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13. ABSTRACT

The emissions of three locomotive engines were measured with ULSD and multiple biofuel blends, including B10, B20, and B40. B20 biodiesel fuel reduced emissions of carbon dioxide ($CO_{2)}$, carbon monoxide (CO), hydrocarbon (HC), and particulate matter (PM). Portable Emissions Measurement Systems (PEMS) were used to measure the exhaust concentrations and emission rates. Measurements were made on an EMD F59PHI and two EMD F59PH passenger locomotives, each with 3,000 hp, 2-stroke turbocharged EMD12-710 prime mover engines. There were no observed adverse impacts of biofuel use on engine wear, operability, or maintenance; however, the fuel has a limited impact on NO_x emissions. Testing revealed that B20 biodiesel fuel led to the largest reductions in CO_2, CO, HC, and PM from railroad locomotives based on rail yard and over-the-rail measurements. This research demonstrates methods for rail yard and over the rail locomotive emissions measurements using PEMS, and these methods can be applied to address a wide variety of study objectives related to locomotives, fuels, duty cycles, emission controls, and others.

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LENGTH (APPROXIMATE)			**LENGTH** (APPROXIMATE)		
1 inch (in)	=	2.5 centimeters (cm)	1 millimeter (mm)	=	0.04 inch (in)
1 foot (ft)	=	30 centimeters (cm)	1 centimeter (cm)	=	0.4 inch (in)
1 yard (yd)	=	0.9 meter (m)	1 meter (m)	=	3.3 feet (ft)
1 mile (mi)	=	1.6 kilometers (km)	1 meter (m)	=	1.1 yards (yd)
			1 kilometer (km)	=	0.6 mile (mi)
AREA (APPROXIMATE)			**AREA** (APPROXIMATE)		
1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)	1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)	1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)	1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)	10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)			
MASS - WEIGHT (APPROXIMATE)			**MASS - WEIGHT** (APPROXIMATE)		
1 ounce (oz)	=	28 grams (gm)	1 gram (gm)	=	0.036 ounce (oz)
1 pound (lb)	=	0.45 kilogram (kg)	1 kilogram (kg)	=	2.2 pounds (lb)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)	1 tonne (t)	=	1,000 kilograms (kg)
				=	1.1 short tons
VOLUME (APPROXIMATE)			**VOLUME** (APPROXIMATE)		
1 teaspoon (tsp)	=	5 milliliters (ml)	1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 tablespoon (tbsp)	=	15 milliliters (ml)	1 liter (l)	=	2.1 pints (pt)
1 fluid ounce (fl oz)	=	30 milliliters (ml)	1 liter (l)	=	1.06 quarts (qt)
1 cup (c)	=	0.24 liter (l)	1 liter (l)	=	0.26 gallon (gal)
1 pint (pt)	=	0.47 liter (l)			
1 quart (qt)	=	0.96 liter (l)			
1 gallon (gal)	=	3.8 liters (l)			
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)	1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)	1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)
TEMPERATURE (EXACT)			**TEMPERATURE** (EXACT)		
[(x-32)(5/9)] °F	=	y °C	[(9/5) y + 32] °C	=	x °F

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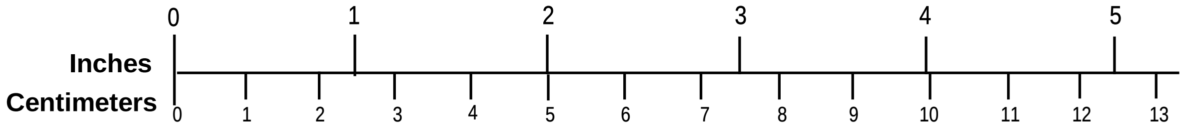

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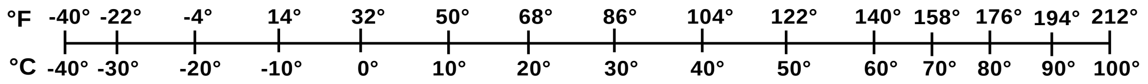

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Executive Summary

In this study, emissions of three locomotive engines were measured in rail yard and over-the-road tests as they burned ultra-low sulfur diesel (ULSD) and multiple biofuel blends, including B10, B20, and B40. B20 biodiesel fuel is shown to reduce emissions of carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (HC), and particulate matter (PM) from railroad locomotives based on the tests conducted in this study. Howeverthe B20 biodiesel has a limited impact on nitrogen oxide ($NO_{x)}$ emissions.

Measurements were made for exhaust concentrations and emission rates of CO_2, CO, HC, NO_x, and PM using Portable Emissions Measurement Systems (PEMS). Measurements were made on an EMD F59PHI and two EMD F59PH passenger locomotives, each with 3,000 hp, 2-stroke turbocharged EMD12-710 prime mover engines. Additional measurements were made with B60, B80, and B100 on one of the locomotives. The North Carolina Department of Transportation (NCDOT) owns the locomotives and provided access, fuel, and technical support. while Amtrak operates the locomotives.

Over 40 hours of rail yard data and over 270 hours of over-the-road data were collected. For each locomotive, three replicates of a prime mover engine test cycle were made at the NCDOT rail yard located in Raleigh, NC. For over-the-road measurements, six one way trips were measured between Raleigh, NC and Charlotte, NC on Amtrak's Piedmont train service. Less than one percent of total data collected were excluded after quality assurance screening.

Analyses of the three test locomotives lubricating oil for trace metals over a multi-year period, including baseline data that was captured before biofuels are used and comparison data that was recorded during biofuel use. From these analyses, biofuel use led to no discernable evidence of unusual engine wear and there were no observed adverse effects of biofuels on piston ring or cylinder head clearances (which might have indicated adverse wear). Furthermore, there were no anecdotal reports from mechanics or engineers regarding maintenance or operability problems. However, compared to the operating life of a locomotive, this study was of limited duration and it represented approximately one to two years of biofuel operation per tested locomotive. Thus, this study cannot answer questions about the implications of long-term biofuel use.

A total of 11 fuel samples were analyzed in terms of gross heating value, net heating value, weight percent of carbon, hydrogen, nitrogen, sulfur content, specific gravity, Cetane number, flash point, viscosity, cloud point, distillation, lubricity, and corrosion. From these analyses, factors that might affect operability, performance, and emissions of the fuels were evaluated. The cold weather operability of B10 and B20 is very similar to that of ULSD, while the higher biofuel blends have substantially higher cloud point temperatures which can result in wax crystals forming in the fuel. B20 biodiesel was found to have beneficial lubricity properties, implying reduced wear of metal surfaces, which can be compared to higher blend ratios.

B20 is also has an advantage over higher blend ratios in terms of viscosity and Cetane number, as both factors increase as the blend ratio increases. Also, a higher Cetane number appears to be related to increases in the NO_x emission rate. The average price increase for B20 versus ULSD was 13 cents per gallon. B20 was readily available from local vendors.

A summary of compared biofuel emissions is given in Table ES-1, based on over-the-road measurements.

Table ES-1. Bottom Line Comparison of Soy-Based Biodiesel Blends Versus Ultra Low Sulfur Diesel (ULSD) Based on Average Over-the-Rail Results for Three In-Use Locomotives.

Fuel	NO_x[a]	HC[b]	CO	PM[c]	CO_2
B10 vs. ULSD	+ 10 (*0.44*)	- 35 (*0.03*)	- 6 (*0.77*)	- 4 (*0.77*)	0 (*0.91*)
B20 vs. ULSD	+ 6 (*0.60*)	- 53 (*<0.01*)	- 38 (*0.02*)	- 23 (*0.09*)	- 5 (*0.02*)
B40 vs. ULSD	+ 21 (*0.15*)	- 39 (*0.04*)	- 27 (*0.04*)	- 17 (*0.10*)	- 2 (*0.52*)

Italicized values in parentheses were coefficients of variation (standard deviation divided by the mean) on the difference in the mean emission rates.

[a] NO_x includes NO and NO_2. Only NO was measured. Typically, NO_x is comprised of 95 vol-% NO. NO_x is always reported as equivalent mass of NO_2. Results include multiplicative correction factor of 1.053 to approximate total NO_x.

[b] HC is measured using non-dispersive infrared (NDIR), which accurately measures some compounds but responds only partially to others. Results include multiplicative correction factor of 2.5 to approximate total HC.

[c] PM is measured using a light scattering technique, which provides useful relative comparisons of particle levels in the exhaust. Results include multiplicative correction factor of 5 to approximate total PM.

Overall, on the average runs of all locomotives, B20 significantly lowered exhaust emissions of HC by 53 percent, CO by 38 percent, and PM by 23 percent. The NO_x emissions increased by 6 percent, but that increase is not statistically significant. Although exhaust CO_2 emission rate decreased somewhat, the more important factor with regard to CO_2 emissions for biodiesel is that less fossil-fuel based carbon is embodied in the fuel. Therefore, the net fossil-fuel based CO_2 emissions were lower for biodiesels than for ULSD. Correction factors in the footnotes of Table ES-1 for NO_x and HC were validated with supplemental measurements.

The study examined specific diesel locomotives for passenger rail service and excluded a variety of other locomotive chassis and prime mover engine models that are currently in service in the United States. It focused on prime mover engines and did not include head end power engines, which are common in passenger service. Finally, the methods demonstrated in this work for rail yard and over the rail measurements could be applied to other locomotives and the methods for tracking wear indicators could also be applied more broadly.

1. Introduction

This study assesses the following:

- The energy intensity of various biofuel blends compared to diesel fuel
- The environmental and energy effects of using various biofuel blends compared to diesel fuel, including emission effects
- The cost of purchasing biofuel blends
- Whether biofuel is readily available
- Any public benefits derived from using biofuels
- The effect of biofuel use on locomotive performance

Locomotive testing with various biofuel blends and diesel fuel was used to determine engine performance and emissions. Based on this research, recommendations are offered regarding choices among fuels and their implications

1.1 Background

Diesel engines, such as those used in locomotives, produce exhaust emissions that affect human health and contribute to climate change (WHO, 2012; Cooper and Alley, 2011; Flagan and Seinfeld, 1998; Clark et al., 2002; USDOT, 2010; US EPA 2008a&b; 2009; 2010; 2013). Significant amounts of nitrogen oxides (NO_x), a precursor to ozone (O_3) formation, are produced by diesel engines. NO_x is comprised of nitric oxide (NO) and nitrogen dioxide (NO_2). Diesel engines also emit particulate matter (PM), carbon monoxide (CO) and hydrocarbons (HCs).

When diesel engines are compared with other emission sources (such as gasoline-fueled vehicles) on a consistent basis such as mass of pollutant emitted per unit of work done by the engine shaft, diesel tends to have relatively high emission rates of NO_x and PM but relatively low emission rates of CO and HC. Additionally, diesel engines operate at high peak pressures and high air-to-fuel ratios, which are conducive to formation of NO_x, and they produce carbonaceous PM as a consequence of the compression ignition process. However, diesel engines tend to have comparatively low emissions of products of incomplete combustion, such as CO and HC, due to the high fuel-air ratios. The suite of pollutants including NO_x, PM, CO, and HC are generally of concern with regard to implications for air quality, human health and other adverse effects.

Biodiesel is a naturally oxygenated diesel replacement fuel made from renewable sources such as vegetable oils or animal fats. It can be used directly in diesel engines without major modifications to the engines and vehicles (US EPA, 2002). Biodiesel can be blended with petroleum diesel fuel at any ratio. A common blend rate is 20% renewable source and 80% petroleum diesel, referred to as B20.

One of the key motivations for the use of biodiesel is to reduce greenhouse gases. The fossil energy contribution to the life cycle for a 20 percent biodiesel and 80 percent petrodiesel blend (B20) is 83 percent, versus 37 percent for pure biodiesel blend stock. The use of B20 instead of petrodiesel will reduce fossil energy consumption and CO_2 emissions by 9 percent, based on soy-based biodiesel stock. The reduction for B100 is 42 percent (Pang *et al*., 2009). These percentages could increase if the share of non-fossil energy resources in power generation and transportation increase.

Many studies have examined the effect of biodiesel fuel on emissions from smaller four-stroke engines used in highway and nonroad applications, such as front loaders, backhoes, and motor graders (e.g., EPA, 2002; Frey and Kim, 2005, 2006, 2009; Frey et al, 2008, 2009; Kim et al., 2008). For example, EPA (2002) reviewed engine dynamometer test data for a variety of diesel engines and discovered that on average, emission rates of PM, CO, and HC are reduced and the emission rate of NO_x increased. On average, all engine types experienced emission decreases for B20 biodiesel versus petroleum diesel by 10% for PM, 11% for CO, and 21% for HC, but NO_x increased by 2%.

However, there are few studies which compare real-world locomotive engine emissions from biodiesel versus petroleum diesel (Fritz, 2000, 2004; Marchese et al., 2009; McKenna et al., 2008; Osborne et al., 2011). Data from these studies suggest that the effect of biodiesel on emission rates from locomotive prime mover engines may be less pronounced than its effect on emission rates for the smaller engines that are used in highway and other nonroad applications. Since there is substantial engine-to-engine and test-to-test variability, these results were deemed to be inconclusive. Also, since these studies were static load tests conducted on either a dynamometer or in a rail yard, there is a need to obtain data measurements for actual over-the-road locomotive operations.

Between 2010 and 2011, Amtrak operated one General Electric P32-8 locomotive on B20 on the Heartland Flyer service in Oklahoma. According to Amtrak, the results of the one-year trial indicated that exhaust emissions were lower than the EPA Tier 0 emission standard for that locomotive compared to conventional diesel fuel. Also, B20 did not increase locomotive wear or decrease locomotive performance and reliability did not decrease with B20 compared to conventional diesel fuel (Amtrak, 2011). Starting in 2012, freight railroad Norfolk Southern began operating locomotives on B100 derived from waste animal fats and grease. No engine modifications were necessary in order to use B100 in the locomotives (Norfolk Southern, 2013).

Previous studies suggest that there is no significant difference in performance or advanced engine wear in a diesel engine caused by the use of biodiesel compared to conventional petroleum diesel (Agarwal *et al*., 2003; Fazal *et al*., 2011). However, none of these studies were conducted on a locomotive engine.

To conduct over-the-road measurements, the project used Portable Emission Measurement Systems (PEMS) (Frey et al., 2012; Frey and Graver, 2012, 2013; Graver and Frey, 2013). The capabilities of PEMS have been compared to approved federal reference methods that are used in dynamometer laboratories (Battelle, 2003). Methods for deployment of PEMS for locomotive emission measurements have been demonstrated in the context of dynamometer engine load tests, rail yard static engine load tests, and over-the-rail measurements during revenue generating service. Although PEMS are used for some on-road truck-related regulatory applications, they are not used to test locomotive engines for regulatory or certification purposes. However, PEMS are useful for making consistent relative comparisons between engine load settings, locomotives, and fuels. PEMS also enables measurements during revenue-generating over-the-road (OTR) locomotive service, and thus enables collection of data for actual locomotive duty cycles.

1.2 Objectives

This research does the following: (1) compares the energy intensity of various biofuel blends to diesel fuel; (2) compares the environmental and energy effects of using various biofuel blends to diesel fuel, including emission effects; (3) evaluates the cost of purchasing biofuel blends; (4) determines whether sufficient biofuel is readily available; (5) describes any public benefits derived from the use of such fuels; and (6) analyzes the effect of biofuel use on locomotive performance.

1.3 Overall Approach

The overall approach included several key focus area, each supported by a methodological approach:

- Three diesel locomotives, which are owned by the North Carolina Department of Transportation (NCDOT) and operated by Amtrak. The engines operate on the Piedmont line and carry passengers between Raleigh, NC and Charlotte, NC. Each locomotive was supplied with ultra-low sulfur diesel (ULSD) and multiple soy-based biodiesel blends, including B10, B20, and B40. One of the locomotives was also operated on B60, B80, and B100.
- Samples of ULSD and biodiesel blends, including B10, B20, B40, B60, B80, and B100 were sent to a fuel characterization laboratory to undergo a battery of standard American Society for Testing and Materials (ASTM) tests regarding physical and chemical fuel properties.
- Lubricating oil samples were taken by NCDOT from each locomotive and analyzed by a local Caterpillar dealer and service shop for indicators of engine wear.
- To detect physical wear, measurements were made by NCDOT's onsite contractors (Herzog and, later, RailPlan) of piston ring and cylinder head clearances during 180 day inspections of the prime mover engines.
- To measure exhaust emissions of CO_2, CO, HC, NO_x, and PM for each combination of locomotive and fuel, static load measurements were conducted at NCDOT's rail yard (RY) in Raleigh, NC, typically based on three replicates measured in one day.
- To measure over-the-road (OTR) exhaust emissions of CO_2, CO, HC, NO_x, and PM for each combination of locomotive and fuel, a series of dynamic load measurements were conducted during Amtrak revenue service between Raleigh, NC and Charlotte, NC, typically based on six one-way trips measured over three days.
- The prices of the ULSD and biofuel fuels purchased by NCDOT were obtained to assess fuel price differential (if any) for the biofuel blends compared to ULSD.
- Literature review was conducted to assess possible implications for the fuel life cycle and discover other impacts of biodiesel fuels.

The emissions from the locomotive prime mover engines were measured using portable emission measurement systems (PEMS) in the RY and OTR tests. To perform PEMS measurements, quality assurance must be performed by maintaining, calibrating, installing, and operating the instruments; quality control must occur when data is synchronized from multiple instruments, identify errors in the data, and correct errors when possible or remove the errant data; and the data must be analyzed and interpreted with regard to variation in emission rates, engine load, and cycle averages based on standard and real-world cycles.

For each locomotive and fuel combination, emission rates were compared between replicates of RY tests to assess inter-replicate variability and gain insight regarding the repeatability of the measurements. Likewise, the OTR emission rate measurements from one-way trips were compared against each other to assess repeatability. For a given locomotive, emission rates for each biofuel blend were compared to those based on ULSD to assess the effect of the biofuels on emission rates.

1.4 Scope

The scope of work completed includes the following:

- Measurements were made for CO_2, CO, HC, NO_x, and PM using Portable Emissions Measurement Systems (PEMS).
- Measurements were made on three NCDOT owned locomotives, including locomotive numbers NC-1797, NC-1810, and NC-1859. NC-1797 is an EMD F59PHI locomotive with EMD12-710 prime mover engine. NC-1810 and NC-1859 are both EMD F59PH locomotives, also with an EMD12-170 prime mover engine.
- For all three locomotives, measurements were made on ULSD, B10, B20, and B40. For NC-1810, additional measurements were made on B60, B80, and B100.
- Typically less than one percent of total data collected were excluded after quality assurance screening.
- Thirty-four lubricating oil analyses from the three test locomotives over a multi-year period, including baseline data prior to the use of the biofuels, were reviewed, including comparison data during biofuel use.
- A total of 11 fuel samples were analyzed with respect to gross heating value, net heating value, weight percent of carbon, hydrogen, and nitrogen, sulfur content, specific gravity, Cetane number, flash point, viscosity, cloud point, distillation, lubricity, and corrosion.

The study focused on specific diesel locomotives for passenger rail service and it did not include other locomotive chassis and prime mover engine models that are in service in the United States. The study concentrated on prime mover engines and did not include head end power engines. Although the study involved measurements of locomotives over a period of time, the time frame of the study is not sufficient to establish the long-term effects of biofuels on engine durability or performance.

1.5 Organization of the Report

The report is organized as follows:

- **Chapter 2: Effect of Biofuels on Engine Performance**.
- **Chapter 3**: **Rail Yard Measurements**.
- **Chapter 4**: **Over-the-Rail Measurements**.

- **Chapter 5**: **Fuel Cycle**.
- **Chapter 6**: **Conclusions**.

2. Effect of Biofuels on Engine Performance

The effect of biodiesel fuels on engine performance was assessed in three ways:

- Quantification of fuel properties
- Identification of indicators of engine wear from lubricating oil samples
- Measurements of engine clearances during 180 day inspections of the locomotive prime mover engines.

More information on fuel measurements is given in Appendix A, while more information on lubricating oil measurements is given in Appendix B.

2.1 Fuel Properties

Based on a review of the literature, key biofuel properties were identified and defined, and the effect of biofuel properties on fuel use and emission rates is discussed. Results for measurements of sampled fuel blends were given.

2.1.1 Fuel Characteristics

The emissions and fuel use of a diesel vehicle are influenced by the fuel's properties. This study evaluates the effects when a locomotive prime mover engine changes from petroleum diesel to biofuel blends or biodiesel fuel. Previous studies reported a decrease in emissions of CO, HC, and PM, and a slight increase in NO_x, when this switch has been made for smaller 4-stroke diesel engines of typically 500 hp or less (EPA, 2002). EPA (2002) reports that fuel density, Cetane number, distillation range, aromatics content, and lower heating value (LHV) has individual or combined effects on one or more of each of the following pollutants: PM, NO_x, HC, CO, and CO_2. The energy density of the fuel will affect the fuel economy (e.g., gallons of fuel used per duty cycle). Physical, chemical, and biological properties of the fuel will influence issues such as biofouling and handling (including the ability of fuel to flow in cold weather versus warm weather). Biofouling refers to the growth of organisms in the fuel during storage (Encinar *et al.*, 2002). Several of these factors are described in more detail elsewhere.

Net Heat of Combustion (ASTM D240)

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. The heating value per mass or volume of a fuel is related to the resulting fuel economy (e.g., miles of vehicle travel per gallon of fuel consumed). When comparing fuels with different heating values and densities, there can be an apparent difference in fuel economy, but not necessarily a difference in energy efficiency. The LHV is also referred to as the net heating value, which is measured using ASTM D240.

Cloud Point (ASTM D2500)

The cloud point is the fuel storage temperature at which small wax crystals appear as the fuel cools. Cloud point is an indicator of the fuel's usability. Other cold weather parameters can be used to characterize biodiesel, including the cold filter plugging point (which is the lowest temperature at which an engine will operate) and the pour point, which is the lowest temperature for which fuel is observed to flow (Durbin *et al.*, 2000). Typically, the cloud point is higher than the cold filter plugging point and the pour point, and it is used by this study to characterize the cold temperature operability of the fuel.

Ultimate Analysis

The ultimate analysis of a fuel is the weight percent of major elements in the fuel, such as carbon, hydrogen, oxygen, sulfur, and nitrogen. Data on the density and weight percent of carbon enables the CO_2 emission ratein grams of CO_2 per gallon of fuel consumed, and the grams of SO_2 per gallon of fuel consumed. The weight percent of C, H, and N is measured using ASTM D5291, and the weight ratio of S (in ppm) is measured using ASTM D2622. The weight percent of O is inferred by difference. The weight percent of C will increase as the biofuel blendstock ratio increases. More oxygen in the fuel typically promotes more complete combustion of the fuel, which reduces CO and HC emissions.

Cetane Number (ASTM D613)

The Cetane number is the standard measure of fuel ignition characteristics when the fuel is injected into a diesel engine, and the Cetane number is measured using ASTM test method D613. The number is related to the delay between when fuel is injected into the cylinder and when ignition occurs (Graboski *et al.*, 2003). Higher Cetane numbers indicate shorter times between fuel injection and its ignition. Good ignition and a high Cetane number assists in easy starting, starting at low temperature, low ignition pressures, and smooth operation with lower knocking characteristics. According to McCormick (1997), PM emissions decrease when Cetane number increases, while NO_x emissions slightly increase.

Copper Corrosion Test (ASTM D130)

The copper corrosion test (ASTM D130) assesses potential difficulties which might occur if copper and bronze fuel system components come into contact with fuel. The results of this test were a categorical rating.

Specific Gravity (ASTM D4052)

The density (ρ) 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 specific gravity. Specific gravity is defined as the ratio of the density of the fuel to the density of water (at 60°F). Density and specific gravity can be determined with the ASTM D4052 test method. According to Durbin and Norbeck (2002), a 3.5 percent increase in fuel density leads to a three to four 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. If the fuel has greater mass, that 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.

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 measured with ASTM test method D86. 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 final boiling point.

Viscosity

Viscosity measures the resistance of a fuel to shear or flow, and it 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.*, 2000). A high viscosity fuel will produce larger droplets 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 B20 and petroleum diesel would significantly account for differences in emissions. 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 were outweighed by other factors. Kinematic viscosity is measured using ASTM D445.

Flash Point (ASTM D93)

The flash point is the lowest temperature at which a flammable liquid can form an ignitable mixture in air. Flash point measures the temperature to which a fuel must be heated in order to ignite a mixture of the vapor and air above the fuel (Kleinschek *et al.*, 1997). This parameter is mainly of concern with respect to fire safety (Ullman, 1989).

Lubricity (ASTM D6079)

Lubricity indicates the amount of wear or scarring that occurs between fuel-covered metal parts that are in contact with each other. Lubricity is inversely proportional to the major and minor axes of wear scars measured during ASTM test D6079. Fuels with higher lubricity may lead to less engine wear and longer component life.

2.1.2 Effects of Fuel Properties on Emissions and Fuel Use

The effect of biodiesel versus petroleum diesel on emissions is based on a review of the literature.

Particulate Matter

Diesel engines emit significant quantities of particulate matter (PM). Substantial reduction in PM emissions can be obtained by adding 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), when B20 is used instead of petroleum diesel, reductions of PM were 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 the Cetane number, an increase in aromatic compounds, and a higher distillation end point. A higher Cetane number helps improve combustion characteristics, but poorer combustion quality makes PM emissions increase. Also, aromatics have a greater tendency to form carbonaceous soot in burning and higher distillation end point temperatures might minimize deposits in the combustion chamber. Thus, B20 and B100, which have high Cetane number, but a lower end point without any aromatics, can reduce PM emissions (Akasaka *et al.*, 1997; McCormick *et al.*, 1997; 2001).

Nitrogen Oxides (NO_x)

Reported average 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) 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. The Cetane number also tends to have a role in slight increase of nitrogen oxides emission effects for heavy duty diesel engines. However, there is substantial inter-vehicle variability in NO_x emissions for B20 versus petroleum diesel, and there is some indication that results obtained for real world duty cycles may differ than those from dynamometer tests (e.g., Frey and Kim, 2006).

Hydrocarbons (HC)

HC emissions are typically from incomplete combustion and are either unburned or partially burned fuel molecules (Flagen and Seinfeld, 1998). According to EPA (2002), a 19 to 32 percent decrease of HC emissions can be expected after switching from petroleum diesel to B20 fuel. This might be due to the higher oxygen content of B20, which tends to promote more complete combustion.

Carbon Monoxide (CO)

CO emissions are a result of incomplete combustion and they are formed when fuels containing carbon are burned in an environment where there is too little oxygen, as a result of poor fuel and air mixing, or as a result of insufficient reaction time for oxidation reactions to reach completion. 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 promotes complete combustion (Durbin and Norbeck, 2002).

Carbon Dioxide (CO_2)

Biodiesel reduces net CO_2 emissions, when the entire fuel cycle is considered (Sheehan *et al.*, 1998). Although the amount of CO_2 emitted from the exhaust pipe with biofuel is slightly higher than for petroleum diesel fuel, a significant portion of the carbon in B20 is based upon biomass from soybeans or other vegetable oils, which in turn is based upon CO_2 taken up by the plants 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 biofuel 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).

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). Tsolakis et al. (2003) estimated that fuel economy will decrease when comparing biodiesel with petroleum diesel. B20 biodiesel has a 2.21 percent lower volume-based heating value than petroleum diesel, which implies that a reduction in fuel economy of approximately two percent is expected when switching from petroleum diesel to B20 biodiesel fuel.

Power Loss

According to Wayne et al. (2004), peak engine horsepower is linked 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, which causes less chemical energy to be 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), using B100 instead of petroleum diesel leads to a small power loss. 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 settings 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 by less than 2 percent. 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.

2.1.3 Fuel Test Results

A total of 11 fuel samples were analyzed for physical and chemical properties, as indicated in Table 2-1 and Appendix A. Three samples were measured for ULSD, two each for B20 and B40, and one each for B10, B20, B60, B80, and B100.

As expected, the net heating value decreases as the biofuel blending ratio increases, ranging from 18,500 BTU/lb for ULSD to 16,100 BTU/lb for B100. The specific gravity increases with blending ratio, randing from 0.8416 for ULSD to 0.8809 for B100. Nonetheless, the energy density in BTU/gallon also decreases with increasing blend ratio.

Table 2-1. Measured Fuel Properties for Ultra-Low Sulfur Diesel (ULSD), B10, B20, B40, B60, B80, and B100 Biodiesel Fuel*

		ULSD**	**B10**	**B20*****	**B40*****	**B60**	**B80**	**B100**
Properties	**Unit**	**Obtained 7/2013 9/2013 10/2013**	**Obtained 9/2013**	**Obtained 12/2013 4/2014**	**Obtained 10/2013 7/2014**	**Obtained 8/2013**	**Obtained 12/2013**	**Obtained 2/2014**
ASTM D130 Copper Corrosion								
Copper Corrosion	rating	IA	IA	IA IC	IA IC	IA	IA	IC
ASTM D240 Gross Heat of Combustion								
Gross Heat	BTU/lb	19,659	19,491	18,900	18,635	18,091	17,714	17,232
Gross Heat	MJ/Kg	45.727	45.336	43.960	43.345	42.080	41.202	40.083
Gross Heat	Cal/g	10,922	10,828	10,500	10,353	10,051	9,840.8	9,573.7
ASTM D240 Net Heat of Combustion								
Net Heat	BTU/lb	18,471	18,279	17,726	17,470	16,955	16,618	16,140
Net Heat	Mj/Kg	42.963	42.517	41.231	40.634	39.437	38.653	37.540
Net Heat	Cal/g	10,262	10,155	9,847.8	9,705.3	9,419.4	9,232.2	8,966.4
ASTM D2500 Cloud Point								
Cloud Point	°C	-11.5	-11.1	-8.4	-0.6	-4.2	-5.0	2.8
ASTM D2622 Sulfur by WDXRF								
Sulfur	ppm	10.8	8.0	7.8	6.7	5.9	4.9	0.8
ASTM D4052 API, Density, Specific Gravity								
API	°	36.6	36.6	34.4	33.4	31.7	30.2	29.1
Specific Gravity @60°F		0.8416	0.8416	0.8534	0.8580	0.8672	0.8753	0.8809
Density @15°C	g/ml	0.8412	0.8411	0.8530	0.8576	0.8667	0.8748	0.8805
ASTM D5291 Carbon Hydrogen Nitrogen								
Carbon	wt%	86.74	85.72	83.41	82.36	80.64	78.90	76.96
Hydrogen	wt%	13.02	13.29	12.9	12.78	12.46	12.01	11.98
Nitrogen	wt%	0.02	0.20	0.09	0.10	0.14	0.10	0.11
ASTM D613 Cetane Number								
Cetane	No.	47.2	49.0	48.6	53.0	48.8	49.2	49.8
ASTM D93 Flash Point								
Flash Point	°C	64.3	61.0	63.5	71.5	73.0	81.0	115
BioDiesel Content by IR								
Biodiesel	vol%	N/A	6.6	22.3	40.5	55.6	N/A	99.6
ASTM D6079 Lubricity								
Wear Scar Diameter	µm	362	265	171	168	159	151	151
Major Axis	mm	0.406	0.297	0.204	0.190	0.189	0.181	0.183
Minor Axis	mm	0.318	0.233	0.137	0.154	0.129	0.120	0.118
Scar Description****		EAO	EAO	EAO LAO	EAO LAO	EAO	LAO	LAO
ASTM D445 Kinematic Viscosity								
Viscosity	cSt	2.498	2.510	2.820	3.042	3.352	3.543	4.052

Continued on Next Page

Table 2-1. Continued

ASTM D86 Distillation								
Initial Boiling Point	°F	332.2	333.5	343.5	351.7	343.5	358.1	N/A
10% Recovered	°F	400.5	398.9	415.5	431.6	469.7	546.8	N/A
50% Recovered	°F	504.1	510.3	567.8	585.4	616.8	630.6	N/A
90% Recovered	°F	621.6	624.9	639.2	637.8	644.5	644.8	N/A
Final Boiling Point	°F	660.5	660.0	661.0	666.3	674.0	664.6	N/A
Recovered	%	97.2	97.9	98.3	98.6	98.7	98.1	N/A
Residue	%	1.3	1.3	1.2	1.0	0.7	1.3	N/A
Loss	%	1.5	0.8	0.5	0.4	0.6	0.6	N/A

* *Biodiesel Blends: B10 is 10% biodiesel and 90% ULSD blend; B20 is 20% biodiesel and 80% ULSD blend; B40 is 40% biodiesel and 60% ULSD blend; B60 is 60% biodiesel and 40% ULSD blend; B80 is 80% biodiesel and 20% ULSD blend; B100 is 100% biodiesel.*

** *ULSD results were averages based on three measurements. B20 and B40 results were averages based on two measurements each. The other biodiesel blends results were based on one measurement each.*

*** *For B20 biodiesel blends, sample obtained on 12/2013 has a copper corrosion rating of IA and a scar description of EAO; sample obtained on 4/2014 has a copper corrosion rating of IC and a scar description of LAO. For B40 biodiesel blends, sample obtained on 10/2013 has a copper corrosion rating of IA and a scar description of EAO; sample obtained on 7/2014 has a copper corrosion rating of IC and a scar description of LAO.*

*** *Scar Description: LAO – Lightly Abraded Oval; EAO – Evenly Abraded Oval.*

The cloud point tends to increase with blend ratio but the trend has some variability. For example, the cloud points of ULSD and B10 are similar at approximately -11^{o}C. The cloud points of B60 and B80 are similar, at -4^{o}C to -5^{o}C. The highest cloud point, as expected, is for B100, at nearly 3^{o}C. The cloud point for B20 is closer to that of ULSD than to B100.

The carbon content typically decreases as the blend ratio increases, ranging from 86.7 percent for ULSD to 77.0 percent for B100, and the hydrogen content also decreases, from 13.0 percent for ULSD to 12.0 percent for B100. However, the nitrogen content is highly variable on a relative basis, with no clear trend versus blend ratio, and typically it is approximately 0.1 weight percent or less. The fuel sulfur content was typically approximately 10 ppm (by weight) or lower), and the B100 blend stock sulfur content was less than 1 ppm.

There was not a clear trend in the Cetane number versus the blending ratio. ULSD had the lowest Cetane number, at 47.2, whereas the measured B40 had the highest, at 53.0. For the other biofuel blends, the Cetane number was approximately 49.

In terms of physical properties, the flash point increased with increasing biofuel blending ratio (as expected), from 64 ^{o}C for ULSD to 115 ^{o}C for B100. The lubricity of the fuel was higher for higher blend stocks and the sear scar diameter decreased by a factor of more than two when B100 was compared to ULSD. Although the wear scar diameter decreased as the blend ratio increased, the relative decrease was large for B20, where the wear scar diameter was approximately half that of ULSD. Conversely, the kinematic viscosity increases with blend ratio. The distillation results were obtained for all fuels except B100. There was not much variation in the final boiling point among the measured fuels, but the temperatures for 10%, 50%, and 90% recovery each tended to increase with increasing fuel blend.

2.2 Lubricating Oil Engine Wear Indicators

When the test locomotives underwent their 90-day inspection by NCDOT, oil samples were taken from the prime mover and head end power (HEP) engines. Then the samples were sent to the Gregory Poole Fluid Analysis Laboratory for analyses that characterize wear metals present in the oil (e.g., Cu, Fe, Cr, Al, Pb, Sn, Si, Na, K, Mo, Ni, Ca, Mg, Zn, P, and Ba) as well as oil condition (e.g., soot, oxidation, nitration, sulfation, water, antifreeze, fuel, and viscosity).

The metals that were measured by the lubricating oil analysis represent specific aspects of engine wear. For example, the presence of aluminum (Al) indicates wear from pistons, bearings, housing metal, thrust washers, converter and pump bushings, and dirt entry.   Chromium (Cr) is a wear indicator for chromed parts such as piston rings and bearings. Iron (Fe) indicates wear from gears, shafts, cylinders, liners, valve train components, other steel components and rust. Molybdenum (Mo) indicates wear from piston rings. Many of the other metals that may be present in the samples were additives to the lubricating oil itself, such as Sodium (Na), Potassium (K), Calcium (Ca), Barium (Ba), Magnesium (Mg), Phosphorus (P), and Zinc. Some of these additives are used as dispersants and detergents, while others serve anti-wear or anti-freeze purposes. Some metals, such as Lead (Pb), Tin (Sn), and Nickel (Ni) are indicators of wear of bearings and bushings, many of which were not in the combustion flow path.

The particle count measurement determines whether there is excessive wear or dirt, and the oxidation and nitration measurements assess how much oxygen and nitrogen has been absorbed by the oil, which is an indicator of wear on the oil itself. The sulfation measurement indicates how much sulfur has been taken up by the oil, which is an indicator for combustion gas that gets past the cylinder rings into the crankcase of the engine (or “blow-by”). Thus, sulfur is an indicator of engine wear, especially for piston rings.

The water, antifreeze, and diesel measurements indicate if the oil has been contaminated by the oil by the coolant and fuel systems, which would point to significant fluid entry. The viscosity measurement is an indicator of lube oil wear; while high viscosity is associated with oxidation of the oil, low viscosity is associated with fuel getting into the crankcase.

Of the various measures of engine wear, the most relevant to the combustion gas flow path were those related to cylinder, piston, and piston ring wear (Al, Cr, Fe, and Mo); elevated levels of Pb, Sn, and Ni are signs of engine wear in the crankcase.

Herzog and RailPlan, NCDOT’s onsite maintenance contractors, obtained lubricating oil analysis results from the Gregory Poole Fluid Analysis Laboratory for all six locomotives in the NCDOT fleet from as far back as possible to as recent as possible. In total, 69 fluid samples were gathered from the prime mover engines in the locomotive fleet and 69 fluid samples were gathered from the HEP engines in the locomotive fleet. Details of the test dates and results for each locomotive are given in Appendix B.

Most of the locomotives in the NCDOT fleet have had oil analysis results with recommendations from the laboratory to monitor or take action on the lubricating oil. Based on the comments from the oil analysis reports, the four wear metals that led to results being coded yellow (for monitor) or red (for take action) were Cu, Fe, Sn, and Pb. To assess the levels of the four wear metals for each engine over time, reported concentrations were graphed and are included in the Appendices.

For the metals that led to yellow or red codes, an increasing trend in the concentration of one or more of these wear metals is observed. The prime mover engine of NC-1755, which is not part of the biofuel test program and was only operated on ULSD, is used as an example. NC-1755 had the concentrations of Cu, Fe, Sn, and Pb increase from August 2010 through January 2013 (see Figure B-3). The first three tests for NC-1755 were coded as no action being required but the results were coded as yellow for the fourth test as the wear metal concentrations continued to increase, and monitoring was advised. The wear metal concentrations continued to increase in the last two tests, and action was recommended. This type of result indicates that lubricating oil wear indicators occur for the baseline ULSD fuel for similar locomotives to those that were the focus of biofuel measurements.

The lubricating oil analyses for the NC-1810 and NC-1859 prime mover engines, both of which were part of this biofuel test program, contain no indication that biodiesel use affected their operations. All analyses have come back with the "No Action Required" while the engines operated with all biodiesel blends used in this study.

The two lube oil analyses from NC-1797, which was also part of this biofuel test program, while the prime mover engine was operating on biodiesel indicated that Cu, Pb, and Sn levels were elevated, indicating possible bearing wear. However, the measured concentrations of these metals began to increase prior to the introduction of biodiesel (see Figure B-3 in Appendix B). Therefore, biodiesel is probably not the initiating cause of apparent engine wear in the NC-1797 prime mover engine.

While Cu, Pb, and Sn concentrations increased in earlier lube oil analyses of the NC-1893 prime mover engine, where one biofuel test was done with B10, it is not likely that the use of B10 biodiesel increased the wear metal concentrations. The most recent lube oil analyses of the prime mover and HEP engines for NC-1893, subsequent to the B10 test, came back as "No Action Required." Unfortunately, NC-1893 was not used for further biofuel tests because of some unrelated problems that caused that locomotive to be taken out of service.

Based on the lube oil analyses, the use of biodiesel by the prime mover and HEP engines does not appear to have an adverse effect on engine wear for NC-1797, NC-1810, NC-1859, and NC-1893, each of which have been tested on biofuels, with NC-1797, NC-1810, and NC-1859 being the three primary locomotives that were the focus of extensive measurements.

2.3 Mechanical Wear

During the 180-day inspections of the prime mover engines, NCDOT and its contractors measured the clearance between the piston ring and the piston as well as the clearance between the top of the piston and the cylinder head.

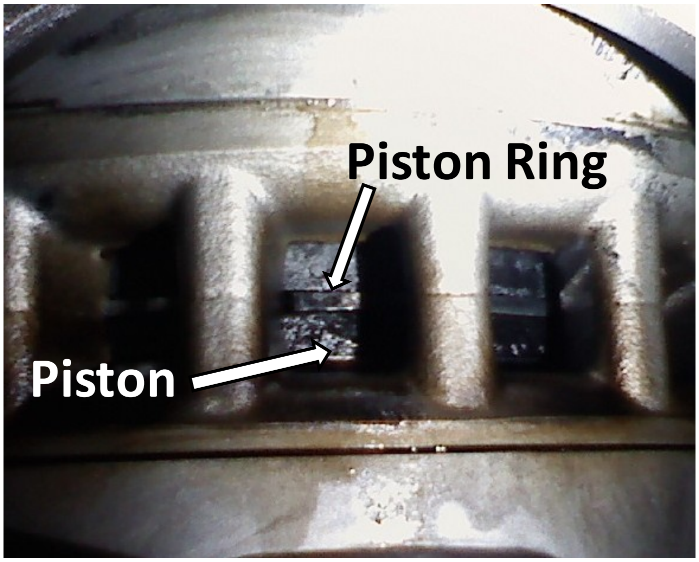


Figure 2-1. Photograph of EMD12-745 Engine Showing Piston and Piston Compression Ring. These can be observed during a rail yard inspection.

The piston-cylinder head clearance is measured with a lead wire inserted into the cylinder; the wire is compressed when the crankshaft is rotated such that the cylinder obtains top dead center. If the reading is higher than 0.100 inches, then a renewal of the power assembly is needed. The trend in readings over time for a given engine, and the rate at which the clearance changes while operating on a given fuel, was assessed.

To determine the piston-ring clearance, the top piston ring, which is the compression ring, is measured for its “land clearance,” which is the vertical “play” between the ring and the groove in the piston within which the ring fits. As the piston ring wears, the clearance will increase. A clearance of greater than 0.025 inches indicates that there is too much wear and renewal is necessary. The rate of piston ring clearance increase will be assessed for each of the fuels used.

According to NCDOT, no changes in these parameters were observed for any of the test locomotives during the study. Thus, there was no evidence of engine wear.

2.4 Anecdotal Observations

Additionally, the NCDOT mechanical staff and Amtrak were asked if they noticed any operational impacts while the locomotives were operating on biofuels, such as lower engine output at a particular notch position, gelling of fuel, and increased filter replacement. NCDOT mechanics reported no changes in any clearance measurements while the locomotives operated on biodiesel. With regard to performance, Amtrak engineers did not report any issues, such as lower engine output.

NCDOT mechanical staff did not identify any major maintenance or repair issues with the prime mover engines (PME). Filters were replaced more frequently due to biodiesel’s strong solvent action. To prevent possible gelling of B100 in NC-1810 during cold temperatures, the PME was not turned off, but rather idled, between trips. NC-1810 operated on biodiesel during the winter and did not experience any adverse effects in terms of fuel operability.

2.5 Implications

The results of the fuel property measurements, lubricating oil measurements, and the mechanical wear engine clearance indicators imply that there was not any observable engine wear attributable to biofuel use. However, this study represented time periods of approximately one to two years of biofuel operation per tested locomotive which is a limited amount of time compared to the overall operating life of a locomotive. Thus, this study cannot answer questions about the effect of biofuel on long-term durability and it did not address whether biofuels were causing deposition, which has been reported anecdotally by some other railroads after they removed and inspected fuel injectors. Removing and inspecting components such as fuel injectors was not part of the scope of this particular study.

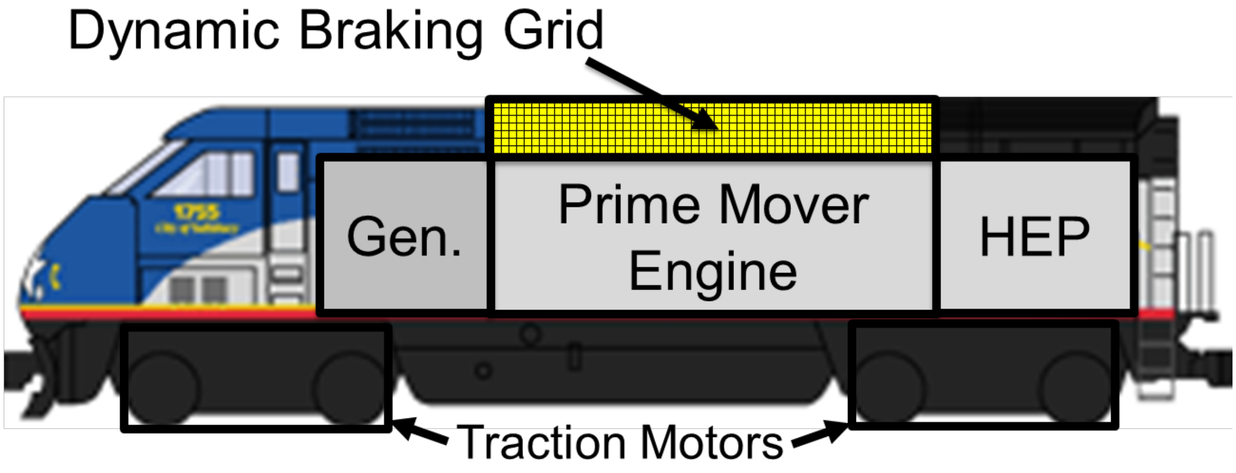
Nonetheless, the consistent results regarding lubricity, lubricating oil wear indicators, and engine clearance measurements indicates that abrasive wear may not be a significant concern with biofuels.

3. Rail Yard Measurements

In this chapter, the methods for performing rail yard measurements on test locomotives and the corresponding results were given. NCDOT owns two EMD F59PHI model and four EMD F59PH model locomotives which are used for passenger rail service. Both F59PHs, numbers NC-1810 and NC-1859, and one F59PHI, numbered NC-1797, were selected for this study. Each locomotive has a 12-cylinder, 140-liter, 2,240-kW EMD 12-710 diesel PME.

A schematic of an F59PHI is shown in Figure 3-1. The key components of this locomotive are the PME, the generator, the dynamic braking grid, and traction motors. Because these locomotives are configured for passenger rail service, they have a separate head end power (HEP) engine-generator set that produces 60 Hz alternating current for "hotel" services in the passenger cars, including lighting, heating, and air conditioning. This study did not focus on HEP engines; it focused on the larger PMEs, which connect via a shaft to a direct current generator that powers the traction motors that propel the train. Excess power can be rejected to an electrical resistor system known as the dynamic braking grid. Furthermore, the traction motors can operate as generators to help slow the locomotive as electricity dissipates in the dynamic braking grid.

Figure 3-1. Schematic of F59PHI Passenger Diesel Locomotive, Depicting the Generator, Prime Mover Engine, Head End Power (HEP) Engine, Dynamic Braking Grid, and Traction Motors.



3.1 Measurement Method

Measurements of the activity and exhaust concentrations of three EMD12-710 prime mover engines were made in the NCDOT Capital Yard Maintenance Facility in Raleigh, NC to quantify notch average, cycle average fuel use, and emissions rates for ULSD, B10, B20, and B40. These measurements were made for locomotives NC-1797, NC-1810, and NC-1859. In addition, for NC-1810, measurements were made with B60, B80, and B100. NCDOT staff, as well as staff from onsite contractors Herzog and RailPlan, provided logistical support and operated the locomotives during rail yard tests. The locomotives were operated by Amtrak for over the rail revenue-generating passenger rail service. NCDOT procured the fuels used in this study, including ULSD and B20 via state contract. Blends of B10, B40, B60, B80, and B100 were obtained by NCDOT from a local fuel vendor. All of the biofuel used in this study was soy-based. Instruments used for data collection included a PEMS with engine sensor array and a locomotive activity data recorder.

3.1.1 Portable Emissions Measurement System

The PEMS used were the OEM-2100 Montana and OEM-2100AX Axion systems, which were manufactured by GlobalMRV, Inc. Both PEMS had two parallel five-gas analyzers, a particulate matter (PM) measurement system, an engine sensor array, a global positioning system (GPS), and an on-board computer (CATI, 2003). The Axion PEMS is in the center of Figure 3-2. This PEMS was selected due to its relatively small size, its portability, and margin of safety. As described in Section 3.1.3, other PEMS use different detection methods and a compressed hydrogen cylinder may be needed; the locomotive owner did not want to bring hazardous materials onboard the locomotive during over-the-rail measurements (see Chapter 4). To ensure a consistent basis for comparison, the same PEMS was used both for rail yard and over-the-rail measurements.

Both PEMS were operated on 12 volt direct current power. For rail yard tests, they used 120 VAC shore power with a 12 VDC transformer. Exhaust sample lines were fitted to the engine exhaust duct and routed to the PEMS. Each PEMS had two exhaust sample lines: one for gases and one for particulate matter. The PEMS also had an in-built GPS receiver which was typically not deployed in rail yard tests, since these tests were conducted at a known location. The PEMS had a “weather station” that measures temperature, relative humidity, and barometric pressure. Engine exhaust was continuously sampled and was vented from the PEMS to the atmosphere via tubing. A sample line for reference air was used to periodically “zero” the gas analyzers to prevent instrument drift. Other components of the PEMS related to the engine sensors are described in Section 3.1.2.

The two parallel gas analyzers simultaneously measured the volume percentage of CO, CO_2, HC, NO, and O_2 in the vehicle exhaust. HC, CO, and CO_2 were measured using non-dispersive infrared (NDIR). The accuracy for CO and CO_2 were excellent. The accuracy of the HC measurement depends on the type of fuel used (Vojtisek-Lom and Allsop, 2001; Andros, 2007). NO was measured using an electrochemical cell. Nitrogen oxides (NO_X) is typically comprised of approximately 95 percent NO (by volume); therefore, NO emissions converted to an equivalent NO_2 mass basis (using the molecular weight of NO_2) were a good indicator of total NO_X emissions. NO_X emissions were typically reported as equivalent NO_2. Prior to each set of measurements, the PEMS was calibrated with a gas (BAR-97 Low) certified by the California Bureau of Automotive Repair (BAR). Each PEMS gas analyzer was re-calibrated using ambient air to “zero” its values every 15 minutes on a staggered schedule, so that typically at least one gas analyzer was measuring while the other was “zeroing.”

Figure 3-2. Components of the Portable Emissions Measurement System (PEMS) and Engine Sensor Array.

