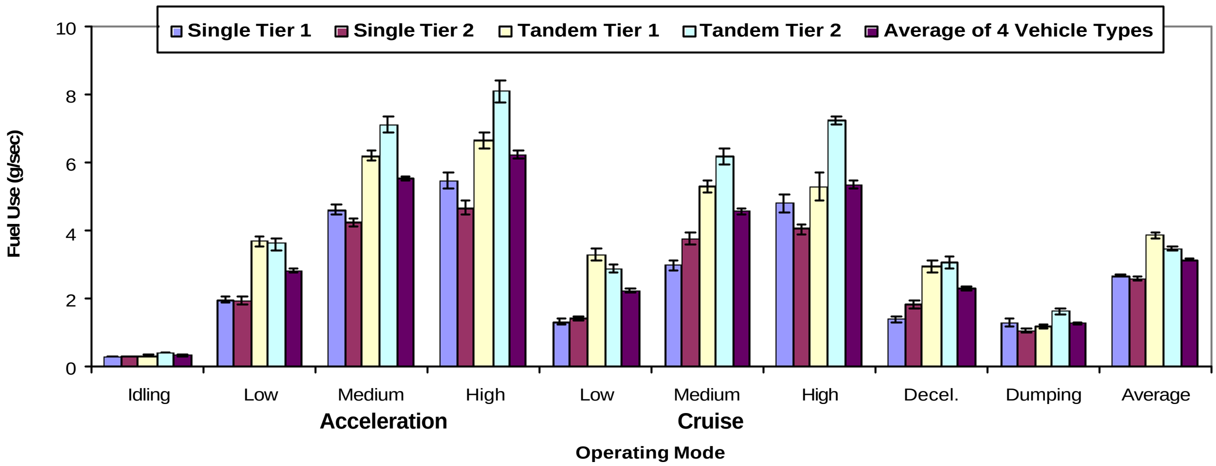


(e) CO_2 Emission

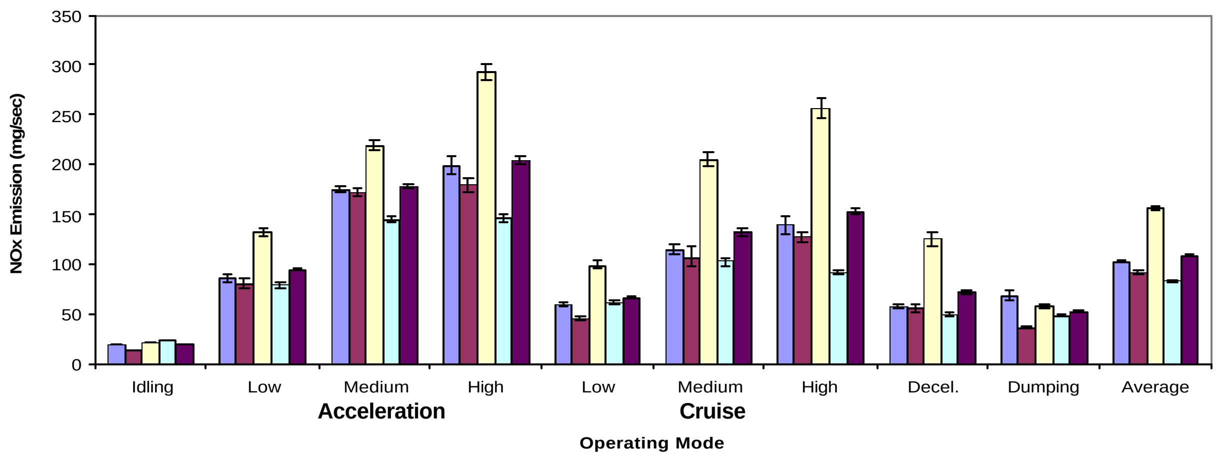


(f) PM Emission

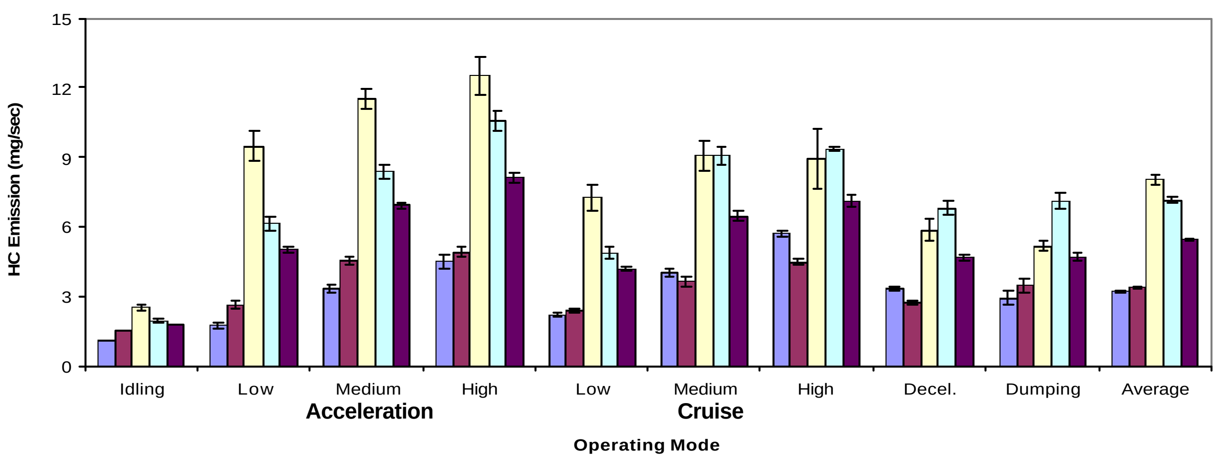
Figure B-4. Continued



(a) Fuel Use

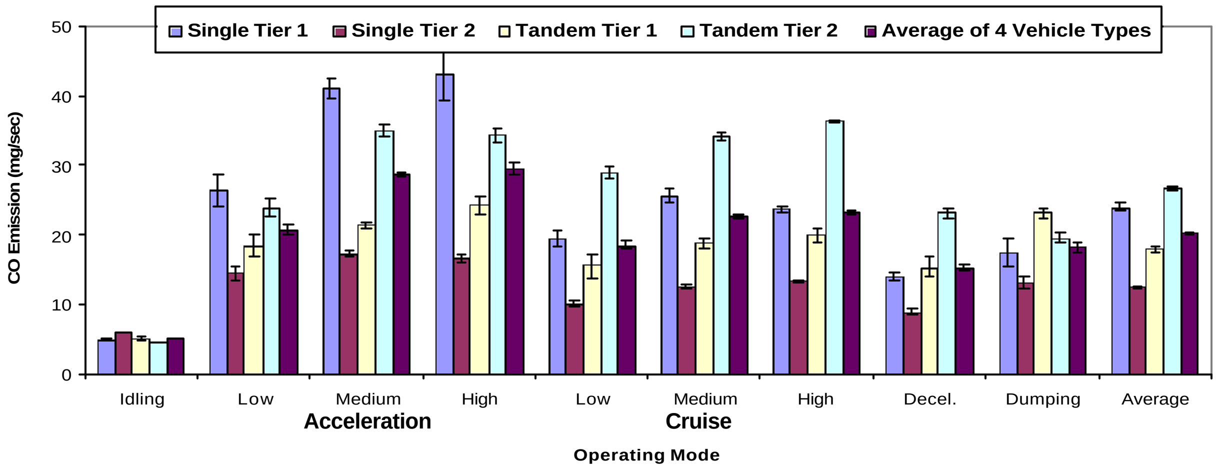