The PEMS reported the mass emission rates estimated using concentration and engine data as detailed elsewhere (Vojtisek-Lom and Allsop, 2001). The precision of this PEMS was ±25 ppm, ±4 ppm, ±0.02%, and ±0.3% for NO, HC, CO and CO_2, respectively (Zhang, 2006). The PEMS was compared with a dynamometer laboratory and it was determined that the Montana system is both precise and accurate. (Meyers *et al.*, 2003; Vojtisek-Lom and Allsop, 2001). Additionally, the Montana system had been evaluated in the Environmental Technology Verification (ETV) program of the U.S. EPA. In an independent study by Battelle (2003), emissions of several vehicles were measured simultaneously on a laboratory grade dynamometer facility and a PEMS. The coefficients of determination (R^2) for the comparison for exceeded 0.86 for all pollutants, which indicated good precision. The slopes of the parity plots for CO, CO_2 and NO ranged from 0.92 to 1.05, which indicated good accuracy. Non-dispersive infrared (NDIR) sensors are well known to respond only partially to the total loading of hydrocarbon species in the exhaust, because they responded well to alkanes but were less responsive for other types of S-3 compounds, such as aromatics (Singer *et al.*, 1998; Stephens *et al.*, 1996a; Stephens *et al.*, 1996b).

Correction factors were used to adjust for biases associated with the methods that the PEMS use to measure emissions. NO_x is typically comprised of 90 to 95% NO by volume. A correction factor of 1.053 (1/0.95) is used to approximate for total NO_x, based on 95% NO in NO_x. An NDIR sensors' response to a mixture of hydrocarbons in engine exhaust is approximately 23% to 68% of the actual total HC (Stephens *et al.*, 1996a). A correction factor of 2.5 is used to approximate for total HC. The accuracy of these correction factors was evaluated with supplemental rail yard measurements using a different PEMS, as described in Section 3.1.3.

When the laser light scattering technique for measuring PM was evaluated, there was up to 80% difference in the emission measurement relative to the FRM (Durbin *et al.*, 2007). Thus, the PM emission rates were based on a correction factor of 5 to approximate total PM.

3.1.2 Engine Sensor Array

As explained in Section 3.1.5, the mass air flow through the engine was estimated with the speed-density method (which is an application of the ideal gas law). The estimate of mass air flow is based on the volume displacement of the piston stroke for all cylinders in the engine, the engine revolutions per minute (RPM), the manifold air pressure (MAP) (also referred to as the "airbox pressure"), and the intake air temperature (IAT). Because the measured locomotives do not have an electronic control unit from which these data can be downloaded, sensors were temporarily installed to measure RPM, MAP, and IAT.

Figure 3-2 depicts key components of the engine sensor array, which include a thermocouple used for measuring temperature in the engine intake air manifold, a pressure sensor used for measuring pressure in the engine intake air manifold, and a detector for measuring engine RPM. To measure RPM, a light source was aimed at the engine flywheel, and then reflective tape was placed on the flywheel. The light source incorporated a light detector to measure the reflection of light and count each revolution of the flywheel. A sensor array box received signals from these detectors and routed them to the PEMS.

3.1.3 Supplemental Measurements of NO_x and HC

Space constraints and high temperatures in the engine compartment, and safety considerations in the locomotive cab, led the team to select a PEMS for OTR measurements for its small size and safety. For OTR measurements, the Axion PEMS manufactured by GlobalMRV was used. This PEMS uses an electrochemical cell to measure nitric oxide (NO) and NDIR to measure HC (CATI, 2003) Thus, it does not measure total NO_x, which also includes nitrogen dioxide (NO_2). To estimate total NO_x emission rates based on measurement of only NO, a total NO_x to NO (NO_x/NO) ratio of 1.053 was used because diesel engine NO_x emissions were typically comprised of about 95% NO and 5% NO_2 by volume (Seinfeld and Pandis, 1998). NDIR does not fully respond to all compounds that comprise total hydrocarbons (THC). In previous laboratory studies, NDIR was compared with Flame Ionization Detection (FID), which is capable of detecting carbon that is associated with any hydrocarbon in the sample (Singer *et al.*, 1998; Stephens *et al.*, 1996). The ratio of FID to NDIR (FID/NDIR) measurements of the same samples varied from 1.5 to 4.41. A "typical" value of 2.5 was used to infer THC from NDIR measurements (Graver and Frey, 2013). However, the NO_x/NO and FID/NDIR ratios have not been evaluated specifically for diesel locomotive engines. Therefore, these ratios must be evaluated so they can provide more accurate estimation of the NO_x and THC emission rates that were inferred from the compact PEMS used in the OTR measurements.

To assess the bias correction for estimating total NO_x by measuring NO and estimate the total hydrocarbons based on NDIR measurement of HC, a second PEMS was used in many rail yard tests. The SEMTECH-DS, manufactured by Sensors, Inc., uses non-dispersive ultraviolet (NDUV) to measure each of NO and NO_2, and uses flame ionization detection (FID) to measure THC, in addition to NDIR. FID requires a "FID fuel" comprised of hydrogen. However, the locomotive operator preferred not to carry FID fuel on-board during revenue generating service since it is hazardous. Both PEMS were calibrated using a California Bureau of Automotive Repair (BAR) certified calibration gas cylinder (BAR-97 Low) prior to each measurement. During measurement, both PEMS were periodically "zeroed" to calibrate the concentrations of CO_2, CO, HC, NO, and O_2 with ambient air to prevent instrument drift.

3.1.4 Locomotive Activity Data Recorder

The NC-1797 locomotive had an EMD EM2000 Locomotive Computer System that records locomotive activity data. Real-time engine RPM and horsepower output data were displayed in the locomotive cab. These and other recorded data, including throttle (notch) position, were used to estimate mass per time fuel use and emission rates. At idle, the on-board readout did not display a value for engine output. Therefore, the engine load at idle was estimated at 10 hp based on measurements of the EMD12-710 prime mover engine of NC-1859 on an engine dynamometer. A similar EMD12-710 prime mover, from NC-1869, was also measured on the dynamometer and had an idle engine output of 9 hp, which is not substantially different than that of NC-1859.

3.1.5 Instrument Installation

The installation of the PEMS for rail yard data collection is shown in Figures 3-3. For rail yard tests, the PEMS was typically placed either in the locomotive cab or adjacent to the locomotive, as shown in Figure 3-3. Exhaust gases were continuously sampled from the PME exhaust duct, as shown in Figure 3-4(a). Pressure and temperature sensors were installed on a modified airbox access port, as shown in Figure 3-4(b). The engine RPM sensor was placed near the flywheel, as shown in Figure 3-4(c). Data regarding engine energy output was recorded from the in-cab display, shown in Figure 3-5. Figure 3-6 depicts the installation of another PEMS in the PME engine compartment; it also features the exhaust sampling line as well as the engine sensor array. Figure 3-7 illustrates another installation of the engine RPM sensor, MAP sensor, and IAT sensor on a PME. Figure 3-8 illustrates the routing of sample lines and placement of the PEMS for another rail yard test.

Figure 3-3. PEMS Placement for F59PH Locomotive Prime Mover Engine Measurement

(a) inside of the locomotive cab; (b) inside an air conditioned vehicle during extreme heat

Figure 3-4. Installation of Sensors on an F59PH Locomotive Prime Mover Engine

(a) exhaust sampling port and metal tubes; (b) manifold absolute pressure (MAP) sensor; (c) RPM sensor

Figure 3-5. Prime Mover Engine Activity Digital Display in F59PH Locomotive Cab

Figure 3-6 Installation of PEMS on an F59PHI Locomotive Prime Mover Engine

(a) PEMS main unit (front-view); (b) exhaust sampling port and metal tubes; (c) sensor array box

Figure 3-7. Installation of Sensors on an F59PHI Locomotive Prime Mover Engine

(a) RPM sensor; (b) manifold absolute pressure (MAP) sensor; (c) intake air temperature (IAT) sensor

Figure 3-8. Installation of PEMS Exhaust Sample Lines in an F59PHI Locomotive

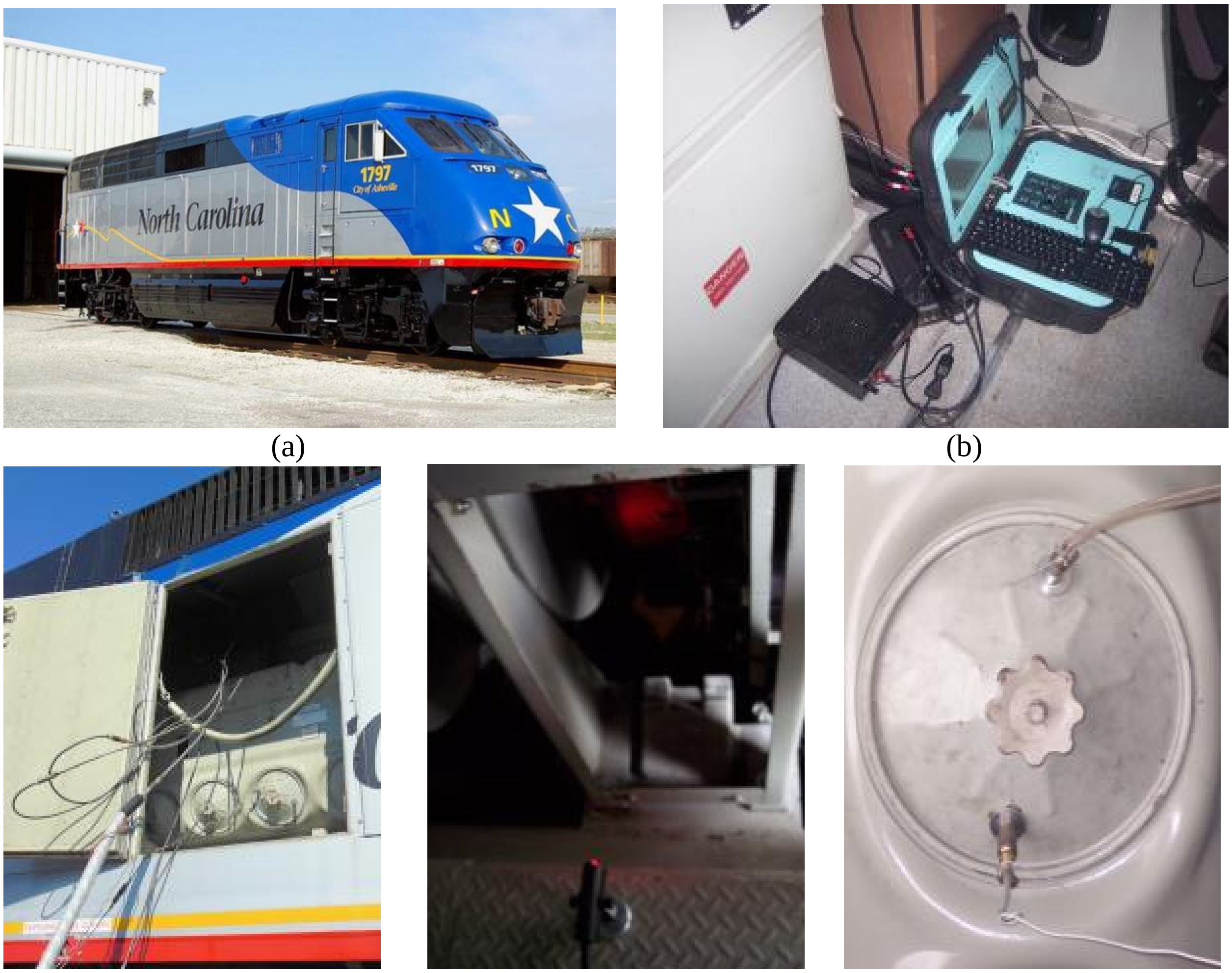
(a) routing sampling hoses and cables; (b) routing sampling hoses through a side door, secured with ties (rear-view); (c) side-view of F59PHI locomotive

Examples of the PEMS installation for each of the three locomotives were given: Figure 3-9 for NC-1797, Figure 3-10 for NC-1810, and Figure 3-11 for NC-1859. Figure 3-10 illustrates the side-by-side use of both the Montana and SEMTECH PEMS for the purpose of assessing bias corrections in NO_x/NO and FID/NDIR HC ratios.

3.1.6 Fuels

Each locomotive was fueled with ULSD to obtain baseline measurements, then they were fueled with various biodiesel blends. Each biodiesel blend combines ULSD with a soy-based biodiesel stock. After each fuel change, the locomotives were operated for at least two weeks prior to RY and OTR measurements to ensure that any previous fuel was completely purged from the fuel system. The team collected a sample of each fuel and sent it to a fuel analysis laboratory to characterize each fuel's properties (See Section 2.1 and Appendix A). The fuels were procured by NCDOT. Data regarding actual fuel price are given in Section 5.2 and Appendix C.

Figure 3-9. Rail Yard Measurements of NC-1797



(a) (b)

(c) (d) (e)

(a) Locomotive NC-1797;
(b) Axion PEMS unit in locomotive cab during over-the-rail measurements
(c) sample lines connecting prime mover engine exhaust pipe to PEMS units;
(d) engine speed sensor placed at prime mover engine flywheel;
(e) intake air temperature and manifold absolute pressure sensor ports on prime mover engine

Figure 3-10. Rail Yard Measurements of NC-1810

(a) (b)

(a) PEMS units placed next to locomotive NC-1810 for prime mover engine measurement; (b)SEMTECH-DS [left] and Montana [right] PEMS units

Figure 3-11. Rail Yard Measurements of NC-1859

3.1.7 Rail Yard Test Procedure

Installing the PEMS components in a typical locomotive took approximately one to four hours per engine. During the static rail yard tests, the prime mover engines were tested under load and the electrical power generated by the prime mover engines was sent to an electrical resistor grid located at the top of the locomotive (where the electrical power was dissipated as heat). After all installation steps were completed, the PEMS was warmed up for approximately 45 minutes in order to ensure that the measurements made by the monitoring system unit were consistent.

Periodic PEMS system checks were conducted during the testing process. For example, all of the system connections with the engine were checked by determining if the engine data properly updated on the display of the PEMS unit, if the gas concentrations were reasonable, and whether the instrument was receiving power. If engine data were “frozen” or missing (which occurred a few times prior to rail yard testing), the engine diagnostic data cable was reinstalled and the engine sensor array was rebooted. If the CO_2 gas concentrations were very low, there may have been a leakage in the sampling line and, therefore, the line was inspected and repositioned. To remove any carbon that was blocking exhaust flow, the exhaust sampling lines were blown out and if that did not work, new exhaust sampling lines were used.

Preparations for field data collection included: (1) Verifying the status of the PEMS and that all necessary parts and consumables were available; (2) Calibrating the PEMS in the laboratory; (3) Completing a field study design; and (4) Coordinating with the locomotive owner/operator to schedule the test and obtain access to the locomotive.

As part of the preparations, NCSU ensured that the PEMS had functioning electrochemical sensors for NO and O_2, and that all consumables were replaced (such as filters in the exhaust sampling line). The PEMS was calibrated with a standard calibration gas before any testing.

The field study design also specified which locomotives were tested, which engine should be tested, when the engine was tested, and what fuel will be used. As part of this project, NCDOT allowed NCSU access to its fleet of locomotives for testing.

The tests of the prime mover engines followed a prescribed sequence and timing of throttle notch settings (see Table 2), including idle and notches one through eight, with sufficient time to enable steady state operation of the engine while avoiding overheating of the dynamic braking grid, particularly at notch settings six through eight.

Table 3-1. Railyard Test Schedule for Prime Mover Engine

Notch Position	Time (min)
Idle for Warm-up	45
Notch 8	3
Idle for Cooling	5
Notch 7	3
Idle for Cooling	5
Notch 6	3
Idle for Cooling	5
Notch 5	3
Notch 4	3
Notch 3	3
Notch 2	3
Notch 1	3
Idle	3

3.1.8 Quality Assurance

The combined data set for a locomotive test was screened to check for errors or possible problems. If errors were identified, the affected data were corrected or not used for data analysis. The types of errors typically encountered are described in this section and a discussion of methods for making corrections is also included.

NCSU has developed a PEMS Quality Assurance System (PQAS) that takes raw data from the PEMS and processes it to identify data quality problems (Frey and Graver, 2012, 2013; Sandhu and Frey, 2013). Where possible, such problems were corrected. If correction is not possible, then the problematic data were omitted from the final database used for analysis. PQAS also takes the exhaust concentrations and engine data obtained from the PEMS to calculate fuel use and emission rates. The following paragraphs describe the PQAS used in the tests.

Occasionally, communication between the PEMS and the engine sensor array (which the RPM sensor is connected to) may be lost. Sometimes the loss of connection is due to a lack of direct electrical contact, which occurred a few times during testing in the rail yard; however, when a lack of contact occurs, this error can be solved easily by restarting the PEMS in the field. After restarting, the on-board computer of the PEMS begins logging a new data file automatically. Loss of engine data is also obvious from the data file, since the missing data were evident and any calculations of emission rates were invalid. There were two types of engine errors that were included in the quality assurance procedure: unusual engine RPM and engine RPM freezing.

The engine speed for the prime mover engine typically varies from not less than 190 RPM (during idling) to about 950 RPM (Notch 8), thus the bounds for possible engine RPMs were set as greater than or equal to 190 RPM and less than or equal to 950 RPM. If a prime mover engine's speed falls outside of the bounds for engine RPM, the data were removed prior to further data analysis. For the HEP engine, the engine speed typically varies from not less than 1600 RPM to about 1900 RPM during idle and if a HEP engine's measured engine speeds fall outside the bounds for possible engine RPM, the data were removed prior to further data analysis.

Engine RPM "freezing" occurs when an engine speed value that is expected to change dynamically on a second-by-second basis becomes 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, a check is performed to identify situations in which engine speed remained constant for more than three seconds. This type of error is rare, and did not occur in this project.

Each PEMS has two gas analyzers, which were referred to as "benches." Most of the time, both benches were in use. Occasionally, one bench is taken offline for zeroing. Therefore, most of the time, the emissions concentrations from each of the two benches can be compared to evaluate the consistency between benches. If both benches were producing consistent concentrations, then the measurements from both were 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 were detected, then an average value was calculated based upon both benches. However, if the relative error exceeds five percent, then further assessment of data quality is needed.

A discrepancy in measurements might be due to: (1) A leakage in the sample exhaust line leading to a bench; (2) Overheating of a bench; or (3) Problems with the sampling pump of a bench, leading to inadequate flow. If one of these problems is identified, then only data obtained from the other bench was used for emissions estimation. When problems were identified, then the team attempted to resolve the problem in the field. For example, if a leak or overheating problem is detected during data collection, the problem is fixed and testing resumes. Data recorded while a leak or overheating event occurs were not included in any further analyses.

For data quality control and assurance purposes, every other gas analyzer bench is zeroed every ten minutes. As it is being zeroed, the gas analyzer intakes ambient air instead of engine exhaust and after zeroing is finished, a period of transition occurs as the solenoid valve changes the gas analyzer intake from ambient air to engine exhaust. In particular, the O_2 sensor needs several seconds to respond to the switching of gases, since there is a large change in O_2 concentration when the switch occurs. To allow adequate time for a complete purging of the previous gas source from the system, a time delay of ten seconds is assumed. Thus, for 10 seconds before zeroing begins, the time period of zeroing (approximately 45 seconds), and 10 seconds after zeroing ends, data for the bench involved in zeroing were excluded from calculations of emission rates, and the emission rates were estimated based only upon the other bench.

Random measurement errors occur and, on occasion, some of the measured concentrations will have negative values that were not statistically different from zero or a small positive value. Diesel engines typically produce less HC emission concentrations than gasoline engines (Durbin *et al.*, 2000). Thus, it is frequently the case that HC emission measurements were 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.

A loss of power to the PEMS results in a complete loss of data collection capabilities while power is not available. However, the system saves data up to the point at which the power loss occurs. After a loss of power, the instrument needs to be restarted, which takes approximately five to ten minutes. While the instrument is being restarted, no data can be collected.

3.2 Method for Estimation of Fuel Use and Emission Rates

Fuel-based emission rates were estimated via exhaust gas and fuel compositions, independently of fuel flow rate data, because fuel use could not be accurately measured during rail yard and over-the-rail measurements—fuel was taken from a large on-board tank and locomotive engines continuously return unspent fuel to the tank. The intake air molar flow rate (M_a) was estimated based on engine data, including engine RPM, manifold absolute pressure (MAP), intake air temperature (IAT), engine displacement, engine compression ratio, and engine volumetric efficiency. This is known as the “speed density” method (Vojtisek-Lom and Cobb, 1997), and is widely used to estimate air flow through an engine. The intake air molar flow rate was calculated as:

$$M_a = \frac{\left(P_M - \frac{P_B}{ER}\right) \times EV \times \left(\frac{ES}{30 \times EC}\right) \times \eta_{ev}}{R \times (T_{int} + 273.15)} \tag{3-1}$$

Where,

EC = engine strokes per cycle (assumption: 2 for prime mover engine)

ER = engine compression ratio

ES = engine speed (RPM)

EV = engine displacement (L)

M_a = intake air molar flow rate (mole/sec)
(assumption: air to be a mixture of 21 vol-% O_2 and 79 vol-% N_2)

P_B = barometric pressure (assumption: 101 kPa)

P_M = engine manifold absolute pressure (kPa)

T_{int} = intake air temperature (°C)

η_{ev} = engine volumetric efficiency

The exhaust molar flow rate on a dry basis (M_e) was needed to estimate the mass of pollutants in the exhaust, and it was estimated based on the intake air molar flow rate (M_a) and the air-to-fuel ratio inferred from the exhaust gas composition. The relation between M_e and M_a is as follows:

$$M_{e,t} = \frac{2 \times 0.21 \times M_{a,t}}{\left(2+\frac{x}{2}-z\right) y_{CO_2,t,dry} + \left(1+\frac{x}{2}-z\right) y_{CO,t,dry} + 2y_{O_2,t,dry} + y_{NO,t,dry} + (3x-7-6z)\, y_{C_6H_{14},t,dry}} \quad (3\text{-}2)$$

Where,

$M_{e,t}$ = dry exhaust molar flow rate for time t (mole/sec)

$y_{i,t,dry}$ = mole fraction of pollutant species i on a dry basis for time t (gmol/gmol dry exhaust gases)

x,z = elemental composition of fuel CH_xO_z (gmol of H or O, respectively, per gmol of carbon in the fuel)

For each second, the PEMS estimated mass emission rates (g/sec) based upon the mole fraction on a dry basis, dry exhaust molar flow rate, and molar weight of exhaust gas as follows:

$$E_{i,t} = y_{i,t,dry} \times M_{e,t} \times MW_i \quad (3\text{-}3)$$

Where,

$E_{i,t}$ = mass emission rate of pollutant species i (g/sec)

MW_i = molecular weight of pollutant species i (g/mol)

Fuel-based emission factors were calculated based on the exhaust gas and fuel composition. The key concept of these emission factors is that the exhaust composition accounts for all of the carbon contained in the fuel, which is emitted as CO_2, CO, and HC. From the mole fractions of these three exhaust components, the fraction of carbon in the fuel emitted as CO_2 was estimated. Therefore, the conversion of carbon in the fuel to CO_2 per gallon of fuel consumed was estimated, since the weight percent of carbon in the fuel is known. Molar ratios of NO to CO_2 and HC to CO_2 were used to estimate the amount of NO and HC, respectively, emitted per gallon of fuel consumed. Since the PEMS gas analyzer was calibrated based on propane as an indicator of HC, propane was used as the basis for characterizing the properties of the hydrocarbons. Since propane has 3 moles of carbon atoms per mole of molecules, the HC mole fraction was multiplied by 3 to estimate the amount of carbon contained in the HC. The fraction of carbon emitted as CO_2 was estimated from:

$$f_C = \frac{y_{CO_2}}{y_{CO_2} + y_{CO} + 3\,y_{HC}} \tag{3-4}$$

Where,

f_c = fraction of carbon as CO_2 in exhaust (gmol C as CO_2/total gmol of C)
y_i = mole fraction of specie *i* (gmol of specie *i*/gmol of mixture of all species)

The carbon density of fuel was estimated based on the weight percent of carbon in the fuel and the fuel density:

$$\rho_C = \rho_f\, p_C \tag{3-5}$$

Where,

p_C = weight proportion of carbon in fuel (g C/g fuel)
ρ_C = carbon density of fuel (g C/gallon of fuel)
ρ_f = density of fuel (g fuel/gallon of fuel)

The fuel-based CO_2 emission factor ($EF_f^{CO_2}$) is:

$$EF^f_{CO_2} = 44\, f_c \left(\frac{\rho_C}{12}\right) \tag{3-6}$$

The fuel-based NO emission factor (EF_f^{NO}) is:

$$EF^f_{NO_x} = \left(\frac{y_{NO}}{y_{CO_2}}\right)\left(\frac{46}{44}\right) EF^f_{CO_2} \tag{3-7}$$

The fuel-based CO emission factor (EF_f^{CO}) is:

$$EF^f_{CO} = \left(\frac{y_{CO}}{y_{CO_2}}\right)\left(\frac{28}{44}\right) EF^f_{CO_2} \tag{3-8}$$

The fuel-based HC emission factor (EF_f^{HC}) is:

$$EF^f_{HC} = \left(\frac{y_{HC}}{y_{CO_2}}\right)\left(\frac{42}{44}\right) EF^f_{CO_2} \tag{3-9}$$

For particulate matter, the gas analyzer reported a mass per volume concentration in units of mg/m^3 on a dry basis. Therefore, the exhaust flow needed to be estimated in dry m^3 per gallon of fuel consumed to calculate an emission rate of PM in units of mass per gallon of fuel consumed.

The fuel-based PM emission rate calculations were based on an air-to-fuel ratio that was based on fuel properties and the observed mole fraction of CO_2 in the exhaust.

Complete combustion of fuel with excess air is represented as the following mass balance:

$$CH_yO_z + a\,O_2 + 3.76\,a\,N_2 \rightarrow b\,CO_2 + c\,H_2O + d\,N_2 + e\,O_2 \tag{3-10}$$

From the fuel properties, the values of y (gmol H/gmol C) and z (gmol O/gmol C) were known. From the exhaust measurements, the mole fraction of CO_2, on a dry basis, was known. Thus, the unknowns were a (inlet gmol O_2/gmol C), b (gmol CO_2/gmol C), c (gmol H_2O/gmol C), d (gmol N_2/gmol C), and e (exhaust gmol O_2/gmol C). These were calculated using a system of equations based on elemental mass balances and the observed mole fraction of CO_2:

Description	**Equation**	**Re-arranged Equation**
Atom balance for C	$1 = b$	$b = 1$
Atom balance for H	$y = 2c$	$c = y/2$
Atom balance for O	$2a + z = 2b + c + 2e$	$a = b + c/2 + e - z/2$
Atom balance for N	$3.76(2)a = 2d$	$d = 3.76a$
Mole Fraction of CO_2, dry basis	$y_{CO_2} = \frac{b}{b + d + e}$	$e = b\left(\frac{1 - y_{CO_2}}{y_{CO_2}}\right) - d$

Substituting into the equation for a (inlet gmol O_2/gmol C):

$$a = \left(\frac{1}{4.76}\right)\left\{b\left[1 + \left(\frac{1 - y_{CO_2}}{y_{CO_2}}\right)\right] + \frac{y}{4} - \frac{z}{2}\right\} \tag{3-11}$$

Hence, a can be solved by knowing values for y and z from the fuel properties and based on the observed mole fraction (dry basis) for CO_2.

The air-to-fuel ratio (g air/g fuel) was estimated as:

$$\left(\frac{m_a}{m_f}\right) = \frac{32a + 28\,(3.76)a}{MW_f} = 137.28\,\frac{a}{MW_f} \tag{3-12}$$

Specific fuel consumption was reported as lb/hp-hr. Therefore, the fuel flow rate (g/sec) was estimated from:

$$m_f = \frac{454\,\dot{m}_f\,W_s}{3{,}600} \tag{3-13}$$

The air flow rate (g/sec) is:

$$m_a = m_f \left(\frac{m_a}{m_f}\right) \tag{3-14}$$

The exhaust flow (g/sec) is the sum of the flow of air and fuel:

$$m_e = m_f + m_a \tag{3-15}$$

While these equations characterize a mass balance for the engine, they include moisture. In order to calculate the PM mass emission rate, the volume flow rate of exhaust on a dry basis was needed. The molar exhaust per mole of C in fuel consumed is equal to the sum of *b*, *d*, and *e* from Equation B10. Fuel flow was known from specific fuel consumption and could be estimated on a molar basis. The molar flow rate (gmol/sec) of the exhaust was estimated using the ideal gas law and conditions of standard temperature and pressure (STP).

$$M_{e,dry} = (b + d + e)\,\frac{m_f}{MW_f} \tag{3-16}$$

The volumetric dry exhaust flow rate (m^3/sec) is:

$$V_{e,dry} = M_{e,dry}\left(\frac{RT}{P}\right) \tag{3-17}$$

Where,

P = barometric pressure (assumption: 101,330 Pa)

R = ideal gas constant (assumption: 8.3144 Pa-m^3/gmol-K)

T = ambient temperature (assumption: 298 K)

The PM mass emission rate (g/sec) was estimated as:

$$E^{t}_{PM} = C^{dry}_{PM}\, V_{e,dry} \tag{3-18}$$

The fuel-based PM emission rate (g/gal) was estimated as:

$$E^{f}_{PM} = \frac{E^{t}_{PM}\,\rho_f}{m_f} \tag{3-19}$$

Engine output-based emission factors calculated by multiplying the fuel-based emission factors (g/gal) and the fuel use rate (gal/bhp-hr).

Equation (3-1) requires an estimate of volumetric efficiency, which is the ratio of actual to theoretical air flow through the engine. Volumetric efficiency was calibrated based on previous dynamometer measurements of EMD12-170 engines.

Dynamometer measurements were conducted on the prime mover engines of locomotives NC-1859 and NC-1869 at the American Motive Power, Inc. (AMP) facility in 2010. Each locomotive has a EMD 12-710G3B prime mover engine. Dynamometer measurements were also conducted on locomotive NC 1792's EMD 16-645E3 prime mover engine at the same facility in 2009.

The AMP facility contains a water brake dynamometer test cell that is used for performance evaluations of engines. A control room is connected to the test cell where the dynamometer operator uses a computer, referred to as the dynamometer control system, to both operate the dynamometer and record engine operation data.

Engine fuel use and horsepower output needed for the calculation emission rates were obtained from the dynamometer control system. Specific fuel consumption rates were estimated by the weight differential of a fuel tank on top of a scale from:

$$SFC = \frac{\Delta w_{fuel}}{(HP)\left(\frac{\Delta t}{3600}\right)} \tag{3-20}$$

Where SFC = specific fuel consumption (lb/hp-hr); Δw_{fuel} = change in fuel tank weight during each notch position (lb); HP = average engine horsepower output during each notch position, derived from the dynamometer torque meter; and Δt = duration of notch position (sec)

Three replicate measurements were made on the water brake dynamometer for each prime mover engine. After a 45-minute warm-up period of the Axion system main unit and an approximately equal time of engine warm-up, the engine was operated at each throttle notch position for approximately 5 minutes, starting at notch 8 and working down to Idle.

Engine operation data were collected once the engine reached a steady state at each notch position. Five-second average engine operation data were logged by the dynamometer control system approximately every 30 seconds during each 5-minute interval.

For each notch position, measurement replicate, and prime mover engine model, the estimated volumetric efficiency was plotted versus a multiplicative function of engine speed and manifold absolute pressure, since the product of these engine parameters were a good indicator of engine power demand, as shown in Figure 3-12 for the EMD 12-710G3B engines and Figure 3-13 for the EMD 16-645E3 engine. A trendline was fit to derive a model that would describe the relationship between VE, RPM, and MAP. The models used to describe the relationship between VE, RPM, and MAP for the datasets had an R^2 value that exceeded 0.95, which indicated that the model explained the variation in data very well. VE has been reported to range up to 1.90 for turbocharged 2-stroke diesel engines (Donaldson Filtration, 2012).

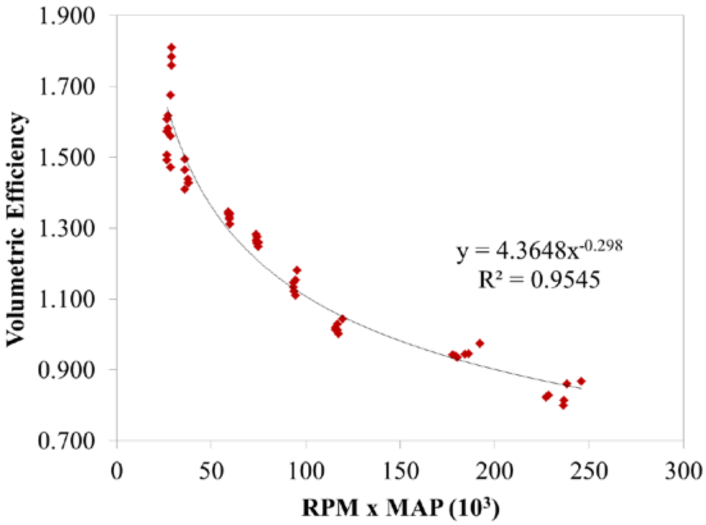


Figure 3-12. Model for volumetric efficiency based on engine speed and manifold absolute pressure of two EMD 12-710G3B prime mover engines measured on a dynamometer.

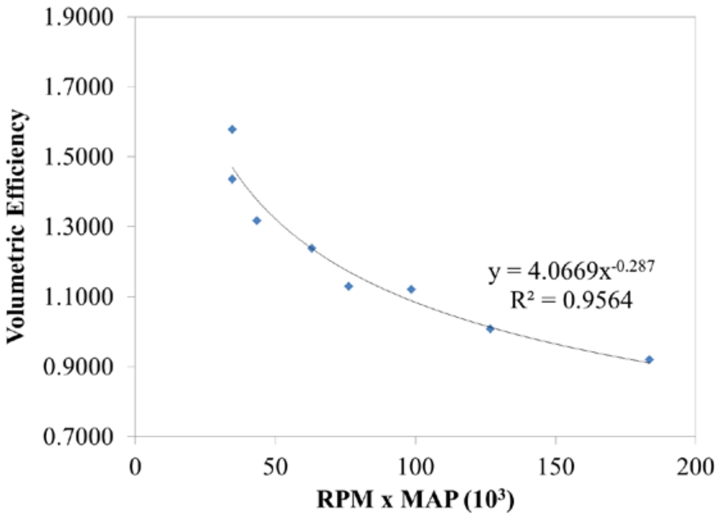


Figure 3-13. Model for volumetric efficiency based on engine speed and manifold absolute pressure of one EMD 16-645E3 prime mover engine measured on a dynamometer.

Cycle average emission rates were calculated as follows:

$$CAER_i = \sum_{Idle}^{8} \frac{ER_{ij} \times DC_j \times hp_j}{\sum_{Idle}^{8} DC_j \times hp_j} \tag{3-21}$$

Where:

$CAER_i$ = cycle average emission rate for pollutant *i* (g/hp-hr)

ER_{ij} = emission rate for pollutant *i* at notch position *j* (g/hp-hr)

Table 3-2. Guide to Detailed Rail Yard Results in Appendices for Each Locomotive and Fuel

Locomotive	Fuel	Appendix
NC-1797	B40	Appendix D, Section D.1
	B20	Appendix D, Section D.2
	B10	Appendix D, Section D.3
	ULSD	Appendix D, Section D.4
NC-1810	B100	Appendix E, Section E.1
	B80	Appendix E, Section E.2
	B60	Appendix E, Section E.3
	B40	Appendix E, Section E.4
	B20	Appendix E, Section E.5
	B10	Appendix E, Section E.4
	ULSD	Appendix E, Section E.6
NC-1859	B40	Appendix F, Section F.1
	B20	Appendix F, Section F.2
	B10	Appendix F, Section F.3
	ULSD	Appendix F, Section F.4

DC_j fractional duty cycle time spent in notch *j* (hr)

hp_j engine horsepower at notch position *j* (hp)

3.3 Results for Notch Average Fuel Use and Emission Rates

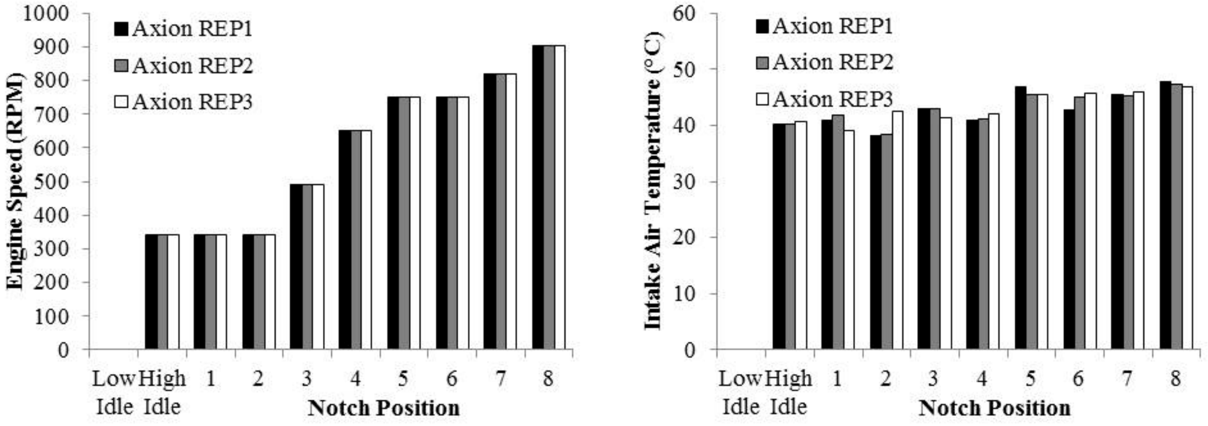
Approximately 40 hours of data were collected during RY measurements. Typically, less than one percent of total data collected were excluded after quality assurance screening.

Detailed results for the rail yard measurements of each locomotive and fuel were given in Appendix D (NC-1797), Appendix E (NC-1810), and Appendix F (NC-159). Table 3-2 provides the specific section of each appendix that provides detailed results for specific combinations of locomotive and fuel. In this section, an example of detailed results is given for one locomotive, based on NC-1797 operated on ULSD. Furthermore, a summary is given of the notch average emission rates for each notch position, each locomotive, and each fuel.

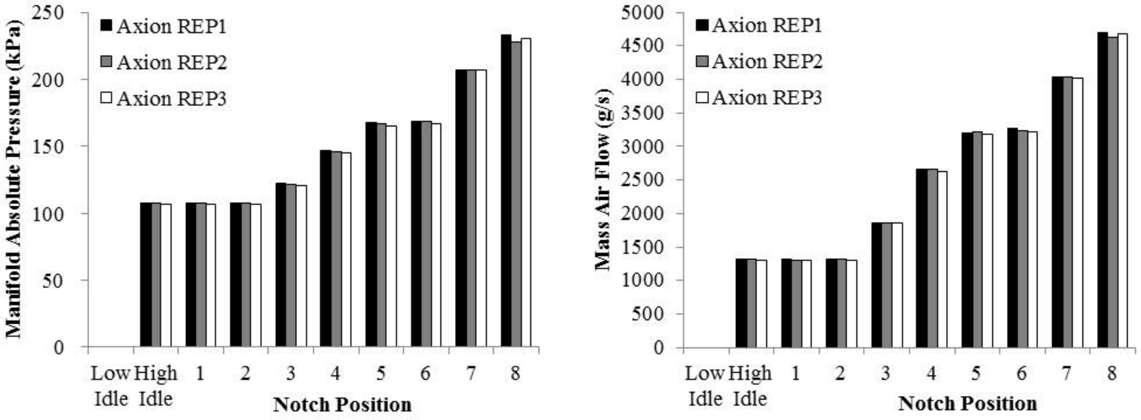
3.3.1 Example Detailed Results for One Locomotive and Fuel

This section contains the results for NC-1797 operating on ULSD. More details on this locomotive and fuel are in Appendix D.4. Rail yard measurements were conducted on October 22, 2013. Three replicates of the rail yard test procedure were conducted. Figure 3-14 illustrates the notch average measured values for engine RPM, IAT, MAP obtained from the sensor array. This engine operates with a high RPM idle, which was consistently at 343 RPM for each of the three replicates of the tests. For each notch position, the standard deviation of inter-replicate variability in RPM was less than 0.1 RPM. Thus, the engine RPM was highly repeatable across the three replicates.

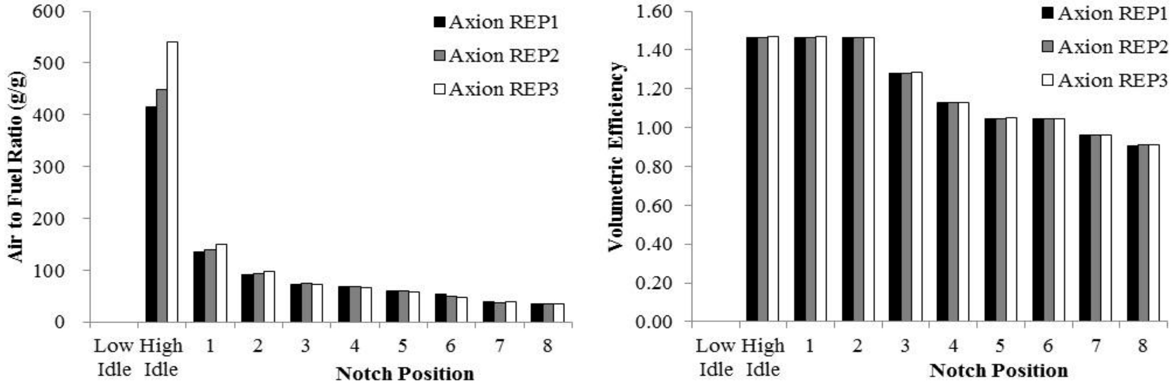
Figure 3-14. Measured and Inferred Engine Activity Data during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on Ultra-Low Sulfur Diesel



(a) Engine Speed (b) Intake Air Temperature

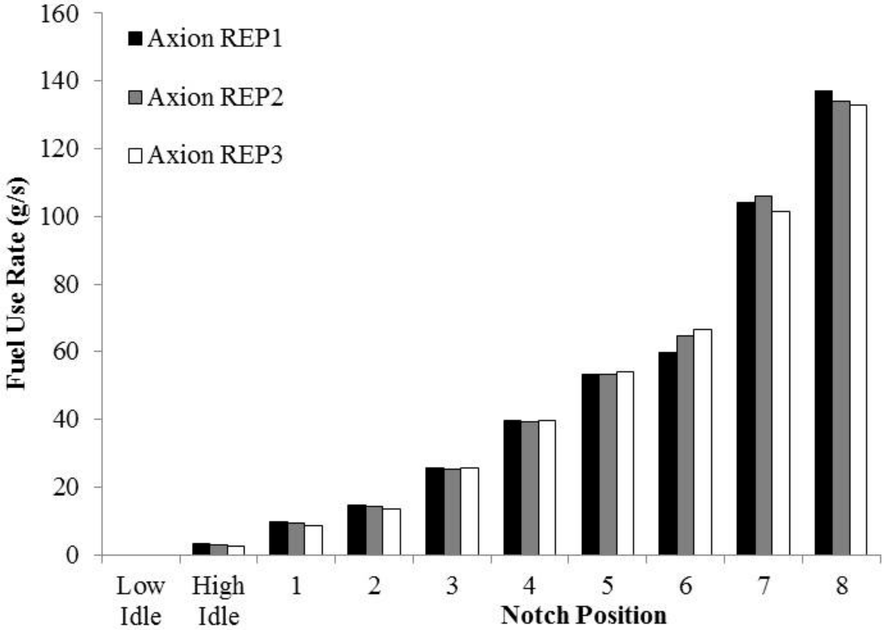


(c) Manifold Absolute Pressure (d) Mass Air Flow



(e) Air-to-Fuel Ratio (f) Volumetric Efficiency

Figure 3-15. Estimated Fuel Use Rates during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on Ultra-Low Sulfur Diesel

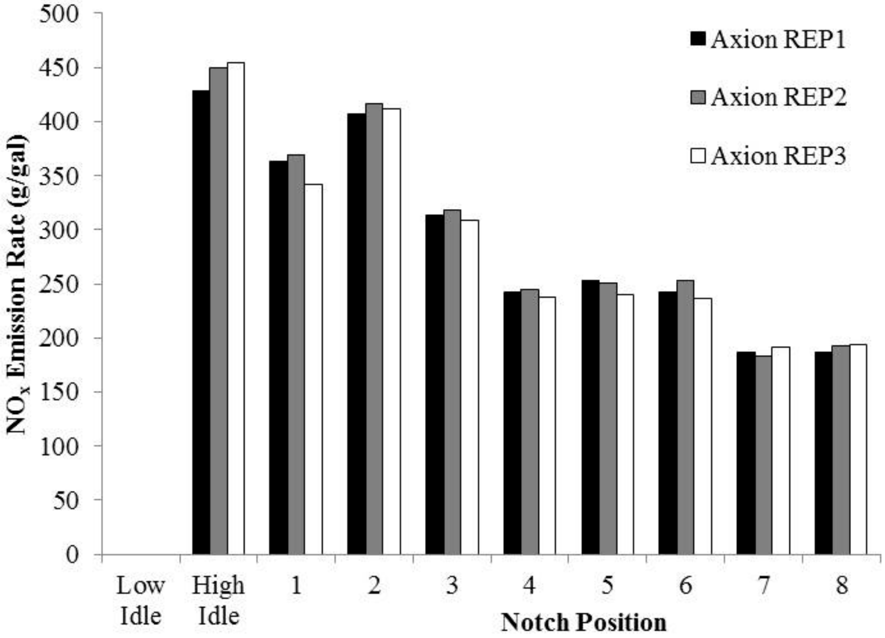


Intake air temperatures varied among the notch positions, with the IAT being slightly higher for high engine load than for low engine load. However, the average difference in temperature for notch 8 versus idle was only 7 ^{o}C. The standard deviation of inter-notch variation in temperature was less than 1^{o} C for most notches, and did not exceed 2.5^{o} C. Thus, the results for IAT were highly repeatable. MAP averaged 107 kPa for idle and 230 kPa for notch 8. The standard deviation of inter-replicate variability in MAP for a given notch was typically less than 1 kPa and did not excel 2.7 kPa. The relative standard deviation, which is the standard deviation divided by the mean and is also known as the coefficient of variation (CV), did not exceed 0.01 for RPM or MAP and did not exceed 0.06 for IAT. Thus, the engine performance was quite consistent from one replicate to another. A high degree of replicability in engine performance is typical for all locomotive PMEs and all fuels.

Figure 3-14 also shows estimates of mass air flow, based on the speed-density method, and estimates of the air-to-fuel ratio inferred from the exhaust concentration that was measured with the PEMS. For each notch position, there was very little inter-replicate variability in the estimated mass air flow. The CV of mass air flow for each notch did not exceed 0.01. The estimated air-to-fuel ratio was quite consistent for non-idle engine loads, with inter-replicate CVs ranging from 0.01 to 0.07 among notches 1 through 8. There was more variability in the result for idle, with a CV of 0.14. The values of the volumetric efficiency used as input to the speed density method are also shown. As explained earlier, these values were estimated based on the product of RPM and MAP, and were calibrated from dynamometer measurements of similar engines.

The inter-notch and inter-replicate variability in fuel flow rate is shown in Figure 3-15. This engine did not have a low idle setting; therefore, values for low idle are not shown here. The fuel mass flow rate (in grams per second), increased monotonically from idle to notch 8, which reflected substantial inter-notch variability related to increasing engine load.

Figure 3-16. Estimated NO_x Emission Rates during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on Ultra-Low Sulfur Diesel

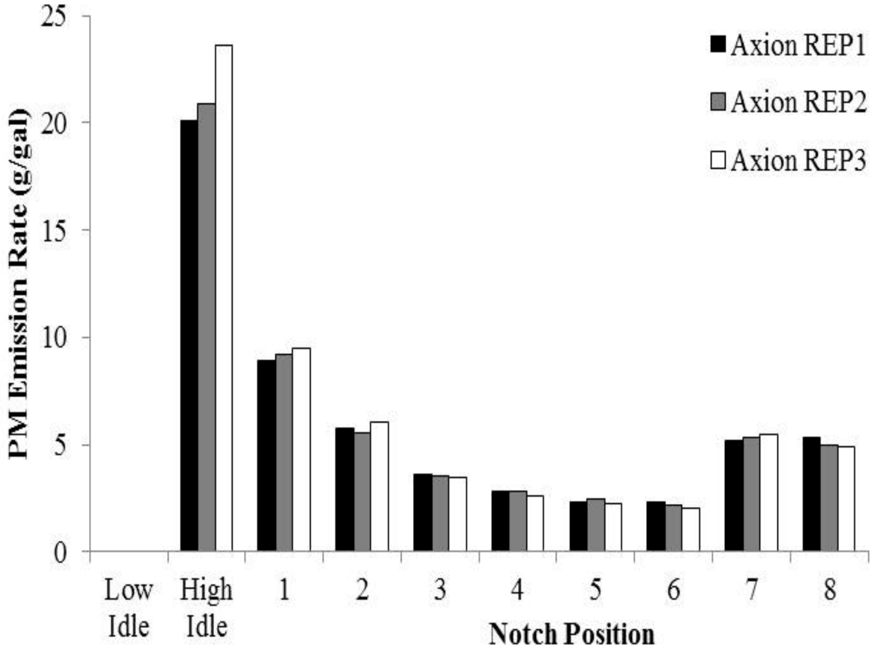


Other than for idle, the CV for inter-replicate variability in fuel flow rate for a given notch was 0.06 or less, and was 0.02 or less for five of the notch positions. Thus, there was good repeatability of the estimated fuel use rate. The relative variability between replicates was larger for idle, for which the CV was 0.14; however, the fuel flow rate at idle was relatively low and thus the magnitude of the variations was relatively small. The standard deviation of fuel flow rate among the replicates was less than 1 g/s for idle through notch 5, and ranges from approximately 2 g/s to 4 g/s for notches 6, 7, and 8. These values were small compared to the notch average values.

Figure 3-16 shows the inter-notch and inter-replicate variability in NO_x emission rate, which was inferred from the measurement of NO as described in the methodology section. These rates depend on the measured NO exhaust concentration, which averaged 184 ppm for idle and 1,075 ppm for notch 8. The standard deviation of the measured NO concentrations ranged from 4 ppm to 44 pm among notches 1 through 8, and was 19 ppm at idle. The CV for inter-replicate variability in measured exhaust concentration was 0.11 at idle and ranged from 0.01 to 0.03 for 6 of the other notch positions, except for values of 0.07 and 0.09 for notches 6 and 1. Overall, the measured NO exhaust concentrations for a given notch were very similar among the three replicates.

On the basis of g/pollutant emitted per gallon/fuel consumed, the NO_x emission rate was highest at idle, averaging 444 g/gallon, and was lowest at notch 8, averaging 191 g/gallon). The CV for inter-replicate variability in fuel-based NO_x emission rate was typically 0.03 or less, except at notch 1 it was 0.04. On a mass per time basis, the grams of NO_x emitted per second ranged from an average of 0.4 g/s at idle to 8.0 g/s at notch 8, with inter-replicate CV of 0.02 or less for five notch positions and less than 0.11 for all notch positions. On an engine output basis, the NO_x emission rates ranged from 9.0 g/hp-hr at notch 7 to 19.6 g/hp-hr at notch 1, with a much higher value at idle of 140 g/hp-hr. The very high value at idle was in part because the engine output was very low (only 9 hp). The emission rate at notch 8 was 9.6 g/hp-hr, which is similar to that of notch 7.

Figure 3-17. Measured PM Concentrations during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on Ultra-Low Sulfur Diesel



The inter-replicate variability in engine output-based NO_x emission rates was comparable to that for other emission factor estimates, with CVs typically below 0.02 for most notch positions, but with some notch positions that have CVs ranging from 0.04 to 0.11. Overall, the NO_x emission rates for a given notch position were deemed to be repeatable.

Because the CO and HC exhaust concentrations from diesel engines tend to be low, there is typically more inter-replicate variability than for NO. For example, the notch average CO exhaust concentrations ranged from essentially zero (undetectable) for many notches to 0.017 volume percent at notch 8. The CO mass emission rates ranged from essentially zero (undetectable) to 0.7 g/sec, 0.09 g/gallon to 18 g/gallon, and essentially zero (undetectable) to 0.9 g/hp-hr among notches 1 to 8, for time-based, fuel-based, and engine output measurements, respectively. The standard deviations of inter-replicate variation were relatively large compared to the mean values, leading to CVs ranging from 0.2 to 1.6 for each set of emission rates (time-based, fuel-based, and engine output-based). Although the CV of notch average rates was very high for some notch positions, this does not mean that cycle average rates had such large inter-replicate variability, as illustrated by the results in the next section. Mostly, the high inter-replicate variability was a result of relatively low emission rates across all notches.

The HC exhaust concentrations averaged from 3 ppm to 30 ppm among the notch positions, with standard deviations ranging from 0.5 ppm to 16 ppm. Thus, the CV for inter-replicate variation in exhaust concentration ranged from 0.1 to as much as 0.9. The CVs for time-based, fuel-based, and engine output-based HC emission factors for each notch position were similar.

The inter-notch and inter-replicate variability in estimated PM emission rates is shown in Figure 3-17. The CV for inter-replicate variability in measured PM concentration was typically quite low, ranging from 0.01 to 0.05 among the notches. Figure 3-17 depicts the fuel-based emission rates in grams per gallon, which was much larger at idle than for any of the notch positions for which there is some engine load. The CV of the fuel-based emission rates at idle is 0.08, and ranges from 0.02 to 0.07 among notches 1 through 8. The CVs for time-based and engine output-based emission rates was slightly smaller.

Overall, the results for NC-1797 and ULSD illustrate that there were discernable inter-notch trends in fuel use rate and the emission rates for NO_x and PM. NO_x and PM were the two pollutants of greatest concern from diesel engines. For these quantities, the measurements were highly repeatable. The CO and HC exhaust concentrations tend to be very low, and thus there is more random variability in the results because many of the measurements were near, at, or below the detection limit of the gas analyzers. The specific results for all locomotives and fuels are found in Appendices D, E, and F, and are summarized in the section 3.3.3.

3.3.2 Results for NO_x/NO and FID/NDIR HC Ratios

To illustrate the methodological approach that was used, this section provides the results for one locomotive (NC-1859) and one fuel (B10 biodiesel blend) for the measured ratios of NO_x/NO and of THC/NDIR HC. Additional results are given in Appendix G.

Ratio of NO_x/NO

Table 3-3 shows the engine output-based emission rates of NO and NO_2 for each notch position from each replicate, based on measurements from the SEMTECH-DS PEMS. Means and standard deviations were estimated based on data from three replicates. For each of the notch positions, each ratio of standard deviation to the mean (CV) was estimated. The average ratios of NO_x/NO were estimated by dividing the sum of average NO and NO_2 rates by average NO rates. For example, the average NO emission rate for idle was 97.0 grams per brake-horsepower-hour (g/bhp-hr) and the average NO_2 emission rate was 11.2 g/bhp-hr. The average NO_x/NO ratio were estimated by dividing the sum of 97.0 g/bhp-hr and 11.2 g/bhp-hr by 97.0 bhp-hr, which was 1.116.

For each notch position, the inter-replicate variability in NO and NO_2 emission rates was quantified and the CVs were less than or equal to 0.08 for NO and NO_2 emission rates, which indicates good repeatability.

The NO_x/NO ratios tended to decrease from idle to notch 4, remain approximately constant through notch 7, and increased at notch 8. The highest ratio was 1.116 during idle and the lowest ratio was 1.057 in notch 6. The mean and standard deviation of the notch-specific average ratios among the nine notch positions were 1.075 and 0.021, respectively. The CV was 0.02. Furthermore, for notches 2 to 8, the ratio varied only between 1.057 and 1.083. Therefore, the inter-notch variability in NO_x/NO ratios was small.

The cycle average NO_x and NO emission rates are shown in Table 3-4. The cycle average NO_x/NO ratio was estimated by dividing the sum of cycle average emission rates of NO and NO_2

by the cycle average emission rate of NO. The NO_x/NO ratio was 1.077. The cycle average NO_x/NO ratio was only 2.3% higher than the previously assumed value of 1.053 on relative basis. Therefore, the previously assumed value seemed to be a reasonable value to use for this locomotive operated on B10 biodiesel blend. The previously assumed value of 1.053 may lead to lower estimates of total NO_x, but the bias would be small.

Table 3-3. Engine Output-Based Emission Rates of NO, NO_2 for Each Replicate, and the Average Ratio of NO_x/NO for Each of the Notch Positions

	NO Emission Rates (g/bhp-hr)						NO_2 Emission Rates (g/bhp-hr)						NO_x/ NO Ratio[c]
Notch Position	REP1 [a]	REP2 [a]	REP3 [a]	Avg [b]	StDev [b]	CV[b]	REP1	REP2	REP3	Avg	StDev	CV	
Idle	98.4	99.4	93.0	97.0	3.58	0.04	10.3	11.6	11.6	11.2	0.93	0.08	1.116
1	12.3	12.0	10.9	11.7	0.70	0.06	1.20	1.22	1.13	1.18	0.05	0.04	1.101
2	11.0	11.0	10.4	10.8	0.31	0.03	0.76	0.80	0.76	0.77	0.02	0.03	1.072
3	10.1	10.1	9.56	9.91	0.30	0.03	0.63	0.67	0.63	0.64	0.02	0.03	1.065
4	8.99	8.82	8.44	8.75	0.28	0.03	0.52	0.55	0.52	0.53	0.02	0.04	1.060
5	8.29	8.19	7.95	8.14	0.18	0.02	0.48	0.50	0.48	0.49	0.01	0.02	1.060
6	8.23	8.35	8.05	8.21	0.15	0.02	0.46	0.48	0.47	0.47	0.01	0.03	1.057
7	6.63	6.85	6.55	6.68	0.15	0.02	0.39	0.42	0.42	0.41	0.02	0.04	1.061
8	5.69	6.06	5.92	5.89	0.19	0.03	0.53	0.46	0.47	0.49	0.04	0.08	1.083

a *REP1 = replicate 1; REP2 = replicate 2; REP3 = replicate 3.*

b *Avg = average, over 3 replicates; StDev = standard deviation, over 3 replicates; CV = coefficient of variation, which was the ratio of standard deviation over average.*

c *NOx/NO Ratio was estimated by dividing the sum of average NO and NO_2 emission rates by average NO emission rates.*

Table 3-4. EPA Line-Haul Cycle, Locomotive Engine Horsepower and Emission Rates of NO, NO_2, FID-Measured HC, and NDIR-Measured HC for Each Notch Positions, and Estimated Cycle Average Emissions Rates

	Notch Position									Cycle Average Emission Rates
	Idle	1	2	3	4	5	6	7	8	
EPA Line-Haul Cycle (fraction of time)	50.5%	6.5%	6.5%	5.2%	4.4%	3.8%	3.9%	3.0%	16.2%	
Horsepower	10	190	350	675	925	1300	1600	2200	2700	
NO (g/bhp-hr)	97.0	11.7	10.8	9.91	8.75	8.14	8.21	6.68	5.89	7.54
NO2 (g/bhp-hr)	11.2	1.18	0.77	0.64	0.53	0.49	0.47	0.41	0.49	0.58
FID HC (g/bhp-hr)	74.8	1.69	0.99	0.72	0.56	0.47	0.60	0.68	0.55	1.13
NDIR HC (g/bhp-hr)	13.1	0.57	0.34	0.25	0.20	0.17	0.20	0.15	0.13	0.26

Table 3-5. Engine Output-Based Emission Rates of FID-Measured HC and NDIR-Measured HC for Each Replicate, and the Average Ratio of FID/NDIR HC for Each of the Notch Positions

	FID-Measured HC Emission Rates (g/bhp-hr)						NDIR-Measured HC Emission Rates (g/bhp-hr)						FID/ NDIR Ratio[c]
Notch Position	REP1[a]	REP2[a]	REP3[a]	Avg[b]	StDev[b]	CV[b]	REP1	REP2	REP3	Avg	StDev	CV	
Idle	88.7	76.4	59.2	74.8	15	0.20	8.87	8.32	10.4	9.18	1.05	0.11	5.7
1	1.85	1.73	1.48	1.69	0.19	0.11	16.4	17.4	17.2	17.0	0.54	0.03	3.0
2	1.09	1.00	0.88	0.99	0.10	0.11	12.6	12.9	13.8	13.1	0.60	0.05	2.9
3	0.80	0.71	0.65	0.72	0.07	0.10	0.57	0.57	0.56	0.57	0.01	0.01	2.9
4	0.63	0.54	0.50	0.56	0.06	0.11	0.33	0.34	0.35	0.34	0.01	0.02	2.8
5	0.56	0.44	0.43	0.47	0.07	0.15	0.25	0.24	0.26	0.25	0.01	0.04	2.8
6	0.68	0.62	0.51	0.60	0.09	0.15	0.20	0.19	0.21	0.20	0.01	0.03	3.1
7	0.84	0.65	0.54	0.68	0.15	0.22	0.17	0.15	0.18	0.17	0.02	0.09	4.5
8	n/a	0.61	0.50	0.55	0.07	0.13	0.19	0.20	0.20	0.20	0.01	0.03	4.2

a *REP1 = replicate 1; REP2 = replicate 2; REP3 = replicate 3.*

b *Avg = average, over 3 replicates; StDev = standard deviation, over 3 replicates; CV = coefficient of variation, which was the ratio of standard deviation over average.*

c *FID/NDIR Ratio was estimated by dividing the FID-measured average HC emission rates by the NDIR-measured average HC emission rates.*

Ratio of FID/NDIR HC

Table 3-5 shows the engine output-based emission rates of FID-measured HC and NDIR-measured HC for each of the notch positions for each replicate. For FID-measured HC emission rates, the inter-replicate variability was moderate, as were the CVs for all notch positions ranging from 0.10 to 0.15, except for idle and notch 7, which were 0.20 and 0.22, respectively. For NDIR-measured HC emission rates, the inter-replicate variability was moderate for idle and notch 7, with CVs of 0.11 and 0.09, respectively, and was small for the other notch positions, with CVs less than or equal to 0.05.

The FID/NDIR HC ratios tended to decrease from idle to notch 1, remain approximately constant through Notch 6, and increased at notch 7 and 8. The highest FID/NDIR ratio was 5.7 during idle and the lowest ratio was 2.8 in notch 4 and 5. The mean and standard deviation of the notch-specific average ratios among the 9 notch positions were 3.5 and 1.03, respectively. The corresponding CV was 0.30, which indicates large inter-notch variability.

Table 3-6. Cycle Average Ratios of NO_2 versus NO for Different Fuels and Locomotive Prime Mover Engines.

Fuel/Locomotive	NC-1797	NC-1810	NC-1859
ULSD	n/a	0.056	0.054
B10	0.069	-	0.077
B20	0.076	-	0.071
B40	0.104	-	0.063
B60	-	0.073	-
B80	-	0.061	-
B100	-	0.068	-

"n/a"indicates measurement was attempted, but the results were invalid; "-" indicates no measurement was done.

Table 3-7. Cycle Average Ratios of Flame Ionized Detection versus Non-Dispersive Infrared Hydrocarbon for Different Fuels and Locomotive Prime Mover Engines.

Fuel/Locomotive	NC-1797	NC-1810	NC-1859
ULSD	4.1	6.0	5.7
B10	3.0	-	3.7
B20	n/a	-	2.0
B40	2.4	-	2.9
B60	-	1.9	-
B80	-	4.0	-
B100	-	5.5	-

"n/a" indicates measurement was attempted, but the results were invalid; "-" indicates no measurement was done.

Results for All Tests

The detailed results for NC-1859 and B10 biodiesel resemble the results for all of the locomotives and fuels in which comparisons between NO_x and NO, and between FID and NDIR measurements of HC, were completed. A summary of all results for NOx are given in Table 3-6, and all results for HC are given in Table 3-7. For NO_x, although there was some variability in the results, the results were not substantially different on a cycle average basis from the assumption that 95 volume percent of NO_x is NO. For HC, the results were also subject to variability, but they were of the same magnitude as the assumption that total HC can be approximately as being a factor of 2.5 greater than HC measured using NDIR.

Implications

A method for quantifying the ratio of NO_x/NO and of FID/NDIR HC with application to engine load measurements of a locomotive engine has been described in this report, and the results illustrate that the NO_x/NO and FID/NDIR HC ratios varied with engine load. Both ratios tend to be highest for idling and very high engine load, and reach a minimum at moderate engine load. There was some inter-replicate variability in the measured ratios, particularly for hydrocarbons. However, the inter-notch position variations were larger than the inter-replicate variability for a given notch. Thus, the trends in ratios with respect to engine load were inferred to be significant.

Although there was variability in the NO_x/NO ratio with engine load, the cycle average NO_x/NO ratio for the EPA line-haul duty cycle was not substantially different from the previously assumed ratio. Similarly, although there was variability in the FID/NDIR ratio for HC, most of the engine load measurements had ratios similar to the previously assumed ratio.

The ratios measured here provide insight into the specification of NO_x and HC emissions for locomotive engines, with respect to the distribution of NO and NO_2 for the former and straight chain versus other hydrocarbons for the latter. The ratios measured in this work were for uncontrolled older in-service two-stroke diesel engines, and they may differ for four-stroke engines, newer engines, and engines with post-combustion emission controls. The methodological approach demonstrated here can be applied to other emission source categories.

3.3.3 Summary of Results for All Locomotives and Fuels

Three replicate rail yard measurements of engine parameters and exhaust concentrations were conducted for each locomotive on each fuel blend. However, only one rail yard measurement was conducted for NC-1810 with B10, B20, and B40 due to scheduling constraints.

Engine parameters, including RPM, MAP, and IAT, were measured for each notch position and compared across the three replicate measurements for each fuel blend, as well as across fuel blends. As the PME was shifted from idle to notch 8 for all locomotives and fuels, the engine load, RPM, and MAP increase, while IAT remained relatively constant across all notches for each locomotive. The coefficient of variation (CV) was the ratio of the standard deviation to the mean, and the CV for inter-replicate variations for a given PME and notch position was 0.05 or less for RPM, MAP, and IAT. Thus the engine parameter measurements were highly repeatable. There was no statistically significant difference in these engine parameters for a given PME across each of the fuel blends.

Emission rates were estimated for each pollutant at each notch position. These are summarized in Table 3-8, which shows detailed results for each locomotive, each fuel, and each throttle notch positive for the emission rates of NO_x, HC, CO, PM, and CO_2, in mass per unit of engine power output (g/kW-hr). The table also shows the CV for inter-replicate variability.

Table 3-8. Engine Output-Based Notch Average Emission Rates from Rail Yard Measurement of Prime Mover Engines

(a) F59PHI Locomotive NC-1797

Fuel	Notch Position	NO as NO_2 (g/kW-hr)	HC (g/kW-hr)	CO (g/kW-hr)	PM (g/kW-hr)	CO_2 (g/kW-hr)
ULSD (4 replicates)	Idle	188 (*0.11*)	81.5 (*0.21*)	7.70 (*0.69*)	6.55 (*0.06*)	4212 (*0.14*)
	1	26.2 (*0.09*)	1.19 (*0.68*)	0.49 (*0.90*)	0.49 (*0.03*)	736 (*0.05*)
	2	24.8 (*0.04*)	0.91 (*0.77*)	0.33 (*0.56*)	0.25 (*0.04*)	606 (*0.05*)
	3	17.7 (*0.01*)	0.41 (*0.25*)	0.08 (*1.24*)	0.15 (*0.03*)	573 (*0.01*)
	4	14.3 (*0.01*)	0.47 (*0.36*)	0.03 (*1.48*)	0.12 (*0.04*)	595 (*0.00*)
	5	15.3 (*0.02*)	0.29 (*0.14*)	0.01 (*1.23*)	0.10 (*0.03*)	621 (*0.01*)
	6	14.5 (*0.06*)	1.39 (*0.77*)	0.01 (*1.63*)	0.09 (*0.02*)	599 (*0.06*)
	7	12.1 (*0.00*)	0.61 (*0.33*)	0.11 (*0.57*)	0.25 (*0.02*)	653 (*0.02*)
	8	12.8 (*0.01*)	0.90 (*0.93*)	1.19 (*0.17*)	0.25 (*0.06*)	676 (*0.01*)
B10 (3 replicates)	Idle	270 (*0.01*)	194 (*0.62*)	28.1 (*0.44*)	5.49 (*0.09*)	6519 (*0.01*)
	1	36.0 (*0.02*)	7.97 (*0.54*)	1.34 (*0.16*)	0.32 (*0.04*)	900 (*0.01*)
	2	34.3 (*0.03*)	7.12 (*0.37*)	1.03 (*0.41*)	0.18 (*0.03*)	744 (*0.01*)
	3	22.8 (*0.02*)	4.80 (*0.16*)	0.62 (*0.22*)	0.12 (*0.01*)	662 (*0.01*)
	4	18.0 (*0.03*)	4.60 (*0.35*)	0.78 (*0.57*)	0.13 (*0.03*)	675 (*0.00*)
	5	18.5 (*0.04*)	2.71 (*0.46*)	0.38 (*0.09*)	0.12 (*0.02*)	657 (*0.01*)
	6	18.0 (*0.01*)	2.98 (*0.36*)	0.33 (*0.92*)	0.10 (*0.01*)	661 (*0.02*)
	7	14.1 (*0.02*)	2.22 (*0.15*)	0.28 (*0.94*)	0.27 (*0.05*)	716 (*0.01*)
	8	15.5 (*0.02*)	2.58 (*0.16*)	0.89 (*0.19*)	0.29 (*0.12*)	697 (*0.00*)
B20 (3 replicates)	Idle	233 (*0.25*)	341 (*0.19*)	36.1 (*0.70*)	4.17 (*0.02*)	5500 (*0.21*)
	1	27.4 (*0.04*)	12.6 (*0.13*)	0.24 (*1.36*)	0.29 (*0.04*)	662 (*0.09*)
	2	27.9 (*0.03*)	8.73 (*0.21*)	0.09 (*0.87*)	0.17 (*0.01*)	571 (*0.08*)
	3	18.5 (*0.03*)	6.80 (*0.21*)	0.06 (*0.98*)	0.11 (*0.02*)	508 (*0.06*)
	4	14.5 (*0.02*)	7.01 (*0.07*)	0.03 (*1.73*)	0.09 (*0.02*)	555 (*0.06*)
	5	15.3 (*0.01*)	3.14 (*0.58*)	0.00 (*n/a*)	0.08 (*0.02*)	531 (*0.00*)
	6	14.8 (*0.02*)	4.76 (*0.32*)	0.12 (*0.96*)	0.07 (*0.01*)	582 (*0.02*)
	7	12.1 (*0.04*)	2.38 (*0.92*)	0.26 (*0.97*)	0.20 (*0.06*)	625 (*0.01*)
	8	13.6 (*0.03*)	4.95 (*0.32*)	0.96 (*0.25*)	0.18 (*0.17*)	641 (*0.09*)
B40 (3 replicates)	Idle	241 (*0.09*)	75.8 (*0.30*)	11.1 (*0.37*)	9.11 (*0.09*)	7641 (*0.02*)
	1	27.4 (*0.03*)	0.00 (*n/a*)	0.55 (*1.21*)	0.69 (*0.09*)	1000 (*0.02*)
	2	28.6 (*0.06*)	0.34 (*1.73*)	0.12 (*1.57*)	0.39 (*0.05*)	778 (*0.01*)
	3	21.5 (*0.02*)	3.84 (*1.73*)	0.04 (*1.73*)	0.24 (*0.04*)	689 (*0.00*)
	4	16.6 (*0.03*)	3.32 (*1.18*)	0.01 (*0.98*)	0.21 (*0.03*)	695 (*0.01*)
	5	17.2 (*0.01*)	1.14 (*1.48*)	0.20 (*1.73*)	0.19 (*0.03*)	695 (*0.01*)
	6	17.1 (*0.03*)	1.52 (*0.72*)	0.00 (*n/a*)	0.18 (*0.03*)	715 (*0.01*)
	7	12.4 (*0.00*)	3.75 (*1.08*)	0.17 (*0.81*)	0.40 (*0.04*)	726 (*0.01*)
	8	15.0 (*0.03*)	1.25 (*1.55*)	0.75 (*0.71*)	0.39 (*0.09*)	768 (*0.01*)

Italicized values in parentheses are coefficients of variation on the mean emission rate.

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Table 3-8. Continued.

(b) F59PH Locomotive NC-1810

Fuel	Notch Position	NO as NO_2 (g/kW-hr)	HC (g/kW-hr)	CO (g/kW-hr)	PM (g/kW-hr)	CO_2 (g/kW-hr)
ULSD (3 replicates)	Low Idle	97.4 (*0.08*)	307 (*0.06*)	39.7 (*0.27*)	3.89 (*0.05*)	3762 (*0.07*)
	High Idle	129 (*0.05*)	429 (*0.03*)	44.4 (*0.21*)	4.53 (*0.11*)	6846 (*0.05*)
	1	13.8 (*0.05*)	15.0 (*0.08*)	1.62 (*0.35*)	0.34 (*0.02*)	819 (*0.01*)
	2	13.6 (*0.04*)	9.41 (*0.10*)	0.99 (*0.44*)	0.23 (*0.02*)	669 (*0.00*)
	3	13.3 (*0.01*)	6.42 (*0.17*)	0.50 (*0.35*)	0.18 (*0.02*)	616 (*0.01*)
	4	12.3 (*0.01*)	4.46 (*0.12*)	0.43 (*0.75*)	0.20 (*0.03*)	609 (*0.01*)
	5	11.7 (*0.02*)	2.73 (*0.11*)	0.31 (*0.68*)	0.23 (*0.03*)	606 (*0.00*)
	6	11.4 (*0.01*)	5.69 (*0.16*)	0.37 (*0.97*)	0.20 (*0.01*)	625 (*0.01*)
	7	9.32 (*0.04*)	2.71 (*0.46*)	1.43 (*0.33*)	0.31 (*0.10*)	630 (*0.00*)
	8	9.01 (*0.01*)	1.68 (*0.25*)	1.74 (*0.06*)	0.47 (*0.15*)	703 (*0.00*)
B10 (1 replicate)	Low Idle	87.2	35.2	4.74	5.57	3853
	High Idle	131	27.0	5.57	5.90	7161
	1	14.7	2.30	1.09	0.54	803
	2	14.1	1.47	0.53	0.40	671
	3	13.3	0.79	0.31	0.28	610
	4	12.3	0.18	0.54	0.29	614
	5	11.1	0.00	0.49	0.35	618
	6	10.8	0.03	0.37	0.32	616
	7	8.85	0.26	1.77	0.35	636
	8	7.77	0.06	2.49	0.47	744
B20 (1 replicate)	Low Idle	78.1	5.80	5.07	7.14	3247
	High Idle	133	41.8	3.34	5.73	154760
	1	13.0	0.00	0.44	0.59	523
	2	12.8	0.02	0.08	0.41	518
	3	13.2	0.09	0.18	0.28	457
	4	11.8	0.00	0.26	0.27	485
	5	11.5	0.00	0.32	0.31	396
	6	11.0	0.14	0.06	0.26	449
	7	9.20	0.45	1.01	0.26	569
	8	7.94	0.62	1.36	0.27	754
B40 (1 replicate)	Low Idle	97.4	27.5	12.8	11.6	2698
	High Idle	n/a	n/a	n/a	n/a	n/a
	1	17.2	1.86	0.11	0.98	619
	2	16.7	1.27	0.01	0.64	585
	3	15.7	1.23	0.05	0.43	489
	4	13.7	1.16	0.22	0.42	531
	5	13.9	0.19	0.01	0.46	514
	6	12.8	0.24	0.12	0.39	566
	7	10.4	0.83	0.12	0.51	559
	8	9.30	0.06	1.30	1.10	628

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Table 3-8. Continued.

Fuel	Notch Position	NO as NO_2 (g/kW-hr)	HC (g/kW-hr)	CO (g/kW-hr)	PM (g/kW-hr)	CO_2 (g/kW-hr)
B60 (# replicates)	Low Idle	95.3 (*0.08*)	45.5 (*0.80*)	31.5 (*0.61*)	3.73 (*0.09*)	3688 (*0.07*)
	High Idle	130 (*0.07*)	47.4 (*0.91*)	35.6 (*0.88*)	2.17 (*0.22*)	6173 (*0.04*)
	1	16.4 (*0.10*)	2.85 (*1.17*)	1.91 (*0.59*)	0.34 (*0.07*)	750 (*0.06*)
	2	15.9 (*0.12*)	1.83 (*1.07*)	1.10 (*0.67*)	0.29 (*0.03*)	750 (*0.07*)
	3	14.5 (*0.12*)	0.95 (*1.24*)	0.57 (*0.90*)	0.17 (*0.07*)	679 (*0.03*)
	4	13.0 (*0.11*)	0.48 (*1.41*)	0.49 (*1.00*)	0.18 (*0.07*)	658 (*0.01*)
	5	12.1 (*0.10*)	0.25 (*1.58*)	0.26 (*1.09*)	0.19 (*0.12*)	667 (*0.00*)
	6	11.9 (*0.09*)	0.66 (*0.99*)	0.46 (*1.35*)	0.19 (*0.14*)	691 (*0.02*)
	7	10.4 (*0.11*)	0.32 (*0.96*)	0.89 (*0.60*)	0.27 (*0.19*)	731 (*0.01*)
	8	9.54 (*0.06*)	0.67 (*1.13*)	1.13 (*0.55*)	0.31 (*0.18*)	743 (*0.02*)
B80 (3 replicates)	Low Idle	63.7 (*0.06*)	12.9 (*0.29*)	4.14 (*0.68*)	4.94 (*0.08*)	3094 (*0.09*)
	High Idle	86.8 (*0.01*)	25.5 (*0.61*)	9.34 (*0.06*)	3.69 (*0.16*)	4651 (*0.01*)
	1	12.0 (*0.01*)	1.08 (*0.21*)	0.34 (*0.61*)	0.29 (*0.02*)	703 (*0.01*)
	2	9.98 (*0.00*)	1.06 (*0.18*)	0.11 (*0.71*)	0.20 (*0.00*)	498 (*0.01*)
	3	11.3 (*0.01*)	0.33 (*0.27*)	0.02 (*0.82*)	0.14 (*0.04*)	551 (*0.00*)
	4	9.68 (*0.01*)	0.34 (*0.35*)	0.03 (*0.77*)	0.15 (*0.04*)	518 (*0.01*)
	5	10.2 (*0.00*)	0.24 (*0.10*)	0.09 (*0.31*)	0.20 (*0.05*)	587 (*0.01*)
	6	10.5 (*0.00*)	0.13 (*0.25*)	0.25 (*0.24*)	0.22 (*0.03*)	675 (*0.01*)
	7	8.41 (*0.02*)	0.10 (*1.35*)	0.75 (*0.12*)	0.26 (*0.08*)	628 (*0.01*)
	8	8.71 (*0.01*)	0.21 (*1.26*)	1.43 (*0.11*)	0.57 (*0.20*)	746 (*0.00*)
B100 (3 replicates)	Low Idle	102 (*0.01*)	191 (*0.42*)	32.4 (*0.23*)	3.76 (*0.05*)	4042 (*0.05*)
	High Idle	165 (*0.11*)	334 (*0.53*)	57.8 (*0.59*)	5.13 (*0.34*)	7061 (*0.05*)
	1	18.2 (*0.01*)	7.90 (*0.53*)	1.03 (*0.75*)	0.30 (*0.02*)	936 (*0.01*)
	2	16.5 (*0.03*)	6.32 (*0.53*)	0.96 (*0.77*)	0.20 (*0.01*)	735 (*0.01*)
	3	16.4 (*0.01*)	3.25 (*0.52*)	0.24 (*0.90*)	0.14 (*0.02*)	715 (*0.01*)
	4	14.4 (*0.02*)	2.14 (*0.58*)	0.19 (*1.18*)	0.14 (*0.02*)	677 (*0.00*)
	5	13.7 (*0.02*)	1.56 (*0.69*)	0.18 (*1.26*)	0.16 (*0.01*)	692 (*0.01*)
	6	13.5 (*0.02*)	1.43 (*0.95*)	0.15 (*1.22*)	0.15 (*0.03*)	712 (*0.00*)
	7	11.7 (*0.03*)	0.90 (*0.95*)	0.12 (*0.36*)	0.24 (*0.10*)	679 (*0.00*)
	8	10.9 (*0.02*)	0.30 (*0.34*)	0.37 (*0.50*)	0.49 (*0.43*)	750 (*0.01*)

Italicized values in parentheses are coefficients of variation on the mean emission rate.

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Table 3-8. Continued.

(b) F59PH Locomotive NC-1859

Fuel	Notch Position	NO as NO$_2$ (g/kW-hr)	HC (g/kW-hr)	CO (g/kW-hr)	PM (g/kW-hr)	CO$_2$ (g/kW-hr)
ULSD (3 replicates)	Low Idle	92.9 (*0.02*)	110 (*0.26*)	32.7 (*0.29*)	9.11 (*0.04*)	4571 (*0.02*)
	High Idle	111 (*0.00*)	685 (*0.37*)	352 (*0.46*)	8.48 (*0.02*)	6771 (*0.02*)
	1	13.2 (*0.02*)	12.1 (*0.15*)	2.57 (*0.31*)	0.69 (*0.02*)	919 (*0.01*)
	2	12.8 (*0.04*)	10.8 (*0.08*)	2.19 (*0.04*)	0.48 (*0.01*)	754 (*0.01*)
	3	12.0 (*0.03*)	8.97 (*0.08*)	1.90 (*0.09*)	0.37 (*0.02*)	676 (*0.00*)
	4	10.6 (*0.02*)	7.55 (*0.18*)	1.97 (*0.34*)	0.34 (*0.02*)	654 (*0.03*)
	5	9.92 (*0.03*)	3.36 (*0.87*)	0.87 (*0.91*)	0.35 (*0.02*)	641 (*0.01*)
	6	10.0 (*0.06*)	0.00 (*n/a*)	0.91 (*0.25*)	0.39 (*0.02*)	676 (*0.02*)
	7	8.92 (*0.09*)	4.85 (*1.12*)	3.26 (*0.85*)	0.49 (*0.05*)	701 (*0.03*)
	8	7.80 (*0.04*)	5.35 (*0.13*)	2.68 (*0.04*)	0.49 (*0.02*)	685 (*0.00*)
B10 (3 replicates)	Low Idle	103 (*0.04*)	106 (*0.55*)	26.2 (*0.56*)	5.87 (*0.05*)	4379 (*0.03*)
	High Idle	133 (*0.05*)	173 (*0.14*)	41.8 (*0.25*)	7.40 (*0.10*)	7098 (*0.01*)
	1	16.4 (*0.06*)	2.83 (*0.54*)	1.05 (*0.46*)	0.33 (*0.02*)	911 (*0.01*)
	2	16.1 (*0.06*)	1.17 (*0.40*)	0.40 (*0.66*)	0.21 (*0.01*)	734 (*0.00*)
	3	15.2 (*0.05*)	0.66 (*0.67*)	0.12 (*0.00*)	0.15 (*0.01*)	657 (*0.00*)
	4	14.0 (*0.06*)	0.35 (*0.40*)	0.06 (*0.87*)	0.14 (*0.07*)	628 (*0.00*)
	5	13.5 (*0.04*)	0.35 (*0.47*)	0.08 (*0.00*)	0.15 (*0.03*)	642 (*0.00*)
	6	13.0 (*0.04*)	0.47 (*0.07*)	0.08 (*0.00*)	0.13 (*0.05*)	640 (*0.00*)
	7	11.2 (*0.04*)	0.38 (*0.34*)	0.30 (*0.27*)	0.19 (*0.06*)	624 (*0.00*)
	8	10.5 (*0.03*)	0.16 (*0.33*)	0.40 (*0.51*)	0.32 (*0.22*)	665 (*0.00*)
B20 (3 replicates)	Low Idle	91.2 (*0.05*)	153 (*0.46*)	34.3 (*0.46*)	2.94 (*0.04*)	3625 (*0.13*)
	High Idle	122 (*0.06*)	224 (*0.14*)	43.3 (*0.21*)	2.88 (*0.09*)	6185 (*0.14*)
	1	15.0 (*0.03*)	8.48 (*0.37*)	2.12 (*0.43*)	0.15 (*0.03*)	782 (*0.02*)
	2	14.6 (*0.02*)	5.67 (*0.30*)	1.26 (*0.28*)	0.11 (*0.04*)	642 (*0.04*)
	3	14.1 (*0.02*)	3.76 (*0.30*)	0.63 (*0.43*)	0.09 (*0.03*)	578 (*0.03*)
	4	12.9 (*0.02*)	2.79 (*0.40*)	0.43 (*0.44*)	0.10 (*0.02*)	569 (*0.02*)
	5	12.5 (*0.02*)	1.35 (*0.40*)	0.06 (*0.87*)	0.10 (*0.03*)	585 (*0.01*)
	6	12.2 (*0.03*)	2.90 (*0.38*)	0.25 (*0.88*)	0.09 (*0.01*)	585 (*0.01*)
	7	10.6 (*0.03*)	4.27 (*0.40*)	0.55 (*0.77*)	0.12 (*0.02*)	575 (*0.01*)
	8	9.71 (*0.04*)	0.48 (*0.63*)	0.41 (*0.20*)	0.20 (*0.15*)	668 (*0.03*)
B40 (3 replicates)	Low Idle	120 (*0.05*)	113 (*0.18*)	40.4 (*0.38*)	6.99 (*0.08*)	3759 (*0.04*)
	High Idle	145 (*0.02*)	152 (*0.26*)	73.6 (*0.14*)	4.92 (*0.16*)	6102 (*0.01*)
	1	18.7 (*0.03*)	1.69 (*0.48*)	2.87 (*0.18*)	0.49 (*0.04*)	865 (*0.03*)
	2	18.0 (*0.02*)	0.82 (*0.32*)	1.32 (*0.42*)	0.31 (*0.02*)	689 (*0.03*)
	3	17.1 (*0.03*)	0.47 (*0.35*)	0.81 (*0.17*)	0.21 (*0.00*)	629 (*0.02*)
	4	14.8 (*0.01*)	0.27 (*0.33*)	0.54 (*0.67*)	0.19 (*0.05*)	575 (*0.04*)
	5	14.5 (*0.02*)	0.21 (*0.88*)	0.33 (*0.15*)	0.18 (*0.05*)	606 (*0.04*)
	6	14.0 (*0.06*)	1.79 (*1.18*)	0.54 (*0.78*)	0.17 (*0.01*)	601 (*0.03*)
	7	11.8 (*0.03*)	0.96 (*0.70*)	0.71 (*0.48*)	0.22 (*0.03*)	593 (*0.05*)
	8	11.6 (*0.04*)	0.39 (*0.29*)	0.80 (*0.48*)	0.27 (*0.08*)	691 (*0.01*)

Italicized values in parentheses are coefficients of variation on the mean emission rate.

End of Table.

For a given locomotive, the relative trend in NO_x emission rate was approximately similar among the throttle notch positions. For example, the highest NO_x emission rates were at idle, and they decreased with increasing engine load to a minimum value. The minimum NO_x emission rate was typically at notch 7 for NC-1797 for all fuels, and at notch 8 for both NC-1810 and NC-1859 for all fuels. Furthermore, the NO_x emission rates for notches 4 to 6 were approximately the same as each other for NC-1797. For NC-1810, the emission rates were similar, typically within 2 g/kW-hr, for notches 1 through 6 for many of the fuels. For most fuels, the notch average NO_x emissions rates for NC-1859 were similar to each other for notches 3 to 6. The non-idle notch average NO_x emission rates ranged from approximately 7.8 g/kW-hr (for NC-1859, ULSD, at notch 8) to as much as 36 g/kW-hr (for NC-1797, B10, notch 1). The minimum notch average emission rates among the locomotives and fuels ranged from 7.8 g/kW-hr (NC-1859, ULSD, at notch 8) to 14.1 g/kW-hr (NC-1797, B10, notch 7). Thus, there was clearly inter-notch variability and inter-engine variability in the emission rates.

For PM, the highest engine output-based emission rate was at idle for all locomotives. The lowest emission rate was typically around notch 6 for all locomotives, although in a few cases the lowest rate was observed for notches 3, 4, or 7. However, the non-idle PM emission rate was less sensitive to engine load, on a relative basis, than the NO_x emission rate. For example, for NC-1810 on B60 for which the minimum PM emission rate was observed for notch 3, the emission rate was approximately the same for notches 3 through 6, ranging only from 0.17 g/kW-hr to 0.19 g/kW-hr. Likewise, for NC-1810 operated on B100, the PM emission rate was lowest in notches 3 and 4 at 0.14 g/kW-hr, but was nearly the same at notches 5 and 6, with values of 0.16 g/kW-hr and 0.15 g/kW-hr, respectively. For NC-1859 operated on B20, the PM emission rate varied only from 0.09 g/kW-hr to 0.11 g/kW-hr from notches 2 to 6. Therefore, some of the variation in the identification of which notch had the lowest emission rate was related to consistently low rates over multiple notches.

Engine output-based NO_x and PM emission rates for all locomotives generally decreased as the PME load increased. For each locomotive and each fuel blend, CV values were less than 0.10 for notch 8, indicating high repeatability of the measurements.

For HC, there was substantial variability in the notch that had the lowest emission rate in part because the measured HC exhaust concentrations were low; this led to imprecision in the estimated emission rates. Most typically, the lowest HC emission rate occurred in notches 5, 7, or 8 over all locomotives and fuels. Similarly, the CO emission rates were imprecise because of low exhaust concentrations that led to relatively large inter-replicate variability. The minimum CO emission rate was typically observed at notches 5, 6, or 7. Emission rates of HC and CO for diesel engines were generally lower than other emission sources.

Engine output-based CO_2 emission rates for all locomotives were typically within 10 percent of each other for notches 2 through 8. The emission rate at Idle was approximately 5 to 10 times higher than the emission rate at notch 8. For each locomotive and each fuel blend, CV values were less than 0.10 for notch 8, indicating high repeatability of the measurements.

Table 3-9. Ultra-Low Sulfur Diesel and Biodiesel Cycle Average Emission Rates for Measured Prime Mover Engines Based on Rail Yard Measurements

(a) NC-1797 – F59PHI Locomotive

Fuel	NO$_x$ (g/kW-hr)[a]	HC (g/kW-hr)[b]	CO (g/kW-hr)	PM (g/kW-hr)[c]	CO$_2$ (g/kW-hr)
ULSD	11.2 (*0.01*)	1.01 (*0.33*)	0.61 (*0.20*)	0.19 (*0.05*)	677 (*0.01*)
B10	14.0 (*0.02*)	3.16 (*0.32*)	0.69 (*0.04*)	0.21 (*0.08*)	736 (*0.01*)
B20	11.9 (*0.03*)	5.34 (*0.07*)	0.65 (*0.20*)	0.14 (*0.05*)	648 (*0.06*)
B40	12.5 (*0.00*)	1.58 (*0.21*)	0.73 (*0.47*)	0.21 (*0.20*)	798 (*0.01*)

(b) NC-1810 – F59PH Locomotive

Fuel	NO$_x$ (g/kW-hr)[a]	HC (g/kW-hr)[b]	CO (g/kW-hr)	PM (g/kW-hr)[c]	CO$_2$ (g/kW-hr)
ULSD	7.9 (*0.01*)	3.81 (*0.09*)	1.20 (*0.09*)	0.32 (*0.10*)	696 (*0.00*)
B10	7.3 (*n/a*)	0.32 (*n/a*)	1.36 (*n/a*)	0.34 (*n/a*)	721 (*n/a*)
B20	7.7 (*n/a*)	1.91 (*n/a*)	0.74 (*n/a*)	0.28 (*n/a*)	663 (*n/a*)
B40	8.5 (*n/a*)	0.15 (*n/a*)	0.60 (*n/a*)	0.30 (*n/a*)	610 (*n/a*)
B60	8.9 (*0.02*)	1.14 (*0.56*)	1.18 (*0.26*)	0.24 (*0.09*)	748 (*0.02*)
B80	7.1 (*0.01*)	0.25 (*0.47*)	0.73 (*0.08*)	0.55 (*0.15*)	704 (*0.01*)
B100	9.5 (*0.01*)	1.79 (*0.47*)	0.40 (*0.17*)	0.31 (*0.33*)	756 (*0.01*)

(c) NC-1859 – F59PH Locomotive

Fuel	NO$_x$ (g/kW-hr)[a]	HC (g/kW-hr)[b]	CO (g/kW-hr)	PM (g/kW-hr)[c]	CO$_2$ (g/kW-hr)
ULSD	7.0 (*0.02*)	4.49 (*0.18*)	1.91 (*0.15*)	0.39 (*0.02*)	714 (*0.00*)
B10	9.2 (*0.04*)	0.79 (*0.42*)	0.37 (*0.45*)	0.22 (*0.15*)	688 (*0.00*)
B20	8.5 (*0.03*)	2.04 (*0.40*)	0.51 (*0.16*)	0.13 (*0.10*)	659 (*0.02*)
B40	10.1 (*0.03*)	1.01 (*0.25*)	0.78 (*0.39*)	0.22 (*0.07*)	683 (*0.02*)

(d) All Three Locomotives

Fuel	NO$_x$ (g/kW-hr)[a]	HC (g/kW-hr)[b]	CO (g/kW-hr)	PM (g/kW-hr)[c]	CO$_2$ (g/kW-hr)
ULSD	8.7 (*0.22*)	3.10 (*0.54*)	1.24 (*0.47*)	0.30 (*0.29*)	696 (*0.02*)
B10	11.0 (*0.26*)	1.74 (*0.85*)	0.65 (*0.57*)	0.23 (*0.22*)	713 (*0.03*)
B20	9.8 (*0.20*)	3.44 (*0.91*)	0.60 (*0.21*)	0.16 (*0.35*)	655 (*0.04*)
B40	10.4 (*0.17*)	0.91 (*0.72*)	0.70 (*0.34*)	0.24 (*0.20*)	722 (*0.11*)

Italicized values in parentheses are coefficients of variation (standard deviation divided by the mean) on the difference in the mean emission rates.

[a] NO$_x$ includes NO and NO$_2$. Only NO was measured. Typically, NO$_x$ is comprised of 95 vol-% NO. NO$_x$ is always reported as equivalent mass of NO$_2$. Results include multiplicative correction factor of 1.053 to approximate total NO$_x$.

[b] HC was measured using non-dispersive infrared (NDIR), which accurately measures some compounds but responds only partially to others. Results include multiplicative correction factor of 2.5 to approximate total HC.

[c] PM was measured using a light scattering technique, which provides useful relative comparisons of particle levels in the exhaust. Results include multiplicative correction factor of 5 to approximate total PM.

3.4 Results for Cycle Average Fuel Use and Emission Rates

Cycle average emission rates were estimated for each PME and fuel blend, based on the EPA line-haul duty cycle. The duty cycle lists the percent of time spent in each notch position during locomotive operations. The EPA has identified a distinct duty cycle that it uses in engine emissions certification based on the movement of freight over a relatively long distance (US EPA, 1998). All measured emission rates are of the same magnitude as published emission rates of the same locomotive model. Table 3-9 compares the biodiesel and ULSD cycle average emission rates for each individual locomotive and fuel blend, as well as across all three locomotives for B10, B20, and B40 versus ULSD. T-tests were conducted to identify statistically significant differences. While CO_2 emissions are not regulated by EPA, cycle average emission rates were estimated so comparisons can be made across fuel blends to determine if biodiesel use affects CO_2 emission rates. Table 3-10 shows the relative differences in the cycle average emission rates for each pollutant for each biofuel blend compared to ULSD.

For NO_x, eight of the comparisons, including B10 and B40 for NC-1797; B40, B60, and B100 for NC-1810; and B10, B20, and B40 for NC-1859, have statistically significant higher values, by 7 to 43 percent, compared to ULSD. A statistically significant decrease was estimated only for one case for B80 versus ULSD for NC-1810. Overall, NO_x emission rates on biofuels tend to be the same or higher than ULSD. This finding was consistent with previous studies that NO_x emissions increase as fuel density and Cetane number increases, which both were associated with increasing biofuel blend. Among the three biofuels measured for all three locomotives, B20 was found to have the lowest relative increases in NO_x emission rate.

For HC, seven of the statistically significant comparisons have lower emission rates on biofuels. The comparison between B20 and ULSD for NC-1797 led to a higher emission rate. Thus, HC emission rates tend to be similar to or lower than for ULSD. Likewise, for CO, the six statistically significant comparisons were 39 to 81 percent lower than for ULSD. Furthermore, 8 of the 12 comparisons were lower on average, even if some were not significant, and there were no comparisons that were significantly higher. This finding was consistent with the expectation that increased oxygen content in biodiesel leads to lower emissions that involve products of incomplete combustion.

For PM, five of the comparisons have statistically significant lower values (by 26 to 66 percent) compared to ULSD. A statistically significant increase was estimated for B80 versus ULSD for NC-1810. Overall, PM emission rates on biofuels tend to be the same or lower than for ULSD. This finding was supported by what we know about the effect on PM by an increased Cetane number and increased oxygen content.

There was variability in the effect biodiesel on locomotive exhaust CO_2 emissions. For CO_2, the emission rates were significantly different for 7 of the 12 comparisons. Overall, the differences in exhaust CO_2 emission rates for B10 or B40 were not statistically significant, and were an average of 6 percent lower for B20.

Given the variability for each of three locomotives when comparing emissions increases or reductions when using a particular biodiesel blend compared to ULSD, a comparison was made in the cycle average emission rates for all three locomotives on B10, B20, and B40 versus ULSD, shown at the bottom of Tables 3-9 and 3-10. These three biodiesel blends produced higher cycle average NO_x emission rates across the three locomotives, compared to ULSD. However, these differences were not statistically significant. These three biodiesel blends produced lower cycle average CO and PM emission rates across the three locomotives, compared to ULSD. The CO emission rates were significantly lower for each of the three biodiesel blends, whereas the PM emission rate was significantly lower only for B20. The 71 percent lower cycle average HC emission rate for B40 versus ULSD was statistically significant. Only the B20 CO_2 cycle average emission rate was statistically lower than ULSD. These results imply that B20 offers significant reductions in CO and PM emissions with insignificant changes in NO_x and HC emissions, and relatively little effect on exhaust CO_2 emissions.

Table 3-10. Comparison of Biodiesel to Ultra-Low Sulfur Diesel Cycle Average Emission Rates for Measured Prime Mover Engines Based on Rail Yard Measurements

(a) NC-1797 – F59PHI Locomotive

Fuel	NO$_x$[a]	HC[b]	CO	PM[c]	CO$_2$
B10 vs. ULSD	+ 25 (*<0.01*)	+ 214 (*0.07*)	+ 14 (*0.37*)	+ 8 (*0.27*)	+ 9 (*<0.01*)
B20 vs. ULSD	+ 6 (*0.07*)	+ 431 (*<0.01*)	+ 7 (*0.72*)	- 28 (*<0.01*)	- 4 (*0.35*)
B40 vs. ULSD	+ 11 (*<0.01*)	+ 57 (*0.10*)	+ 20 (*0.61*)	+ 9 (*0.54*)	+ 18 (<0.01)

(b) NC-1810 – F59PH Locomotive

Fuel	NO$_x$[a]	HC[b]	CO	PM[c]	CO$_2$
B10 vs. ULSD	- 8	- 92	+ 14	+ 4	+ 4
B20 vs. ULSD	- 3	- 50	- 38	- 14	- 5
B40 vs. ULSD	+ 7 (*0.01*)	- 96 (*<0.01*)	- 50 (*0.01*)	- 8 (*0.32*)	- 12 (*0.01*)
B60 vs. ULSD	+ 13 (*<0.01*)	- 70 (0.01)	- 2 (*0.92*)	- 26 (*0.02*)	+ 8 (*0.02*)
B80 vs. ULSD	- 10 (*<0.01*)	- 93 (*<0.01*)	- 39 (*0.01*)	+ 70 (*0.02*)	+ 1 (*0.07*)
B100 vs. ULSD	+ 20 (*<0.01*)	- 53 (0.03)	- 66 (*<0.01*)	- 3 (*0.88*)	+ 9 (*<0.01*)

(c) NC-1859 – F59PH Locomotive

Fuel	NO$_x$[a]	HC[b]	CO	PM[c]	CO$_2$
B10 vs. ULSD	+ 31 (*0.01*)	- 82 (*0.01*)	- 81 (*<0.01*)	- 42 (*0.01*)	- 4 (*<0.01*)
B20 vs. ULSD	+ 21 (*<0.01*)	- 55 (*0.02*)	- 73 (*0.01*)	- 66 (*<0.01*)	- 8 (*0.02*)
B40 vs. ULSD	+ 43 (*<0.01*)	- 78 (*0.02*)	- 59 (*0.01*)	- 43 (*<0.01*)	- 4 (*0.08*)

(d) All Three Locomotives

Fuel	NO$_x$[a]	HC[b]	CO	PM[c]	CO$_2$
B10 vs. ULSD	+ 26 (*0.11*)	- 44 (*0.10*)	- 48 (*0.03*)	- 23 (*0.07*)	+ 3 (*0.14*)
B20 vs. ULSD	+ 13 (*0.27*)	+ 11 (*0.71*)	- 51 (*0.01*)	- 48 (*<0.01*)	- 6 (*<0.01*)
B40 vs. ULSD	+ 19 (*0.08*)	- 71 (*<0.01*)	- 43 (*0.03*)	- 19 (*0.11*)	+ 4 (*0.40*)

Italicized values in parentheses are coefficients of variation (standard deviation divided by the mean) on the difference in the mean emission rates.

[a] NO$_x$ includes NO and NO$_2$. Only NO was measured. Typically, NO$_x$ is comprised of 95 vol-% NO. NO$_x$ is always reported as equivalent mass of NO$_2$. Results include multiplicative correction factor of 1.053 to approximate total NO$_x$.

[b] HC was measured using non-dispersive infrared (NDIR), which accurately measures some compounds but responds only partially to others. Results include multiplicative correction factor of 2.5 to approximate total HC.

[c] PM was measured using a light scattering technique, which provides useful relative comparisons of particle levels in the exhaust. Results include multiplicative correction factor of 5 to approximate total PM.

4. Over-the-Rail Measurements

This chapter describes the methods for making over-the-rail (OTR) measurements of selected locomotives and fuels and also provides the results of these measurements. The scope of this study was to measure three locomotives as they used ULSD and multiple biodiesel fuel blends. The locomotives were provided by NCDOT and operated by Amtrak for passenger service between Raleigh, NC and Charlotte, NC. The measurement and analysis methods for OTR data were similar to those for RY, differing primarily in that the measurements were made on-board the locomotive for actual trips. They were similar in terms of instrumentation, quality assurance, and data analysis procedures.