(b) NO_x Emission

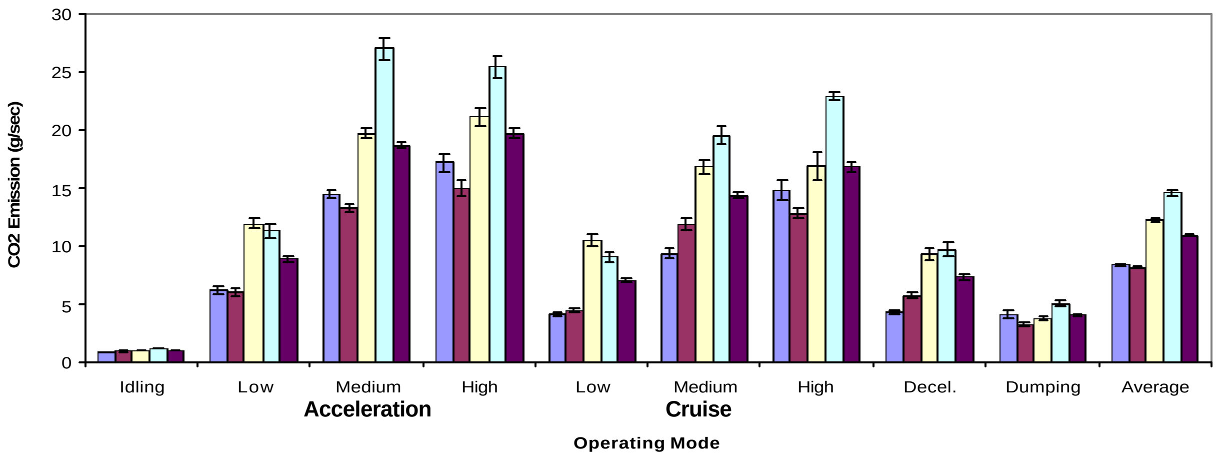


(c) HC Emission

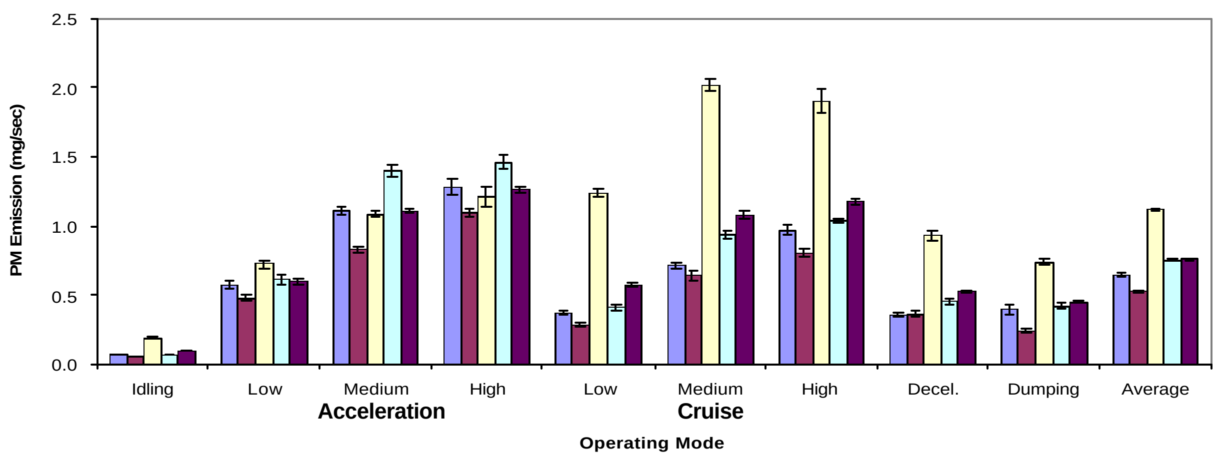
Figure B-5. Fuel Use and Emission Rates on a Per Time Basis by Driving Mode and Vehicle Type for Petroleum Diesel fuel (Loaded only)