4.1 Measurement Method

The measurement method for over-the-rail measurements is the same as for the rail yard measurements (see Section 3.1) with some key differences:

- All of the instruments were placed on-board the locomotive. The PEMS was placed in the main cab. Although there was some space in the engine compartment, the temperature was too hot for the PEMS. Exhaust sampling lines and engine sensor array wires were routed from the engine compartment to the cab.
- The PEMS was powered by electricity from the HEP engine-generator.
- The OTR test procedure was observational rather than controlled. Thus, unlike rail yard tests, there was not a predetermined test schedule (e.g., Table 3-1). Instead, measurements were made during one-way trips between Raleigh, NC and Charlotte, NC, and vice versa, on the Amtrak-operated Piedmont train service, as depicted in Figure 4-1. The schedule for both directions is shown in Table 4-1.

Detailed results for all of the over-the-rail measurements are given in the appendices. Table 4-2 locates the results for specific combinations of locomotives and fuels within the appendices.

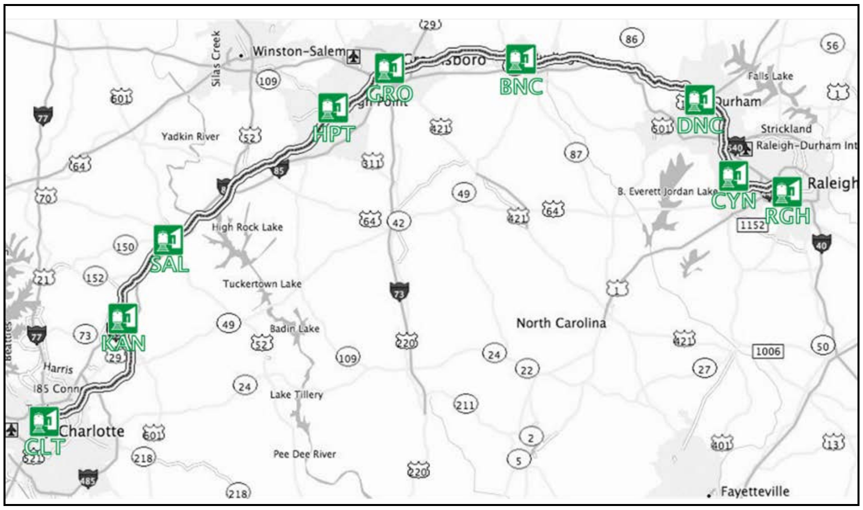

Figure 4-1. Route map of the North Carolina AMTRAK Piedmont passenger rail service.

Table 4-1. North Carolina AMTRAK Piedmont Passenger Rail Service Timetable

(a) Southbound Trains

Station	Train 73	Train 75
Raleigh (RGH)	06:45	11:45
Cary (CYN)	06:57	11:57
Durham (DNC)	07:17	12:17
Burlington (BNC)	07:53	12:53
Greensboro (GRO)	08:18	13:18
High Point (HPT)	08:34	13:34
Salisbury (SAL)	09:08	14:08
Kannapolis (KAN)	09:24	14:24
Charlotte (CLT)	(arrival) 09:55	(arrival) 14:55

(b) Northbound Trains

Station	Train 74	Train 76
Charlotte (CLT)	12:00	17:15
Kannapolis (KAN)	12:25	17:40
Salisbury (SAL)	12:41	17:56
High Point (HPT)	13:14	18:29
Greensboro (GRO)	13:34	18:49
Burlington (BNC)	13:55	19:10
Durham (DNC)	14:33	19:48
Cary (CYN)	14:53	20:08
Raleigh (RGH)	(arrival) 15:11	(arrival) 20:26

Timetable was current as of July 4, 2014. Times are departure times, unless indicated.

For OTR measurements, the locomotives were operated normally on the North Carolina Amtrak Piedmont rail service by Amtrak engineers. The twice-daily Piedmont service makes a one-way trip of 280 kilometers in three hours and 10 minutes (as set by the schedule). Typically, a train has one locomotive, one baggage/lounge car, and two passenger cars; additional passenger cars were added if needed. When data was collected, the goal was to obtain data for at least six one-way OTR on each locomotive for each fuel.

Table 4-2. Guide to Detailed Over-the-Rail Results in Appendices for Each Locomotive and Fuel

Locomotive	Fuel	Appendix
NC-1797	B40	Appendix D, Section D.1
	B20	Appendix D, Section D.2
	B10	Appendix D, Section D.3
	ULSD	Appendix D, Section D.4
NC-1810	B100	Appendix E, Section E.1
	B80	Appendix E, Section E.2
	B60	Appendix E, Section E.3
	B40	Appendix E, Section E.4
	B20	Appendix E, Section E.5
	B10	Appendix E, Section E.4
	ULSD	Appendix E, Section E.6
NC-1859	B40	Appendix F, Section F.1
	B20	Appendix F, Section F.2
	B10	Appendix F, Section F.3
	ULSD	Appendix F, Section F.4

4.2 Method for Estimation of Fuel Use and Emission Rates

The method for estimation of fuel use and emission rates for OTR measurements was the same as that for rail yard measurements. See Section 3.2 for more details.

4.3 Results for Notch Average Fuel Use and Emission Rates

Approximately 270 hours of data were collected during the OTR measurement process. Typically, less than one percent of total data collected were excluded after quality assurance screening.

For each locomotive and each one-way run, the notch average engine output-based emission rates were estimated for idle, dynamic brake, and the eight notch positions. The notch average emission rates over all runs for each locomotive, fuel, and pollutant are given in Table 4-3.

Values of RPM, IAT, and MAP for each notch position were taken during the OTR measurement process and were similar to those measured in the RY. Therefore, differences (if any) in cycle average emission rates between RY and OTR measurements were not attributed to these engine parameters. Furthermore, notch average values of RPM, IAT, and MAP measured during OTR were repeatable, with inter-run CV typically less than 0.05. PME output was similar between RY and OTR measurements for idle through notch 6. Engine output at notches 7 and 8 were 220 kW higher for OTR versus RY measurements for all locomotives, because of the way the engine was programmed for load testing by the engine manufacturer.

Table 4-3. Engine Output-Based Notch Average Emission Rates from Over-the-Rail Measurement of Prime Mover Engines

(a) F59PHI Locomotive NC-1797

Fuel	Notch Position	NO as NO$_2$ (g/kW-hr)	HC (g/kW-hr)	CO (g/kW-hr)	PM (g/kW-hr)	CO$_2$ (g/kW-hr)
ULSD (6 trips)	Idle	266 (*0.10*)	303 (*0.54*)	45.8 (*0.59*)	6.29 (*0.08*)	6176 (*0.19*)
	DB	267 (*0.13*)	298 (*0.76*)	60.3 (*1.00*)	6.95 (*0.17*)	6409 (*0.14*)
	1	29.5 (*0.15*)	12.4 (*0.60*)	1.59 (*0.58*)	0.46 (*0.11*)	681 (*0.21*)
	2	25.6 (*0.21*)	8.38 (*0.44*)	1.00 (*0.54*)	0.30 (*0.05*)	573 (*0.27*)
	3	29.1 (*0.06*)	5.04 (*0.63*)	0.61 (*0.65*)	0.15 (*0.14*)	542 (*0.15*)
	4	27.7 (*0.06*)	6.01 (*0.37*)	0.69 (*0.43*)	0.11 (*0.13*)	589 (*0.10*)
	5	25.7 (*0.07*)	5.02 (*0.36*)	0.58 (*0.31*)	0.11 (*0.26*)	601 (*0.08*)
	6	18.9 (*0.07*)	3.24 (*0.54*)	0.57 (*0.84*)	0.10 (*0.15*)	575 (*0.09*)
	7	12.5 (*0.17*)	2.20 (*0.64*)	0.55 (*0.79*)	0.17 (*0.31*)	449 (*0.28*)
	8	13.3 (*0.03*)	1.68 (*0.37*)	0.87 (*0.21*)	0.19 (*0.10*)	578 (*0.07*)
B10 (6 trips)	Idle	277 (*0.07*)	242 (*0.26*)	31.0 (*0.29*)	5.16 (*0.04*)	7063 (*0.11*)
	DB	283 (*0.09*)	252 (*0.33*)	36.7 (*0.21*)	4.58 (*0.05*)	7155 (*0.08*)
	1	33.0 (*0.13*)	11.4 (*0.41*)	1.30 (*0.52*)	0.32 (*0.04*)	844 (*0.13*)
	2	25.7 (*0.18*)	6.83 (*0.38*)	0.68 (*0.72*)	0.21 (*0.08*)	618 (*0.15*)
	3	30.3 (*0.09*)	4.35 (*0.32*)	0.30 (*0.46*)	0.12 (*0.04*)	638 (*0.08*)
	4	27.8 (*0.14*)	3.46 (*0.52*)	0.30 (*0.73*)	0.14 (*0.12*)	645 (*0.06*)
	5	25.6 (*0.07*)	3.69 (*0.43*)	0.32 (*0.74*)	0.12 (*0.07*)	636 (*0.08*)
	6	22.3 (*0.07*)	2.54 (*0.48*)	0.20 (*0.85*)	0.10 (*0.09*)	585 (*0.14*)
	7	14.5 (*0.06*)	2.57 (*0.38*)	0.34 (*0.81*)	0.17 (*0.38*)	500 (*0.20*)
	8	14.5 (*0.04*)	1.12 (*0.43*)	0.43 (*0.59*)	0.22 (*0.13*)	620 (*0.02*)
B20 (6 trips)	Idle	77.2 (*0.10*)	4.76 (*0.66*)	4.15 (*0.64*)	4.37 (*0.30*)	5977 (*0.11*)
	DB	128 (*0.12*)	36.3 (*1.03*)	14.5 (*0.22*)	4.85 (*0.19*)	5692 (*0.14*)
	1	14.3 (*0.11*)	1.91 (*0.91*)	0.97 (*0.37*)	0.50 (*0.10*)	654 (*0.18*)
	2	10.4 (*0.14*)	1.03 (*1.15*)	0.54 (*0.19*)	0.41 (*0.15*)	574 (*0.16*)
	3	9.45 (*0.16*)	0.52 (*0.98*)	0.53 (*0.36*)	0.30 (*0.11*)	555 (*0.14*)
	4	9.09 (*0.11*)	0.41 (*0.90*)	0.42 (*0.66*)	0.32 (*0.10*)	542 (*0.10*)
	5	9.32 (*0.05*)	0.30 (*1.51*)	0.59 (*0.43*)	0.34 (*0.08*)	559 (*0.12*)
	6	9.29 (*0.06*)	0.24 (*1.12*)	0.83 (*0.63*)	0.32 (*0.19*)	524 (*0.11*)
	7	7.17 (*0.12*)	0.12 (*1.03*)	0.92 (*0.16*)	0.32 (*0.24*)	510 (*0.15*)
	8	6.94 (*0.07*)	0.08 (*0.54*)	1.97 (*0.21*)	0.34 (*0.20*)	558 (*0.05*)
B40 (6 trips)	Idle	134 (*0.44*)	8.11 (*0.87*)	6.47 (*0.60*)	5.04 (*0.63*)	7822 (*0.03*)
	DB	149 (*0.18*)	24.9 (*0.57*)	10.2 (*0.46*)	12.8 (*0.23*)	7730 (*0.05*)
	1	14.1 (*0.16*)	1.01 (*0.73*)	0.90 (*0.46*)	0.77 (*0.36*)	900 (*0.11*)
	2	9.06 (*0.14*)	0.49 (*0.31*)	0.47 (*0.21*)	0.36 (*0.32*)	677 (*0.12*)
	3	9.22 (*0.09*)	0.28 (*0.55*)	0.44 (*0.44*)	0.34 (*0.28*)	669 (*0.03*)
	4	8.93 (*0.17*)	0.23 (*0.41*)	0.35 (*0.30*)	0.25 (*0.26*)	661 (*0.06*)
	5	9.54 (*0.11*)	0.14 (*1.03*)	0.54 (*0.44*)	0.30 (*0.14*)	677 (*0.06*)
	6	9.75 (*0.12*)	0.05 (*1.27*)	0.32 (*0.66*)	0.33 (*0.23*)	628 (*0.07*)
	7	7.58 (*0.05*)	0.10 (*0.97*)	0.34 (*0.67*)	0.20 (*0.30*)	453 (*0.06*)
	8	6.82 (*0.11*)	0.05 (*0.74*)	1.18 (*0.14*)	0.38 (*0.11*)	625 (*0.02*)

Italicized values in parentheses are coefficients of variation on the mean emission rate.

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Table 4-3. Continued.

(b) F59PH Locomotive NC-1810

Fuel	Notch Position	NO as NO$_2$ (g/kW-hr)	HC (g/kW-hr)	CO (g/kW-hr)	PM (g/kW-hr)	CO$_2$ (g/kW-hr)
ULSD (6 trips)	Low Idle	95.8 (*0.09*)	204 (*0.34*)	31.1 (*0.30*)	3.98 (*0.09*)	4081 (*0.08*)
	High Idle	156 (*0.07*)	333 (*0.33*)	46.0 (*0.29*)	5.03 (*0.05*)	7831 (*0.10*)
	DB	149 (*0.09*)	342 (*0.26*)	52.2 (*0.48*)	4.39 (*0.04*)	8114 (*0.11*)
	1	14.1 (*0.08*)	17.7 (*0.44*)	2.73 (*0.41*)	0.35 (*0.04*)	776 (*0.08*)
	2	12.3 (*0.11*)	8.21 (*0.25*)	1.31 (*0.18*)	0.26 (*0.07*)	628 (*0.07*)
	3	11.7 (*0.09*)	6.68 (*0.41*)	0.88 (*0.28*)	0.24 (*0.10*)	615 (*0.05*)
	4	10.9 (*0.04*)	4.35 (*0.40*)	0.80 (*0.36*)	0.28 (*0.08*)	603 (*0.04*)
	5	11.0 (*0.03*)	9.19 (*1.37*)	0.97 (*0.56*)	0.26 (*0.19*)	603 (*0.06*)
	6	10.4 (*0.06*)	4.53 (*0.35*)	1.02 (*0.47*)	0.26 (*0.16*)	651 (*0.04*)
	7	7.34 (*0.15*)	3.64 (*0.41*)	1.41 (*0.56*)	0.35 (*0.19*)	538 (*0.05*)
	8	7.63 (*0.03*)	2.08 (*0.37*)	2.08 (*0.25*)	0.40 (*0.11*)	655 (*0.02*)
B10 (6 trips)	Low Idle	82.9 (*0.21*)	24.2 (*1.01*)	2.49 (*1.45*)	5.43 (*0.14*)	3302 (*0.41*)
	High Idle	132 (*0.09*)	89.3 (*0.77*)	14.9 (*0.25*)	6.19 (*0.16*)	7315 (*0.16*)
	DB	118 (*0.10*)	104 (*0.62*)	14.7 (*0.50*)	6.54 (*0.20*)	6917 (*0.07*)
	1	10.8 (*0.20*)	13.0 (*1.83*)	1.23 (*0.49*)	0.58 (*0.12*)	678 (*0.21*)
	2	9.82 (*0.21*)	1.52 (*0.46*)	0.76 (*0.41*)	0.45 (*0.08*)	562 (*0.19*)
	3	9.39 (*0.14*)	2.82 (*1.30*)	0.59 (*0.32*)	0.39 (*0.11*)	533 (*0.17*)
	4	8.41 (*0.16*)	0.91 (*0.73*)	0.69 (*0.31*)	0.44 (*0.19*)	519 (*0.15*)
	5	8.46 (*0.07*)	3.95 (*2.13*)	0.87 (*0.40*)	0.52 (*0.16*)	557 (*0.13*)
	6	8.39 (*0.04*)	0.38 (*0.72*)	0.96 (*0.18*)	0.55 (*0.13*)	616 (*0.04*)
	7	5.75 (*0.05*)	0.44 (*0.80*)	1.84 (*0.43*)	0.53 (*0.31*)	514 (*0.08*)
	8	5.71 (*0.06*)	0.58 (*1.94*)	3.63 (*0.17*)	0.62 (*0.05*)	624 (*0.04*)
B20 (6 trips)	Low Idle	77.2 (*0.10*)	21.7 (*1.02*)	4.15 (*0.64*)	4.37 (*0.30*)	3242 (*0.18*)
	High Idle	142 (*0.07*)	72.1 (*0.61*)	13.9 (*0.24*)	4.53 (*0.20*)	7142 (*0.10*)
	DB	128 (*0.12*)	83.3 (*0.50*)	14.5 (*0.22*)	4.85 (*0.19*)	7621 (*0.15*)
	1	14.3 (*0.11*)	3.75 (*0.63*)	0.97 (*0.37*)	0.50 (*0.10*)	711 (*0.14*)
	2	10.4 (*0.14*)	2.00 (*0.52*)	0.54 (*0.19*)	0.41 (*0.15*)	513 (*0.19*)
	3	9.45 (*0.16*)	1.00 (*0.48*)	0.53 (*0.36*)	0.30 (*0.11*)	483 (*0.23*)
	4	9.09 (*0.11*)	0.81 (*0.47*)	0.42 (*0.66*)	0.32 (*0.10*)	470 (*0.17*)
	5	9.50 (*0.05*)	0.68 (*0.57*)	0.60 (*0.43*)	0.35 (*0.08*)	530 (*0.10*)
	6	9.29 (*0.06*)	0.52 (*0.80*)	0.83 (*0.63*)	0.32 (*0.19*)	546 (*0.08*)
	7	5.97 (*0.51*)	0.35 (*0.90*)	0.76 (*0.52*)	0.26 (*0.55*)	505 (*0.08*)
	8	6.93 (*0.07*)	0.70 (*0.62*)	1.97 (*0.21*)	0.34 (*0.20*)	596 (*0.06*)
B40 (5 trips)	Low Idle	118 (*0.22*)	8.62 (*0.93*)	7.09 (*0.60*)	3.81 (*0.30*)	4097 (*0.18*)
	High Idle	198 (*0.15*)	18.7 (*0.22*)	12.1 (*0.25*)	11.6 (*0.25*)	9684 (*0.22*)
	DB	160 (*0.12*)	19.5 (*0.17*)	10.2 (*0.53*)	12.3 (*0.24*)	8820 (*0.22*)
	1	13.7 (*0.06*)	0.74 (*0.35*)	0.95 (*0.47*)	0.66 (*0.09*)	717 (*0.25*)
	2	9.33 (*0.15*)	0.47 (*0.34*)	0.48 (*0.23*)	0.33 (*0.27*)	498 (*0.12*)
	3	9.60 (*0.08*)	0.29 (*0.60*)	0.44 (*0.51*)	0.31 (*0.21*)	458 (*0.07*)
	4	9.44 (*0.16*)	0.26 (*0.35*)	0.36 (*0.33*)	0.23 (*0.09*)	427 (*0.13*)
	5	10.4 (*0.08*)	0.18 (*0.84*)	0.47 (*0.24*)	0.29 (*0.12*)	478 (*0.15*)
	6	10.4 (*0.06*)	0.07 (*1.10*)	0.39 (*0.42*)	0.30 (*0.13*)	490 (*0.21*)
	7	6.18 (*0.56*)	0.08 (*1.19*)	0.28 (*0.92*)	0.16 (*0.65*)	450 (*0.09*)
	8	7.11 (*0.09*)	0.06 (*0.68*)	1.22 (*0.16*)	0.36 (*0.06*)	574 (*0.04*)

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Table 4-3. Continued.

Fuel	Notch Position	NO as NO_2 (g/kW-hr)	HC (g/kW-hr)	CO (g/kW-hr)	PM (g/kW-hr)	CO_2 (g/kW-hr)
B60 (6 trips)	Low Idle	89.9 (*0.22*)	83.1 (*0.87*)	108 (*1.23*)	6.39 (*0.38*)	3385 (*0.19*)
	High Idle	143 (*0.10*)	87.6 (*0.26*)	108 (*0.85*)	7.75 (*0.42*)	6258 (*0.10*)
	DB	158 (*0.05*)	86.5 (*0.48*)	118 (*1.11*)	8.25 (*0.44*)	7281 (*0.12*)
	1	15.5 (*0.11*)	4.45 (*0.36*)	3.62 (*0.59*)	0.64 (*0.36*)	681 (*0.12*)
	2	13.8 (*0.06*)	3.66 (*1.35*)	1.84 (*0.73*)	0.51 (*0.32*)	541 (*0.10*)
	3	14.3 (*0.11*)	2.39 (*0.78*)	0.88 (*0.82*)	0.43 (*0.41*)	568 (*0.09*)
	4	12.3 (*0.07*)	1.86 (*0.97*)	2.05 (*0.91*)	0.45 (*0.37*)	561 (*0.08*)
	5	12.4 (*0.05*)	2.32 (*1.70*)	2.29 (*1.55*)	0.49 (*0.42*)	580 (*0.11*)
	6	11.7 (*0.18*)	1.08 (*0.77*)	1.66 (*1.62*)	0.49 (*0.48*)	599 (*0.17*)
	7	9.52 (*0.13*)	0.67 (*1.24*)	0.83 (*1.32*)	0.41 (*0.63*)	549 (*0.27*)
	8	8.52 (*0.06*)	1.24 (*0.85*)	1.40 (*0.47*)	0.62 (*0.46*)	601 (*0.06*)
B80 (5 trips)	Low Idle	61.1 (*0.32*)	57.6 (*0.81*)	11.3 (*0.64*)	3.85 (*0.26*)	2428 (*0.55*)
	High Idle	128 (*0.09*)	153 (*0.41*)	25.1 (*0.24*)	4.13 (*0.10*)	5988 (*0.14*)
	DB	142 (*0.16*)	183 (*0.55*)	24.3 (*0.32*)	4.23 (*0.14*)	6937 (*0.29*)
	1	12.8 (*0.14*)	7.74 (*0.41*)	1.27 (*0.23*)	0.34 (*0.14*)	545 (*0.35*)
	2	11.0 (*0.14*)	5.16 (*0.43*)	0.64 (*0.26*)	0.26 (*0.17*)	479 (*0.28*)
	3	12.3 (*0.07*)	2.82 (*0.50*)	0.39 (*0.46*)	0.19 (*0.10*)	518 (*0.27*)
	4	11.3 (*0.08*)	2.84 (*0.43*)	0.37 (*0.21*)	0.20 (*0.06*)	519 (*0.21*)
	5	11.8 (*0.05*)	2.28 (*0.67*)	0.33 (*0.66*)	0.20 (*0.02*)	573 (*0.20*)
	6	11.3 (*0.09*)	1.56 (*0.19*)	0.55 (*0.43*)	0.23 (*0.17*)	617 (*0.19*)
	7	8.64 (*0.01*)	1.62 (*0.53*)	0.51 (*0.13*)	0.38 (*0.19*)	544 (*0.11*)
	8	8.55 (*0.05*)	1.65 (*0.66*)	0.61 (*0.37*)	0.40 (*0.12*)	630 (*0.04*)
B100 (4 trips)	Low Idle	108 (*0.10*)	142 (*0.31*)	23.8 (*0.29*)	3.54 (*0.09*)	4119 (*0.09*)
	High Idle	175 (*0.09*)	230 (*0.22*)	41.6 (*0.20*)	5.10 (*0.13*)	7666 (*0.07*)
	DB	181 (*0.14*)	276 (*0.27*)	51.2 (*0.31*)	4.41 (*0.20*)	8113 (*0.17*)
	1	17.1 (*0.13*)	12.8 (*0.24*)	2.33 (*0.20*)	0.32 (*0.17*)	826 (*0.12*)
	2	12.5 (*0.21*)	7.34 (*0.25*)	1.24 (*0.38*)	0.23 (*0.16*)	592 (*0.20*)
	3	14.1 (*0.15*)	3.70 (*0.31*)	0.54 (*0.15*)	0.18 (*0.25*)	660 (*0.07*)
	4	12.7 (*0.08*)	3.91 (*0.40*)	0.60 (*0.47*)	0.18 (*0.17*)	628 (*0.01*)
	5	13.0 (*0.03*)	4.12 (*0.63*)	0.63 (*0.86*)	0.17 (*0.13*)	652 (*0.01*)
	6	12.6 (*0.04*)	2.64 (*0.34*)	0.42 (*0.34*)	0.20 (*0.06*)	687 (*0.02*)
	7	8.80 (*0.12*)	1.39 (*0.29*)	0.44 (*0.36*)	0.25 (*0.11*)	536 (*0.10*)
	8	9.16 (*0.05*)	1.28 (*0.46*)	0.63 (*0.32*)	0.43 (*0.13*)	651 (*0.01*)

Italicized values in parentheses are coefficients of variation on the mean emission rate.

Continued on Next Page

Table 4-3. Continued.

(b) F59PH Locomotive NC-1859

Fuel	Notch Position	NO as NO$_2$ (g/kW-hr)	HC (g/kW-hr)	CO (g/kW-hr)	PM (g/kW-hr)	CO$_2$ (g/kW-hr)
ULSD (6 trips)	Low Idle	86.6 (*0.11*)	105 (*1.97*)	10.4 (*1.13*)	10.2 (*0.08*)	3737 (*0.24*)
	High Idle	121 (*0.10*)	309 (*0.76*)	43.9 (*0.82*)	10.5 (*0.11*)	6493 (*0.18*)
	DB	132 (*0.08*)	304 (*0.85*)	36.9 (*1.03*)	11.0 (*0.09*)	7466 (*0.15*)
	1	12.9 (*0.10*)	18.5 (*0.97*)	2.35 (*0.60*)	0.80 (*0.08*)	795 (*0.18*)
	2	11.3 (*0.04*)	5.24 (*0.77*)	1.37 (*0.63*)	0.58 (*0.09*)	576 (*0.09*)
	3	10.7 (*0.04*)	7.17 (*0.82*)	1.56 (*1.64*)	0.46 (*0.10*)	583 (*0.08*)
	4	10.1 (*0.06*)	5.13 (*0.81*)	0.60 (*0.73*)	0.45 (*0.17*)	530 (*0.07*)
	5	9.77 (*0.04*)	5.32 (*0.82*)	0.53 (*0.98*)	0.46 (*0.13*)	601 (*0.05*)
	6	9.52 (*0.07*)	4.84 (*0.74*)	0.57 (*0.68*)	0.52 (*0.29*)	605 (*0.08*)
	7	6.73 (*0.08*)	3.17 (*1.10*)	0.37 (*0.97*)	0.44 (*0.25*)	530 (*0.09*)
	8	6.72 (*0.03*)	3.16 (*0.51*)	1.06 (*0.11*)	0.53 (*0.13*)	588 (*0.01*)
B10 (6 trips)	Low Idle	105 (*0.15*)	234 (*0.39*)	33.2 (*0.47*)	4.69 (*0.20*)	4039 (*0.21*)
	High Idle	160 (*0.09*)	273 (*0.32*)	44.1 (*0.37*)	5.76 (*0.18*)	8099 (*0.05*)
	DB	172 (*0.24*)	326 (*0.32*)	49.3 (*0.36*)	5.45 (*0.19*)	10086(*0.47*)
	1	16.4 (*0.10*)	13.1 (*0.47*)	2.01 (*0.63*)	0.33 (*0.20*)	812 (*0.05*)
	2	13.6 (*0.15*)	6.71 (*0.49*)	1.07 (*0.71*)	0.21 (*0.19*)	634 (*0.07*)
	3	14.2 (*0.12*)	4.29 (*0.41*)	0.66 (*0.50*)	0.16 (*0.17*)	615 (*0.04*)
	4	12.9 (*0.10*)	3.36 (*0.44*)	0.48 (*0.66*)	0.16 (*0.21*)	584 (*0.01*)
	5	12.8 (*0.11*)	3.27 (*0.42*)	0.49 (*0.61*)	0.15 (*0.17*)	597 (*0.03*)
	6	12.8 (*0.08*)	2.80 (*0.44*)	0.40 (*0.55*)	0.16 (*0.14*)	607 (*0.03*)
	7	9.71 (*0.07*)	1.85 (*0.63*)	0.24 (*0.83*)	0.23 (*0.19*)	509 (*0.03*)
	8	9.26 (*0.08*)	1.92 (*0.28*)	0.37 (*0.50*)	0.31 (*0.20*)	566 (*0.05*)
B20 (6 trips)	Low Idle	93.0 (*0.13*)	149 (*0.51*)	33.6 (*0.45*)	4.64 (*0.47*)	3855 (*0.11*)
	High Idle	148 (*0.03*)	206 (*0.55*)	39.6 (*0.35*)	4.97 (*0.53*)	7009 (*0.18*)
	DB	145 (*0.07*)	209 (*0.56*)	40.5 (*0.36*)	4.40 (*0.53*)	7554 (*0.10*)
	1	15.3 (*0.05*)	10.4 (*0.69*)	1.93 (*0.35*)	0.31 (*0.52*)	791 (*0.08*)
	2	12.9 (*0.14*)	5.13 (*0.61*)	0.96 (*0.58*)	0.22 (*0.49*)	616 (*0.08*)
	3	13.0 (*0.08*)	3.41 (*0.59*)	0.66 (*0.64*)	0.15 (*0.44*)	596 (*0.05*)
	4	11.8 (*0.09*)	2.83 (*0.58*)	0.46 (*0.57*)	0.15 (*0.38*)	561 (*0.05*)
	5	11.9 (*0.06*)	3.03 (*0.71*)	0.56 (*0.85*)	0.12 (*0.43*)	592 (*0.04*)
	6	11.8 (*0.03*)	2.52 (*0.57*)	0.35 (*0.63*)	0.11 (*0.39*)	596 (*0.04*)
	7	9.29 (*0.10*)	1.90 (*0.46*)	0.38 (*0.65*)	0.17 (*0.36*)	501 (*0.06*)
	8	8.71 (*0.04*)	1.33 (*0.74*)	0.44 (*0.42*)	0.21 (*0.18*)	577 (*0.04*)
B40 (6 trips)	Low Idle	93.5 (*0.12*)	109 (*0.43*)	24.4 (*0.26*)	7.48 (*0.06*)	3431 (*0.05*)
	High Idle	142 (*0.07*)	161 (*0.47*)	34.5 (*0.29*)	5.47 (*0.10*)	6697 (*0.04*)
	DB	149 (*0.10*)	172 (*0.40*)	39.8 (*0.27*)	5.76 (*0.08*)	7142 (*0.11*)
	1	14.3 (*0.13*)	8.20 (*0.43*)	1.78 (*0.41*)	0.48 (*0.11*)	651 (*0.10*)
	2	10.9 (*0.17*)	3.94 (*0.21*)	0.74 (*0.38*)	0.32 (*0.15*)	487 (*0.15*)
	3	12.9 (*0.07*)	2.54 (*0.37*)	0.55 (*0.48*)	0.23 (*0.04*)	556 (*0.06*)
	4	11.9 (*0.05*)	2.02 (*0.36*)	0.42 (*0.27*)	0.22 (*0.08*)	530 (*0.05*)
	5	12.2 (*0.04*)	1.86 (*0.45*)	0.40 (*0.51*)	0.20 (*0.09*)	564 (*0.06*)
	6	12.0 (*0.02*)	1.49 (*0.25*)	0.34 (*0.41*)	0.20 (*0.06*)	588 (*0.04*)
	7	9.12 (*0.10*)	1.22 (*0.34*)	0.42 (*0.37*)	0.21 (*0.39*)	486 (*0.07*)
	8	9.12 (*0.04*)	0.97 (*0.54*)	0.52 (*0.26*)	0.23 (*0.10*)	584 (*0.04*)

Italicized values in parentheses are coefficients of variation on the mean emission rate.

The trends in the emission rates versus notch position for a given pollutant were qualitative similar to those from the rail yard. For example, the minimum engine output-based NO_x emission rate typically occured in notches 7 or 8. These minimum rates varied from as low as 5.7 g/kW-hr (for NC-1810, B10, notch 8) to as high as 14.5 g/kW-hr (NC 1979, B10, notch 8). The notch 1 NO_x emission rates were typically around 13 g/kW-hr to 15 g/kW-hr, but varied from 10.8 g/kW-hr (NC-1810, B10) to 33.0 g/kW-hr (NC-1797, B10). Thus, there was considerable inter-notch and inter-engine variability.

The minimum HC emission rate occurs most typically for notch 8, but for some locomotive and fuel combinations the lowest rate was observed at notch 6 or 7. The lowest CO emission rate was typically at notches 6 or 7. The lowest PM emission rate was also typically at notches 6 or 7. However, the PM emission rates tend to be very similar among notches 3 to 7 in most cases; therefore, the minimum value was not much different from values in adjacent notches.

4.4 Results for Cycle Average Fuel Use and Emission Rates

Cycle average emission rates were estimated for each PME and fuel blend, based on the EPA line-haul duty cycle. All measured emission rates were of the same magnitude as published emission rates of the same locomotive model (EPA, 1998). Table 4-4 compares the biodiesel and ULSD cycle average emission rates for each individual locomotives and fuel blends, as well as across all three locomotives for B10, B20, and B40 versus ULSD. Table 4-5 shows the relative difference in the emission rates of each pollutant for each biofuel blend versus ULSD for each locomotive as well as the average of the three locomotives.

For NO_x, 9 of the individual locomotive and biofuel comparisons have statistically significant higher values, by 7 to 36 percent, compared to ULSD. There were no statistically significant decreases, thus NO_x emission rates on biofuels were either the same or higher than for ULSD.

For HC, all five of the statistically significant comparisons have lower emission rates on biofuels, and there were no statistically significant comparisons with higher rates. Thus, HC emission rates tend to be similar to or lower than for ULSD. For CO, the five statistically significant comparisons were 45 to 79 percent lower than for ULSD, 9 of the 12 comparisons were lower on average, even if some were not significant, and there were no comparisons that are significantly higher.

For PM, there was variability in the results by locomotive and fuel. For example, while the PM emission rates on biofuels from NC-1859 were significantly lower than ULSD by 49 to 62 percent, they were either significantly higher by 20 to 58 percent for NC-1810 or not significantly different. For NC-1797, they were significantly lower for B20 but significantly higher for B40.

For CO_2, the emission rates were not significantly different for 7 of the 12 comparisons. For NC-1797, they were significantly higher for B40 but for NC-1810 they were significantly lower for B10, B20, B40, and B60.

Table 4-4. Ultra-Low Sulfur Diesel and Biodiesel Cycle Average Emission Rates for Measured Prime Mover Engines Based on Over-the-Rail Measurements

(a) NC-1797 – F59PHI Locomotive

Fuel	**NO$_x$ (g/kW-hr)**[a]	**HC (g/kW-hr)**[b]	**CO (g/kW-hr)**	**PM (g/kW-hr)**[c]	**CO$_2$ (g/kW-hr)**
ULSD	13.6 (*0.03*)	3.51 (*0.44*)	0.82 (*0.33*)	0.16 (*0.08*)	608 (*0.07*)
B10	14.5 (*0.04*)	2.74 (*0.32*)	0.45 (*0.48*)	0.17 (*0.10*)	655 (*0.04*)
B20	13.9 (*0.04*)	2.13 (*0.34*)	0.17 (*0.50*)	0.13 (*0.12*)	589 (*0.09*)
B40	16.1 (*0.03*)	4.45 (*0.32*)	0.99 (*0.43*)	0.25 (*0.28*)	684 (*0.05*)

(b) NC-1810 – F59PH Locomotive

Fuel	**NO$_x$ (g/kW-hr)**[a]	**HC (g/kW-hr)**[b]	**CO (g/kW-hr)**	**PM (g/kW-hr)**[c]	**CO$_2$ (g/kW-hr)**
ULSD	7.0 (*0.02*)	3.57 (*0.29*)	1.45 (*0.27*)	0.28 (*0.08*)	668 (*0.02*)
B10	6.7 (*0.06*)	1.10 (*1.28*)	1.92 (*0.16*)	0.45 (*0.07*)	621 (*0.06*)
B20	7.7 (*0.06*)	0.74 (*0.31*)	1.13 (*0.19*)	0.34 (*0.14*)	592 (*0.04*)
B40	8.1 (*0.08*)	0.15 (*0.32*)	0.71 (*0.08*)	0.27 (*0.09*)	569 (*0.08*)
B60	7.8 (*0.03*)	1.47 (*0.66*)	1.63 (*0.62*)	0.45 (*0.43*)	615 (*0.08*)
B80	6.8 (*0.16*)	1.93 (*0.31*)	0.49 (*0.36*)	0.27 (*0.12*)	626 (*0.16*)
B100	8.2 (*0.05*)	2.49 (*0.29*)	0.59 (*0.29*)	0.27 (*0.13*)	675 (*0.01*)

(c) NC-1859 – F59PH Locomotive

Fuel	**NO$_x$ (g/kW-hr)**[a]	**HC (g/kW-hr)**[b]	**CO (g/kW-hr)**	**PM (g/kW-hr)**[c]	**CO$_2$ (g/kW-hr)**
ULSD	6.0 (*0.05*)	3.64 (*0.77*)	0.77 (*0.34*)	0.42 *0.14*)	611 (*0.04*)
B10	8.2 (*0.10*)	3.10 (*0.33*)	0.49 (*0.46*)	0.21 (*0.17*)	607 (*0.03*)
B20	7.5 (*0.06*)	2.23 (*0.59*)	0.52 (*0.48*)	0.16 (*0.29*)	605 (*0.04*)
B40	7.8 (*0.04*)	1.62 (*0.32*)	0.50 (*0.21*)	0.20 (*0.09*)	592 (*0.03*)

(d) All Three Locomotives

Fuel	**NO$_x$ (g/kW-hr)**[a]	**HC (g/kW-hr)**[b]	**CO (g/kW-hr)**	**PM (g/kW-hr)**[c]	**CO$_2$ (g/kW-hr)**
ULSD	8.9 (*0.39*)	3.57 (*0.51*)	1.01 (*0.43*)	0.29 (*0.39*)	629 (*0.07*)
B10	9.8 (*0.36*)	2.31 (*0.60*)	0.96 (*0.78*)	0.28 (*0.47*)	627 (*0.05*)
B20	9.5 (*0.32*)	1.67 (*0.65*)	0.63 (*0.71*)	0.22 (*0.49*)	596 (*0.06*)
B40	10.8 (*0.38*)	2.19 (*0.92*)	0.74 (*0.44*)	0.24 (*0.22*)	618 (*0.09*)

Italicized values in parentheses are coefficients of variation (standard deviation divided by the mean) on the difference in the mean emission rates. The measured OTR notch average emission rates are weighted by the EPA line-haul cycle.

[a] NO$_x$ includes NO and NO$_2$. Only NO was measured. Typically, NO$_x$ is comprised of 95 vol-% NO. NO$_x$ is always reported as equivalent mass of NO$_2$. Results include multiplicative correction factor of 1.053 to approximate total NO$_x$.

[b] HC is measured using non-dispersive infrared (NDIR), which accurately measures some compounds but responds only partially to others. Results include multiplicative correction factor of 2.5 to approximate total HC.

[c] PM is measured using a light scattering technique, which provides useful relative comparisons of particle levels in the exhaust. Results include multiplicative correction factor of 5 to approximate total PM.

Table 4-5. Comparison of Biodiesel to Ultra-Low Sulfur Diesel Cycle Average Emission Rates for Measured Prime Mover Engines Based on Over-the-Rail Measurements

(a) NC-1797 – F59PHI Locomotive

Fuel	NO_x[a]	HC[b]	CO	PM[c]	CO_2
B10 vs. ULSD	+ 7 (*0.02*)	- 22 (*0.32*)	- 45 (*0.03*)	+ 3 (*0.64*)	+ 8 (*0.14*)
B20 vs. ULSD	+ 2 (*0.31*)	- 39 (*0.09*)	- 79 (*<0.01*)	- 21 (*<0.01*)	- 3 (*0.56*)
B40 vs. ULSD	+ 18 (*<0.01*)	+ 27 (*0.30*)	+ 21 (*0.43*)	+ 54 (*0.03*)	+ 13 (*0.03*)

(b) NC-1810 – F59PH Locomotive

Fuel	NO_x[a]	HC[b]	CO	PM[c]	CO_2
B10 vs. ULSD	- 5 (*0.07*)	- 69 (*0.01*)	+ 33 (*0.05*)	+ 58 (*<0.01*)	- 7 (*0.01*)
B20 vs. ULSD	+ 10 (*0.01*)	- 79 (*<0.01*)	- 22 (*0.12*)	+ 20 (*0.04*)	- 11 (*0.01*)
B40 vs. ULSD	+ 15 (*0.03*)	- 96 (*<0.01*)	- 51 (*0.01*)	- 5 (*0.33*)	- 15 (*<0.01*)
B60 vs. ULSD	+ 11 (*<0.01*)	- 59 (*<0.01*)	+ 12 (*0.71*)	+ 59 (*0.09*)	- 8 (*0.03*)
B80 vs. ULSD	- 3 (*0.66*)	- 46 (*0.01*)	- 66 (*<0.01*)	- 5 (*0.44*)	- 6 (*0.20*)
B100 vs. ULSD	+ 17 (*0.01*)	- 30 (*0.09*)	- 59 (*<0.01*)	- 3 (*0.66*)	+ 1 (*0.28*)

(c) NC-1859 – F59PH Locomotive

Fuel	NO_x[a]	HC[b]	CO	PM[c]	CO_2
B10 vs. ULSD	+ 36 (*<0.01*)	- 15 (*0.68*)	- 36 (*0.08*)	- 49 (*<0.01*)	- 1 (*0.62*)
B20 vs. ULSD	+ 24 (*<0.01*)	- 39 (*0.30*)	- 33 (*0.12*)	- 62 (*<0.01*)	- 1 (*0.61*)
B40 vs. ULSD	+ 29 (*<0.01*)	- 55 (*0.14*)	- 35 (*0.05*)	- 52 (*<0.01*)	- 3 (*0.13*)

(d) All Three Locomotives

Fuel	NO_x[a]	HC[b]	CO	PM[c]	CO_2
B10 vs. ULSD	+ 10 (*0.44*)	- 35 (*0.03*)	- 6 (*0.77*)	- 4 (*0.77*)	0 (*0.91*)
B20 vs. ULSD	+ 6 (*0.60*)	- 53 (*<0.01*)	- 38 (*0.02*)	- 23 (*0.09*)	- 5 (*0.02*)
B40 vs. ULSD	+ 21 (*0.15*)	- 39 (*0.04*)	- 27 (*0.04*)	- 17 (*0.10*)	- 2 (*0.52*)

Italicized values in parentheses are coefficients of variation (standard deviation divided by the mean) on the difference in the mean emission rates. The measured OTR notch average emission rates are weighted by the EPA line-haul cycle.

[a] NO_x includes NO and NO_2. Only NO was measured. Typically, NO_x is comprised of 95 vol-% NO. NO_x is always reported as equivalent mass of NO_2. Results include multiplicative correction factor of 1.053 to approximate total NO_x.

[b] HC was measured using non-dispersive infrared (NDIR), which accurately measures some compounds but responds only partially to others. Results include multiplicative correction factor of 2.5 to approximate total HC.

[c] PM was measured using a light scattering technique, which provides useful relative comparisons of particle levels in the exhaust. Results include multiplicative correction factor of 5 to approximate total PM.

A comparison was made in the cycle average emission rates for all three locomotives on B10, B20, and B40 versus ULSD. All three biodiesel blends produced higher cycle average NO_x emission rates across the three locomotives, compared to ULSD. However, these differences were not statistically significant. All three biodiesel blends produced lower cycle average HC, CO, PM, and CO_2 emission rates across the three locomotives, compared to ULSD. The lower cycle average HC emission rates for biodiesel were statistically significant and the lower cycle average CO emission rates for B20 and B40 versus ULSD were statistically significant. However, the lower cycle average PM emission rates were not statistically significant. Only the B20 CO_2 cycle average emission rate was statistically lower than ULSD.

Among B10, B20, and B40, B20 appears to offer the best environmental performance. The largest reductions in HC, CO, PM, and CO_2 emissions are observed for B20, and the apparent increase in NO_x emissions was the smallest.

4.5 Consistency of Insights from Rail Yard and Over the Rail Results

The team wanted to determine if the difference in emission rates for a biodiesel blend versus ULSD was consistent between RY and OTR measurements, and a total of 60 comparisons were analyzed between the three locomotives on up to six biodiesel blends for five pollutants to detect if there were any sign changes between RY and OTR measurements. The focus was on cases for which the opposite signs were each statistically significant. Only three such cases were found. Significantly, the B20 cycle average PM emission rate for NC-1810 was 14 percent lower than the ULSD PM rate in the RY, but significantly 20 percent higher OTR. The B10 cycle average CO_2 emission rate for NC-1810 was significantly 4 percent higher than the ULSD CO_2 rate in the RY, but significantly 7 percent lower OTR. Finally, the B60 cycle average CO_2 emission rate for NC-1810 was significantly 8 percent higher than the ULSD CO_2 rate, in the RY, but significantly 8 percent lower OTR. There were 9 additional comparisons where there was a sign change between RY and OTR measurements; however, in each of these comparisons, one or more of the differences in biodiesel versus ULSD emission rates were not statistically significant. Therefore, the comparisons of biodiesel versus biodiesel for the three locomotives were generally consistent when comparing RY and OTR measurements.

5. Fuel Cycle

Chapters 3 and 4 examine the exhaust emissions from the prime mover engine of a locomotive and determine how these emissions change if biodiesel was used instead of petroleum diesel. However, fuel switching affects upstream energy use and emissions associated with the fuel production cycle. Therefore, this chapter discusses fuel cycle energy use and emissions implications of using biodiesel versus petroleum diesel. Fuel switching also can have a price differential, so the extent to which the cost of biodiesel differs from that of ULSD was studied Furthermore, we comment on the availability of the fuels needed for this study.

5.1 Fuel Cycle Energy Use and Emissions

Fuels were compared with life cycle inventories (LCI), which take into account energy consumption and emissions for fuel production and use. Production of soy-based B100 blendstock includes: soybean farming, soy oil extraction, and biodiesel production. Most U.S. soy oil extraction plants use a solvent to extract oil from soybeans (Erickson, 1995). In November 2004, EPA promulgated New Source Performance Standards (NSPS) applicable to the solvent extraction process (EPA, 2004). The standards require reduction of emissions of volatile organic compounds (VOCs) from vegetable oil production facilities. Pang et al. (2009) updated and modified a LCI to improve the evaluation of the benefits of biodiesel and to assess the fuel cycle and emissions from production of biodiesel.

The key LCI system components for petroleum diesel (PD) production include crude oil recovery, crude oil transport, crude oil refining, diesel transport, and vehicle operation. The key system components for biodiesel production include soybean agriculture, soy oil production, soy oil transport, biodiesel production, biodiesel transport, and vehicle operation. Fossil energy was consumed by operating farm equipment and for manufacturing, procuring, and distributing fertilizers, herbicides, and pesticides (Huo *et al*., 2008;DeLuchi, 2003). Most soybeans are transported to an oil production plant within 75 miles of the farming area (Erickson, 1995). At a biodiesel plant, biodiesel was produced by transesterification which converts soy oil to biodiesel.

The key processes that contribute the most to the fuel cycle energy use and emissions for production of petroleum diesel are shown in Figure 5-1, based on results of Pang *et al*. (2009). Crude oil refining contributes the largest share of PM, SO_2, and CO_2 emissions, and a substantial share of VOC, CO, and NO_x emissions. Transport of crude oil, typically by ship, produces a large share of VOC, NO_x, and SO_2 emissions. Crude oil recovery at the oilfield was associated with the largest share of CO emissions.

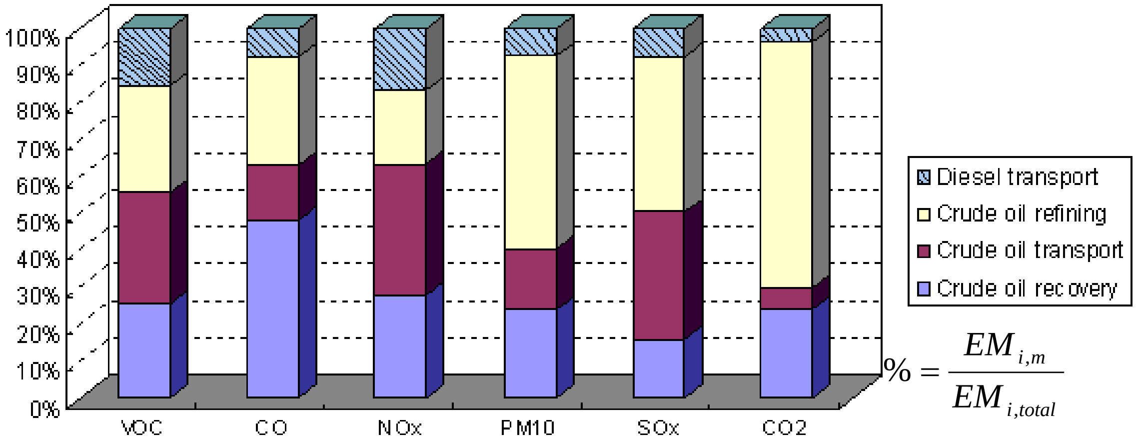
Figure 5-2 shows estimates of the distribution of fuel cycle emissions for soy-based B100 biodiesel blend stock. By far, soy-bean farming contributes the largest share of emissions of CO, NO_x, PM, and SO_2. In contrast, soy oil extraction was the main source of VOC emissions. CO_2 emissions are distributed among farming, extraction, and transesterification.

Pang et al. (2009) estimated that the average differences in life cycle emissions for B20 versus diesel for selected types of diesel construction vehicles are: 3.5% higher for NO_x; 11.8% lower for PM, 1.6% higher for HC, and 4.1% lower for CO. However, fuel cycle emissions are likely to occur in rural areas and the tailpipe emissions are likely to occur in more populated areas.

Pang et al. estimated that local urban tailpipe emissions would be 24% lower for HC, 20% lower for CO, 17% lower for PM, and 0.9% lower for NO_x.

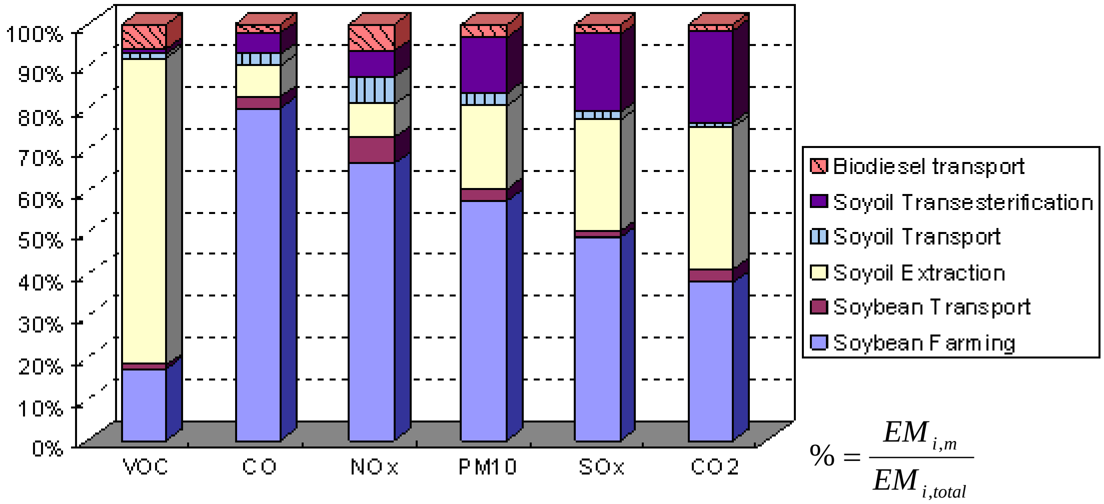
The total energy consumed to produce B20 or B100 was higher than for petroleum diesel (PD), but less fossil energy was used. The fossil energy contribution to the B20 life cycle was 83%, versus 37% for pure B100 blend stock. The use of B20 instead of PD will reduce fossil energy consumption and CO_2 emissions by 9% based on NSPS soy oil plants, while the reduction for B100 was 42%. These percentages could increase if the share of non-fossil energy resources in power generation and transportation increase.

Most of the current soybean yield in the U.S. is located in Iowa, Illinois, Minnesota, and Indiana (USDA, 2002). Biodiesel fuel production occurs mostly in Midwest states and ozone non-attainment areas are located mostly in California or the Northeast.



$$\% = \frac{EM_{i,m}}{EM_{i,total}}$$

Figure 5-1. Distributions of Pollutant Emissions from Petroleum Diesel Fuel Cycle (Source; Pang et al., 2009)



$$\% = \frac{EM_{i,m}}{EM_{i,total}}$$

Figure 5-2. Emissions from Biodiesel (B100) Fuel Cycle Based on NSPS Soyoil Plant (Source: Pang et al., 2009)

5.2 Fuel Price

Figure 5-3 depicts the price of ULSD per gallon based on NCDOT procurement costs during the course of this project. Figure 5-4 depicts the difference in price between six different biodiesel blends (B10, B20, B40, B60, B80, and B100) and ULSD. Figure 5-5 depicts the average difference in price between the six difference biodiesel blends compared to ULSD, and the range in price differences. In some instances, the cost of B10, B20, B60, B80, and B100 biodiesel was less per gallon than ULSD. On average, the cost of a gallon of ULSD during the time period was \$3.12, and varied from \$2.74 to \$3.45. On average, B10, B20, B40, and B60 biodiesel cost 14, 13, 26, and 19 cents more per gallon compared to ULSD, respectively. Assuming that a locomotive consumes 200 gallons of fuel during a one-way trip between Raleigh and Charlotte, regardless of the fuel being used, the use of B20 biodiesel would cost an additional \$26.00 one-way. On average, the cost of B80 and B100 biodiesel was 16 and 20 cents per gallon *less* than the cost of ULSD, respectively. In most instances, the cost of a gallon of B80 (11 out of 15 fuel purchases) or B100 (6 out of 7 fuel purchases) was less than the cost of a gallon of ULSD.

NCDOT purchases ULSD and B20 on state contract. The other fuel blends were purchased at market prices. It is possible that actual fuel costs would be lower for some of the other biofuel blends if they were procured more regularly and added to the state contract.

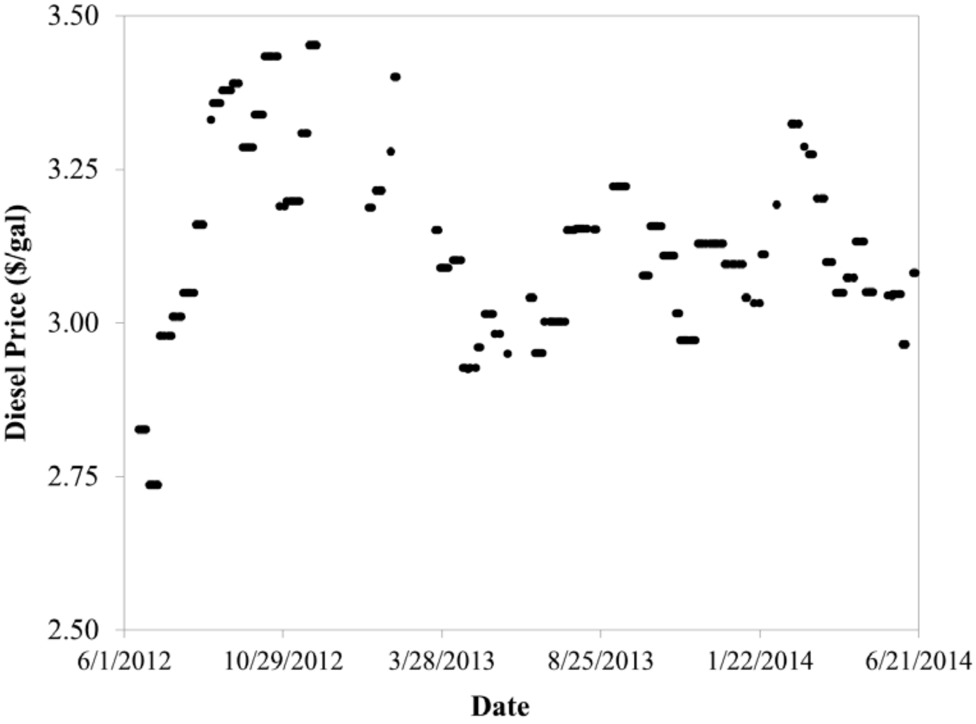


Figure 5-3. Ultra-low sulfur diesel prices for June 2012 through June 2014

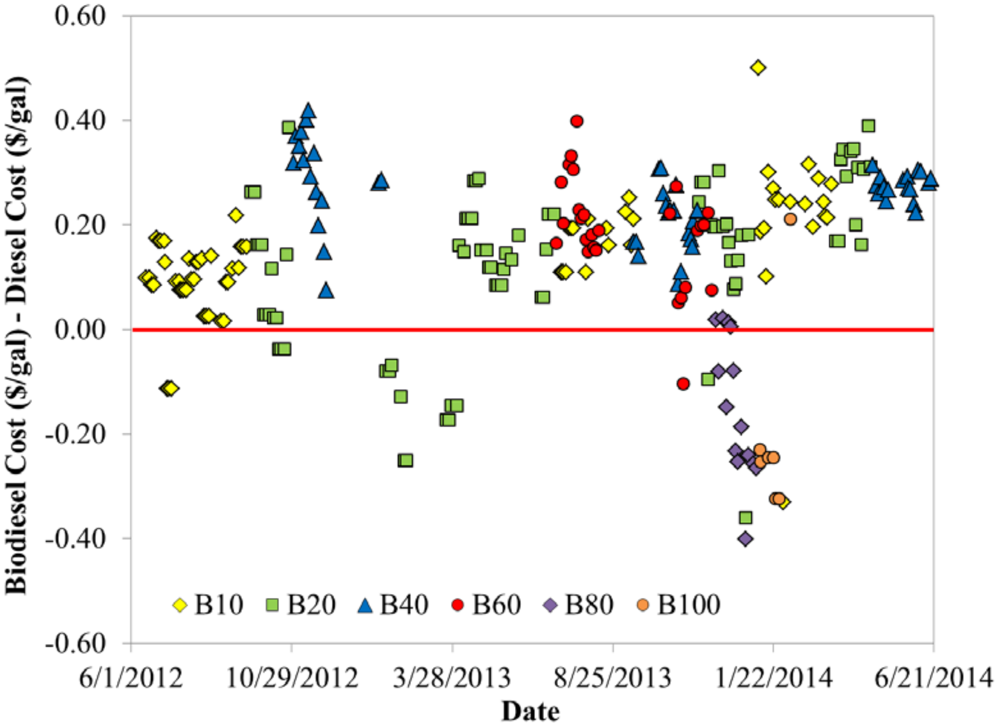


Figure 5-4. Difference in price per gallon for biodiesel blends versus ultra-low sulfur diesel for June 2012 through June 2014

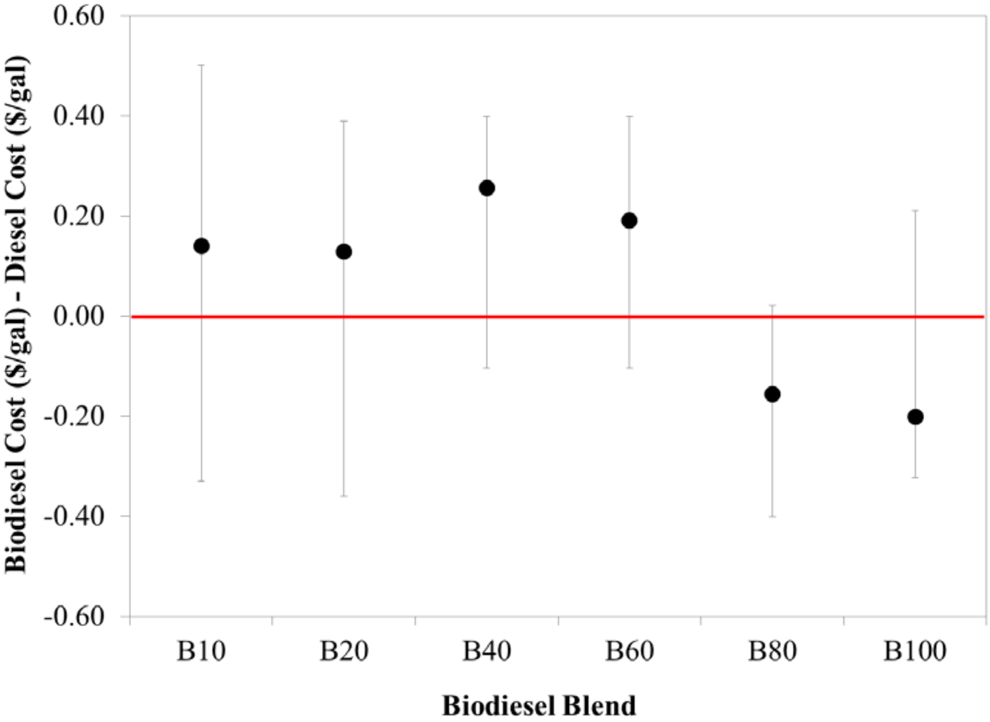


Figure 5-5. Average differences in price per gallon for biodiesel blends versus ultra-low sulfur diesel

5.3 Biofuel Availability

There was no difficulty in obtaining biofuels during the course of this project, in terms of available supply from vendors in the local area. NCDOT regularly purchases ULSD and B20 biodiesel via state contract, and there was no difficulty in obtaining soy-based B20 or soy-based B100 that could be used either as “neat” B100 or as a blending component with ULSD to create other blend ratios.

The NCDOT rail yard does not have onsite storage dedicated to biofuels. Therefore, biofuel was delivered by truck and pumped directly into the locomotive. Deliveries typically took place once per week as needed. At any given time, the three locomotives were operating on different fuels; therefore, it would have been infeasible in terms of cost to have sufficient fuel storage on site for three different fuels. While B20 was a common blend ratio, other blend ratios were “splash-mixed” by the vendor based on how much ULSD and biofuel blend stock were separately put into the tanker truck, with mixing taking place as the truck traveled from the vendor’s fuel depot to the NCDOT rail yard.

The actual biofuel blend ratios were assessed by testing fuel samples, with results given in Table 2-1. Biodiesel content was analyzed using an infrared detection method. The measured biodiesel content was typically consistent with the requested biodiesel content. For example, B20 was found to be comprised of 22.3 percent biodiesel blend stock, B40 was found to be comprised of 40.5 percent biodiesel blend stock, and B100 was found to be comprised of 99.6 biodiesel blend stock. However, the blending ratio for B10 may have been a little “short,” at an average ratio of 6.6% and the B60 blend may also have been slightly short at 55.6 percent. Nonetheless, within some range of variation, the received fuels corresponded to the placed order with respect to blending ratio.

6. Conclusions

The emissions of three locomotive engines were measured for ULSD and multiple biofuel blends. Measurements were made for exhaust concentrations and emission rates of CO_2, CO, HC, NO_x, and PM using Portable Emissions Measurement Systems (PEMS).

Measurements were made on three NCDOT owned locomotives, including locomotive numbers NC-1797, NC-1810, and NC-1859. NC-1797 was an EMD F59PHI locomotive with EMD12-710 prime mover engine. NC-1810 and NC-1859 are both EMD F59PH locomotives, also with an EMD12-170 prime mover engine. For all three locomotives, measurements were made on ULSD, B10, B20, and B40. For NC-1810, additional measurements were made on B60, B80, and B100.

Over 40 hours of rail yard and over 270 hours of over the rail data were collected. Typically, less than one percent of total data collected were excluded after quality assurance screening. A total of 34 lubricating oil analyses were reviewed; the oil samples were taken from the three test locomotives over a multi-year period, including baseline data prior to the use of the biofuels, and comparison data during biofuel use. A total of 11 fuel samples were analyzed with respect to gross heating value, net heating value, weight percent of carbon, hydrogen, and nitrogen, sulfur content, specific gravity, Cetane number, flash point, viscosity, cloud point, distillation, lubricity, and corrosion.

The rail yard and over-the-rail measurements were qualitatively consistent in terms of trends in emission rates with respect to engine load and between biofuels for each locomotive. The over the rail emission rates tended to differ, and often were lower, than for rail yard measurements, because the engine operated with higher power output in notches 7 and 8 for the former.

Assumptions made regarding the ratio of NO_x to NO and of total HC to HC measurable using NDIR were validated based on supplemental measurements.

Biodiesel has higher fuel density and a higher Cetane number compared to ULSD, which correlate with increased NO_x emissions. The increased oxygen content of biodiesel, compared to ULSD, corresponds to decreased HC and CO emissions. It was expected that PM emissions would decrease with biodiesel use, because of the typically higher Cetane number and oxygen content of biodiesel compared to ULSD. This was observed with NC-1859 both in the RY and OTR.

No biodiesel blend significantly reduced cycle average emission rates for every measured pollutant for every locomotive. However, a blend of 20 percent soy-based biodiesel and 80 percent petroleum diesel had lower CO, PM, and CO_2 emission rates that were statistically significant compared to ULSD based on RY measurements, and statistically significantly lower HC, CO, and CO_2 emission rates compared to ULSD based on OTR measurements. The differences in cycle average NO_x emission rates both during RY and OTR measurements were not statistically significant. Of the various biofuel blends evaluated in this work, B20 tends to be more like ULSD with regard to operability (e.g., cold handling properties) while offering advantages of biodiesel with regard to lubricity.

There was no evidence of adverse impact of biofuel use on the prime mover engines. The field measurements in this study were conducted over a period of approximately two years, during which evidence of engine wear was sought via lubricating oil samples and engine piston and cylinder clearance measurements. No adverse effects were found. There were also no reports of maintenance or operability problems by mechanics or engineers, respectively.

Biofuel is a “drop-in” replacement for petroleum diesel that does not require modification to the engine, and no difficulties were encountered while obtaining the biofuels from local vendors. There was no substantial price differential for biofuels versus ULSD. From a life cycle perspective, soy-based biodiesel leads to a net reduction in CO_2 emissions, which contribute to greenhouse gas concentration in the atmosphere. Although agricultural regions of the U.S. that produce biofuel blend stock may encounter increases in fuel cycle emissions, there is a net reduction in the exhaust emissions from the locomotive engine for CO, HC, and PM. The apparent increase in NO_x emissions may have some adverse implications in particular airsheds where tropospheric ozone levels are sensitive to NO_x concentration; however, not all airsheds are equally sensitive.

The work here focused on specific diesel locomotives for passenger rail service, and it did not include a variety of other locomotive chassis and prime mover engine models that are in service in the United States, such as for freight. The study focused on prime mover engines and did not include head end power engines. Although the study measured locomotives over a period of time, the time frame of the study was not sufficient to establish the long-term effects of biofuels on engine durability or performance. However, the methods demonstrated in this work for rail yard and over the rail measurements could be applied to other locomotives and the methods for tracking wear indicators could also be applied more broadly.

Overall, the use of B20 biodiesel is recommended for consideration by locomotive owners and operators who are interested in making reductions in net emissions of CO_2, CO, HC, and PM, with limited impact on potential increase in NO_x emissions.

This research demonstrates the application of methods for rail yard and over the rail measurements using PEMS, including factors related to study design (e.g., choices of locomotives, fuels, test procedures, routes), instrumentation, installation, data collection, quality assurance, and data analysis. These methods can be applied more widely to address a wide variety of study objectives related to locomotives, fuels, duty cycles, emission controls, and others.

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Appendix A.
Results of Fuel Measurements

INTRODUCTION

To determine the properties of fuels used in locomotives in the North Carolina Department of Transportation (NCDOT) fleet, fuel samples were collected and sent to a laboratory for analysis. Samples have been collected and analyzed for the following seven fuels: (1) ultra -low sulfur diesel (ULSD); (2) 10 percent biodiesel and 90 percent ULSD blend (B10); (3) 20 percent biodiesel and 80 percent ULSD blend (B20); (4) 40 percent biodiesel and 60 percent ULSD blend (B40); (5) 60 percent biodiesel and 40 percent ULSD blend (B60); (6) 80 percent biodiesel and 20 percent ULSD blend (B80); and 100% biodiesel (B100).

METHODS

At the start of this project, we estimated the physical and chemical characteristics of each fuel blend based on literature data. Fuel properties for ULSD and B100 were based on page 11 of "Biodiesel Handling and Use Guide, 4th Edition" prepared by National Renewable Energy Laboratory (NREL). Fuel properties for the other biodiesel blends were inferred based on the volume ratios of ULSD and B100. The literature based fuel properties are given in Table A-1.

During the course of the project, fuel samples were obtained and sent to Southwest Research Institute for physical and chemical characterization. The results are shown in Table A-2.

RESULTS

The measured fuel properties in Table A-2 are generally similar to the estimates based on literature as reported in Table A-1. A detailed comparison of measured and literature values is given for two fuels, B20 and B80 in Tables A-3 and A-4, respectively.

For B20 biodiesel, the measured gross heating value and net heating value are within 1.7% of the literature values. The wt-% C was within 2.8% (relative basis), wt-% H was within 0.8%, and specific gravity was within 0.2% for measured average versus literature values.

For B80 biodiesel, the gross heating value and net heating value are within 0.2% for measured versus literature values. The wt-% C was within 0.2% (relative basis), wt-% H was within 1.6%, and specific gravity was within 0.2% for measured versus literature values.

The numbers used in the mass balance calculations for fuel use and emission rates include specific gravity, wt-% C, wt-% H, and wt-% O. Results for fuel use and emission rates are calculated and reported based on literature values. However, since the differences in measured versus literature values of these key parameters are small, there was not a substantial difference in results compared to the actual fuel properties.

Table A-1. Literature Fuel Properties for Ultra Low Sulfur Diesel, B10, B20, B40, B60, B80, and B100 Biodiesel Fuels*

Properties	Unit	ULSD	B10	B20	B40	B60	B80	B100
Gross Heat	BTU/lb	19386	19188	18989	18593	18196	17800	17403
Gross Heat	MJ/Kg	45.092	44.630	44.169	43.247	42.324	41.402	40.479
Gross Heat	Cal/g	10777	10667	10557	10336	10116	9895	9675
Net Heat	BTU/lb	18176	17977	17778	17381	16983	16585	16188
Net Heat	Mj/Kg	42.278	41.815	41.353	40.428	39.503	38.578	37.653
Net Heat	Cal/g	10105	9994	9883	9662	9441	9220	8999
Cloud Point	°C	-35 to 5	-31.8 to 6	-28.6 to 7	-22.2 to 9	-15.8 to 11	-9.4 to 13	-3 to 15
Sulfur	ppm	≤ 15	≤ 15.9	≤ 16.8	≤ 18.6	≤ 20.4	≤ 22.2	≤ 24
Specific Gravity @60°F		0.850	0.853	0.856	0.862	0.868	0.874	0.880
Density @15°C	g/ml	0.8501	0.8525	0.8549	0.8596	0.8644	0.8692	0.8740
Carbon	wt%	87.00	86.00	85.00	83.00	81.00	79.00	77.00
Hydrogen	wt%	13.00	12.90	12.80	12.60	12.40	12.20	12.00
Oxygen	wt%	0.0	1.10	2.20	4.40	6.60	8.80	11.00
Cetane	No.	40 to 55	40.8 to 56	41.6 to 57	43.2 to 59	44.8 to 61	46.4 to 63	48 to 65
Flash Point	°C	60 to 80	64 to 89	68 to 98	76 to 116	84 to 134	92 to 152	100 to 170
Biodiesel	vol%	0.0	10.0	20.0	40.0	60.0	80.0	100.0
Viscosity	cSt	1.30 to 4.10	1.57 to 4.29	1.84 to 4.48	2.38 to 4.86	2.92 to 5.24	3.46 to 5.62	4.00 to 6.00
Initial Boiling Point	°F	180 to 340	194 to 341	207 to 342	234 to 344	261 to 346	288 to 348	315 to 350

* *Literature fuel properties for ULSD and B100 are based on "Biodiesel Handling and Use Guide, 4th Edition" prepared by National Renewable Energy Laboratory. Fuel properties for the other biodiesel blends are inferred based on the volume ratios of ULSD and B100.*

Table A-2. Measured Fuel Properties for Ultra-Low Sulfur Diesel (ULSD), B10, B20, B40, B60, B80, and B100 Biodiesel Fuel*

		ULSD**	**B10**	**B20*****	**B40*****	**B60**	**B80**	**B100**
Properties	**Unit**	**Obtained 7/2013 9/2013 10/2013**	**Obtained 9/2013**	**Obtained 12/2013 4/2014**	**Obtained 10/2013 7/2014**	**Obtained 8/2013**	**Obtained 12/2013**	**Obtained 2/2014**
ASTM D130 Copper Corrosion								
Copper Corrosion	rating	IA	IA	IA IC	IA IC	IA	IA	IC
ASTM D240 Gross Heat of Combustion								
Gross Heat	BTU/lb	19659	19491	18900	18635	18091	17714	17232
Gross Heat	MJ/Kg	45.727	45.336	43.960	43.345	42.080	41.202	40.083
Gross Heat	Cal/g	10922	10828	10500	10353	10051	9840.8	9573.7
ASTM D240 Net Heat of Combustion								
Net Heat	BTU/lb	18471	18279	17726	17470	16955	16618	16140
Net Heat	Mj/Kg	42.963	42.517	41.231	40.634	39.437	38.653	37.540
Net Heat	Cal/g	10262	10155	9847.8	9705.3	9419.4	9232.2	8966.4
ASTM D2500 Cloud Point								
Cloud Point	°C	-11.5	-11.1	-8.4	-0.6	-4.2	-5.0	2.8
ASTM D2622 Sulfur by WDXRF								
Sulfur	ppm	10.8	8.0	7.8	6.7	5.9	4.9	0.8
ASTM D4052 API, Density, Specific Gravity								
API	°	36.6	36.6	34.4	33.4	31.7	30.2	29.1
Specific Gravity @60°F		0.8416	0.8416	0.8534	0.8580	0.8672	0.8753	0.8809
Density @15°C	g/ml	0.8412	0.8411	0.8530	0.8576	0.8667	0.8748	0.8805
ASTM D5291 Carbon Hydrogen Nitrogen								
Carbon	wt%	86.74	85.72	83.41	82.36	80.64	78.90	76.96
Hydrogen	wt%	13.02	13.29	12.9	12.78	12.46	12.01	11.98
Nitrogen	wt%	0.02	0.20	0.09	0.10	0.14	0.10	0.11
ASTM D613 Cetane Number								
Cetane	No.	47.2	49.0	48.6	53.0	48.8	49.2	49.8
ASTM D93 Flash Point								
Flash Point	°C	64.3	61.0	63.5	71.5	73.0	81.0	115
BioDiesel Content by IR								
Biodiesel	vol%	N/A	6.6	22.3	40.5	55.6	N/A	99.6
ASTM D6079 Lubricity								
Wear Scar Diameter	µm	362	265	171	168	159	151	151
Major Axis	mm	0.406	0.297	0.204	0.190	0.189	0.181	0.183
Minor Axis	mm	0.318	0.233	0.137	0.154	0.129	0.120	0.118
Scar Description****		EAO	EAO	EAO LAO	EAO LAO	EAO	LAO	LAO
ASTM D445 Kinematic Viscosity								
Viscosity	cSt	2.498	2.510	2.820	3.042	3.352	3.543	4.052
ASTM D86 Distillation								
Initial Boiling Point	°F	332.2	333.5	343.5	351.7	343.5	358.1	N/A
10% Recovered	°F	400.5	398.9	415.5	431.6	469.7	546.8	N/A
50% Recovered	°F	504.1	510.3	567.8	585.4	616.8	630.6	N/A
90% Recovered	°F	621.6	624.9	639.2	637.8	644.5	644.8	N/A
Final Boiling	°F	660.5	660.0	661.0	666.3	674.0	664.6	N/A

Point								
Recovered	%	97.2	97.9	98.3	98.6	98.7	98.1	N/A
Residue	%	1.3	1.3	1.2	1.0	0.7	1.3	N/A
Loss	%	1.5	0.8	0.5	0.4	0.6	0.6	N/A

* *Biodiesel Blends: B10 is 10% biodiesel and 90% ULSD blend; B20 is 20% biodiesel and 80% ULSD blend; B40 is 40% biodiesel and 60% ULSD blend; B60 is 60% biodiesel and 40% ULSD blend; B80 is 80% biodiesel and 20% ULSD blend; B100 is 100% biodiesel.*

** *ULSD results are averages based on three measurements. B20 and B40 results are averages based on two measurements each. The other biodiesel blends results are based on one measurement each.*

*** *For B20 biodiesel blends, sample obtained on 12/2013 has a copper corrosion rating of IA and a scar description of EAO; sample obtained on 4/2014 has a copper corrosion rating of IC and a scar description of LAO. For B40 biodiesel blends, sample obtained on 10/2013 has a copper corrosion rating of IA and a scar description of EAO; sample obtained on 7/2014 has a copper corrosion rating of IC and a scar description of LAO.*

*** *Scar Description: LAO – Lightly Abraded Oval; EAO – Evenly Abraded Oval.*

Table A-3. Literature and Measured Fuel Properties for B20 Biodiesel Fuel

Properties	Unit	B20 Biodiesel Literature-Based Estimate*	 SwRI Measured Obtained 12/18/2013
ASTM D130 Copper Corrosion			
Copper Corrosion	rating	N/A	1A
ASTM D240 Gross Heat of Combustion			
Gross Heat	BTU/lb	18989	18681
Gross Heat	MJ/Kg	44.169	43.452
Gross Heat	Cal/g	10557	10378
ASTM D240 Net Heat of Combustion			
Net Heat	BTU/lb	17778	17522
Net Heat	Mj/Kg	41.353	40.756
Net Heat	Cal/g	9883	9734.4
ASTM D2500 Cloud Point			
Cloud Point	°C	-28.6 to 7	-7.9
ASTM D2622 Sulfur by WDXRF			
Sulfur	ppm	≤ 16.8	7.4
ASTM D4052 API, Density, Specific Gravity			
API	°	N/A	33.5
Specific Gravity @60°F		0.856	0.8577
Density @15°C	g/ml	0.8549	0.8573
ASTM D5291 Carbon Hydrogen Nitrogen			
Carbon	wt%	85.00	82.75
Hydrogen	wt%	12.80	12.7
Nitrogen	wt%	N/A	0.06
ASTM D613 Cetane Number			
Cetane	No.	41.6 to 57	45.5
ASTM D93 Flash Point			
Flash Point	°C	68 to 98	61.0
BioDiesel Content by IR			
Biodiesel	vol%	20.0	N/A
ASTM D6079 Lubricity			
Wear Scar Diameter	µm	N/A	188
Major Axis	mm	N/A	0.225
Minor Axis	mm	N/A	0.150
Scar Description		N/A	EAO**
ASTM D445 Kinematic Viscosity			
Viscosity	cSt	1.84 to 4.48	2.846
ASTM D86 Distillation			
Initial Boiling Point	°F	207 to 342	335.8
10% Recovered	°F	N/A	414.6
50% Recovered	°F	N/A	585.5
90% Recovered	°F	N/A	642.6
Final Boiling Point	°F	N/A	659.9
Recovered	%	N/A	97.9
Residue	%	N/A	1.4
Loss	%	N/A	0.7

* *Literature fuel properties for ULSD and B100 are based on "Biodiesel Handling and Use Guide, 4th Edition" prepared by National Renewable Energy Laboratory. Fuel properties for B10 were inferred based on the volume ratios of each of ULSD and B100 that are reported by NREL.*

*** EAO – Evenly Abraded Oval*

Table A-4. Literature and Measured Fuel Properties for B80 Biodiesel Fuel

		B80 Biodiesel	
Properties	**Unit**	**Literature-Based Estimates***	**SwRI Measured Obtained 12/23/2013**
ASTM D130 Copper Corrosion			
Copper Corrosion	rating	N/A	1A
ASTM D240 Gross Heat of Combustion			
Gross Heat	BTU/lb	17800	17714
Gross Heat	MJ/Kg	41.402	41.202
Gross Heat	Cal/g	9895	9840.8
ASTM D240 Net Heat of Combustion			
Net Heat	BTU/lb	16585	16618
Net Heat	Mj/Kg	38.578	38.653
Net Heat	Cal/g	9220	9232.2
ASTM D2500 Cloud Point			
Cloud Point	°C	-9.4 to 13	-5.0
ASTM D2622 Sulfur by WDXRF			
Sulfur	ppm	≤ 22.2	4.9
ASTM D4052 API, Density, Specific Gravity			
API	°	N/A	30.2
Specific Gravity @60°F		0.874	0.8753
Density @15°C	g/ml	0.8692	0.8748
ASTM D5291 Carbon Hydrogen Nitrogen			
Carbon	wt%	79.00	78.90
Hydrogen	wt%	12.20	12.01
Nitrogen	wt%	N/A	0.10
ASTM D613 Cetane Number			
Cetane	No.	46.4 to 63	49.2
ASTM D93 Flash Point			
Flash Point	°C	92 to 152	81.0
BioDiesel Content by IR			
Biodiesel	vol%	80.0	N/A
ASTM D6079 Lubricity			
Wear Scar Diameter	µm	N/A	151
Major Axis	mm	N/A	0.181
Minor Axis	mm	N/A	0.120
Scar Description		N/A	LAO**
ASTM D445 Kinematic Viscosity			
Viscosity	cSt	3.46 to 5.62	3.543
ASTM D86 Distillation			
Initial Boiling Point	°F	288 to 348	358.1
10% Recovered	°F	N/A	546.8
50% Recovered	°F	N/A	630.6
90% Recovered	°F	N/A	644.8
Final Boiling Point	°F	N/A	664.6
Recovered	%	N/A	98.1
Residue	%	N/A	1.3
Loss	%	N/A	0.6

* *Literature fuel properties for ULSD and B100 are based on "Biodiesel Handling and Use Guide, 4th Edition" prepared by National Renewable Energy Laboratory. Fuel properties for B40 were inferred based on the volume ratios of each of ULSD and B100 that are reported by NREL.*

*** LAO – Lightly Abraded Oval*

Appendix B.
Results of Lubricating Oil Measurements

INTRODUCTION

To determine the effect of biofuel use on locomotive performance and warranty specifications, periodic tests are necessary to be used as indicators of engine wear. These include engine lubrication oil analyses. An increase in engine wear metals measured in lubrication oil analyses may indicate an increase in prime mover engine wear due to the use biodiesel.

Table B-1 outlines the locomotives that have operated on biodiesel blends, the composition of the biodiesel blends, and dates of operation. All biodiesel blends were derived from petrodiesel and a 100 percent soy-based biodiesel stock.

Table B-1. Schedule of Biodiesel Operation by Locomotives in the NCDOT Fleet

Fuel Blend		NC-1797	NC-1810	NC-1859	NC-1893
B10	10% biodiesel 90% petrodiesel	2/2014 - 3/2014	6/2012 - 9/2012	1/2014 - 2/2014	7/2013 - 9/2013
B20	20% biodiesel 80% petrodiesel	3/2014 - 4/2014	9/2012 - 10/2012 1/2013 - 7/2013	11/2013 - 12/2013	n/a
B40	40% biodiesel 60% petrodiesel	4/2014 - 6/2014	10/2012 - 1/2013	9/2013 - 11/2013	n/a
B60	60% biodiesel 40% petrodiesel	n/a	7/2013 - 11/2013	n/a	n/a
B80	80% biodiesel 20% petrodiesel	n/a	11/2013 - 1/2014	n/a	n/a
B100	100% biodiesel	n/a	1/2014 - 2/2014	n/a	n/a

The lubricating oil analyses for all locomotives in the NCDOT fleet serve as baselines for comparison when these locomotives are operated with varying biodiesel blends, rather than ultra low sulfur diesel.

This appendix summarizes engine lubrication oil analyses for all locomotives in the NCDOT fleet obtained from Herzog Transit Services NC to date.

METHODS

As a part of the 90-day inspection of each locomotive in the NCDOT fleet, oil samples were taken from the prime mover and head end power (HEP) engines and sent to the Gregory Poole Fluid Analysis Laboratory. These fluid analyses characterize wear metals present in the oil (e.g., Cu, Fe, Cr, Al, Pb, Sn, Si, Na, K, Mo, Ni, Ca, Mg, Zn, P, and Ba) as well as oil condition (e.g., soot, oxidation, nitration, sulfation, water, antifreeze, fuel, and viscosity).

Each of the wear metals measured in the lubricating oil analysis is indicative of specific aspects of engine wear. For example, Aluminum (Al) is indicative of wear of pistons, bearings, housing metal, thrust washers, converter and pump bushings, and dirt entry. Chromium (Cr) is a wear indicator for chromed parts such as piston rings and bearings. Iron (Fe) indicates wear of gears, shafts, cylinders, liners, valve train components, other steel components and rust. Molybdenum (Mo) indicates wear on piston rings. Many of the other metals analyzed are additives to the lubricating oil itself, such as Sodium (Na), Potassium (K), Calcium (Ca), Barium (Ba), Magnesium (Mg), Phosphorus (P), and Zinc. Some of these additives are used as dispersants and detergents, while others are for anti-wear or anti-freeze. Some metals, such as Lead (Pb), Tin (Sn), and Nickel (Ni) are indicators of wear of bearings and bushings, many of which are not in the combustion flow path.

The particle count measurement helps assess whether there is excessive wear or dirt. The oxidation and nitration measurements assess how much the oil has absorbed oxygen and nitrogen, which is an indicator of wear of the oil itself. The sulfation measurement indicates how much sulfur has been taken up by the oil, which is an indicator of blow-by. Blow-by is combustion gas that gets past the cylinder rings into the crankcase of the engine. Thus, sulfur is an indicator of engine wear, especially for the piston rings.

The water, antifreeze, and diesel measurements indicate contamination of the oil by the coolant and fuel systems, which would indicate a significant fluid entry.

The viscosity measurement is an indicator of lube oil wear. High viscosity is associated with oxidation of the oil. Low viscosity is associated with fuel getting into the crankcase.

Of the various measures of engine wear from the lube oil analysis, the most relevant to the combustion gas flow path are those related to cylinder, piston, and piston ring wear, which are Al, Cr, Fe, and Mo. Signs of engine wear in the crankcase are elevated levels of Pb, Sn, and Ni.

Each set of lubricating oil analyses was given one of three color-coded conclusions:

- Green: No Action Required
- Yellow: Monitor
- Red: Action Required

According to a member of the Gregory Poole Fluid Analysis Laboratory, these color-coded conclusions are based on trends among wear metals over previous samples. There are not any specific criteria that determine the conclusions made; the conclusions are based on the discretion of the laboratory analyst. In general, there are ranges in metal concentrations that the laboratory analyst looks for to determine whether engine wear may be present. However, these concentration ranges are proprietary and not available to the public.

For the prime mover engine, if a fluid analysis recommends action (coded red) a second sample of the engine oil is sent 90 days later for analysis to determine whether the engine oil needs to be replaced, or whether the first test result might have been a false-positive. If the retest is also coded red by the laboratory, then all of the lubricating oil in the prime mover engine is drained and replaced.

For the HEP engine, all lubricating oil is drained during the 180-day inspection of each locomotive, after an oil sample has been taken and sent for analysis.

RESULTS

Lubricating oil analyses conducted by the Gregory Poole Fluid Analysis Laboratory were obtained from Herzog for all six locomotives in the NCDOT fleet from as far back to as most recent as possible. In total, 69 fluid analyses test results were gathered from the prime mover engines in the locomotive fleet and 69 fluid analyses test results were gathered from the HEP engines in the locomotive fleet, as shown in Table B-2.

Table B-2. Oil Sample Dates for Prime Mover and Head End Power Engines of NCDOT Locomotive Fleet

(a) Prime Mover Engine

NC-1755 (F59PHI)	**NC-1797 (F59PHI)**	**NC-1810 (F59PH)**	**NC-1859 (F59PH)**	**NC-1869 (F59PH)**	**NC-1893 (F59PH)**
11/21/2010	9/1/2010	12/21/2010	12/20/2011	10/21/2011	2/23/2012
1/4/2011	12/8/2010	8/21/2011	3/18/2012	1/19/2012	9/20/2012
3/23/2011	3/14/2011	3/8/2012	6/19/2012	4/1/2012	11/17/2012
10/10/2012	8/6/2012	6/4/2012	9/14/2012	6/26/2012	1/24/2013
11/1/2012	8/15/2012	8/15/2012	12/25/2012	9/27/2012	5/1/2013
1/12/2013	2/4/2013	2/22/2013	3/27/2013	12/31/2012	7/24/2013
5/3/2013	5/7/2013	9/8/2013	6/29/2013	4/6/2013	10/24/2013
5/15/2013	5/15/2013	1/14/2014	9/21/2013	7/10/2013	2/19/2014
6/24/2013	8/6/2013	3/10/2014	12/31/2013	10/16/2013	5/25/2014
9/25/2013	11/8/2013	6/12/2014	3/24/2014	2/18/2013	8/27/2014
12/25/2013	2/12/2014		6/25/2014	4/16/2014	
3/19/2014	5/9/2014			7/15/2014	
7/19/2014	8/28/2014				

(b) Head End Power Engine

NC-1755 (F59PHI)	**NC-1797 (F59PHI)**	**NC-1810 (F59PH)**	**NC-1859 (F59PH)**	**NC-1869 (F59PH)**	**NC-1893 (F59PH)**
8/13/2010	7/15/2010	5/20/2011	12/20/2011	10/21/2011	2/23/2012
11/21/2010	9/1/2010	5/27/2011	3/18/2012	1/19/2012	9/20/2012
1/4/2011	12/8/2010	8/21/2011	6/19/2012	4/1/2012	11/17/2012
10/10/2012	8/6/2012	3/8/2012	9/14/2012	6/26/2012	1/24/2013
11/1/2012	2/4/2013	5/21/2012	12/25/2012	9/27/2012	5/1/2013
1/12/2013	5/7/2013	6/4/2012	3/27/2013	12/31/2012	7/24/2013
5/3/2013	8/6/2013	8/15/2012	6/29/2013	4/6/2013	10/24/2013
5/15/2013	11/8/2013	2/22/2013	9/21/2013	7/10/2013	2/19/2014
6/24/2013	2/12/2014	9/8/2013	12/31/2013	10/16/2013	5/25/2014
9/25/2013	5/9/2014	1/14/2014	3/24/2014	2/18/2013	8/27/2014

12/25/2013 3/19/2014 7/19/2014	8/28/2014	3/10/2014 6/12/2014	6/25/2014	4/16/2014 7/15/2014	

The results of the oil analyses of the prime mover engines in the NCDOT fleet are summarized in Table B-3. The results of the oil analyses of the head end power engines in the NCDOT fleet are summarized in Table B-4.

It was apparent that, over time, most of the locomotives in the NCDOT fleet have had oil analyses come back with recommendations from the laboratory to monitor (yellow) or take action on (red) the lubricating oil. Based on the comments given on the oil analysis reports, the four wear metals that lead to results being coded yellow or red are copper (Cu), iron (Fe), tin (Sn), and Lead (Pb). In order to assess the trends of these four wear metals over time for each engine, reported concentrations were graphed, and are included below. For the oil analysis that return coded yellow or red, an increasing trend in the concentration of one or more of these wear metals is observed. For example, the concentrations of copper, iron, tin, and lead have all increased from August 2010 through January 2013 for the prime mover engine of NC-1755, as shown in Figure B-3. The first three tests were coded as no action being required. In the fourth test, as the wear metal concentrations continued to increase, the results were coded as yellow and monitoring requested. The wear metal concentrations continued to increase in the last two tests, and action was recommended.

There was no indication from the lubricating oil analyses that biodiesel use affected the operation of the NC-1810 and NC-1859 prime mover engines. All analyses have come back as “No Action Required” during the operation of the engine on all biodiesel blends used in this study.

With NC-1797, the two lube oil analyses that were conducted while the prime mover engine was operating on biodiesel indicated that copper, lead, and tin levels were elevated, indicating possible bearing wear. However, the measured concentrations of these metals began to increase prior to the introduction of biodiesel, shown in Figure B-3. Therefore, it is the opinion that biodiesel use did not affect engine wear of the NC-1797 prime mover engine.

While copper, lead, and tin concentrations have increased in earlier lube oil analyses of the NC-1893 prime mover engine, it was not believed that the use of B10 biodiesel has caused the increased wear metal concentrations. The most recent lube oil analyses for the prime mover and HEP engines for NC-1893 came back as “No Action Required.”

CONCLUSION

Engine lubricating oil analyses conducted by the Gregory Poole Fluid Analysis Laboratory for locomotives in the North Carolina Department of Transportation (NCDOT) fleet were collected from Herzog Transit Services NC. Based on the current lube oil analyses, the use of biodiesel by the prime mover and HEP engines does not appear to have an adverse effect on engine wear for NC-1797, NC-1810, NC-1859, and NC-1893.

Table B-3. Summary of Oil Analyses of Prime Mover Engines in NCDOT Locomotive Fleet

(a) NC-1755 (F59PHI)

Date	Summary	Fuel
11/21/2010	No Action Required	ULSD
1/4/2011	No Action Required	ULSD
3/23/2011	No Action Required	ULSD
10/10/2012	Monitor: Wear metals and additives have changed	ULSD
11/1/2012	Action Required: Copper, iron, tin, and lead have all increased and may indicate some crank and bearing wear	ULSD
1/12/2013	Monitor: Copper, lead, and tin are elevated. Possible bearing wear.	ULSD
5/3/2013	Action Required: Fuel dilution is high. Schedule unit for inspection to evaluate possible sources of fuel entry.	ULSD
5/15/2013	Action Required: Fuel dilution is high. Schedule unit for inspection to evaluate possible sources of fuel entry.	ULSD
6/24/2013	No Action Required	ULSD
9/25/2013	No Action Required	ULSD
12/25/2013	No Action Required	ULSD
3/19/2014	Monitor: Lead and tin are elevated. Possible bearing wear.	ULSD
7/19/2014	Monitor: Lead and tin are elevated. Possible bearing wear.	ULSD

(b) NC-1797 (F59PHI)

Date	Summary	Fuel
9/1/2010	No Action Required	ULSD
12/8/2010	No Action Required	ULSD
3/14/2011	No Action Required	ULSD
8/6/2012	Monitor: Wear metals and oil additives have changed a great deal; silicon levels may indicate some dirt entry or may be residue from a recent repair; iron, tin, and lead have increase and may indicate some crank and bearing wear	ULSD

8/15/2012	Action Required: Copper, iron, tin, and lead have increased and may indicate some crank and bearing wear	ULSD
2/14/2013	Action Required: Copper, lead and tin remains elevated. Possible bearing wear.	ULSD
5/7/2013	Action Required: Copper, lead and tin are increasing. Possible bearing wear.	ULSD
5/15/2013	Action Required: Copper, lead and tin are increasing. Possible bearing wear.	ULSD
8/6/2013	Action Required: Copper, lead and tin remain elevated. Possible bearing wear.	ULSD
11/8/2013	No Action Required	ULSD
2/12/2014	No Action Required	ULSD
5/9/2014	Monitor: Lead and tin are elevated. Possible bearing wear.	B40
8/28/2014	Monitor: Copper, lead, and tin are elevated. Possible bearing wear.	B10/B20

(c) NC-1810 (F59PH)

Date	**Summary**	**Fuel**
12/21/2010	No Action Required	ULSD
8/21/2011	No Action Required	ULSD
3/8/2012	No Action Required	ULSD
6/4/2012	No Action Required	ULSD
8/15/2012	Monitor: Iron and lead continue to increase and may indicate some crank and bearing wear	B10
2/22/2013	No Action Required	B10/B20/B40
9/8/2013	No Action Required	B20/B60
1/14/2014	No Action Required	B60/B80
3/10/2014	No Action Required	B100/ULSD
6/12/2014	No Action Required	ULSD

(d) NC-1859 (F59PH)

Date	**Summary**	**Fuel**
12/20/2011	Monitor: Copper, tin, and lead are higher than normal and may indicate some bearing wear	ULSD
3/18/2012	Monitor: No significant increase in wear detected	ULSD
6/19/2012	No Action Required	ULSD
9/14/2012	No Action Required	ULSD
12/25/2012	No Action Required	ULSD
3/27/2013	No Action Required	ULSD
6/29/2013	No Action Required	ULSD
9/21/2013	No Action Required	ULSD/B40
12/31/2013	No Action Required	B20/B40
3/24/2014	No Action Required	ULSD
6/25/2014	No Action Required	ULSD

(e) NC-1869 (F59PH)

Date	Summary	Fuel
10/21/2011	Monitor: Copper, tin, and lead are elevated and may indicate some bearing wear; other analysis readings appear normal; more sample history needed to establish a normal wear trend	ULSD
1/19/2012	No Action Required	ULSD
4/1/2012	Monitor: Tin and lead have increased; possible bearing wear	ULSD
6/26/2012	Monitor: Sample is about the same as last time	ULSD
9/27/2012	No Action Required	ULSD
12/31/2012	No Action Required	ULSD
4/6/2013	No Action Required	ULSD
7/10/2013	No Action Required	ULSD
10/16/2013	No Action Required	ULSD
2/18/2014	No Action Required	ULSD
4/16/2014	No Action Required	ULSD
7/15/2014	No Action Required	ULSD

(f) NC-1893 (F59PH)

Date	Summary	Fuel
2/23/2012	No Action Required	ULSD
9/20/2012	No Action Required	ULSD
11/17/2012	No Action Required	ULSD
1/24/2013	No Action Required	ULSD
5/1/2013	No Action Required	ULSD

7/24/2013	Monitor: Copper, lead, and tin are elevated. Possible bearing wear.	B10
10/24/2013	Monitor: Copper, lead, and tin are elevated. Possible bearing wear.	B10
2/19/2014	No Action Required	ULSD
5/25/2014	Monitor: Lead and tin are elevated. Possible bearing wear.	ULSD
8/27/2014	Monitor: Lead and tin are elevated. Possible bearing wear.	ULSD

Table B-4. Summary of Oil Analyses of Head End Power Engines in NCDOT Locomotive Fleet

(a) NC-1755 (F59PHI)

Date	Summary	Fuel
8/13/2010	No Action Required	ULSD
11/21/2010	No Action Required	ULSD
1/4/2011	No Action Required	ULSD
10/10/2012	Monitor: Wear metals and additives have changed	ULSD
11/1/2012	Action Required: Silicon is higher than normal and may indicate some dirt entry; copper is high and lead is elevated and may indicate some bearing wear	ULSD
1/12/2013	Monitor: Silicon (dirt) remains elevated. Check for possible sources of dirt entry. Copper has increased. Possible bearing wear.	ULSD
5/3/2013	No Action Required	ULSD
5/15/2013	No Action Required	ULSD
6/24/2013	No Action Required	ULSD
9/25/2013	No Action Required	ULSD
12/25/2013	No Action Required	ULSD
3/19/2014	No Action Required	ULSD
7/19/2014	No Action Required	ULSD

(b) NC-1797 (F59PHI)

Date	Summary	Fuel
7/15/2010	No Action Required	ULSD
9/1/2010	No Action Required	ULSD
12/8/2010	No Action Required	ULSD
8/6/2012	No Action Required	ULSD

2/4/2012	No Action Required	ULSD
5/7/2013	Action Required: Fuel dilution is high	ULSD
8/6/2013	Action Required: Viscosity is low. Fuel dilution is high.	ULSD
11/8/2013	No Action Required	ULSD
2/12/2014	No Action Required	ULSD
5/9/2014	No Action Required	B40
8/28/2014	Monitor: Fuel dilution is high. All other tests appear normal.	B10/B20

(c) NC-1810 (F59PH)

Date	**Summary**	**Fuel**
5/20/2011	Monitor: Silicon is higher than normal and may indicate some dirt entry; copper is high and lead is elevated and may indicate some bearing wear	ULSD
5/27/2011	No Action Required	ULSD
8/21/2011	No Action Required	ULSD
3/8/2012	No Action Required	ULSD
5/21/2012	Monitor: Copper has increased and may indicate some bearing wear	ULSD
5/21/2012	Action Required: Iron, tin, and lead have increased and may indicate some crank and bearing wear	ULSD
6/4/2012	No Action Required	ULSD
8/15/2012	No Action Required	B10
2/22/2013	No Action Required	B10/B20/B40
9/8/2013	Monitor: Lead is elevated. Possible bearing wear	B20/B60
1/14/2014	No Action Required	B60/B80
3/10/2014	No Action Required	ULSD
6/12/2014	Monitor: Lead is elevated. Possible bearing wear	ULSD

(d) NC-1859 (F59PH)

Date	**Summary**	**Fuel**
12/20/2011	No Action Required	ULSD
3/18/2012	No Action Required	ULSD
6/19/2012	No Action Required	ULSD
9/14/2012	No Action Required	ULSD
12/25/2012	No Action Required	ULSD
3/27/2013	No Action Required	ULSD
6/29/2013	No Action Required	ULSD
9/21/2013	No Action Required	ULSD/B40*
12/31/2013	No Action Required	B20/B40
3/24/2014	No Action Required	ULSD
6/25/2014	No Action Required	ULSD

* B40 introduced to the engine one week prior to lube oil sample being taken.