(d) CO Emission

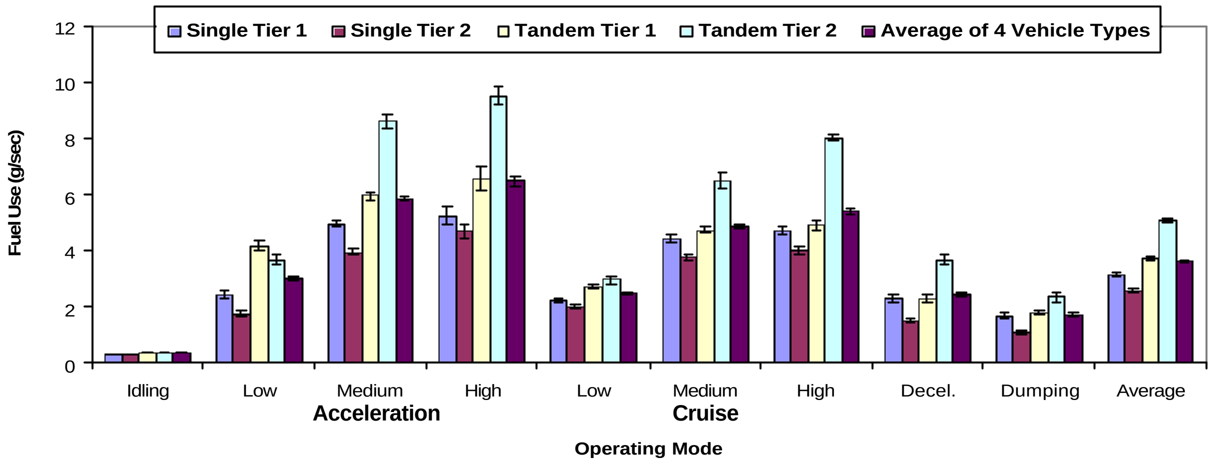


(e) CO_2 Emission

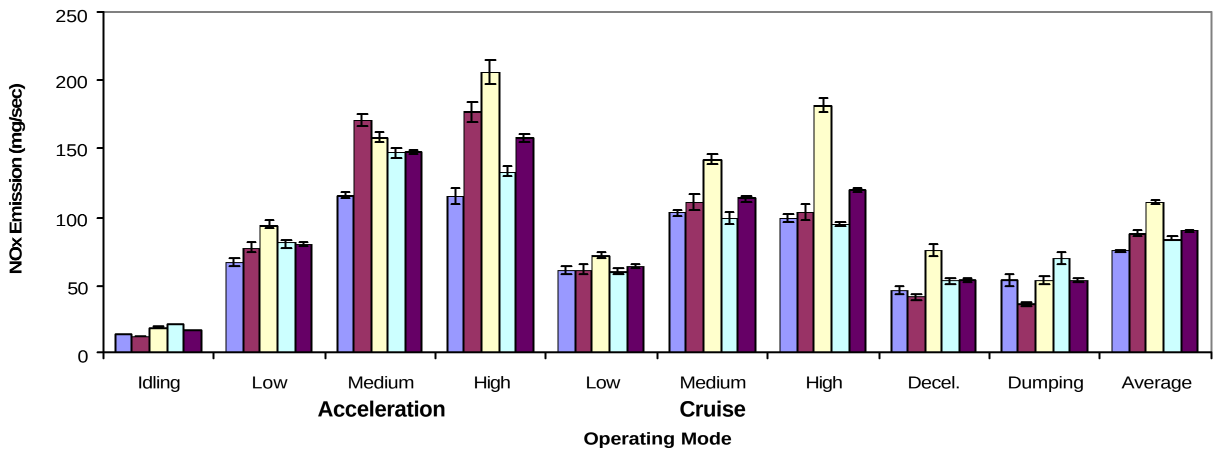


(f) PM Emission

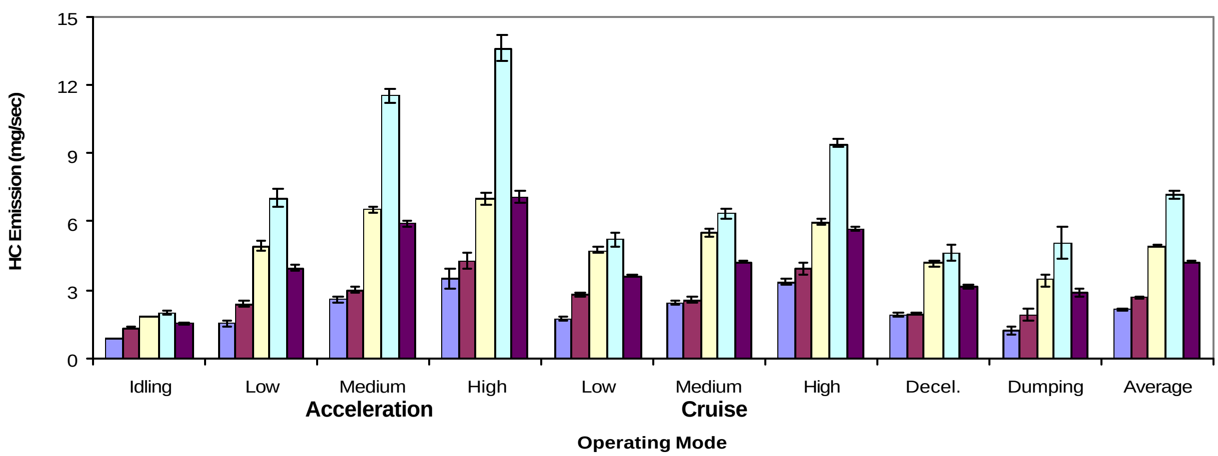
Figure B-5. Continued



(a) Fuel Use

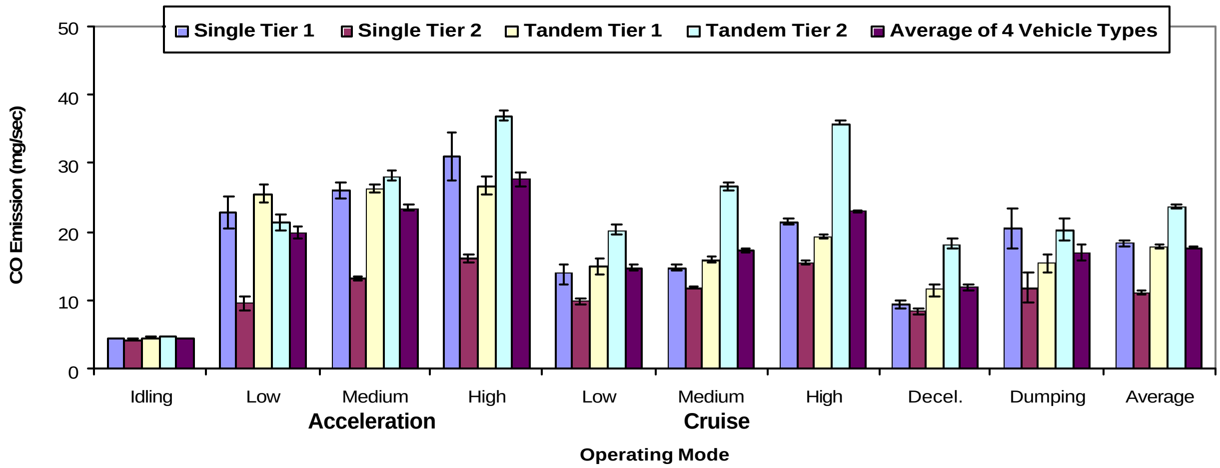