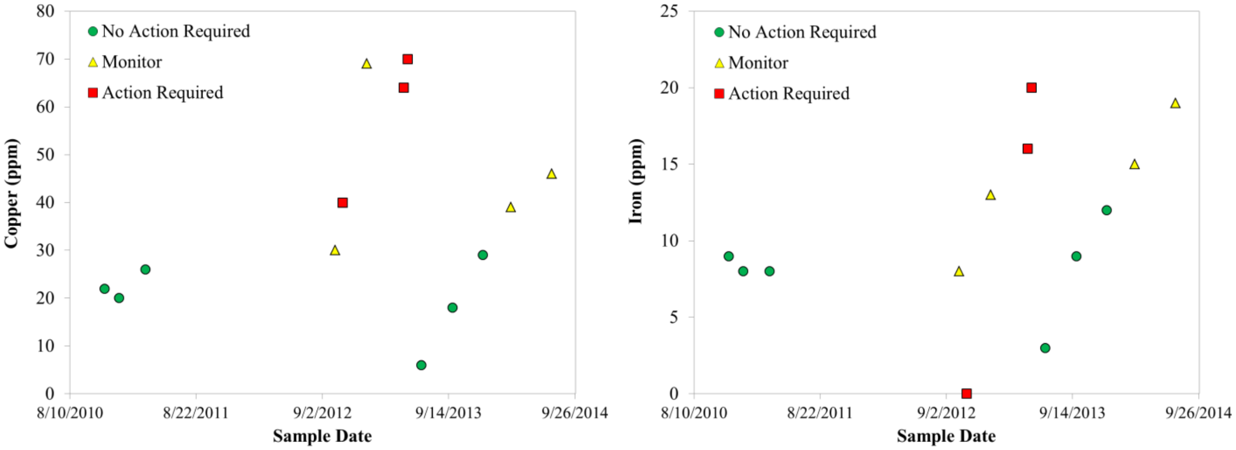
(e) NC-1869 (F59PH)

Date	**Summary**	**Fuel**
10/21/2011	No Action Required	ULSD
1/19/2012	No Action Required	ULSD
4/1/2012	No Action Required	ULSD
6/26/2012	No Action Required	ULSD
9/27/2012	No Action Required	ULSD
12/31/2012	No Action Required	ULSD
4/6/2013	No Action Required	ULSD
7/10/2013	No Action Required	ULSD
10/16/2013	No Action Required	ULSD
2/18/2014	No Action Required	ULSD
4/16/2014	No Action Required	ULSD
7/15/2014	No Action Required	ULSD

(f) NC-1893 (F59PH)

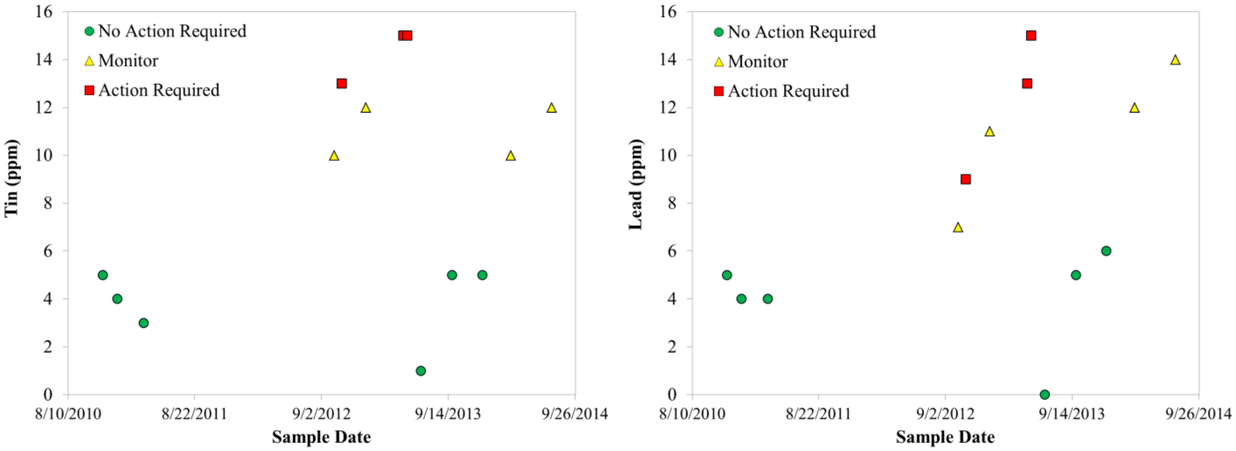
Date	**Summary**	**Fuel**
2/23/2012	Monitor: Copper and silicon are higher than normal; viscosity is a 30 weight; silicon may be residue from a recent repair or could indicate some dirt entry	ULSD
9/20/2012	Action Required: viscosity is a 20 weight	ULSD
11/17/2012	No Action Required	ULSD
1/24/2013	No Action Required	ULSD
5/1/2013	No Action Required	ULSD

7/24/2013	Monitor: Fuel dilution is high. Copper has increased. Possible bearing wear.	B10
10/24/2013	No Action Required	B10
2/19/2014	No Action Required	ULSD
5/25/2014	No Action Required	ULSD
8/27/2014	No Action Required	ULSD



(a) Copper (Cu)

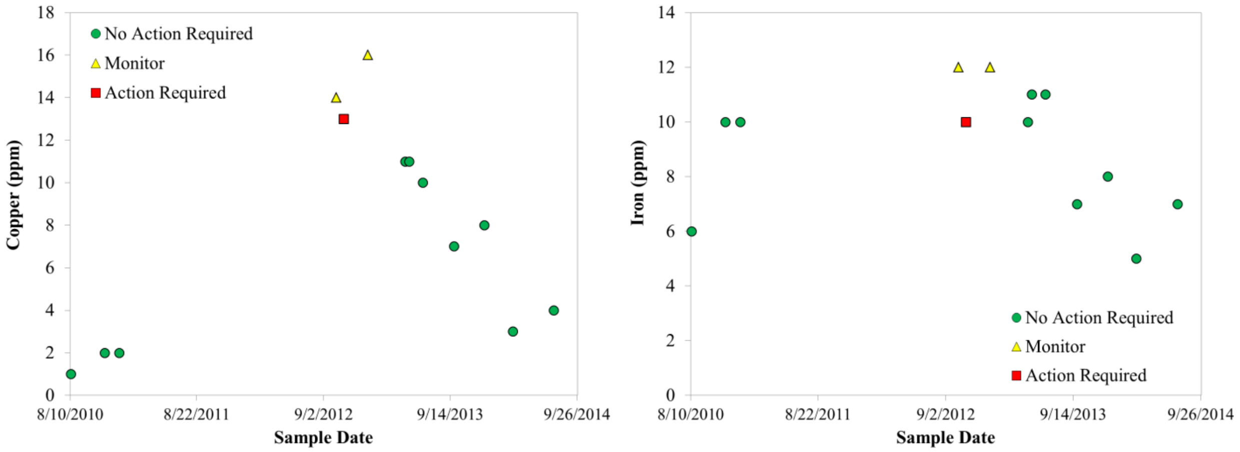
(b) Iron (Fe)



(c) Tin (Sn)

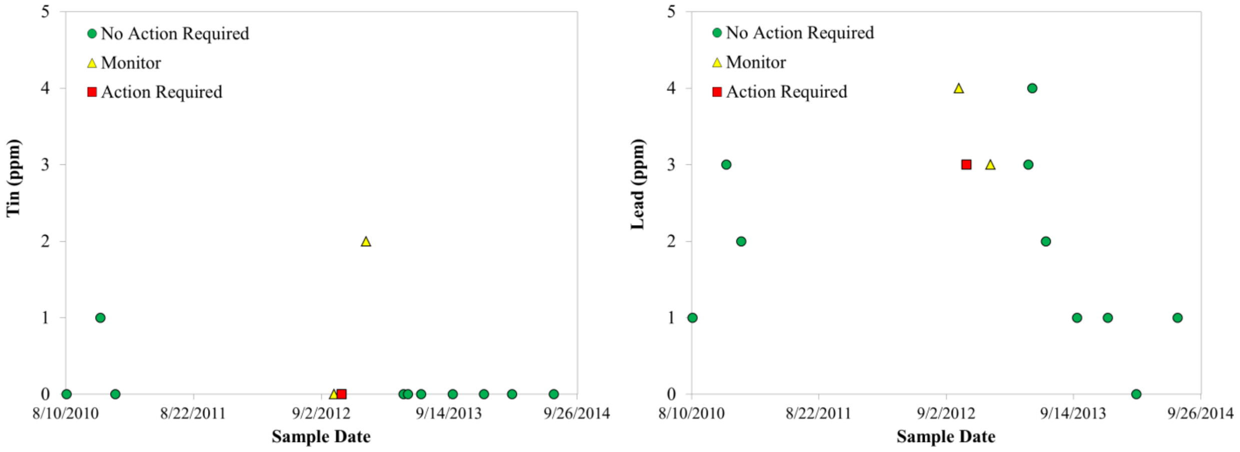
(d) Lead (Pb)

Figure B-1. Wear Metal Concentrations in Oil Samples from NC-1755 Prime Mover Engine



(a) Copper (Cu)

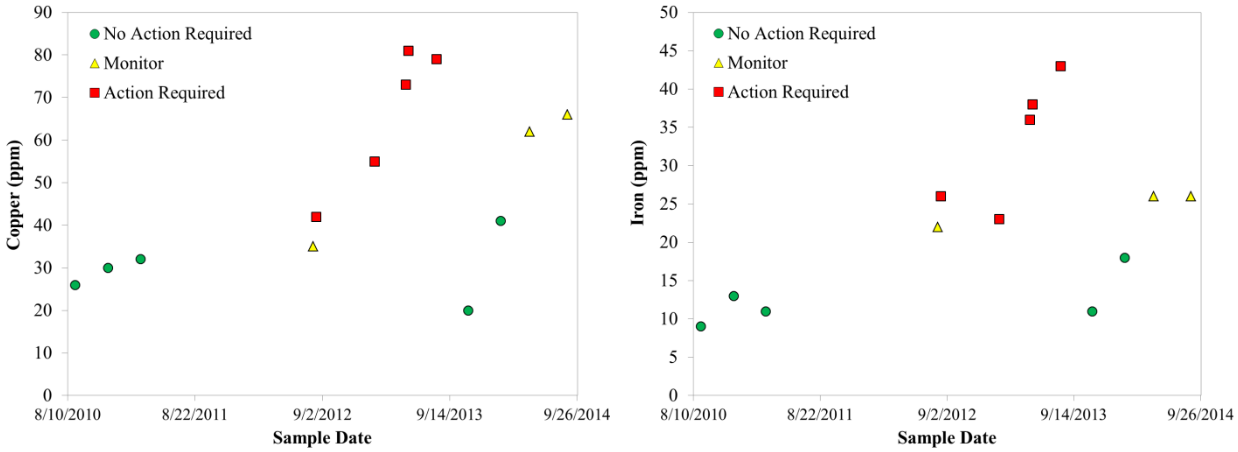
(b) Iron (Fe)



(c) Tin (Sn)

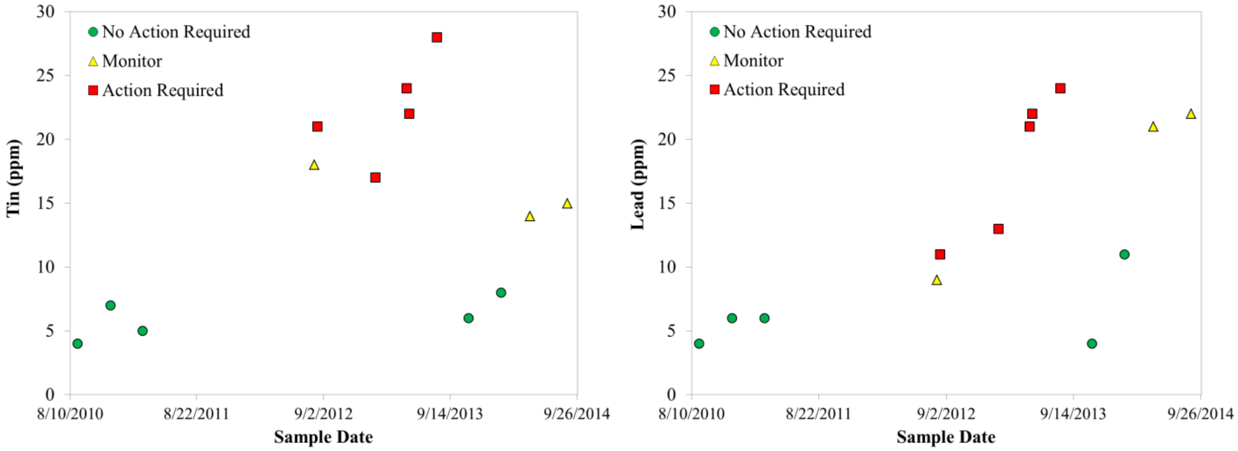
(d) Lead (Pb)

Figure B-2. Wear Metal Concentrations in Oil Samples from NC-1755 Head End Power Engine



(a) Copper (Cu)

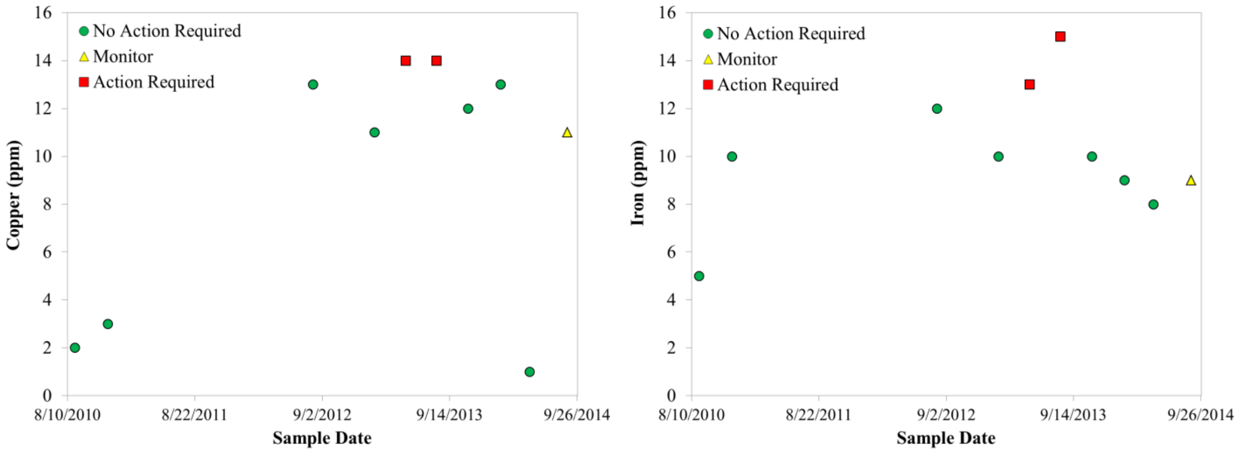
(b) Iron (Fe)



(c) Tin (Sn)

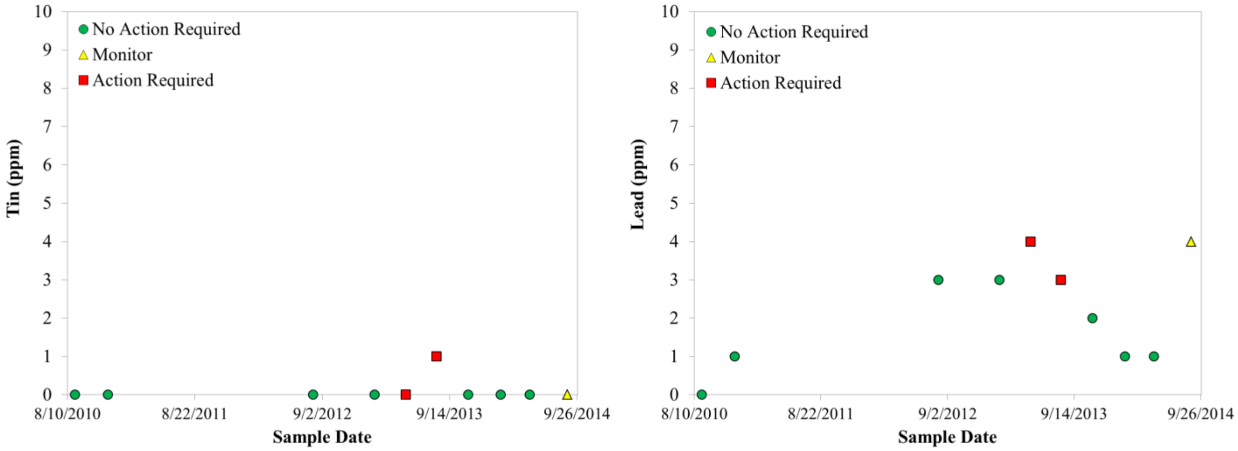
(d) Lead (Pb)

Figure B-3. Wear Metal Concentrations in Oil Samples from NC-1797 Prime Mover Engine



(a) Copper (Cu)

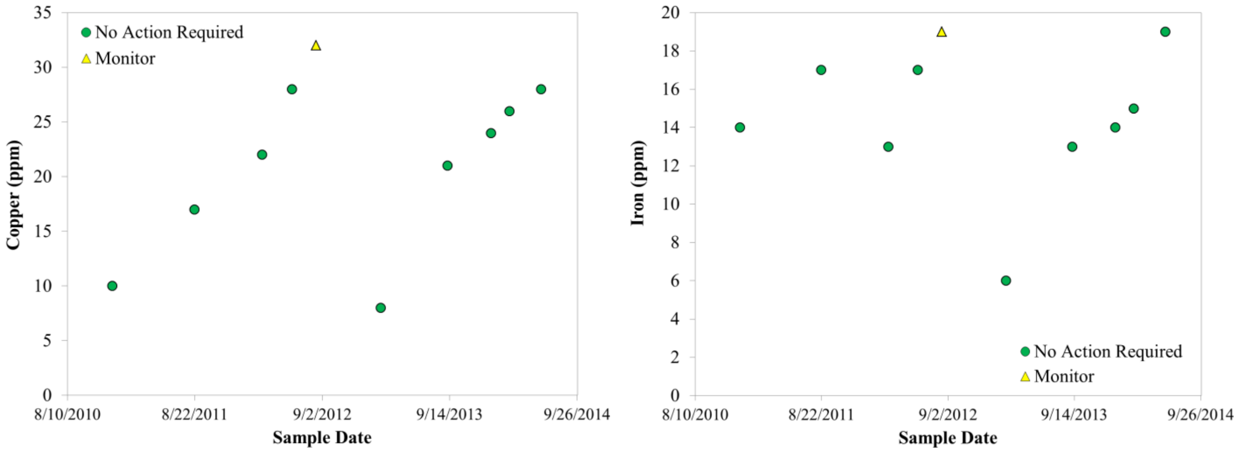
(b) Iron (Fe)



(c) Tin (Sn)

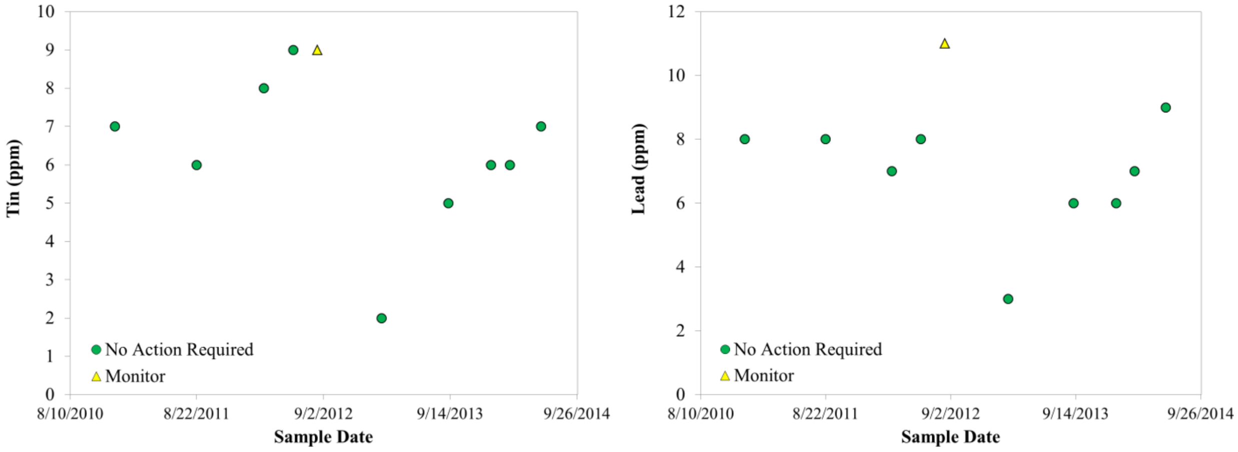
(d) Lead (Pb)

Figure B-4. Wear Metal Concentrations in Oil Samples from NC-1797 Head End Power Engine



(a) Copper (Cu)

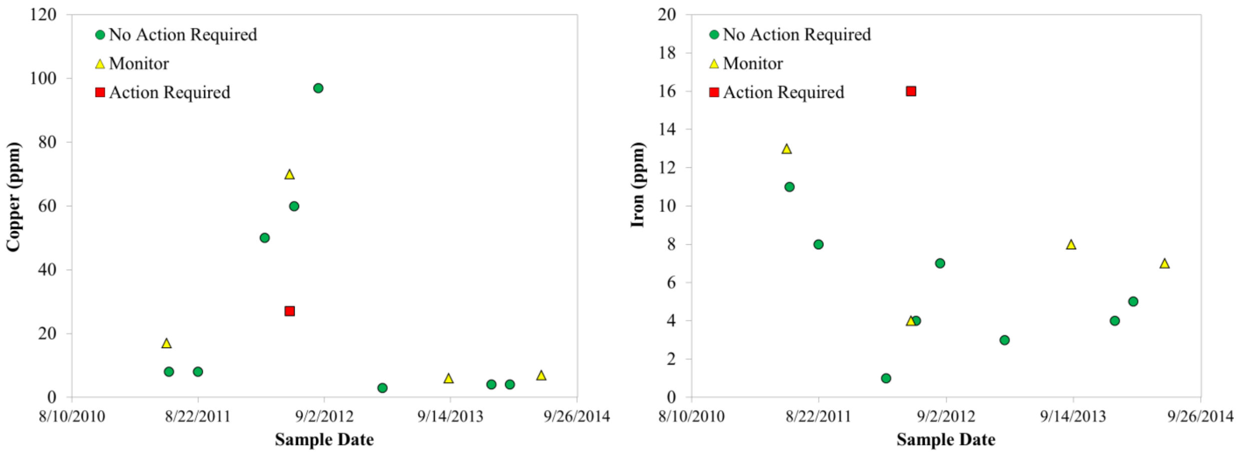
(b) Iron (Fe)



(c) Tin (Sn)

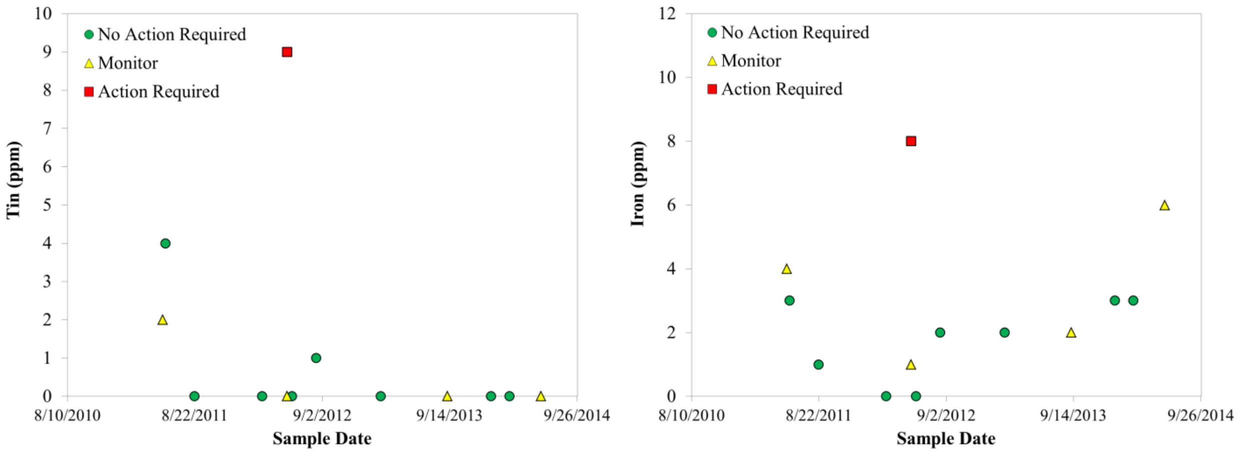
(d) Lead (Pb)

Figure B-5. Wear Metal Concentrations in Oil Samples from NC-1810 Prime Mover Engine



(a) Copper (Cu)

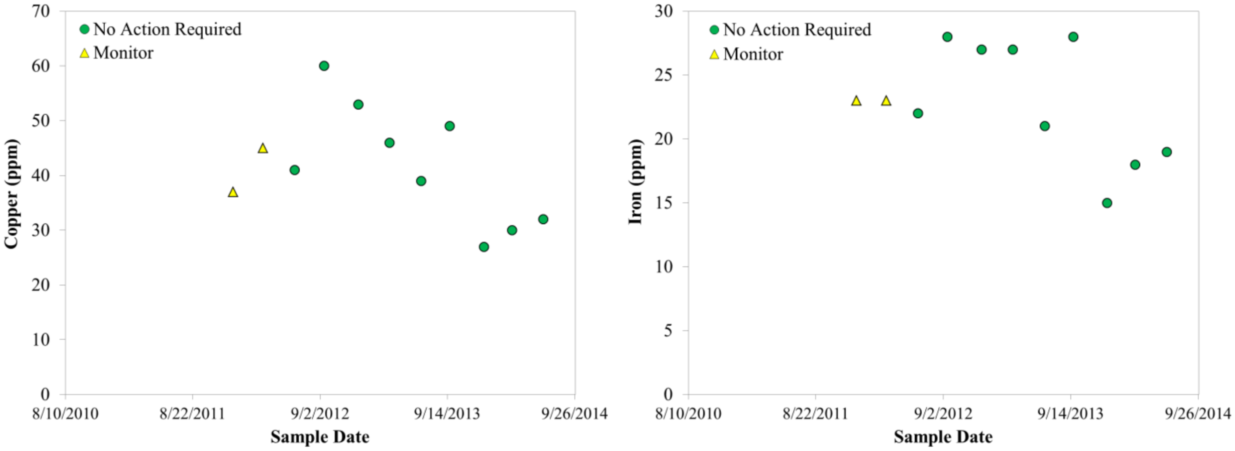
(b) Iron (Fe)



(c) Tin (Sn)

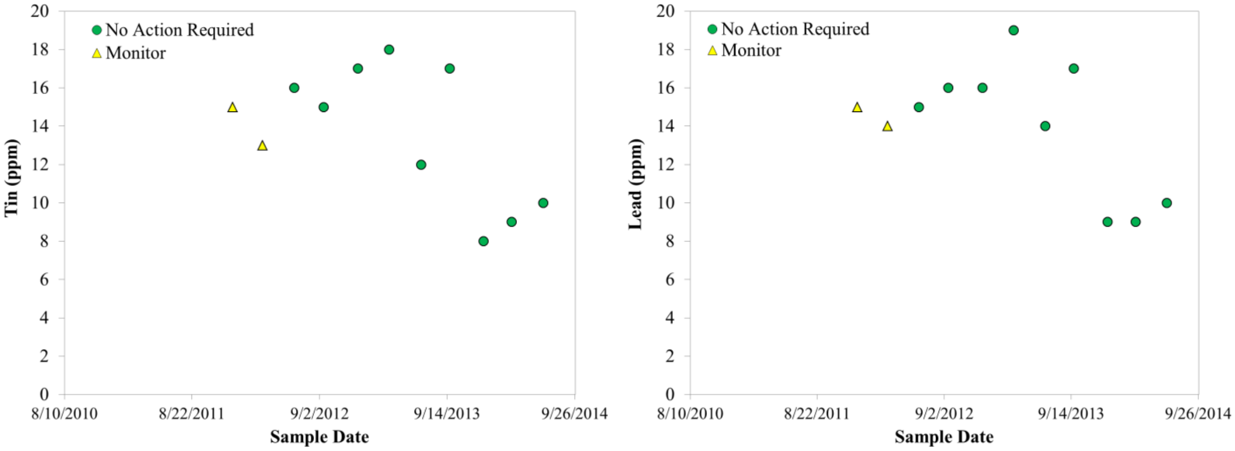
(d) Lead (Pb)

Figure B-6. Wear Metal Concentrations in Oil Samples from NC-1810 Head End Power Engine



(a) Copper (Cu)

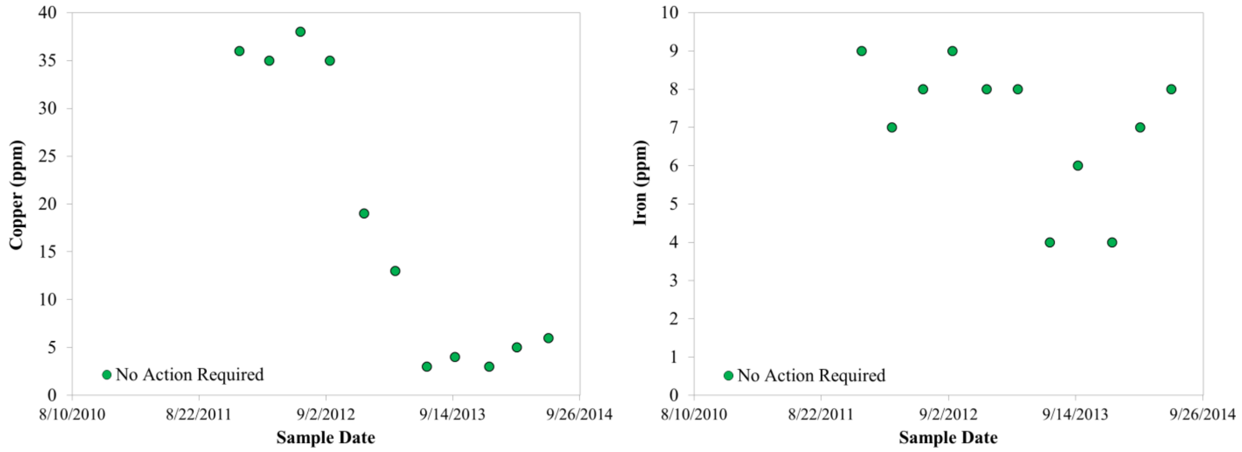
(b) Iron (Fe)



(c) Tin (Sn)

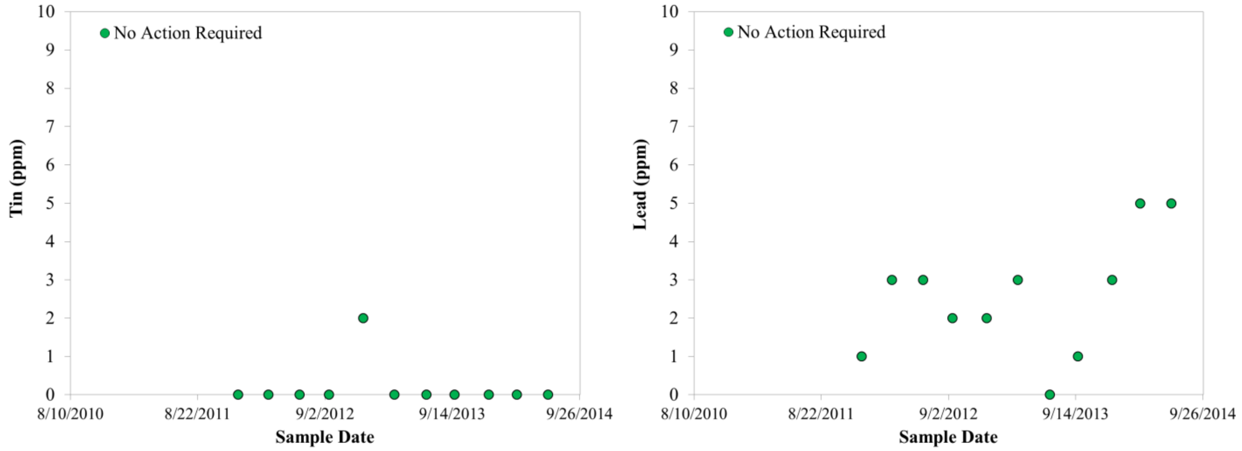
(d) Lead (Pb)

Figure B-7. Wear Metal Concentrations in Oil Samples from NC-1859 Prime Mover Engine



(a) Copper (Cu)

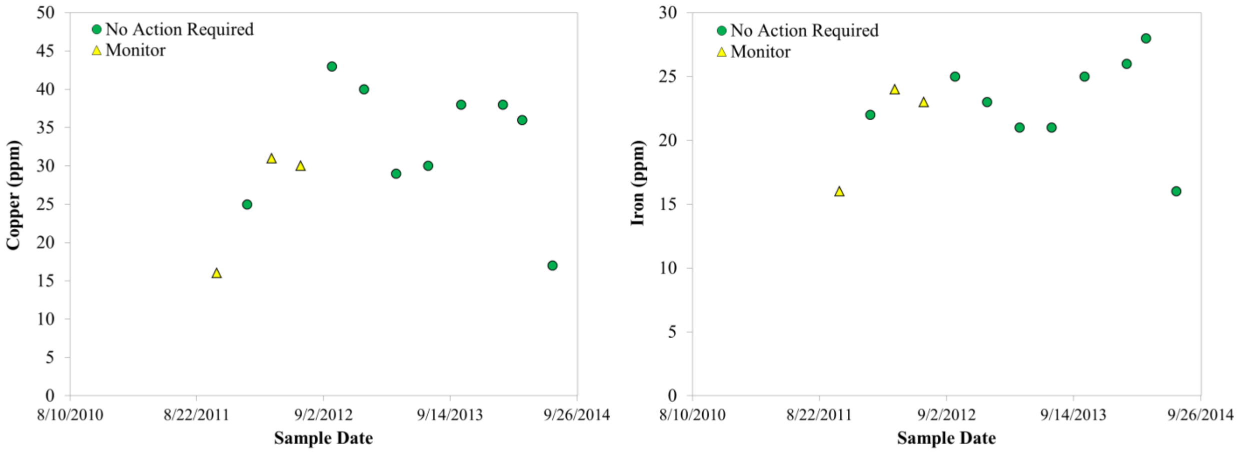
(b) Iron (Fe)



(c) Tin (Sn)

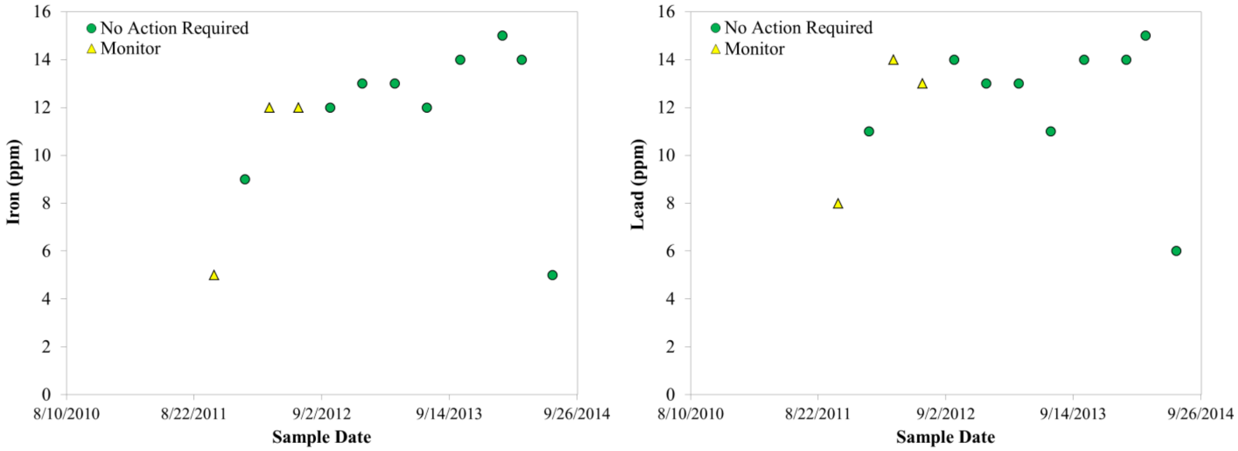
(d) Lead (Pb)

Figure B-8. Wear Metal Concentrations in Oil Samples from NC-1859 Head End Power Engine



(a) Copper (Cu)

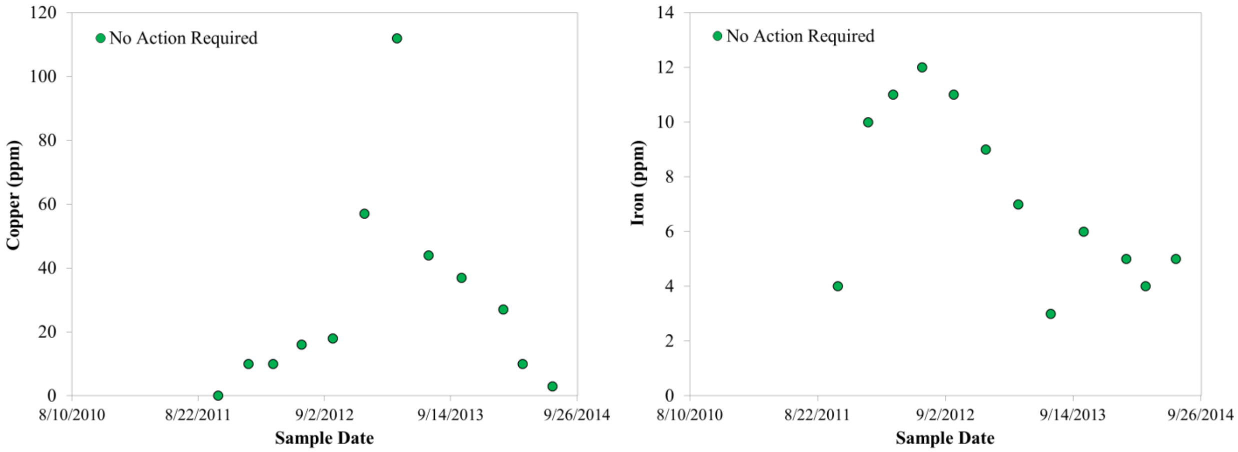
(b) Iron (Fe)



(c) Tin (Sn)

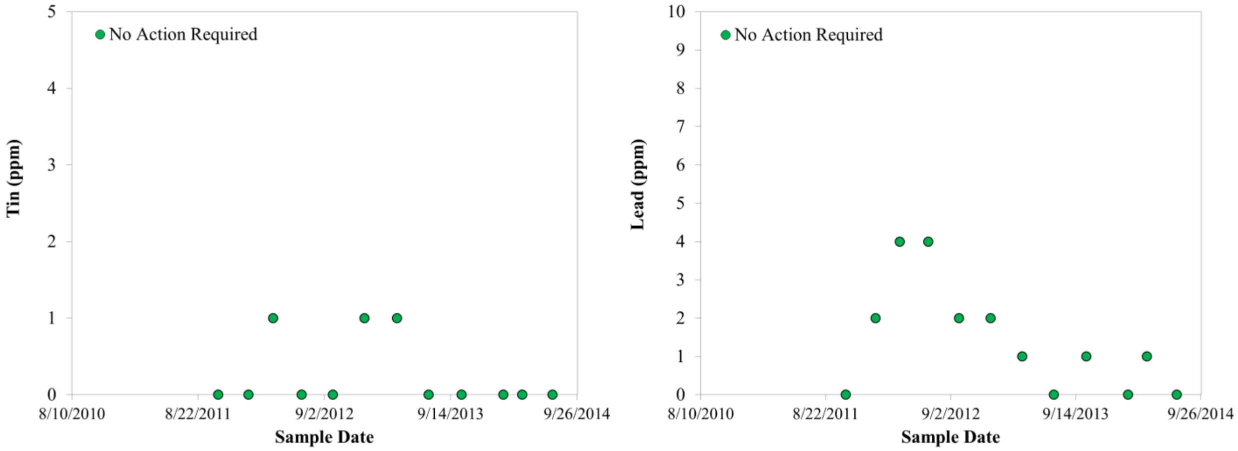
(d) Lead (Pb)

Figure B-9. Wear Metal Concentrations in Oil Samples from NC-1869 Prime Mover Engine



(a) Copper (Cu)

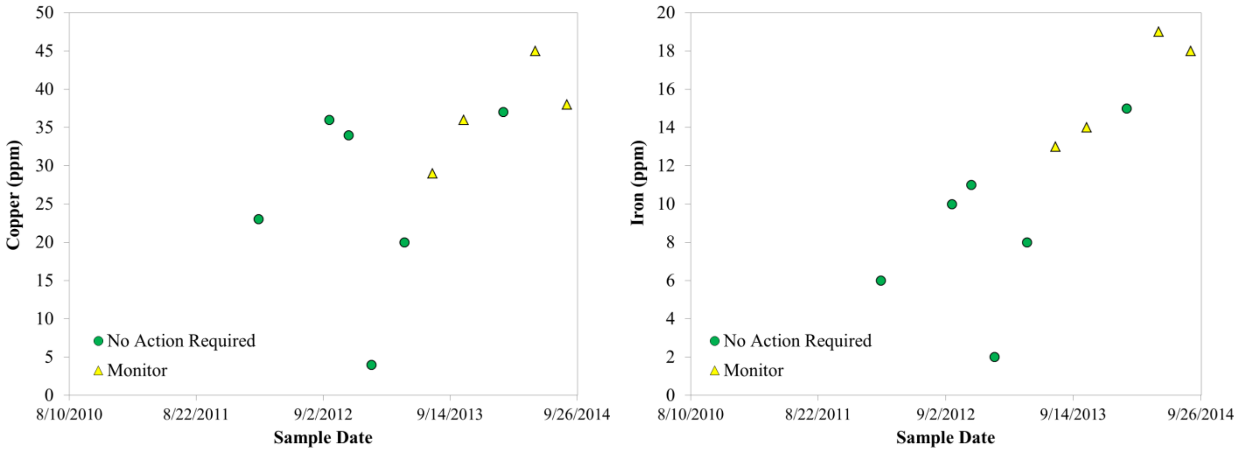
(b) Iron (Fe)



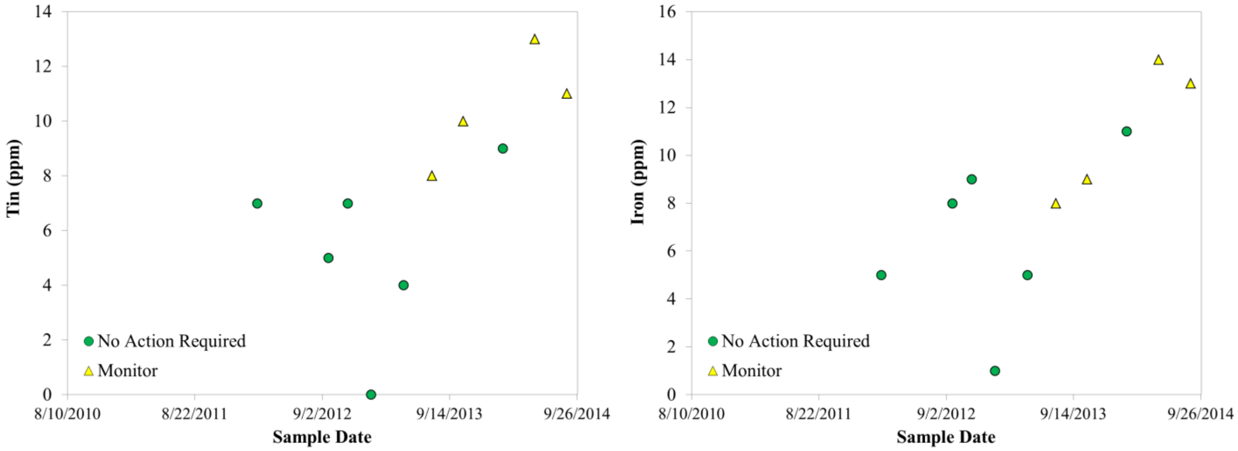
(c) Tin (Sn)

(d) Lead (Pb)

Figure B-10. Wear Metal Concentrations in Oil Samples from NC-1869 Head End Power Engine

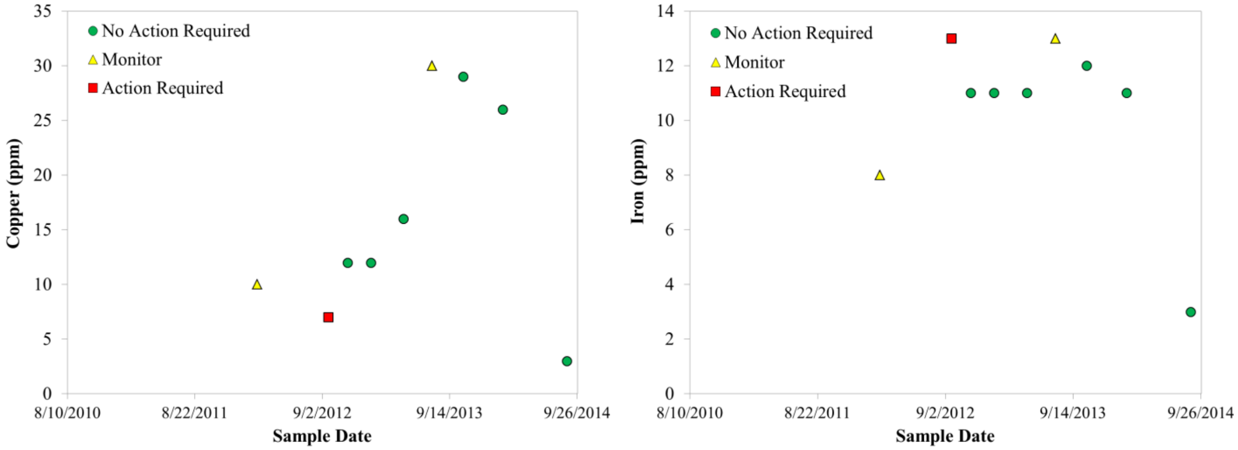


(a) Copper (Cu) (b) Iron (Fe)



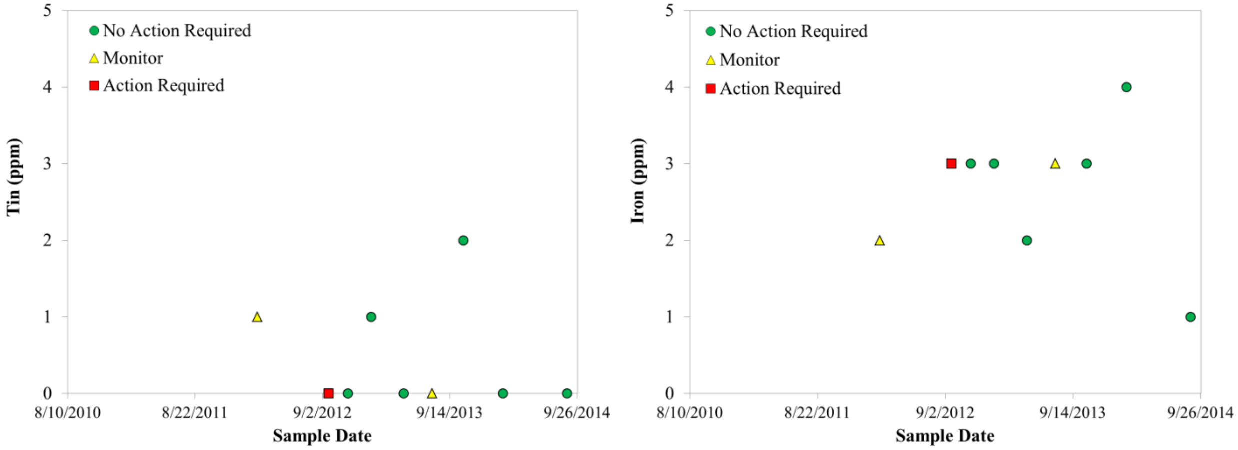
(c) Tin (Sn) (d) Lead (Pb)

Figure B-11. Wear Metal Concentrations in Oil Samples from NC-1893 Prime Mover Engine



(a) Copper (Cu)

(b) Iron (Fe)



(c) Tin (Sn)

(d) Lead (Pb)

Figure B-12. Wear Metal Concentrations in Oil Samples from NC-1893 Head End Power Engine

Appendix C.
Fuel Price Data

BACKGROUND

To determine the difference in fuel costs for operating the North Carolina Department of Transportation (NCDOT) fleet on various blends of biodiesel compared to ultra-low sulfur diesel (ULSD), the fuel receipts for all ULSD and biodiesel deliveries were collected and analyzed.

Four locomotives in the NCDOT fleet have operated on biodiesel. Table C-1 outlines the locomotives that have operated on biodiesel blends, the composition of the biodiesel blends, and dates of operation. All biodiesel blends were derived from petrodiesel and a 100 percent soy-based biodiesel stock.

Table C-1. Schedule of Biodiesel Operation by Locomotives in the NCDOT Fleet

Fuel Blend		**NC-1797**	**NC-1810**	**NC-1859**	**NC-1893**
B10	10% biodiesel 90% petrodiesel	2/2014 - 3/2014	6/2012 - 9/2012	1/2014 - 2/2014	7/2013 - 9/2013
B20	20% biodiesel 80% petrodiesel	3/2014 - 4/2014	9/2012 - 10/2012 1/2013 - 7/2013	11/2013 - 12/2013	n/a
B40	40% biodiesel 60% petrodiesel	4/2014 - 6/2014	10/2012 - 1/2013	9/2013 - 11/2013	n/a
B60	60% biodiesel 40% petrodiesel	n/a	7/2013 - 11/2013	n/a	n/a
B80	80% biodiesel 20% petrodiesel	n/a	11/2013 - 1/2014	n/a	n/a
B100	100% biodiesel	n/a	1/2014 - 2/2014	n/a	n/a

The fuel cost data to date were obtained from RailPlan International, In. B20 biodiesel is obtained via a North Carolina state procurement contract, while the other biodiesel blends were purchased without any discount.

RESULTS

Figure C-1 depicts the price of ULSD per gallon from the start of the research project to present. Figure C-2 depicts the difference in price between six different biodiesel blends (B10, B20, B40, B60, B80, and B100) and ULSD. Figure C-3 depicts the average difference in price between the six difference biodiesel blends compared to ULSD, and the range in price differences. In some instances, the cost of B10, B20, B60, B80, and B100 biodiesel cost less per gallon than ULSD. On average, the cost of a gallon of ULSD during the time period was $3.12, and varied from $2.74 to $3.45. On average, B10, B20, B40, and B60 biodiesel cost 14, 13, 26, and 19 cents more per gallon compared to ULSD, respectively. Assuming that a locomotive consumes 200 gallons of fuel during a one-way trip between Raleigh and Charlotte, regardless of the fuel being used, the use of B20 biodiesel would cost an additional $26.00 one-way. On average, the cost B80 and B100 biodiesel were 16 and 20 cents per gallon less than the cost of ULSD, respectively. In most instances, the cost of a gallon of B80 (11 out of 15 fuel purchases) or B100 (6 out of 7 fuel purchases) was less than the cost of a gallon of ULSD.

CONCLUSION

The cost of ULSD and biodiesel blends has varied since the beginning of the research project. The average price premium for B20 biodiesel was 4.1% more than the price of ultra-low sulfur diesel. The cost of B10, B20, B40, and B60 biodiesel per gallon was more than ULSD, while B80 and B100 cost less than ULSD per gallon. However, the cost of ULSD and biodiesel fluctuates from week to week.