(b) NO_x Emission

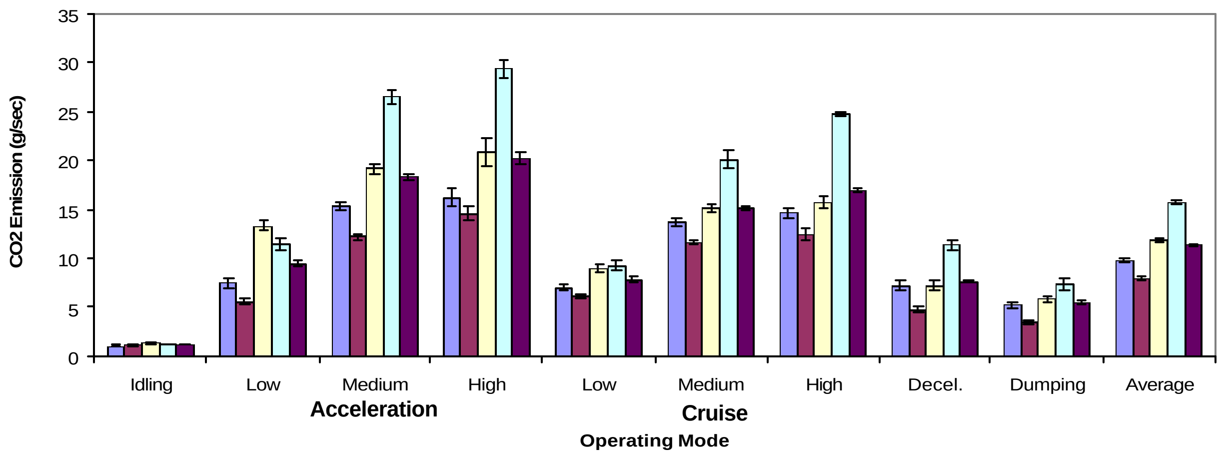


(c) HC Emission

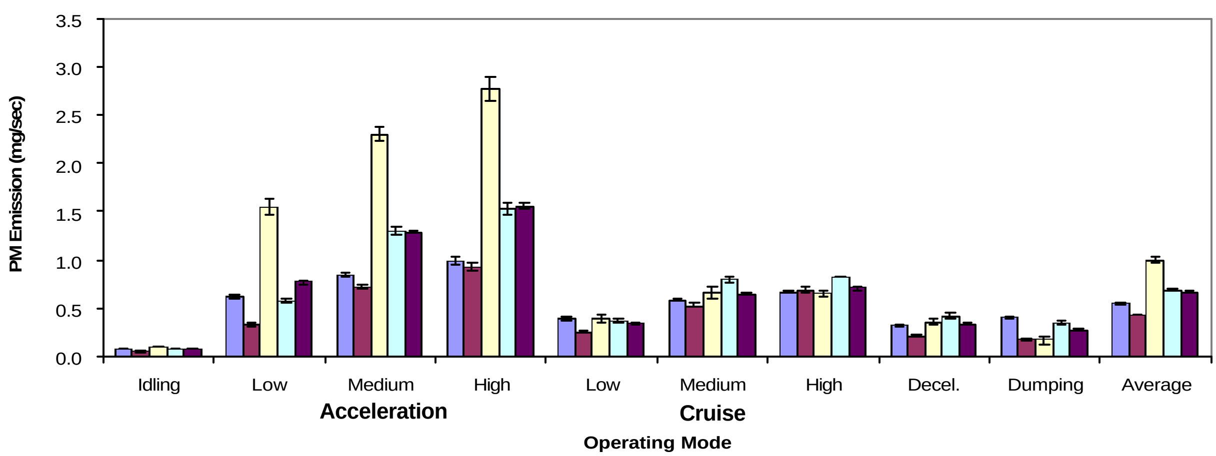
Figure B-6. Fuel Use and Emission Rates on a Per Time Basis by Driving Mode and Vehicle Type for Soy-Based B20 (Loaded only)



(d) CO Emission



(e) CO_2 Emission



(f) PM Emission

Figure B-6. Continued

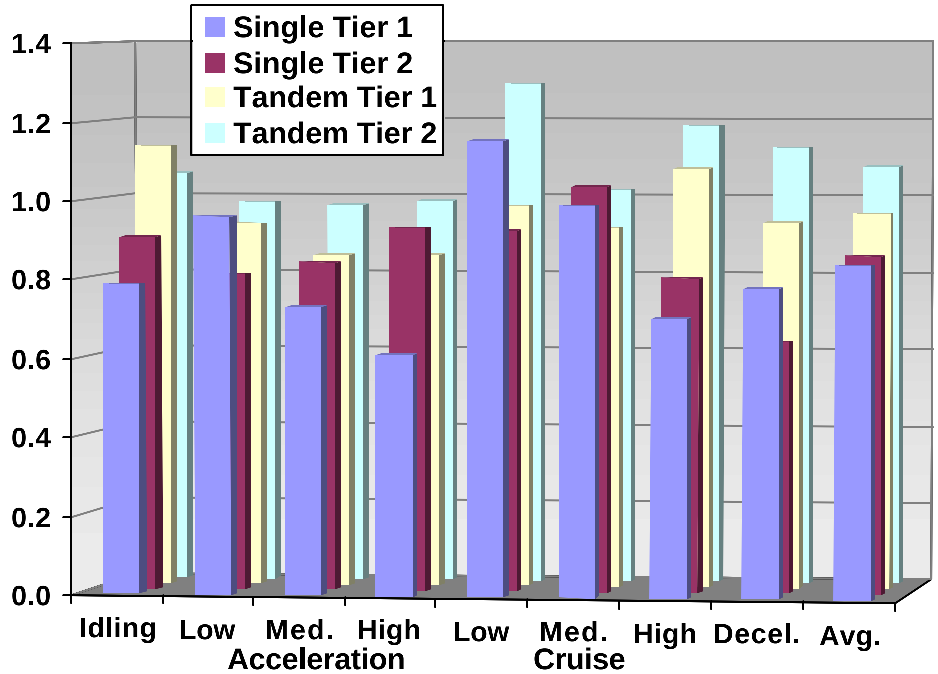


Figure B-7. Ratio of Corrected NO_x on Unloaded Driving Cycle by Driving Mode and Vehicle Type (g/sec Basis)