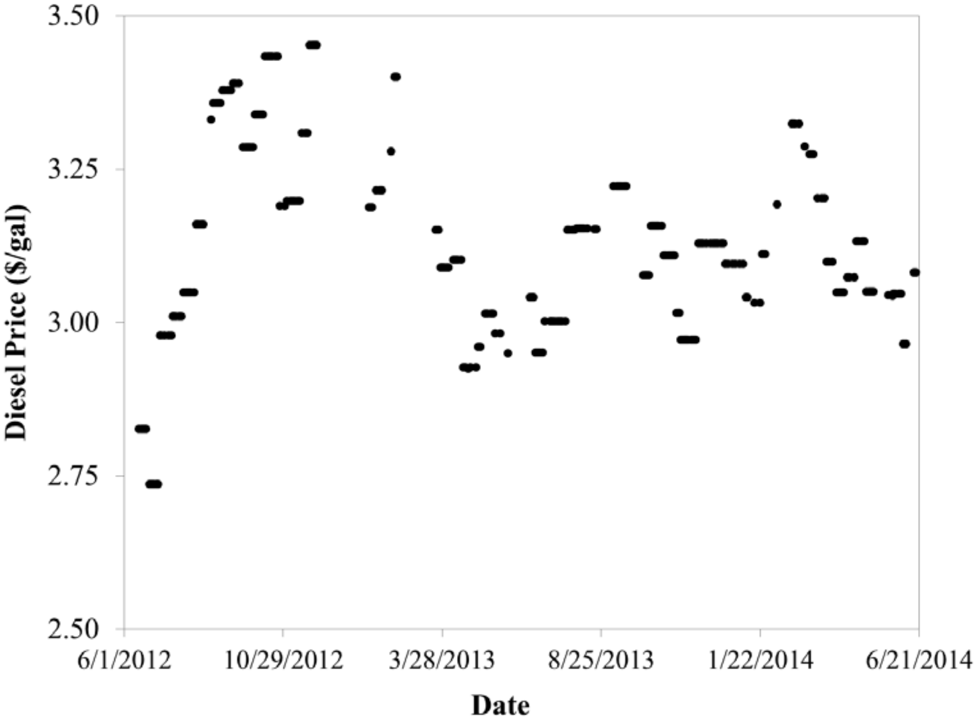


Figure C-1. Ultra-low sulfur diesel prices for June 2012 through June 2014

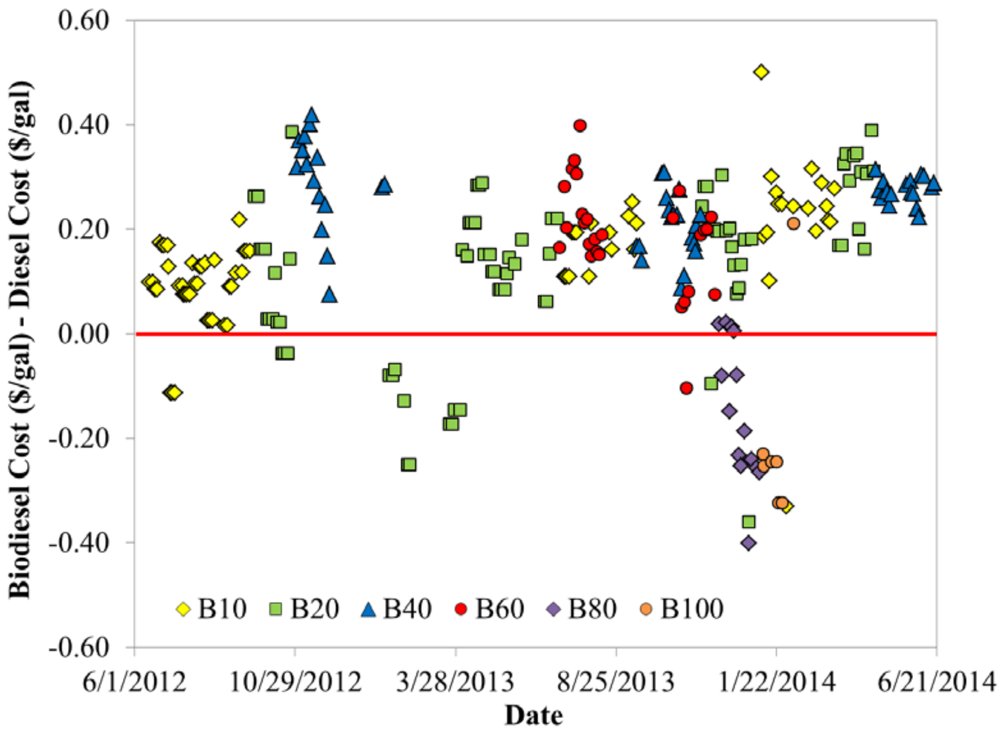


Figure C-2. Difference in price per gallon for biodiesel blends versus ultra-low sulfur diesel for June 2012 through June 2014

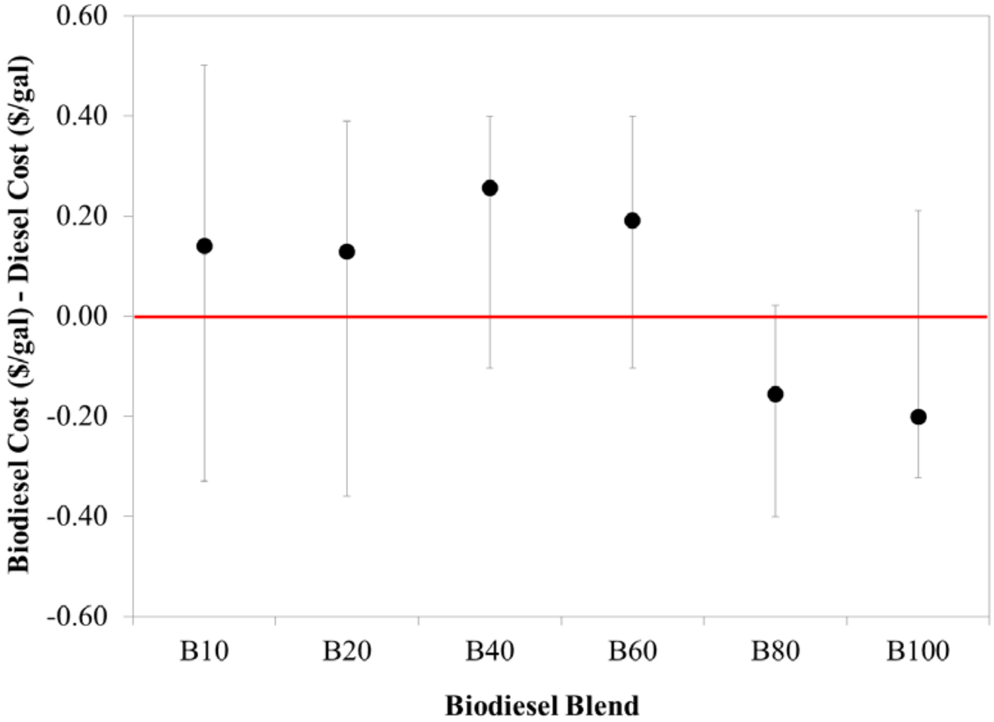


Figure C-3. Range of differences in price per gallon for biodiesel blends versus ultra-low sulfur diesel

Appendix D.
Results of Rail Yard and Over the Rail Measurements for NC-1797

D.1 Summary of Results for NC-1797 on B40

The purpose of these rail yard and over-the-rail emissions measurements of a locomotive prime mover engine was to compare fuel use and emission rates for an ultra-low sulfur diesel (ULSD) baseline and multiple biodiesel fuel blends. These measurements were conducted as part of a Federal Railroad Administration (FRA) research project to evaluate the emissions implications of locomotive biodiesel use compared to ULSD.

Rail yard and over-the-rail measurements were conducted in July 2014 on the prime mover engine of locomotive NC-1797 operating on 40 percent soy-based biodiesel and 60 percent ULSD (B40). Rail yard and over-the-rail measurements were previously conducted on the same locomotive prime mover engine using ULSD, 10 percent soy-based biodiesel and 90 percent ULSD (B10), and 20 percent soy-based biodiesel and 80 percent ULSD (B20). The dates of the measurements of the NC-1797 prime mover engine in the rail yard and over the rail are given in Table 1. Each rail yard measurement involved three replicates of a measurement cycle. Each over-the-rail measurement typically comprised of six one-way trips between Raleigh and Charlotte, NC.

Table D-1. Fuel Characteristics and Dates Measured on NC-1797 Prime Mover Engine

Fuel Name	Percent Petrodiesel	Percent Biodiesel	Dates of Measurements	
			Rail Yard	Over-The-Rail
ULSD	100	0	October 22, 2013	October 9-11, 2013
B10	90	10	March 10, 2014	March 11-13, 2014
B20	80	20	April 14, 2014	April 15-17, 2014
B40	60	40	July 21, 2014	July 16-18, 22, 2014

The prime mover engine is an EMD 12-710G3B. The engine was originally manufactured in 1998 and was rebuilt by AMTRAK in 2012. The 140-liter engine has a peak engine output of 3000 horsepower (hp) at an engine speed of 900 revolutions per minute (rpm).

The fuel use and emission rates are inferred from measurements made with a Portable Emissions Measurement System (PEMS). The PEMS utilized for measurements was the Axion system manufactured by Clean Air Technologies International, Inc. (CATI). Prior to each set of measurements, each PEMS was calibrated with a California Bureau of Automotive Repair (BAR) certified calibration gas (BAR-97 Low).

RESULTS

The cycle average emission rates for the rail yard and over-the-rail measurements are shown in Table D-2. The cycle average emission rates are based on the line-haul duty cycle used by the U.S. Environmental Protection Agency (EPA) for regulatory purposes. The EPA line-haul duty cycle specifies the percentage of operating time spent in idle, in all eight throttle notch positions, and in dynamic braking. Dynamic braking takes place during over-the-rail operation, but cannot be simulated in the rail yard. During dynamic braking, the traction motors act as generators, and the resulting electrical current was dissipated in a resistor grid. Thus, the time apportioned for dynamic braking in the line-haul duty cycle (12.5 percent) is combined with the time apportioned for idling in the duty cycle (38.0 percent). Therefore, idling accounts for 50.5 percent of the duty cycle used to calculate rail yard cycle average emission rates. During over-the-rail measurements, dynamic braking was observed.

Table D-2 summarizes cycle average results for each fuel that has been evaluated averaged over multiple rail yard replicates and over-the-rail trips. The results are described in more detail subsequently. The NO_x emission rates range from 14.1 to 16.1 g/bhp-hr from the over-the-rail results which, although quantitatively higher, are the same magnitude as the rail yard results. Similarly, the results for HC, CO, and PM are of similar magnitude when comparing over-the-rail to rail yard measurements.

METHODS

A PEMS was used to quantify the fuel use and emission rates of the NC-1797 prime mover engine for rail yard measurements conducted at the NCDOT Capital Yard Maintenance Facility in Raleigh, NC and for over-the-rail measurements conducted during real-world passenger rail service.

Instruments

Instruments used for data collection include a PEMS with engine sensor array and a locomotive activity data recorder.

Portable Emissions Measurement System

The Axion PEMS is comprised of two parallel five-gas analyzers; a laser light scattering, real-time PM detection system, an engine sensor array, and an on-board computer. The engine sensor array was used to measure manifold absolute pressure (MAP), intake air temperature (IAT), and engine speed (RPM). To measure MAP and IAT, a pressure sensor and thermistor were attached to barb fittings installed on an engine cylinder cover. The RPM optical sensor was used in combination with reflective tape to measure the time interval of revolutions of the flywheel which rotates at the same speed as the engine crankshaft. Emission concentrations and engine activity data were recorded on a second-by-second basis.

Table D-2. Preliminary EPA Line-Haul Cycle Average Emission Rates for the NC-1797 Prime Mover Engine Operated on Multiple Fuels in the Rail Yard and Over-the-Rail[a,b,c]

(a) Rail Yard Measurements

Measurement	NO_x (g/bhp-hr)	HC (g/bhp-hr)	CO (g/bhp-hr)	Opacity-based PM (g/bhp-hr)
ULSD	11.2	1.01	0.6	0.19
B10	14.0	3.16	0.7	0.21
B20	11.9	5.34	0.7	0.14
B40	12.5	1.58	0.7	0.21

(b) Over-the-Rail Measurements

Measurement	NO_x (g/bhp-hr)	HC (g/bhp-hr)	CO (g/bhp-hr)	Opacity-based PM (g/bhp-hr)
ULSD	14.1	3.49	0.8	0.16
B10	15.1	2.81	0.5	0.17
B20[d]	14.2	2.19	0.2	0.13
B40	16.1	4.45	1.0	0.25

[a] *The cycle average emission rates are based on the U.S. EPA line-haul duty cycle used for regulatory purposes.*

[b] *NO_x, HC, and opacity-based PM emission rates from the Axion are adjusted with multipliers of 1.053, 2.5, and 5, respectively, as bias correction.*

[c] *Dynamic braking not observed during rail yard measurements. Therefore, idling accounts for 50.5 percent of the duty cycle used to calculate rail yard cycle average emission rates.*

[d] *The cycle average emission rates for over-the-rail measurements on B20 are based on 5 one-way trips.*

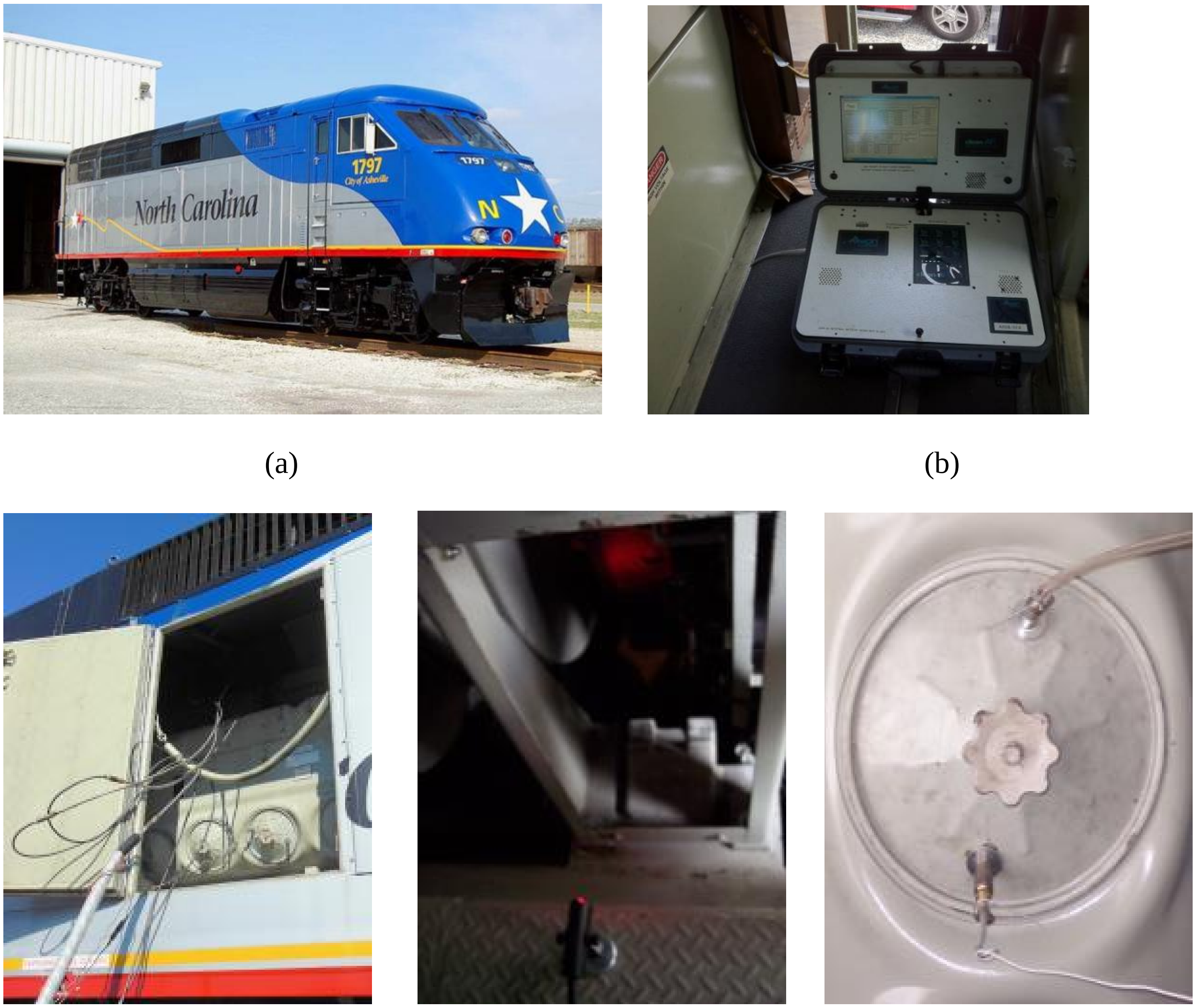
The Axion measures NO with an electrochemical cell. Diesel engine NO_x emissions typically comprise of approximately 95 vol-% NO and 5 vol-% NO_2. Therefore, a multiplicative correction factor of 1.053 was included to approximate for total NO_x. CO and HC are measured using non-dispersive infrared (NDIR). NDIR responds well to straight chain hydrocarbons, but, on average, it detects or responds to only about half of the actual HC concentrations. Based on literature review, a multiplicative correction factor of 2.5 was used to approximate for total HC. As reported in Appendix E, supplemental measurements are being conducted in the rail yard with an additional PEMS that is able to measure NO and NO_2, and to measure HC using both NDIR and flame ionization detection (FID). Based on these supplemental measurements, these correction factors will be verified or adjusted. In previous work, we compared average PM emission rates estimated based on the PEMS measurements to average emission rates reported for similar engines based on Federal Reference Method (FRM) measurements. Based on this comparison, a multiplicative correction factor of 5 was inferred to approximate for total PM.

Photographs of the PEMS setup during rail yard and over-the-rail measurements of NC-1797 are given in Figure D-1.

Locomotive Activity Data Recorder

The NC-1797 locomotive has an EMD EM2000 Locomotive Computer System that records locomotive activity data. Real-time engine RPM and horsepower output data are displayed in the locomotive cab. These and other recorded data, including throttle (notch) position, were used to estimate mass per time fuel use and emission rates. At idle, the on-board readout does not display a value for engine output. Therefore, the engine load at idle was assumed to be 10 hp based on measurements of another EMD12-710 prime mover engine on an engine dynamometer.

Figure D-1. Measurement of F59PHI Locomotive NC-1797



(a) (b)

(c) (d) (e)

(a) Locomotive NC-1797 at the NCDOT Capital Yard Maintenance Facility;

(b) Axion Portable Emissions Measurement System unit in locomotive cab for use during over-the-rail measurements;

(c) Sample lines connecting prime mover engine exhaust pipe to PEMS unit;

(d) Engine speed sensor placed at prime mover engine flywheel;

(e) Intake air temperature and manifold absolute pressure sensor ports on prime mover engine

Fuel Use and Emissions

Fuel-based emission rates, in g/gal, are estimated based on the estimation of mass air flow (MAF) through the engine and inference of the air-to-fuel ratio (AFR) from the measured exhaust composition. MAF was estimated based upon the "speed density" method, which depends on engine displacement, compression ratio, IAT, MAP, RPM, and volumetric efficiency (VE). VE was the ratio of the actual volume of air that flows through the engine cylinder versus the physical cylinder volume. VE was estimated based on the product of measured RPM and MAP observed during dynamometer measurements of similar EMD 12-710 prime mover engines.

Mass emission rates, in g/s, are estimated based upon the mole fraction of each pollutant on a dry basis, dry exhaust molar flow rate, and molecular weight of exhaust gas. Engine output-based emission rates, in g/bhp-hr, are estimated based on the mass emission rate, divided by the engine output observed from the locomotive activity data recorder.

For particulate matter, the PEMS reports milligrams per cubic meter concentration on a dry basis. The dry exhaust flow per gallon of fuel consumed was estimated by inferring the air-to-fuel ratio from the exhaust composition based on the volume percent of carbon in the exhaust. The volume of exhaust produced per gallon of fuel was multiplied with the mass per volume concentration of PM to estimate the g/gal PM emission rate. The latter was multiplied by fuel flow per unit engine output to estimate the engine output-based PM emission rate, in g/bhp-hr.

RESULTS

This section discusses the results of the rail yard and over-the-rail measurements of the NC-1797 prime mover engine operated on B40 biodiesel, and includes a comparison to previously reported measurements on ULSD.

Rail Yard Measurements

Three rail yard emissions measurement replicates were conducted on July 21, 2014. Emissions measurements were taken continuously, including steady state at each notch position and transitions between notch positions. During data analysis, only steady state data were used to calculate notch average emission rates. The idle and notch average emission rates were weighted by the EPA line-haul duty cycle to estimate cycle average rates.

The EPA line-haul cycle average emission rates were shown previously in Table D-2. These cycle average emission rates are based on the measured engine activity data (RPM, MAP, and IAT), inferred engine activity data (MAF and AFR), and measured exhaust concentrations. The measured engine activity data and exhaust NO concentrations were repeatable between replicates, as indicated in Figure D-2. The inter-replicate ratios of the standard deviation to the mean (coefficient of variation) were less than 0.03 for all notch positions for RPM, IAT, MAP, MAF, and AFR. This indicates that the prime mover engine was operating consistently during all three replicate measurements.

An increasing trend in fuel use rate was apparent with increasing notch position, as shown in Figure D-3. Fuel use rates range from 5.1 g/s during Idle to 145 g/s during notch 8. Consistent fuel use rates among the three replicates were observed for all notch positions, as the standard deviations were typically less than 1.5 g/s.

The NO concentrations were consistent among the three replicates, as the coefficient of variation was less than 0.03 for all notch positions. Similarly, the NO emission rates among the three replicates were consistent, as shown in Figure D-4. The inter-replicate coefficient of variation for each notch position for the mass per gallon of fuel NO emission rates less than 0.02, which indicates small variability between replicates.

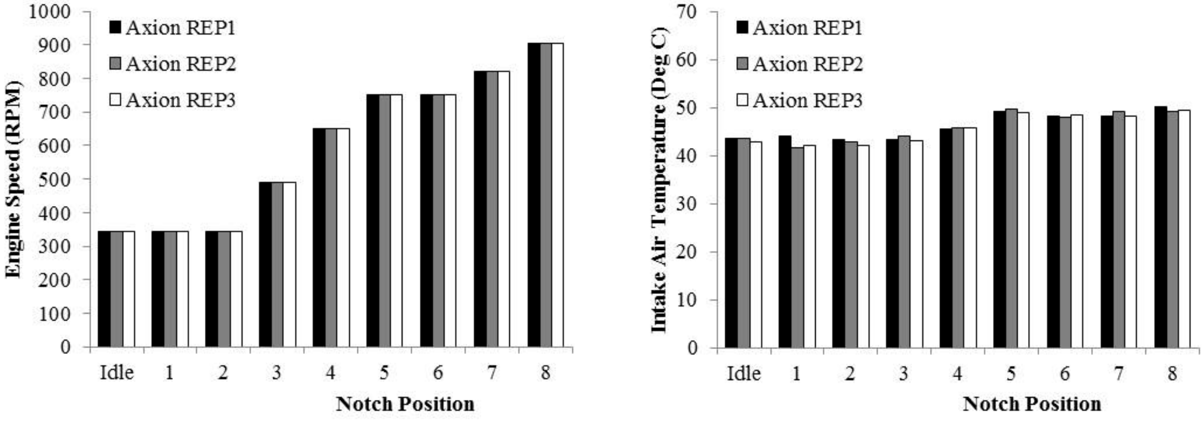
For HC emission rates across the three replicates, the coefficient of variation varied from 0.28 to 1.64, depending on the notch position. Approximately 53 percent of the notch-specific HC concentration measurements are below the detection limit of the PEMS and, therefore, are not significantly different than zero. Differences in measured exhaust HC concentrations are the primary reason for inter-replicate variability in the notch-specific HC emission rates, as shown in Figure D-5. The inter-replicate coefficient of variation in the estimated HC emission rates was 1.07, on average for each notch position.

There was also variability in the estimated notch-specific CO emission rates between the three replicate measurements, as shown in Figure D-6. Approximately 77 percent of the notch-specific CO concentrations measured were below the PEMS detection limit and, therefore, are not significantly different than zero. However, because of imprecision in the measurements at or below the detection limit, there was large variability in estimated average concentrations. The inter-replicate coefficient of variation in the estimated CO emission rates was 1.31, on average, for each notch position. However, on an absolute basis, the exhaust CO concentrations were typically less than 0.007 volume percent, except for notch 8. Exhaust CO concentrations averaged 0.015 volume percent for Notch 8, with an inter-replicate coefficient of variation of 0.25.

PM emission rates, as shown in Figure D-7, were consistent across the three replicates, with inter-replicate coefficients of variation less than 0.07 for all notch positions except for Notch 8, which was 0.28.

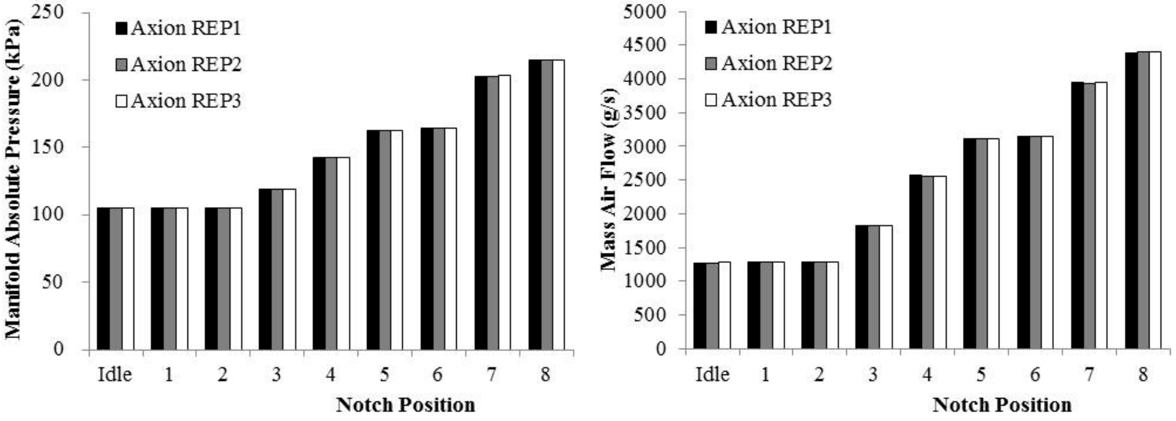
All of the NO, CO, HC, and PM concentrations measured were of the same magnitude as previous rail yard measurements of the same engine operating on ULSD, B10, and B20.

Figure D-2. Measured Engine Activity Data during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on B40 Biodiesel



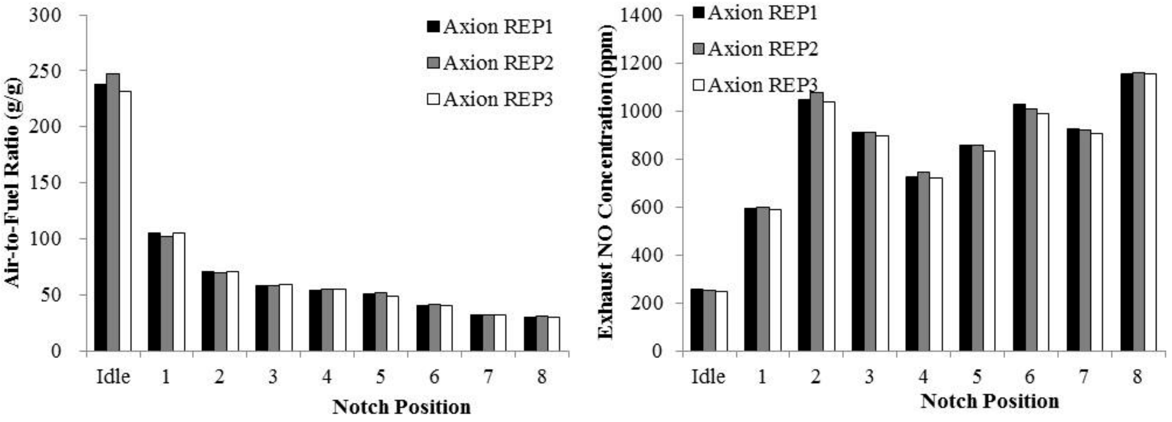
(a) Engine Speed

(b) Intake Air Temperature



(c) Manifold Absolute Pressure

(d) Mass Air Flow



(e) Air-to-Fuel Ratio

(f) Exhaust NO Concentration

Figure D-3. Estimated Fuel Use Rates during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on B40 Biodiesel

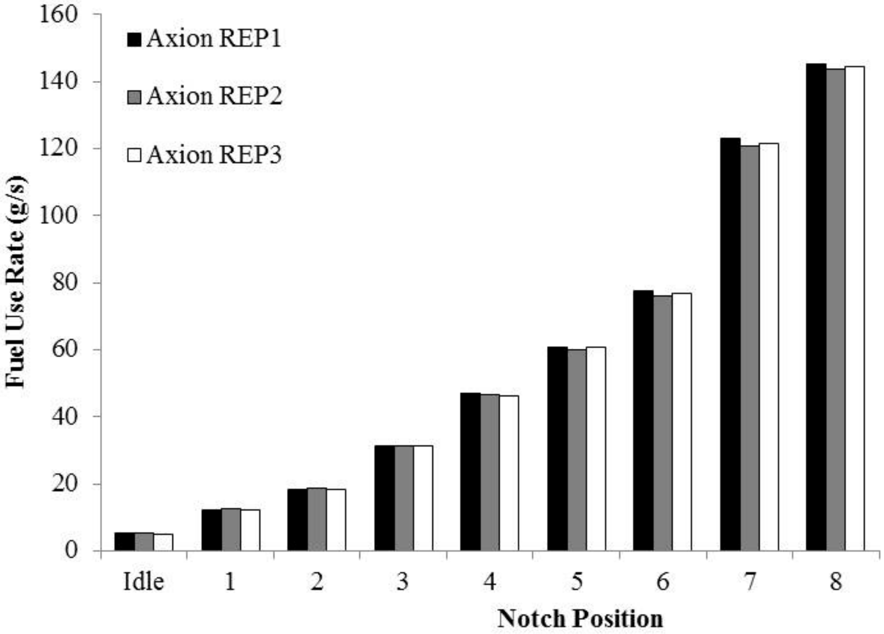


Figure D-4. Estimated NO_x Emission Rates during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on B40 Biodiesel

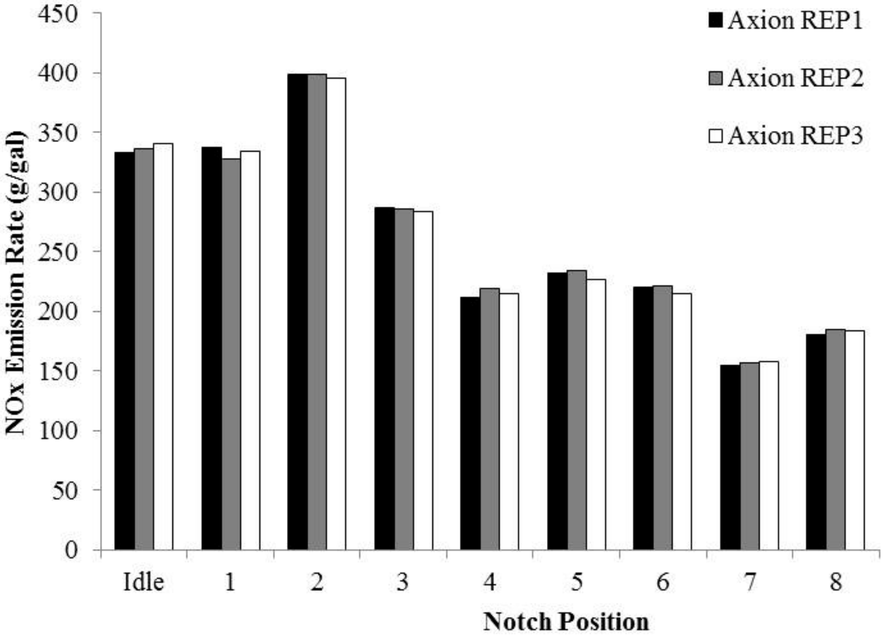


Figure D-5. Estimated HC Emission Rates during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on B40 Biodiesel

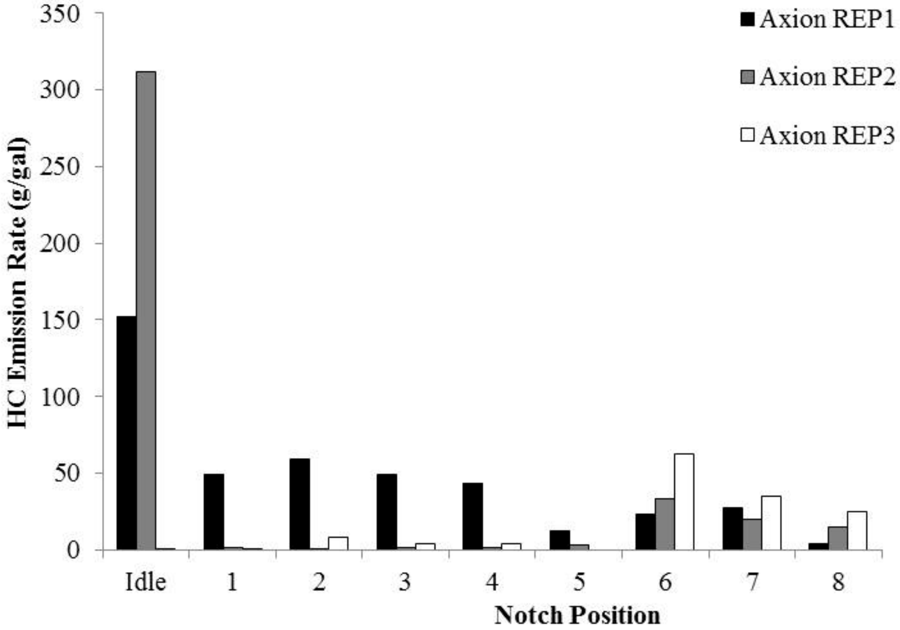


Figure D-6. Estimated CO Emission Rates during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on B40 Biodiesel

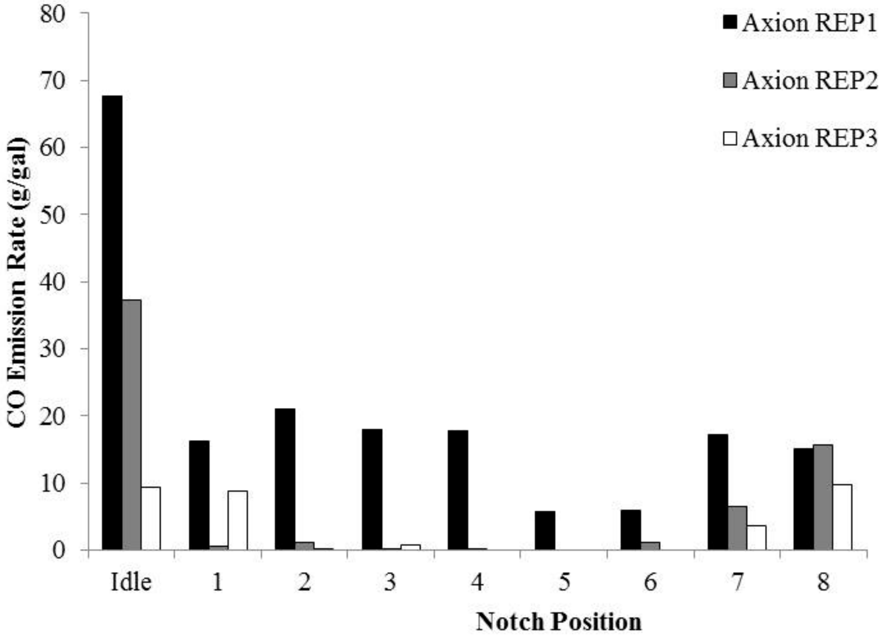
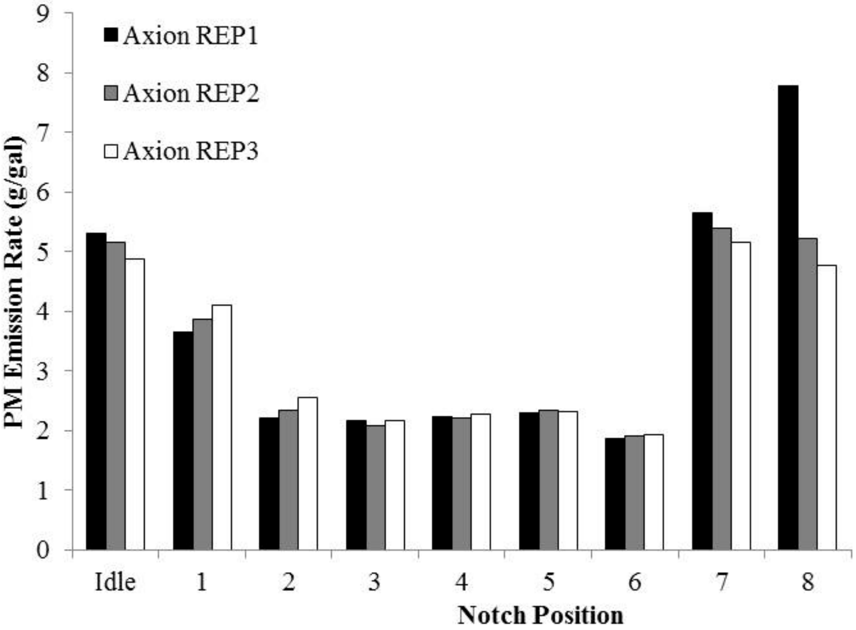


Figure D-7. Measured PM Emission Rate during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on B40 Biodiesel



Estimated EPA line-haul duty cycle average emission rates for each of the three replicate rail yard measurements are given in Table D-3. The NO_x cycle average emission rates were consistent among the replicates, with coefficients of variation less than 0.01. The coefficients of variation for PM, HC, and CO emission rates are 0.20, 0.21, and 0.47, respectively. Differences in emission rates are attributable to differences in measured exhaust concentrations. Values for engine activity parameters (i.e., RPM, IAT, MAP) were similar across all measurements, as given in Figure D-2, and thus are not significant factors in inter-replicate variation in emission rates.

Table D-3. Estimated EPA Line-Haul Cycle Average Emission Rates for Rail Yard Replicate Measurements of NC-1797 Prime Mover Engine Operated on B40 Biodiesel

	NO_x **(g/bhp-hr)**	**HC** **(g/bhp-hr)**	**CO** **(g/bhp-hr)**	**Opacity-based PM** **(g/bhp-hr)**
Replicate 1	12.5	1.43	1.1	0.26
Replicate 2	12.5	1.95	0.7	0.19
Replicate 3	12.4	1.35	0.4	0.18
Average of 3 Replicates	**12.5**	**1.58**	**0.7**	**0.21**
Coefficient of Variation	**<0.01**	**0.21**	**0.47**	**0.20**

NO_x, HC, and PM are adjusted with multipliers of 1.053, 2.5, and 5, respectively, as bias correction.

Cycle average emission rates are based on EPA Line-Haul duty cycle.

Over-the-Rail Measurements

Six one-way trips of over-the-rail measurements were conducted on July 16, 17, 18, and 22, 2014. All six one-way trips were used for cycle average emissions rates analysis, and observed duty cycles for all six one-way trips were quantified.

Based on over-the-rail measurements, steady state notch average emission rates were estimated for idle, dynamic braking, and notches 1 to 8. To enable comparisons with other data, the notch average emission rates were weighted based on the EPA line-haul duty cycle. The EPA line-haul cycle average emission rates for the over-the-rail measurements of the NC-1797 prime mover engine operating on B40 biodiesel are shown in Table D-4. For each set of measurements, there was little variability between measured engine activity data during all days of measurements. The inter-run coefficients of variation were typically less than 0.04 for RPM, MAP, and absolute IAT. This indicates that the prime mover engine was operating consistently during over-the-rail measurements. Measured engine activity data during over-the-rail measurements were similar in magnitude to the measured engine activity data during rail yard measurements.

For notch average NO_x rates, the coefficient of variation was less than 0.14 for each notch position amongst the six one-way trips. The coefficients of variation for HC and CO are relatively high for each notch position. The coefficients of variation for HC typically ranged from 0.27 to 0.50. For CO, the coefficients of variation ranged from 0.24 to 1.03. However, 52 percent of the notch-specific CO concentrations were below the detection limit. These concentrations led to imprecision that contributes to large inter-run variability. For PM, the coefficients of variation ranged from 0.19 to 0.51 for all notch positions except for notch 7, for which the coefficients of variations were 1.05, respectively. Differences in measured exhaust pollutant concentrations and small sample size for some notch positions were the key reasons for the variability.

The EPA line-haul duty cycle average emission rates based on the average of the six over-the-rail measurements are quantitatively similar to the EPA line-haul duty cycle average emission rates based on the three rail yard replicates. The over-the-rail cycle average NO_x, CO, and HC emission rates were higher than the rail yard cycle average emission rate by 29 percent, 36 percent, and 182 percent, respectively. The cycle average over-the-rail PM emission rate were 19 percent higher than the cycle average rail yard emission rates, but the differences were only 0.04 g/bhp-hr on an absolute basis.

Differences in cycle average emission rates between rail yard and over-the-rail measurements can be attributed to various factors. RPM and MAP were essentially the same for rail yard and over-the-rail measurements. IAT differed on an absolute basis by less than 6 percent from run-to-run during over-the-rail measurements, indicating little to no inter-run differences. At notch 8, the engine output during rail yard measurements was 2,800 horsepower, while engine output was 3,000 horsepower during over-the-rail measurements. With notch 8 accounting for 16 percent of the EPA line-haul duty cycle, higher engine output decreases engine output-based emission rates and, therefore, cycle average emission rates. Finally, differences in measured exhaust concentrations between rail yard and over-the-rail measurements lead to differences in fuel use and emission rates. For example, for notches 3 through 7, the over-the-rail average NO_x concentrations for each of these notches were approximately 40 percent higher than for the rail yard. The over-the-rail average HC concentrations were all notch positions were approximately 50 percent lower than for the rail yard. CO concentrations were typically below the detection limit for all notch positions for both the rail yard and over-the-rail measurements, which leads to imprecision.

Table D-4. EPA Line-Haul Cycle Average Emission Rates for Over-the-Rail Measurements of NC-1797 Prime Mover Engine Operated on B40 Biodiesel

	NO_x (g/bhp-hr)	**HC** (g/bhp-hr)	**CO** (g/bhp-hr)	**Opacity-based PM** (g/bhp-hr)
Jul. 16, 2014 – Train 75	16.1	3.75	0.6	0.31
Jul. 16, 2014 – Train 76	15.9	3.58	0.7	0.35
Jul. 17, 2014 – Train 75	16.6	5.75	1.1	0.27
Jul. 17, 2014 – Train 76	16.6	6.38	1.8	0.22
Jul. 18, 2014 – Train 75	16.1	4.71	1.1	0.19
Jul. 22, 2014 – Train 76	15.2	2.54	0.7	0.16
Average	**16.1**	**4.45**	**1.0**	**0.25**
Coefficient of Variation	**0.03**	**0.32**	**0.43**	**0.28**

NO_x, HC, and PM are adjusted with multipliers of 1.05, 2.5, and 5, respectively, as bias correction.

Cycle average emission rates are based on EPA Line-Haul driving cycle.

Throttle notch position data obtained from the locomotive data activity recorder were used to quantify the actual real-world duty cycles for the over-the-rail measurements. The measured duty cycles are compared to the EPA line-haul duty cycle in Table D-5. The prime mover engine operated in notch 8 during the over-the-rail measurements more than double the percentage of time, on average, than EPA estimates a line-haul locomotive operates in notch 8. For the other notch positions, the observed time was on average less than the EPA line-haul duty cycle. Although not shown here, the real-world duty cycles can be used to estimate inter-cycle variability in cycle average for fuel use and emission rates.

Table D-5. Observed Real-World Over-the-Rail Duty Cycles from Measurement of NC-1797 Operated on B40 Biodiesel

Notch	Percent Time in Each Notch							
	EPA Line-Haul	Measured Over-the-Rail						
		Average	7/16/2014 Train 75	7/16/2014 Train 76	7/17/2014 Train 75	7/17/2014 Train 76	7/18/2014 Train 75	7/21/2014 Train 76
Idle	38.0	37.3	37.7	50.1	28.5	20.9	41.0	45.4
DB	12.5	3.8	9.2	1.5	4.9	1.5	3.3	2.5
1	6.5	3.8	0.9	1.2	1.1	8.5	5.0	6.1
2	6.5	5.6	2.9	1.7	14.3	8.8	4.1	2.0
3	5.2	3.1	1.9	2.8	3.0	6.4	2.4	2.1
4	4.4	2.8	2.4	2.9	3.0	6.3	1.2	1.1
5	3.8	1.4	0.8	1.8	0.7	1.8	1.9	1.3
6	3.9	1.0	1.1	1.1	0.3	1.3	1.7	0.8
7	3.0	0.2	0.2	0.4	0.1	0.1	0.4	0.2
8	16.2	41.0	42.9	36.6	44.3	44.5	39.1	38.5

Train 75 is from Raleigh to Charlotte. Train 76 is from Charlotte to Raleigh.

Comparison of Emission Rates from Multiple Biodiesel Fuels versus Ultra Low Sulfur Diesel

A comparison of the cycle average emission rates measured during rail yard and over-the-rail measurements with ULSD and multiple biodiesel fuels is shown in Table D-6. All of the comparisons are based on the EPA line-haul duty cycle.

For B10 biodiesel versus ULSD, during rail yard and over-the-rail measurements, cycle average NO_x and PM emission rates were moderately higher, from 6 to 25 percent. Cycle average HC emission rates were 213 percent higher for B10 compared to ULSD during rail yard measurements, but 19 percent lower during over-the-rail measurements. Cycle average CO emission rates were 17 percent higher during rail yard measurements, but 38 percent lower during over-the-rail measurements for B10 versus ULSD.

During rail yard and over-the-rail measurements, there were little to no differences in cycle average NO_x emission rates for B20 biodiesel versus ULSD. Cycle average HC emission rates were 429 percent higher for B20 compared to ULSD during rail yard measurements, but 37 percent lower during over-the-rail measurements. Cycle average CO emission rates were 17 percent higher during rail yard measurements, but 75 percent lower during over-the-rail measurements for B10 versus ULSD. Cycle average PM emission rates were moderately lower by 26 percent for B20 versus ULSD during rail yard measurements, but were moderately higher by 13 percent during over-the-rail measurements.

For B40 biodiesel versus ULSD, during rail yard and over-the-rail measurements, cycle average NO_x and CO emission rates were moderately higher, from 11 to 24 percent. Cycle average HC emission rates were 56 percent and 28 percent higher during rail yard and over-the-rail measurements, respectively. Cycle average PM emission rates were 11 percent and 57 percent higher during rail yard and over-the-rail measurements, respectively.

In our final report, we will compare results from NC-1797, NC-1810, and NC-1859. One preliminary observation was that there is substantial inter-engine variability in the results, which was consistent with the limited previously published literature. Thus, the results for one locomotive should not be extrapolated as representative of an entire fleet.

Table D-6. Comparison of EPA Line-Haul Cycle Average Emission Rates for Rail Yard and Over-the-Rail Measurements of NC-1797 Prime Mover Engine Operating for Multiple Biodiesel versus Ultra Low Sulfur Diesel

	NO_x	HC[a]	CO	Opacity-based PM
	(g/bhp-hr)	(g/bhp-hr)	(g/bhp-hr)	(g/bhp-hr)
B10 vs. ULSD				
Rail Yard	+25%	+210%	+17%	+11%
Over-the-Rail	+7%	-19%	-38%	+6%
B20 vs. ULSD				
Rail Yard	+6%	+430%	+17%	-26%
Over-the-Rail	+1%	-37%	-75%	+13%
B40 vs. ULSD				
Rail Yard	+11%	+56%	+21%	+11%
Over-the-Rail	+14%	+28%	+24%	+57%

SUPPLEMENTAL MATERIAL

Details of results of rail yard and over-the-rail measurements of NC-1797 using B40 biodiesel are given in attached supplemental tables.

Table D-7 summarizes the average measured engine speed (RPM), intake air temperature (IAT), manifold absolute pressure (MAP), estimated mass air flow (MAF), and air-to-fuel ratio (AFR) for each throttle notch position and for each rail yard (RY) replicate and one-way over-the-rail (OTR) trip. Engine speed ranges from 343 to 903 RPM in both RY and OTR measurements, depending on notch position. For the RY measurements, engine RPM was highly repeatable among replicates for a given notch position, with a standard deviation of less than 0.2 RPM for all notch positions. For the OTR measurements, the RPM was also repeatable among replicates for a given notch position, with a standard deviation of less than 0.5 RPM for all notch positions.

For some one-way trips, the sample sizes in these notches are too small to infer a steady-state engine operating speed. The intake air temperature varies with ambient temperature and was generally in the range of 42 to 58 degrees Celsius during all measurements. MAP was highly repeatable in the RY measurements, ranging from 105 to 215 kPa depending on notch position. The inter-replicate standard deviation of measured MAP was less than 1 kPa for each notch position. For OTR measurements, there was slightly more inter-run variability in MAP. However, the coefficient of variation for each notch position was typically 0.01 or less.

Estimated MAF was highly repeatable for both RY and OTR measurements, with the coefficient of variation typically 0.01 or less for all notch position. The MAF ranged from 1,270 to 4,400 g/s, depending on notch position. Estimated AFR was repeatable among replicates for a given notch position in the RY measurements, with coefficient of variation less than 0.03 for all notches. For OTR measurements, there was slightly more inter-run variability in AFR for each notch position, but the coefficient of variation was less than 0.12 for all notch positions. Overall, the engine RPM, absolute IAT, MAP, and MAF during the measurements was consistent for the three replicates in the rail yard, and from run to run for the five one-way trips observed between Raleigh and Charlotte.

Table D-8 summarizes the estimated fuel use rates inferred from the engine data of Table A-1. For the RY measurements, fuel use rates range from 5.1 to 145 g/sec depending on notch position, and were highly repeatable among replicates for a given notch position, with a coefficient of variation of 0.03 or less. There was more variability in run-to-run estimates of fuel use for the OTR measurements, in part because the amount of time spent in some notch positions was low. The OTR estimated fuel use ranged from 5.2 to 130 g/sec, depending on notch position. The coefficient of variation for all notches was less than 0.13 for all notch positions.

During RY measurements, the maximum engine output was 2,800 hp, whereas during OTR measurements the maximum engine output was 3,000 hp. Furthermore, as shown later in Table A-7, the average CO_2 concentrations for each notch position are lower for OTR than for RY measurements, which implies a lower fuel-to-air ratio. Because the engine activity and, therefore, engine air flow, are approximately the same for OTR versus RY measurements, the combination of higher engine output and lower fuel-to-air ratio lead to higher values of fuel-specific engine output (FSEO) in bhp-hr per gallon of fuel consumed, as shown in Table A-2. The FSEO was highly repeatable for the OTR measurements of each notch position, especially Notch 8, which represents significant portion of the observed duty cycle.

The measured NO exhaust concentration and the estimated NO_x emission rates are shown in Table D-9 for each notch position, each RY replicate, and each OTR one-way run. The average measured concentrations range among notch positions from approximately 250 to 1,160 parts per million (ppm) in the RY measurements, and 320 to 1,800 ppm in the OTR measurements, depending on notch position. The measurements are highly repeatable among replicates for a given notch position for both the RY and OTR measurements, with coefficients of variation typically less than 0.02 for all notch positions for the former and less than 0.14 for all notch positions for the latter. The estimated mass emission rates range from 0.5 to 8.2 g/sec for the RY measurements and 0.6 to 9.5 g/sec for the OTR measurements, depending on notch position. Because the observed concentrations tend to be higher for the OTR versus RY measurements, the mass emission rates also tend to be slightly higher for the OTR versus RY measurements.

On a fuel basis, the average NO_x emission rates range from 180 to 340 g/gallon for the RY measurements and 220 to 490 g/gallon for the OTR measurements, depending on notch position. For the RY measurements, the fuel-based emission rates are highly repeatable among replicates for a given notch position, with coefficient of variation typically less than 0.02. For the OTR measurements, the coefficients of variation were typically less than 0.17 for all notch positions. The fuel-based emission rates tend to be lowest at high load.

On an engine output basis, excluding Idle and Dynamic Braking, the notch average NO_x emission rates range from 10.4 g/bhp-hr at Notch 8 to 24.0 g/bhp-hr at notch 1 in the RY measurements, and range from 10.2 g/bhp-hr at Notch 8 to 32.0 g/bhp-hr at notch 1 in the OTR measurements. The notch average NO_x emission rates for Idle and Dynamic Braking were higher than the other notch positions. In general, the emission rates on an engine output basis are higher for the OTR measurements than for the RY measurements. This results from a combination of lower exhaust concentration and higher engine output, especially at Notch 8.