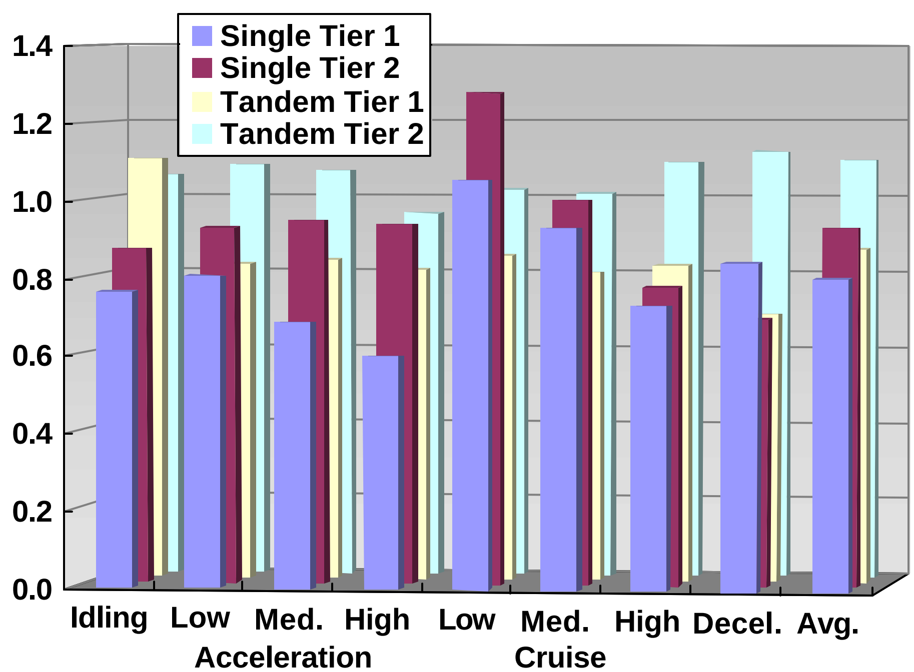


Figure B-8. Ratio of Corrected NO_x on Loaded Driving Cycle by Driving Mode and Vehicle Type (g/sec Basis)

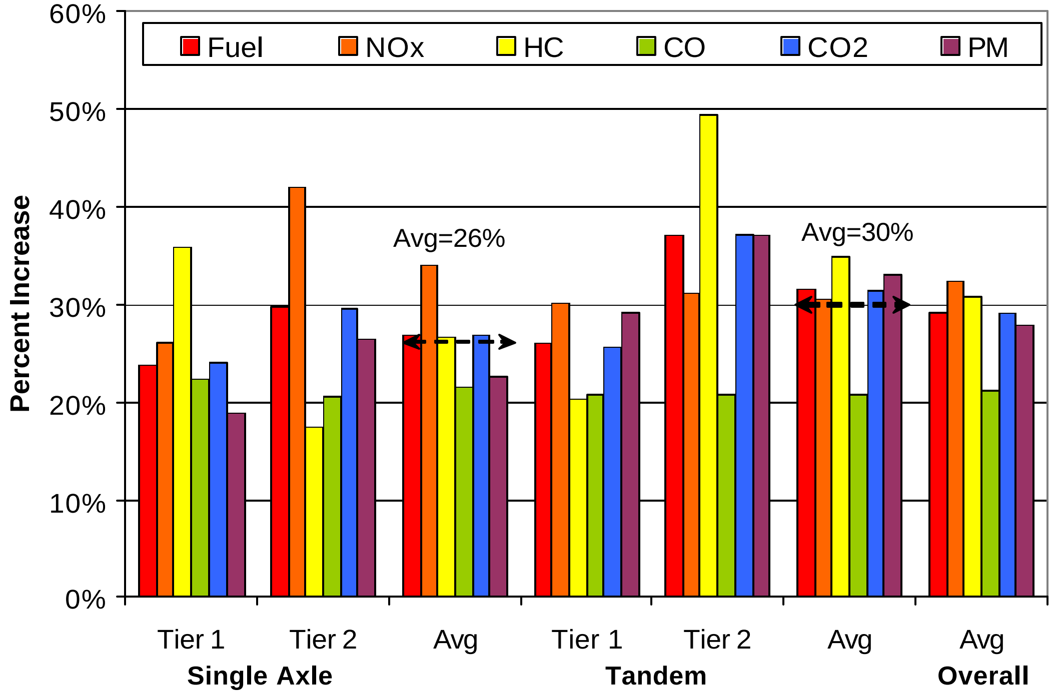


Figure B-9. Overall Comparison of Loaded vs Unloaded for Fuel Use and Emissions by Vehicle Type fueled with B20 Biodiesel.

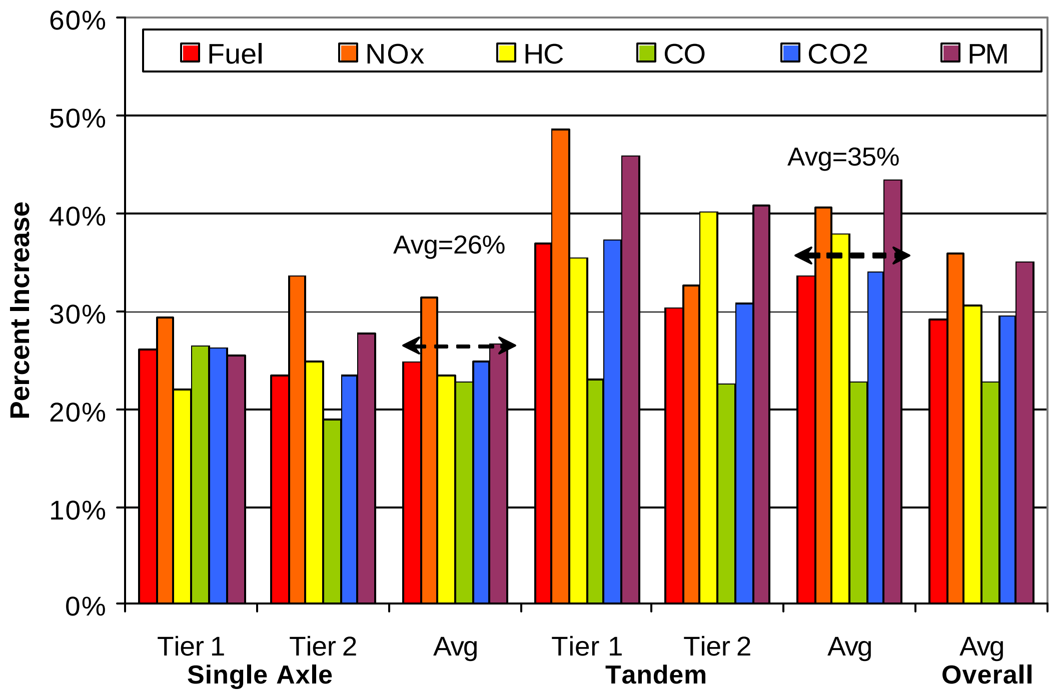


Figure B-10. Overall Comparison of Loaded vs Unloaded for Fuel Use and Emissions by Vehicle Type fueled with Petroleum Diesel.

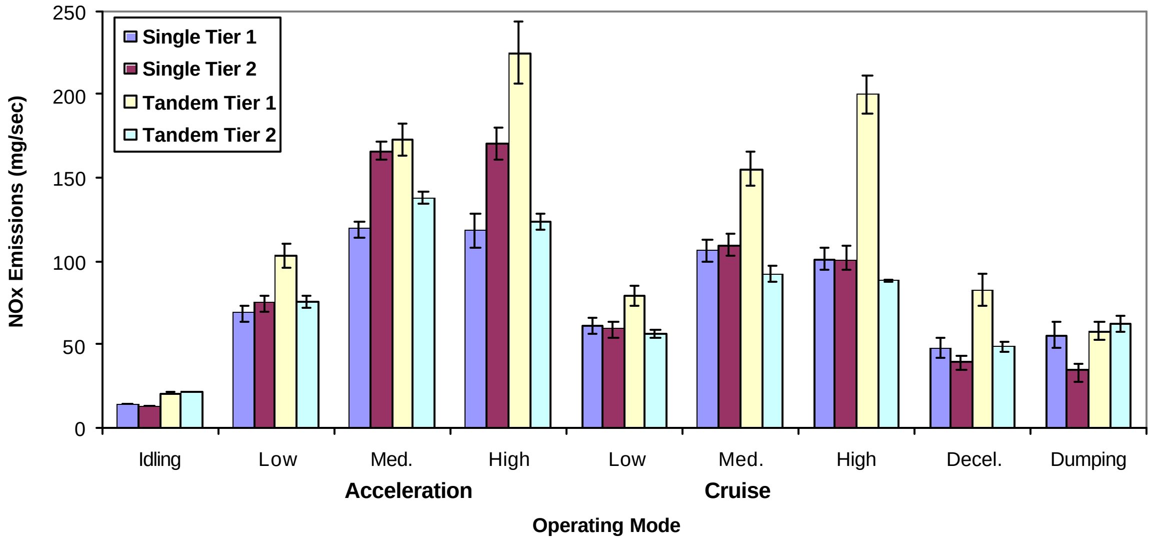


Figure B-11. B20 Based Estimate of Corrected NO_x Emissions by Driving Mode and Vehicle Type for Loaded Vehicles (mg/sec basis)

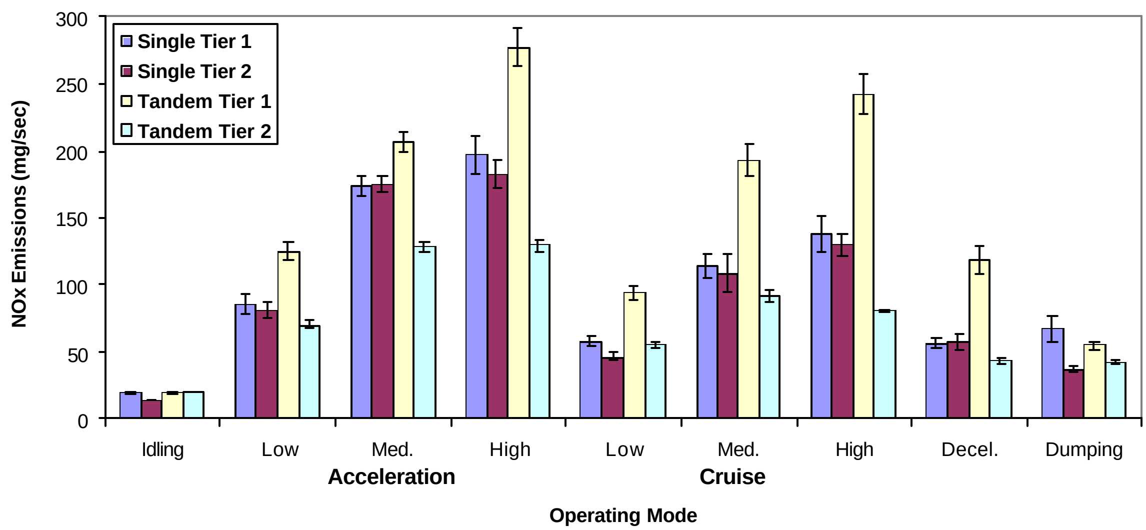


Figure B-12. Petroleum Diesel Based Estimate of Corrected NO_x Emissions by Driving Mode and Vehicle Type for Loaded Vehicles (mg/sec basis)

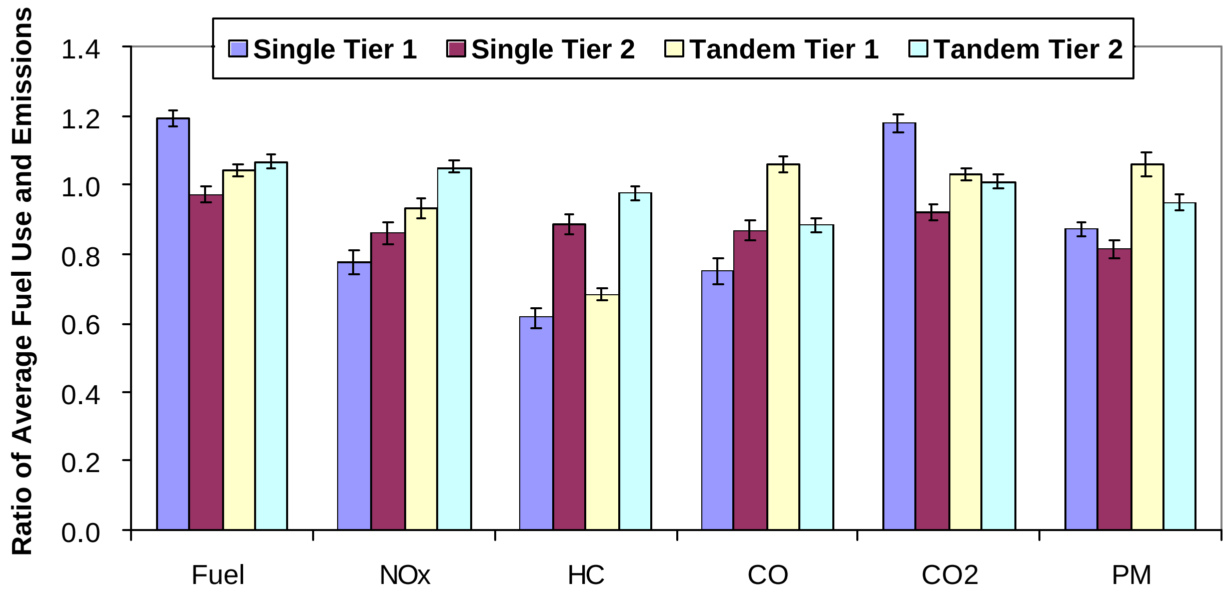


Figure B-13. Ratio of B20 to Petroleum Diesel for Average Fuel Use and Emissions for Unloaded Driving Cycle by Vehicle Type

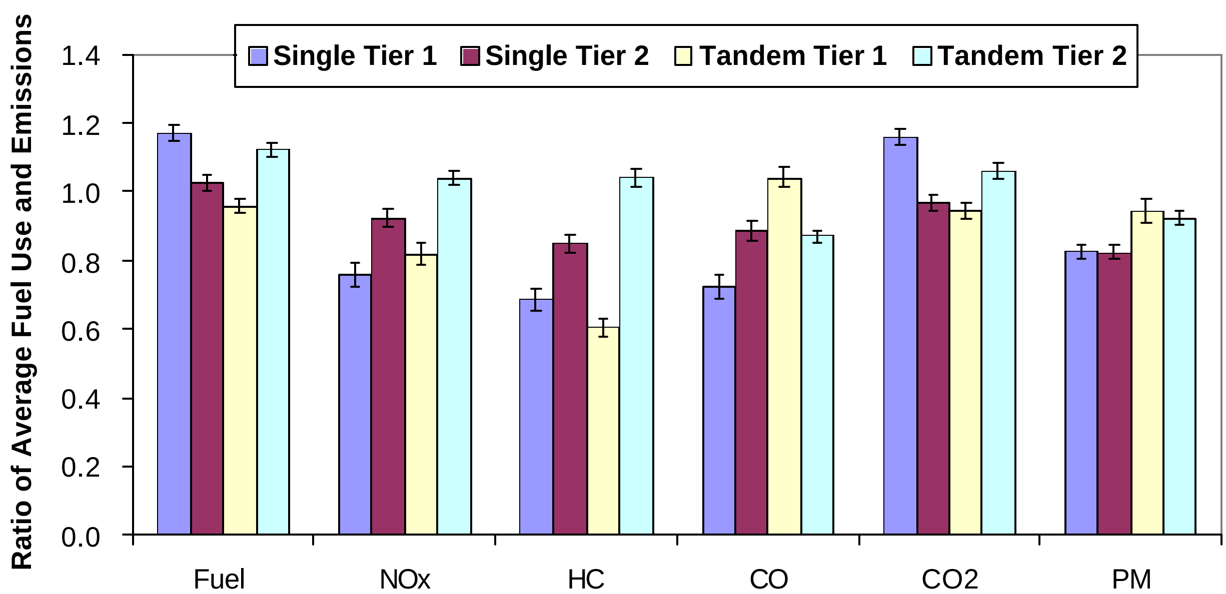


Figure B-14. Ratio of B20 to Petroleum Diesel for Average Fuel Use and Emissions for Loaded Driving Cycle by Vehicle Type