Results are given for exhaust concentrations and emission rates in Tables D-10, D-11, D-12, and D-13 for CO, HC, PM, and CO_2, respectively. The CO exhaust concentrations during OTR measurements are slightly higher than during RY measurements. Thus, the cycle average CO emission rates are also slightly higher for OTR than RY measurements. On average, the HC and PM exhaust concentrations and average emission rates tend to be higher for OTR than RY. However, CO, HC, and PM emission rates are low on an absolute basis, and some of the measured average concentrations for a given notch position and replicate or run are below the gas analyzer detection limit. The trends in CO_2 emission rates are similar to those for fuel use on a mass per time and mass per engine output basis. CO_2 emission rates are also shown on a g/gallon basis. Since typically over 99 percent of the carbon in the fuel was emitted as CO_2, the fuel-based CO_2 emission rates are approximately constant.

SUMMARY

In these measurements, a procedure was demonstrated for rail yard and over-the-rail characterization of emission rates for B40 biodiesel. The rail yard engine activity and emission concentration measurements were consistent across the three replicates. For rail yard measurements, NO_x, CO, HC, and PM cycle average emission rates were higher for B40 biodiesel versus ULSD.

The cycle average over-the-rail emission rates was of similar magnitude as the cycle average rail yard emission rates. For B40, the cycle average over-the-rail NO_x, CO, HC, and PM emission rates were higher than during rail yard measurements.

Table D-7. Measured Engine Parameters for NC-1797 and B40.

Engine Speed (RPM)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	7/21	7/21	7/21	3 Reps	3 Reps	3 Reps	7/16	7/16	4/17	4/17	7/18	7/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Low Idle	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!	--	199	--	--	--	--	199	#DIV/0!	#DIV/0!
High Idle	343	343	343	343	0.02	0.00	343	343	343	343	343	343	343	0.04	0.00
Dyn Brake	--	--	--	--	--	--	343	342	343	343	343	342	343	0.41	0.00
1	343	343	343	343	0.02	0.00	343	342	342	342	343	343	342	0.31	0.00
2	343	343	343	343	0.03	0.00	343	344	343	343	343	344	343	0.55	0.00
3	490	490	490	490	0.03	0.00	489	489	490	490	490	490	490	0.31	0.00
4	651	651	651	651	0.19	0.00	650	651	651	651	652	651	651	0.47	0.00
5	750	750	750	750	0.03	0.00	749	750	750	750	750	750	750	0.32	0.00
6	750	750	750	750	0.04	0.00	749	750	750	750	750	750	750	0.38	0.00
7	820	820	820	820	0.08	0.00	--	820	--	--	819	--	819	0.31	0.00
8	903	903	903	903	0.05	0.00	903	903	903	903	903	903	903	0.09	0.00

Intake Air Temeprature (°C)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	7/21	7/21	7/21	3 Reps	3 Reps	3 Reps	7/16	7/16	4/17	4/17	7/18	7/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Low Idle	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!	--	54	--	--	--	--	54	#DIV/0!	#DIV/0!
High Idle	44	43	43	43	0.41	0.01	51	52	52	52	57	52	53	1.90	0.04
Dyn Brake	--	--	--	--	--	--	52	52	53	52	58	52	53	2.56	0.05
1	44	42	42	43	1.29	0.03	51	52	53	52	55	52	53	1.14	0.02
2	43	43	42	43	0.66	0.02	52	53	53	53	57	51	53	1.99	0.04
3	43	44	43	43	0.46	0.01	52	52	52	53	57	51	53	2.12	0.04
4	45	46	46	46	0.21	0.00	51	52	53	53	58	50	53	2.78	0.05
5	49	50	49	49	0.40	0.01	51	52	52	55	54	55	53	1.61	0.03
6	48	48	49	48	0.30	0.01	53	53	53	54	56	52	53	1.29	0.02
7	48	49	48	49	0.53	0.01	--	53	--	--	54	--	53	0.75	0.01
8	50	49	49	50	0.49	0.01	52	53	53	53	57	53	54	1.93	0.04

Manifold Absolute Pressure (kPa)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	7/21	7/21	7/21	3 Reps	3 Reps	3 Reps	7/16	7/16	4/17	4/17	7/18	7/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Low Idle	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!	--	92	--	--	--	--	92	#DIV/0!	#DIV/0!
High Idle	105	105	105	105	0.17	0.00	102	100	101	101	100	102	101	1.02	0.01
Dyn Brake	--	--	--	--	--	--	101	100	102	102	100	104	102	1.44	0.01
1	105	105	105	105	0.03	0.00	102	99	101	102	100	102	101	0.98	0.01
2	105	105	105	105	0.03	0.00	102	100	102	102	100	101	101	1.04	0.01
3	119	119	119	119	0.02	0.00	115	114	116	115	114	116	115	0.92	0.01
4	143	143	143	143	0.03	0.00	139	136	139	138	137	138	138	1.19	0.01
5	163	163	163	163	0.07	0.00	157	155	160	157	156	157	157	1.45	0.01
6	164	164	164	164	0.10	0.00	158	156	160	158	157	158	158	1.18	0.01
7	203	203	204	203	0.52	0.00	--	174	--	--	174	--	174	0.36	0.00
8	215	215	215	215	0.25	0.00	204	201	203	202	199	203	202	1.55	0.01

Mass Air Flow (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	7/21	7/21	7/21	3 Reps	3 Reps	3 Reps	7/16	7/16	4/17	4/17	7/18	7/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Low Idle	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!	--	--	--	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!
High Idle	1274	1275	1280	1276	3.29	0.00	1212	1195	1204	1206	1173	1214	1200	15.31	0.01
Dyn Brake	--	--	--	--	--	--	1207	1198	1207	1220	1171	1232	1206	20.78	0.02
1	1275	1285	1283	1281	4.99	0.00	1215	1186	1200	1209	1187	1208	1201	12.11	0.01
2	1280	1282	1285	1283	2.68	0.00	1210	1191	1206	1213	1176	1213	1202	14.85	0.01
3	1828	1823	1829	1827	2.80	0.00	1729	1713	1744	1725	1693	1741	1724	18.93	0.01
4	2565	2563	2563	2564	1.31	0.00	2467	2422	2450	2440	2393	2471	2441	29.35	0.01
5	3110	3105	3111	3109	3.38	0.00	3013	2981	3042	2981	2967	2980	2994	28.17	0.01
6	3145	3145	3142	3144	1.94	0.00	3015	2980	3031	3002	2975	3018	3003	22.18	0.01
7	3943	3929	3953	3942	11.86	0.00	--	3460	--	--	3440	--	3450	14.42	0.00
8	4388	4408	4404	4400	10.52	0.00	4189	4144	4170	4151	4058	4170	4147	46.27	0.01

Air to Fuel Ratio (g/g)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	7/21	7/21	7/21	3 Reps	3 Reps	3 Reps	7/16	7/16	4/17	4/17	7/18	7/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Low Idle	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!	--	--	--	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!
High Idle	238	247	231	239	7.83	0.03	222	231	214	206	211	235	220	11.54	0.05
Dyn Brake	--	--	--	--	--	--	221	207	230	204	216	241	220	14.04	0.06
1	105	102	105	104	1.56	0.02	98	92	107	95	112	123	105	11.94	0.11
2	70	69	71	70	0.77	0.01	74	79	66	65	80	90	76	9.33	0.12
3	58	58	59	58	0.23	0.00	56	57	57	54	55	61	57	2.27	0.04
4	54	55	55	55	0.46	0.01	54	54	53	52	54	62	55	3.81	0.07
5	51	52	49	51	1.30	0.03	50	54	48	48	52	51	51	2.53	0.05
6	41	41	40	41	0.51	0.01	41	46	46	41	46	47	45	2.94	0.07
7	32	33	32	32	0.25	0.01	--	40	--	--	44	--	42	2.40	0.06
8	30	31	31	30	0.25	0.01	33	33	33	32	32	34	33	0.78	0.02

Table D-8. Estimated Fuel Use Rates for NC-1797 and B40.

Time-Based Fuel Use Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	7/21	7/21	7/21	3 Reps	3 Reps	3 Reps	7/16	7/16	4/17	4/17	7/18	7/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Low Idle	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!	--	--	--	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!
High Idle	5.4	5.2	5.1	5.2	0.15	0.03	5.5	5.2	5.6	5.9	5.6	5.2	5.5	0.3	0.05
Dyn Brake	--	--	--	--	--	--	5.4	5.8	5.2	6.0	5.4	5.1	5.5	0.3	0.06
1	12.2	12.6	12.2	12.3	0.22	0.02	12.4	12.9	11.2	12.7	10.6	9.8	11.6	1.3	0.11
2	18.2	18.5	18.2	18.3	0.19	0.01	16.3	15.1	18.1	18.7	14.6	13.5	16.1	2.0	0.13
3	31.3	31.3	31.1	31.2	0.09	0.00	30.9	30.0	30.7	31.8	31.0	28.7	30.5	1.0	0.03
4	47.1	46.5	46.3	46.6	0.41	0.01	45.9	44.6	46.5	46.8	44.6	39.6	44.7	2.7	0.06
5	60.8	59.9	60.6	60.4	0.49	0.01	60.8	54.9	63.3	62.1	56.5	58.1	59.3	3.3	0.06
6	77.5	76.0	76.7	76.7	0.75	0.01	74.0	64.5	65.6	73.1	64.3	63.7	67.5	4.7	0.07
7	123.1	120.8	121.4	121.7	1.19	0.01	--	85.9	--	--	78.8	--	82.4	5.1	0.06
8	145.4	143.7	144.3	144.5	0.85	0.01	125.4	126.8	128.0	129.4	125.2	121.9	126.1	2.6	0.02

Engine Output-Based Fuel Use Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	7/21	7/21	7/21	3 Reps	3 Reps	3 Reps	7/16	7/16	4/17	4/17	7/18	7/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Low Idle	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!	--	--	--	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!
High Idle	1.5	1.6	1.6	1.6	0.04	0.03	1.5	1.6	1.5	1.4	1.5	1.6	1.5	0.1	0.05
Dyn Brake	--	--	--	--	--	--	1.5	1.4	1.6	1.4	1.5	1.6	1.5	0.1	0.06
1	12.8	12.3	12.7	12.6	0.22	0.02	12.5	12.1	13.9	12.2	14.7	15.8	13.5	1.5	0.11
2	15.7	15.4	15.7	15.6	0.16	0.01	17.5	18.9	15.8	15.3	19.5	21.2	18.0	2.3	0.13
3	17.6	17.6	17.7	17.7	0.05	0.00	17.8	18.4	17.9	17.4	17.8	19.2	18.1	0.6	0.04
4	17.3	17.6	17.7	17.5	0.16	0.01	17.8	18.3	17.6	17.4	18.3	20.6	18.3	1.2	0.06
5	17.5	17.7	17.5	17.6	0.14	0.01	17.5	19.3	16.8	17.1	18.8	18.3	18.0	1.0	0.06
6	16.9	17.2	17.0	17.0	0.17	0.01	17.7	20.3	19.9	17.9	20.3	20.5	19.4	1.3	0.07
7	16.6	16.9	16.8	16.8	0.16	0.01	--	25.7	--	--	28.0	--	26.8	1.6	0.06
8	15.7	15.9	15.9	15.8	0.09	0.01	19.5	19.3	19.1	18.9	19.6	20.1	19.4	0.4	0.02

Table D-9. Measured NOx Emission Rates for NC-1797 and B40.

Time-Based NOx Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	**7/21**	**7/21**	**7/21**	**3 Reps**	**3 Reps**	**3 Reps**	**7/16**	**7/16**	**4/17**	**4/17**	**7/18**	**7/22**	**6 Trains**	**6 Trains**	**6 Trains**
Position	**Axion REP1**	**Axion REP2**	**Axion REP3**	**Average**	**StDev**	**CV**	**Train 75**	**Train 76**	**Train 75**	**Train 76**	**Train 75**	**Train 76**	**Average**	**StDev**	**CV**
Low Idle	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!	--	--	--	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!
High Idle	0.55	0.53	0.53	0.54	0.01	0.02	0.67	0.64	0.67	0.70	0.68	0.91	0.71	0.1	0.14
Dyn Brake	--	--	--	--	--	--	0.66	0.68	0.65	0.66	0.68	0.54	0.64	0.1	0.08
1	1.26	1.27	1.25	1.26	0.01	0.00	1.59	1.69	1.54	1.65	1.37	1.13	1.49	0.2	0.14
2	2.23	2.27	2.21	2.23	0.03	0.01	2.20	2.12	2.59	2.65	2.10	1.82	2.25	0.3	0.14
3	2.76	2.74	2.71	2.74	0.03	0.01	4.66	4.75	4.89	4.72	4.79	4.33	4.69	0.2	0.04
4	3.07	3.13	3.05	3.08	0.04	0.01	6.78	6.07	7.03	5.59	7.37	5.82	6.44	0.7	0.11
5	4.34	4.31	4.23	4.29	0.06	0.01	8.72	8.22	6.79	8.53	7.01	7.85	7.85	0.8	0.10
6	5.25	5.17	5.07	5.16	0.09	0.02	6.80	9.13	9.21	8.46	9.30	6.96	8.31	1.1	0.14
7	5.85	5.83	5.87	5.85	0.02	0.00	--	8.98	--	--	9.63	--	9.31	0.5	0.05
8	8.07	8.15	8.13	8.12	0.04	0.01	9.14	9.23	9.39	9.45	9.30	8.50	9.17	0.3	0.04

Fuel-Based NOx Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	**7/21**	**7/21**	**7/21**	**3 Reps**	**3 Reps**	**3 Reps**	**7/16**	**7/16**	**4/17**	**4/17**	**7/18**	**7/22**	**6 Trains**	**6 Trains**	**6 Trains**
Position	**Axion REP1**	**Axion REP2**	**Axion REP3**	**Average**	**StDev**	**CV**	**Train 75**	**Train 76**	**Train 75**	**Train 76**	**Train 75**	**Train 76**	**Average**	**StDev**	**CV**
Low Idle	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!	--	--	--	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!
High Idle	333	336	341	337	3.85	0.01	401	403	387	388	397	573	425	72.7	0.17
Dyn Brake	--	--	--	--	--	--	392	385	405	357	409	344	382	26.1	0.07
1	338	328	334	333	4.99	0.01	416	427	449	423	423	375	419	24.1	0.06
2	399	399	395	398	2.27	0.01	439	458	465	462	467	438	455	12.8	0.03
3	287	285	283	285	1.87	0.01	491	515	518	484	504	491	500	14.0	0.03
4	212	219	215	215	3.56	0.02	481	443	493	388	538	478	470	50.6	0.11
5	232	235	227	231	3.84	0.02	467	487	349	447	404	440	432	49.3	0.11
6	221	222	215	219	3.48	0.02	299	461	457	377	471	355	404	70.2	0.17
7	155	157	157	157	1.43	0.01	--	340	--	--	398	--	369	40.7	0.11
8	181	185	183	183	2.03	0.01	237	237	239	238	242	227	237	5.0	0.02

Engine Output-Based NOx Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	**7/21**	**7/21**	**7/21**	**3 Reps**	**3 Reps**	**3 Reps**	**7/16**	**7/16**	**4/17**	**4/17**	**7/18**	**7/22**	**6 Trains**	**6 Trains**	**6 Trains**
Position	**Axion REP1**	**Axion REP2**	**Axion REP3**	**Average**	**StDev**	**CV**	**Train 75**	**Train 76**	**Train 75**	**Train 76**	**Train 75**	**Train 76**	**Average**	**StDev**	**CV**
Low Idle	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!	--	--	--	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!
High Idle	197.4	191.9	191.1	193.5	3.44	0.02	242.3	231.0	240.9	251.6	243.7	326.7	256.0	35.3	0.14
Dyn Brake	--	--	--	--	--	--	236.0	246.0	234.8	236.1	244.7	194.4	232.0	19.0	0.08
1	23.9	24.0	23.8	23.9	0.12	0.00	30.1	32.0	29.2	31.3	26.0	21.4	28.3	4.0	0.14
2	22.9	23.3	22.7	23.0	0.32	0.01	22.6	21.8	26.7	27.2	21.6	18.7	23.1	3.3	0.14
3	14.7	14.6	14.4	14.6	0.14	0.01	24.8	25.3	26.1	25.2	25.5	23.1	25.0	1.0	0.04
4	11.0	11.3	11.0	11.1	0.15	0.01	24.4	21.8	25.3	20.1	26.5	20.9	23.2	2.6	0.11
5	12.0	11.9	11.7	11.9	0.17	0.01	24.2	22.8	18.8	23.6	19.4	21.7	21.7	2.2	0.10
6	11.8	11.6	11.4	11.6	0.20	0.02	15.3	20.5	20.7	19.0	20.9	15.7	18.7	2.6	0.14
7	8.4	8.4	8.5	8.4	0.03	0.00	--	12.0	--	--	12.8	--	12.4	0.6	0.05
8	10.4	10.5	10.5	10.4	0.05	0.01	11.0	11.1	11.3	11.3	11.2	10.2	11.0	0.4	0.04
Duty Cycle Avg (Raw)	11.9	11.9	11.8	11.8	0.05	0.00	15.3	15.1	15.8	15.8	15.3	14.5	15.3	0.5	0.03
uty Cycle Avg (Adjusted	12.5	12.5	12.4	12.5	0.05	0.00	16.1	15.9	16.6	16.6	16.1	15.2	16.1	0.5	0.03

Exhaust NOx Concentrations (ppm)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	**7/21**	**7/21**	**7/21**	**3 Reps**	**3 Reps**	**3 Reps**	**7/16**	**7/16**	**4/17**	**4/17**	**7/18**	**7/22**	**6 Trains**	**6 Trains**	**6 Trains**
Position	**Axion REP1**	**Axion REP2**	**Axion REP3**	**Average**	**StDev**	**CV**	**Train 75**	**Train 76**	**Train 75**	**Train 76**	**Train 75**	**Train 76**	**Average**	**StDev**	**CV**
Low Idle	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!	--	298	--	--	--	--	298	#DIV/0!	#DIV/0!
High Idle	259	252	249	253	5.08	0.02	333	320	330	339	339	455	353	50.6	0.14
Dyn Brake	--	--	--	--	--	--	326	337	320	316	346	263	318	29.1	0.09
1	596	599	589	595	4.83	0.01	779	834	779	805	684	563	741	100.6	0.14
2	1046	1074	1036	1052	19.66	0.02	1088	1060	1274	1281	1054	893	1108	147.8	0.13
3	909	911	895	905	8.71	0.01	1597	1644	1683	1611	1679	1484	1616	73.6	0.05
4	726	742	721	730	11.08	0.02	1656	1496	1707	1355	1811	1429	1576	176.4	0.11
5	857	855	833	849	13.31	0.02	1740	1655	1337	1695	1415	1577	1570	161.4	0.10
6	1029	1007	986	1007	21.50	0.02	1357	1838	1848	1661	1861	1373	1657	237.2	0.14
7	924	919	906	916	8.88	0.01	--	1518	--	--	1663	--	1591	102.5	0.06
8	1154	1159	1155	1156	2.47	0.00	1334	1364	1375	1379	1392	1243	1348	54.9	0.04

Table D-10. Estimated CO Emission Rates for NC-1797 and B40.

Time-Based CO Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	7/21	7/21	7/21	3 Reps	3 Reps	3 Reps	7/16	7/16	4/17	4/17	7/18	7/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Low Idle	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!	--	--	--	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!
High Idle	0.111	0.059	0.015	0.062	0.05	0.79	0.035	0.075	0.231	0.331	0.222	0.056	0.16	0.1	0.76
Dyn Brake	--	--	--	--	--	--	0.164	0.177	0.177	0.506	0.144	0.368	0.26	0.1	0.58
1	0.061	0.002	0.033	0.032	0.03	0.92	0.145	0.068	0.029	0.152	0.111	0.029	0.09	0.1	0.62
2	0.117	0.006	0.000	0.041	0.07	1.60	0.193	0.064	0.113	0.168	0.065	0.033	0.11	0.1	0.60
3	0.172	0.002	0.007	0.060	0.10	1.60	0.275	0.069	0.071	0.125	0.175	0.029	0.12	0.1	0.72
4	0.256	0.001	0.000	0.086	0.15	1.73	0.038	0.132	0.255	0.251	0.284	0.000	0.16	0.1	0.76
5	0.105	0.000	0.000	0.035	0.06	1.73	0.022	0.203	0.083	0.284	0.202	0.080	0.15	0.1	0.68
6	0.142	0.026	0.000	0.056	0.08	1.35	0.000	0.127	0.007	0.266	0.220	0.042	0.11	0.1	1.03
7	0.650	0.243	0.132	0.342	0.27	0.80	--	0.199	--	--	0.080	--	0.14	0.1	0.60
8	0.674	0.689	0.428	0.597	0.15	0.25	0.310	0.390	0.504	0.617	0.535	0.400	0.46	0.1	0.24

Fuel-Based CO Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	7/21	7/21	7/21	3 Reps	3 Reps	3 Reps	7/16	7/16	4/17	4/17	7/18	7/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Low Idle	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!	--	--	--	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!
High Idle	67.69	37.26	9.37	38.11	29.17	0.77	20.6	47.4	133.6	184.1	130.1	35.6	91.9	66.2	0.72
Dyn Brake	--	--	--	--	--	--	97.7	99.9	109.9	275.2	86.8	234.6	150.7	82.1	0.54
1	16.23	0.57	8.78	8.53	7.84	0.92	37.9	17.2	8.6	39.0	34.2	9.8	24.5	14.2	0.58
2	20.95	1.08	0.05	7.36	11.78	1.60	38.5	13.9	20.2	29.4	14.5	7.9	20.7	11.3	0.55
3	17.92	0.21	0.74	6.29	10.07	1.60	29.0	7.5	7.6	12.8	18.4	3.2	13.1	9.4	0.72
4	17.71	0.04	0.00	5.91	10.21	1.73	2.7	9.6	17.8	17.4	20.8	0.0	11.4	8.7	0.76
5	5.64	0.00	0.00	1.88	3.25	1.73	1.2	12.0	4.3	14.9	11.6	4.5	8.1	5.5	0.68
6	5.95	1.10	0.00	2.35	3.17	1.35	0.0	6.4	0.4	11.8	11.2	2.1	5.3	5.3	1.00
7	17.21	6.56	3.53	9.10	7.18	0.79	--	7.6	--	--	3.3	--	5.4	3.0	0.55
8	15.09	15.61	9.66	13.45	3.29	0.24	8.0	10.0	12.8	15.5	13.9	10.7	11.8	2.8	0.23

Engine Output-Based CO Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	7/21	7/21	7/21	3 Reps	3 Reps	3 Reps	7/16	7/16	4/17	4/17	7/18	7/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Low Idle	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!	--	--	--	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!
High Idle	40.08	21.27	5.25	22.20	17.43	0.79	12.48	27.17	83.12	119.31	79.95	20.31	57.05	43.1	0.76
Dyn Brake	--	--	--	--	--	--	58.88	63.86	63.72	182.07	51.90	132.50	92.15	53.0	0.58
1	1.15	0.04	0.63	0.61	0.55	0.92	2.74	1.29	0.56	2.89	2.11	0.56	1.69	1.0	0.62
2	1.20	0.06	0.00	0.42	0.68	1.60	1.99	0.66	1.16	1.73	0.67	0.34	1.09	0.7	0.60
3	0.92	0.01	0.04	0.32	0.52	1.60	1.47	0.37	0.38	0.66	0.93	0.15	0.66	0.5	0.72
4	0.92	0.00	0.00	0.31	0.53	1.73	0.14	0.48	0.92	0.90	1.02	0.00	0.58	0.4	0.76
5	0.29	0.00	0.00	0.10	0.17	1.73	0.06	0.56	0.23	0.79	0.56	0.22	0.40	0.3	0.68
6	0.32	0.06	0.00	0.13	0.17	1.35	0.00	0.28	0.02	0.60	0.50	0.09	0.25	0.3	1.03
7	0.94	0.35	0.19	0.49	0.39	0.80	--	0.27	--	--	0.11	--	0.19	0.1	0.60
8	0.87	0.89	0.55	0.77	0.19	0.25	0.37	0.47	0.60	0.74	0.64	0.48	0.55	0.1	0.24
Duty Cycle Avg (Raw)	1.07	0.71	0.39	0.73	0.34	0.47	0.62	0.68	1.10	1.75	1.09	0.72	0.99	0.43	0.43
uty Cycle Avg (Adjusted	1.07	0.71	0.39	0.73	0.34	0.47	0.62	0.68	1.10	1.75	1.09	0.72	0.99	0.43	0.43

Exhaust CO Concentrations (%)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	7/21	7/21	7/21	3 Reps	3 Reps	3 Reps	7/16	7/16	4/17	4/17	7/18	7/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Low Idle	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!	--	0.000	--	--	--	--	0.000	#DIV/0!	#DIV/0!
High Idle	0.009	0.005	0.001	0.005	0.00	0.79	0.003	0.007	0.020	0.028	0.019	0.005	0.014	0.0	0.75
Dyn Brake	--	--	--	--	--	--	0.014	0.015	0.015	0.042	0.013	0.031	0.022	0.0	0.56
1	0.005	0.000	0.003	0.003	0.00	0.92	0.012	0.006	0.003	0.013	0.010	0.003	0.008	0.0	0.61
2	0.009	0.001	0.000	0.003	0.01	1.60	0.017	0.006	0.010	0.014	0.006	0.003	0.009	0.0	0.60
3	0.010	0.000	0.000	0.003	0.01	1.60	0.016	0.004	0.004	0.007	0.011	0.002	0.007	0.0	0.72
4	0.010	0.000	0.000	0.004	0.01	1.73	0.002	0.006	0.011	0.011	0.012	0.000	0.007	0.0	0.76
5	0.004	0.000	0.000	0.001	0.00	1.73	0.001	0.007	0.003	0.010	0.007	0.003	0.005	0.0	0.68
6	0.005	0.001	0.000	0.002	0.00	1.36	0.000	0.004	0.000	0.009	0.008	0.001	0.004	0.0	1.02
7	0.018	0.007	0.004	0.009	0.01	0.80	--	0.006	--	--	0.002	--	0.004	0.0	0.59
8	0.017	0.017	0.011	0.015	0.00	0.25	0.008	0.010	0.013	0.016	0.014	0.010	0.012	0.0	0.25

Table D-11. Estimated Hydrocarbon Emission Rates for NC-1797 and B40.

Time-Based HC Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	**7/21**	**7/21**	**7/21**	**3 Reps**	**3 Reps**	**3 Reps**	**7/16**	**7/16**	**4/17**	**4/17**	**7/18**	**7/22**	**6 Trains**	**6 Trains**	**6 Trains**
Position	**Axion REP1**	**Axion REP2**	**Axion REP3**	**Average**	**StDev**	**CV**	**Train 75**	**Train 76**	**Train 75**	**Train 76**	**Train 75**	**Train 76**	**Average**	**StDev**	**CV**
Low Idle	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!	--	--	--	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!
High Idle	0.25	0.49	0.00	0.25	0.25	0.99	0.44	0.58	1.24	1.16	1.06	0.33	0.80	0.4	0.50
Dyn Brake	--	--	--	--	--	--	0.75	1.05	1.06	1.48	0.87	0.57	0.96	0.3	0.33
1	0.18	0.00	0.00	0.06	0.10	1.63	0.74	0.64	0.23	0.94	0.64	0.15	0.56	0.3	0.55
2	0.33	0.01	0.05	0.13	0.18	1.38	0.77	0.82	0.95	0.99	0.57	0.30	0.73	0.3	0.35
3	0.47	0.02	0.04	0.18	0.25	1.44	1.25	0.84	0.50	1.24	0.88	0.79	0.92	0.3	0.31
4	0.63	0.02	0.06	0.24	0.34	1.45	0.64	0.99	1.99	1.66	1.73	1.66	1.44	0.5	0.36
5	0.23	0.06	0.00	0.10	0.12	1.24	1.64	1.37	1.57	1.80	1.34	0.72	1.41	0.4	0.27
6	0.55	0.78	1.48	0.94	0.48	0.52	1.33	0.91	0.33	1.89	1.44	1.24	1.19	0.5	0.44
7	1.04	0.72	1.31	1.02	0.29	0.28	--	1.79	--	--	0.87	--	1.33	0.7	0.49
8	0.17	0.65	1.11	0.65	0.47	0.72	1.11	0.72	1.73	1.49	1.24	0.57	1.14	0.4	0.39

Fuel-Based HC Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	**7/21**	**7/21**	**7/21**	**3 Reps**	**3 Reps**	**3 Reps**	**7/16**	**7/16**	**4/17**	**4/17**	**7/18**	**7/22**	**6 Trains**	**6 Trains**	**6 Trains**
Position	**Axion REP1**	**Axion REP2**	**Axion REP3**	**Average**	**StDev**	**CV**	**Train 75**	**Train 76**	**Train 75**	**Train 76**	**Train 75**	**Train 76**	**Average**	**StDev**	**CV**
Low Idle	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!	--	--	--	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!
High Idle	152	312	1	155	155.51	1.00	261	365	718	642	620	205	469	218.4	0.47
Dyn Brake	--	--	--	--	--	--	449	594	655	807	522	366	565	156.5	0.28
1	49	1	1	17	27.67	1.64	195	161	66	240	195	50	151	76.7	0.51
2	59	1	8	23	31.78	1.39	154	176	171	172	127	72	145	40.4	0.28
3	49	2	4	18	26.52	1.44	132	91	53	127	93	89	97	29.0	0.30
4	44	1	4	16	23.59	1.45	45	72	139	115	126	137	106	38.3	0.36
5	12	3	0	5	6.39	1.23	88	81	81	94	77	40	77	18.9	0.25
6	23	34	63	40	20.58	0.52	59	46	16	84	73	63	57	23.7	0.42
7	27	20	35	27	7.76	0.28	--	68	--	--	36	--	52	22.6	0.44
8	4	15	25	15	10.57	0.72	29	19	44	37	32	15	29	11.0	0.37

Engine Output-Based HC Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	**7/21**	**7/21**	**7/21**	**3 Reps**	**3 Reps**	**3 Reps**	**7/16**	**7/16**	**4/17**	**4/17**	**7/18**	**7/22**	**6 Trains**	**6 Trains**	**6 Trains**
Position	**Axion REP1**	**Axion REP2**	**Axion REP3**	**Average**	**StDev**	**CV**	**Train 75**	**Train 76**	**Train 75**	**Train 76**	**Train 75**	**Train 76**	**Average**	**StDev**	**CV**
Low Idle	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!	--	--	--	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!
High Idle	90.10	177.96	0.43	89.50	88.76	0.99	157.86	209.07	446.83	415.99	380.98	117.16	287.98	143.3	0.50
Dyn Brake	--	--	--	--	--	--	270.67	379.69	379.92	533.74	312.07	206.53	347.10	113.0	0.33
1	3.46	0.08	0.05	1.20	1.96	1.63	14.11	12.04	4.27	17.80	12.03	2.87	10.52	5.8	0.55
2	3.41	0.06	0.48	1.32	1.82	1.38	7.96	8.40	9.79	10.14	5.87	3.05	7.54	2.7	0.35
3	2.51	0.10	0.23	0.94	1.36	1.44	6.68	4.47	2.66	6.61	4.70	4.20	4.89	1.5	0.31
4	2.27	0.07	0.21	0.85	1.23	1.45	2.31	3.58	7.15	5.96	6.22	5.98	5.20	1.8	0.36
5	0.64	0.17	0.00	0.27	0.33	1.24	4.55	3.79	4.34	4.98	3.70	2.00	3.89	1.0	0.27
6	1.23	1.76	3.32	2.10	1.09	0.52	2.99	2.05	0.75	4.26	3.24	2.79	2.68	1.2	0.44
7	1.49	1.04	1.88	1.47	0.42	0.28	--	2.39	--	--	1.16	--	1.77	0.9	0.49
8	0.22	0.84	1.43	0.83	0.60	0.72	1.34	0.87	2.07	1.78	1.49	0.69	1.37	0.5	0.39
Duty Cycle Avg (Raw)	0.57	0.78	0.54	0.63	0.13	0.21	1.50	1.43	2.30	2.55	1.89	1.02	1.78	0.58	0.32
uty Cycle Avg (Adjusted	1.43	1.95	1.35	1.58	0.33	0.21	3.75	3.58	5.75	6.38	4.71	2.54	4.45	1.44	0.32

Exhaust HC Concentrations (ppm)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	**7/21**	**7/21**	**7/21**	**3 Reps**	**3 Reps**	**3 Reps**	**7/16**	**7/16**	**4/17**	**4/17**	**7/18**	**7/22**	**6 Trains**	**6 Trains**	**6 Trains**
Position	**Axion REP1**	**Axion REP2**	**Axion REP3**	**Average**	**StDev**	**CV**	**Train 75**	**Train 76**	**Train 75**	**Train 76**	**Train 75**	**Train 76**	**Average**	**StDev**	**CV**
Low Idle	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!	--	3	--	--	--	--	3	#DIV/0!	#DIV/0!
High Idle	27	53	0	26	26.25	0.99	49	65	138	126	119	37	89	43.9	0.49
Dyn Brake	--	--	--	--	--	--	84	117	117	161	99	63	107	33.6	0.31
1	19	0	0	7	10.99	1.63	82	71	26	103	71	17	62	33.5	0.54
2	35	1	5	14	18.75	1.38	86	92	105	107	65	33	81	28.4	0.35
3	35	1	3	13	18.92	1.44	97	65	39	95	70	61	71	22.1	0.31
4	34	1	3	13	18.22	1.45	35	55	109	91	96	92	80	28.1	0.35
5	10	3	0	4	5.31	1.23	74	62	70	81	61	33	63	16.7	0.26
6	24	34	65	41	21.14	0.51	60	41	15	84	65	55	53	23.3	0.44
7	37	26	45	36	9.88	0.27	--	68	--	--	34	--	51	24.3	0.48
8	6	21	36	21	14.95	0.72	37	24	57	49	42	19	38	14.5	0.38

Table D-12. Estimated Particulate Matter Emission Rates for NC-1797 and B40.

Time-Based PM Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	7/21	7/21	7/21	3 Reps	3 Reps	3 Reps	7/16	7/16	4/17	4/17	7/18	7/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Low Idle	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!	--	--	--	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!
High Idle	0.01	0.01	0.01	0.01	0.00	0.07	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.0	0.37
Dyn Brake	--	--	--	--	--	--	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.0	0.33
1	0.01	0.01	0.01	0.01	0.00	0.06	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.0	0.19
2	0.01	0.01	0.01	0.01	0.00	0.07	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.0	0.25
3	0.01	0.01	0.01	0.01	0.00	0.02	0.03	0.02	0.02	0.02	0.02	0.01	0.02	0.0	0.26
4	0.02	0.02	0.02	0.02	0.00	0.01	0.04	0.06	0.03	0.03	0.03	0.02	0.03	0.0	0.38
5	0.03	0.03	0.03	0.03	0.00	0.01	0.06	0.09	0.06	0.03	0.03	0.03	0.05	0.0	0.51
6	0.03	0.03	0.03	0.03	0.00	0.01	0.06	0.10	0.04	0.04	0.04	0.03	0.05	0.0	0.51
7	0.16	0.15	0.14	0.15	0.01	0.05	--	0.43	--	--	0.06	--	0.25	0.3	1.05
8	0.25	0.17	0.15	0.19	0.05	0.28	0.28	0.25	0.24	0.20	0.18	0.15	0.22	0.0	0.23

Fuel-Based PM Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	7/21	7/21	7/21	3 Reps	3 Reps	3 Reps	7/16	7/16	4/17	4/17	7/18	7/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Low Idle	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!	--	--	--	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!
High Idle	5.32	5.16	4.88	5.12	0.22	0.04	8.69	14.04	9.06	6.28	5.93	5.23	8.21	3.2	0.40
Dyn Brake	--	--	--	--	--	--	10.18	12.70	10.57	6.38	7.28	5.69	8.80	2.8	0.31
1	3.66	3.87	4.10	3.88	0.22	0.06	5.37	5.77	6.81	4.11	5.00	5.17	5.37	0.9	0.17
2	2.21	2.33	2.55	2.37	0.17	0.07	4.49	5.82	3.85	2.53	3.50	3.92	4.02	1.1	0.27
3	2.18	2.08	2.17	2.14	0.05	0.03	4.36	3.79	3.30	2.45	2.94	2.28	3.19	0.8	0.25
4	2.23	2.21	2.27	2.24	0.03	0.01	3.81	5.41	3.19	2.35	2.87	2.03	3.28	1.2	0.37
5	2.29	2.34	2.32	2.32	0.03	0.01	4.61	7.97	4.10	2.55	2.53	2.17	3.99	2.2	0.55
6	1.87	1.92	1.93	1.90	0.03	0.02	3.95	6.96	2.56	2.59	2.58	2.11	3.46	1.8	0.53
7	5.65	5.40	5.15	5.40	0.25	0.05	--	21.52	--	--	3.49	--	12.50	12.8	1.02
8	7.77	5.22	4.78	5.92	1.62	0.27	10.02	8.95	8.51	7.02	6.63	5.37	7.75	1.7	0.22

Engine Output-Based PM Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	7/21	7/21	7/21	3 Reps	3 Reps	3 Reps	7/16	7/16	4/17	4/17	7/18	7/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Low Idle	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!	--	--	--	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!
High Idle	2.86	2.68	2.49	2.68	0.19	0.07	4.78	7.32	5.13	3.70	3.31	2.72	4.5	1.7	0.37
Dyn Brake	--	--	--	--	--	--	4.39	5.81	4.38	3.02	3.11	2.30	3.8	1.3	0.33
1	0.16	0.18	0.18	0.18	0.01	0.06	0.24	0.27	0.28	0.19	0.19	0.19	0.2	0.0	0.19
2	0.09	0.10	0.10	0.10	0.01	0.07	0.17	0.20	0.16	0.11	0.12	0.12	0.1	0.0	0.25
3	0.08	0.08	0.08	0.08	0.00	0.02	0.16	0.13	0.12	0.09	0.11	0.08	0.1	0.0	0.26
4	0.09	0.08	0.09	0.09	0.00	0.01	0.14	0.20	0.12	0.09	0.11	0.07	0.1	0.0	0.38
5	0.08	0.08	0.08	0.08	0.00	0.01	0.16	0.26	0.15	0.09	0.08	0.07	0.1	0.1	0.51
6	0.07	0.07	0.07	0.07	0.00	0.01	0.15	0.22	0.08	0.09	0.08	0.07	0.1	0.1	0.51
7	0.23	0.22	0.21	0.22	0.01	0.05	--	0.57	--	--	0.08	--	0.3	0.3	1.05
8	0.32	0.21	0.20	0.25	0.07	0.28	0.34	0.30	0.29	0.24	0.22	0.17	0.3	0.1	0.23
Duty Cycle Avg (Raw)	0.05	0.04	0.04	0.04	0.01	0.20	0.06	0.07	0.05	0.04	0.04	0.03	0.05	0.01	0.28
uty Cycle Avg (Adjusted	0.26	0.19	0.18	0.21	0.04	0.20	0.31	0.35	0.27	0.22	0.19	0.16	0.25	0.07	0.28

Exhaust PM Concentrations (mg/m^3)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	7/21	7/21	7/21	3 Reps	3 Reps	3 Reps	7/16	7/16	4/17	4/17	7/18	7/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Low Idle	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!	--	--	--	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!
High Idle	1.5	1.4	1.3	1.4	0.10	0.07	2.5	3.9	2.7	1.9	1.8	1.5	2.4	0.9	0.37
Dyn Brake	--	--	--	--	--	--	2.4	3.2	2.4	1.6	1.7	1.2	2.1	0.7	0.33
1	1.7	1.8	1.9	1.8	0.11	0.06	2.6	2.9	3.0	2.0	2.1	2.0	2.4	0.5	0.19
2	1.7	1.8	1.9	1.8	0.13	0.07	3.2	3.9	3.1	2.0	2.3	2.3	2.8	0.7	0.25
3	2.0	1.9	2.0	2.0	0.04	0.02	4.1	3.5	3.1	2.4	2.8	2.0	3.0	0.8	0.26
4	2.3	2.3	2.3	2.3	0.03	0.01	4.0	5.6	3.4	2.5	2.9	1.8	3.4	1.3	0.39
5	2.4	2.4	2.4	2.4	0.01	0.01	4.8	7.6	4.4	2.7	2.5	2.2	4.0	2.1	0.51
6	2.6	2.6	2.6	2.6	0.03	0.01	5.3	8.2	3.1	3.4	3.0	2.4	4.2	2.2	0.52
7	10.0	9.4	8.8	9.4	0.59	0.06	--	28.5	--	--	4.3	--	16.4	17.1	1.04
8	14.5	9.5	8.8	10.9	3.09	0.28	16.4	15.0	14.3	11.9	11.1	8.6	12.9	2.9	0.22

Table D-13. Estimated CO_2 Emission Rates for NC-1797 and B40.

Time-Based CO2 Emission Rates (g/s)															
Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	7/21	7/21	7/21	3 Reps	3 Reps	3 Reps	7/16	7/16	4/17	4/17	7/18	7/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Low Idle	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!	--	--	--	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!
High Idle	16	16	16	16	0	0.02	17	16	16	17	16	16	16	0.5	0.03
Dyn Brake	--	--	--	--	--	--	16	17	15	17	16	15	16	0.8	0.05
1	37	39	38	38	1	0.02	38	39	34	39	32	30	35	3.7	0.11
2	56	57	56	56	1	0.01	50	46	55	57	45	42	49	6.1	0.12
3	96	97	96	96	0	0.00	94	92	95	97	95	88	94	3.1	0.03
4	145	144	143	144	1	0.01	142	137	142	144	136	121	137	8.2	0.06
5	188	185	188	187	1	0.01	187	169	195	191	174	179	182	10.1	0.06
6	239	235	236	237	2	0.01	228	199	203	225	198	196	208	14.4	0.07
7	379	373	375	375	3	0.01	--	264	--	--	243	--	254	15.1	0.06
8	449	443	445	446	3	0.01	387	391	394	398	386	376	389	7.8	0.02

Fuel-Based CO2 Emission Rates (g/gal)															
Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	7/21	7/21	7/21	3 Reps	3 Reps	3 Reps	7/16	7/16	4/17	4/17	7/18	7/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Low Idle	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!	--	--	--	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!
High Idle	9874	9824	10059	9919	124	0.01	9882	9776	9423	9391	9489	9892	9642	233.3	0.02
Dyn Brake	--	--	--	--	--	--	9645	9553	9499	9146	9618	9481	9490	180.2	0.02
1	10019	10073	10060	10050	28	0.00	9895	9948	10020	9865	9900	10028	9943	68.4	0.01
2	10005	10072	10069	10049	38	0.00	9919	9944	9938	9923	9973	10018	9952	37.5	0.00
3	10016	10073	10070	10053	32	0.00	9948	10007	10030	9976	9988	10014	9994	29.5	0.00
4	10020	10073	10072	10055	31	0.00	10042	10015	9961	9976	9964	9990	9991	31.7	0.00
5	10058	10072	10074	10068	9	0.00	10018	10005	10018	9993	10009	10042	10014	16.6	0.00
6	10051	10052	10036	10046	9	0.00	10038	10036	10064	10004	10012	10032	10031	21.2	0.00
7	10030	10052	10047	10043	11	0.00	--	10021	--	--	10047	--	10034	18.6	0.00
8	10048	10041	10044	10044	4	0.00	10044	10047	10027	10027	10033	10048	10038	9.9	0.00

Engine Output-Based CO2 Emission Rates (g/bhp-hr)															
Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	7/21	7/21	7/21	3 Reps	3 Reps	3 Reps	7/16	7/16	4/17	4/17	7/18	7/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Low Idle	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!	--	--	--	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!
High Idle	5847	5608	5637	5698	131	0.02	5975	5600	5861	6085	5831	5645	5833	186.6	0.03
Dyn Brake	--	--	--	--	--	--	5811	6106	5508	6051	5753	5355	5764	294.6	0.05
1	710	738	716	721	15	0.02	716	745	651	731	609	572	671	70.8	0.11
2	574	589	578	580	8	0.01	511	474	570	585	461	427	505	62.6	0.12
3	513	516	513	514	1	0.00	503	492	505	519	506	471	499	16.4	0.03
4	522	518	515	518	3	0.01	510	494	512	517	491	437	493	29.4	0.06
5	520	513	519	518	4	0.01	518	468	539	528	481	496	505	28.1	0.06
6	538	528	532	533	5	0.01	513	447	456	506	445	442	468	32.5	0.07
7	546	537	539	541	5	0.01	--	353	--	--	324	--	338	20.1	0.06
8	577	570	572	573	4	0.01	464	470	473	478	463	451	466	9.3	0.02

Exhaust CO2 Concentrations (%)															
Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	7/21	7/21	7/21	3 Reps	3 Reps	3 Reps	7/16	7/16	4/17	4/17	7/18	7/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Low Idle	--	--	--	#DIV/0!	#DIV/0!	#DIV/0!	--	0.77	--	--	--	--	0.77	#DIV/0!	#DIV/0!
High Idle	0.84	0.81	0.81	0.82	0.02	0.02	0.90	0.85	0.88	0.90	0.89	0.87	0.88	0.0	0.02
Dyn Brake	--	--	--	--	--	--	0.88	0.92	0.83	0.89	0.89	0.80	0.87	0.0	0.05
1	1.95	2.03	1.96	1.98	0.04	0.02	2.04	2.14	1.91	2.07	1.76	1.66	1.93	0.2	0.10
2	2.89	2.98	2.91	2.93	0.05	0.02	2.70	2.53	3.00	3.03	2.48	2.25	2.67	0.3	0.12
3	3.49	3.54	3.50	3.51	0.03	0.01	3.56	3.52	3.59	3.66	3.66	3.33	3.55	0.1	0.03
4	3.78	3.76	3.73	3.75	0.03	0.01	3.81	3.72	3.80	3.83	3.69	3.29	3.69	0.2	0.06
5	4.08	4.04	4.07	4.07	0.02	0.00	4.11	3.74	4.22	4.17	3.86	3.96	4.01	0.2	0.05
6	5.16	5.03	5.07	5.08	0.07	0.01	5.01	4.40	4.48	4.86	4.36	4.27	4.56	0.3	0.07
7	6.58	6.47	6.37	6.47	0.11	0.02	--	4.92	--	--	4.62	--	4.77	0.2	0.04
8	7.06	6.93	6.96	6.99	0.07	0.01	6.21	6.36	6.35	6.40	6.36	6.05	6.29	0.1	0.02

D.2 Summary of Results for NC-1797 on B20

This section discusses the results of the rail yard and over-the-rail measurements of the NC-1797 prime mover engine operated on B20 biodiesel, and includes a comparison to previously reported measurements on ULSD.

Rail Yard Measurements

Three rail yard emissions measurement replicates on the prime mover engine of NC-1797 on B20 biodiesel were conducted on April 14, 2014. In the rail yard, emissions measurements were taken continuously. During data analysis, collected data were selected when the engine reached steady state at idle settings and each of eight notch positions. Only steady state data were used to calculate notch average emission rates. The idle and notch average emission rates were weighted by the EPA line-haul cycle to estimate cycle average rates.

The EPA line-haul cycle average emission rates are shown in Table D-14. These cycle average emission rates are based on the measured engine activity data (RPM, MAP, and IAT), inferred engine activity data (MAF and AFR), and measured exhaust concentrations. The measured engine activity data and exhaust NO concentration were repeatable between replicates, as indicated in Figure D-8. The inter-replicate ratios of the standard deviation to the mean (coefficient of variation) were less than 0.03 for all notch positions for RPM, IAT, MAP, and MAF. For AFR and NO concentration, the inter-replicate coefficient of variations were typically less than 0.10, except for Idle. This indicates that the prime mover engine was operating consistently during all three replicate measurements.

An increasing trend in fuel use rate was apparent with increasing notch position, as shown in Figure D-9. Fuel use rates ranges from 3.3 g/s during Idle to 140 g/s during notch 8. Consistent fuel use rates among the three replicates were observed for idle and notches 1 through 7, as the standard deviations were typically less than 1.5 g/s. Slightly higher variations among the three replicates were observed during notch 8, which was because of variability in the estimated AFR as a result of variation in measured CO_2 concentrations.

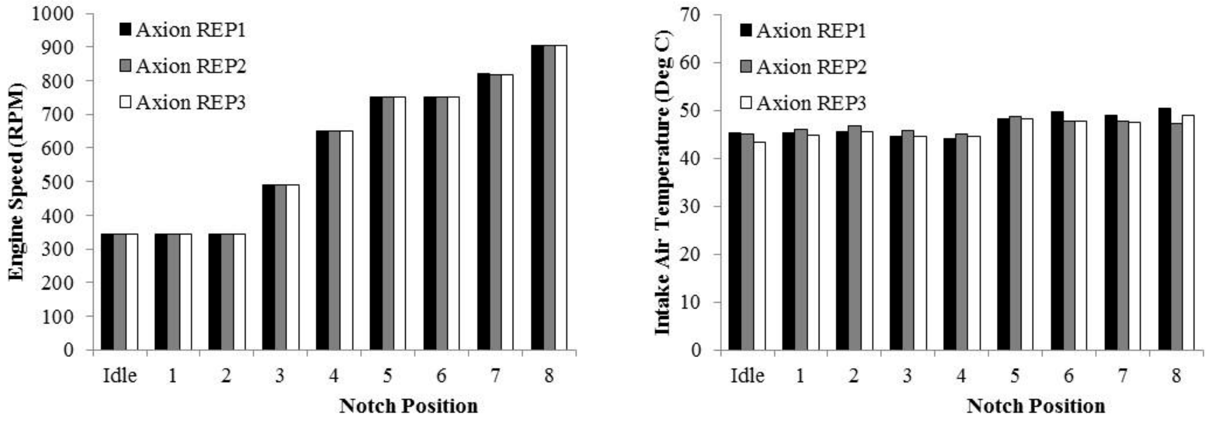
The NO emission rates among the three replicates were consistent, as shown in Figure D-10. The inter-replicate coefficient of variation for each notch position for the mass per gallon of fuel NO emission rates range from 0.01 to 0.07, which indicates small variability between replicates.

For exhaust HC concentrations across the three replicates, the coefficient of variation varied from 0.08 to 0.58, depending on the notch position. Differences in measured exhaust HC concentrations are the primary reason for inter-replicate variability in the notch-specific HC emission rates, as shown in Figure D-11. The inter-replicate coefficient of variation in the estimated HC emission rates were 34 percent, on average for each notch position.

There is also variability in the estimated notch-specific CO emission rates between the three replicate measurements, as shown in Figure D-12. Approximately 85 percent of the notch-specific CO concentrations measured were below the detection limit. These concentrations are not significantly different than zero. However, because of imprecision in the measurements at or below the detection limit, there was large variability in estimated average concentrations. The inter-replicate coefficient of variation in the estimated CO emission rates were 99 percent, on average, for each notch position. However, on an absolute basis, the exhaust CO concentrations were typically less than 0.007 volume percent, except for notch 8. Exhaust CO concentrations averaged 0.014 volume percent for notch 8, with an inter-replicate coefficient of variation of 0.28.

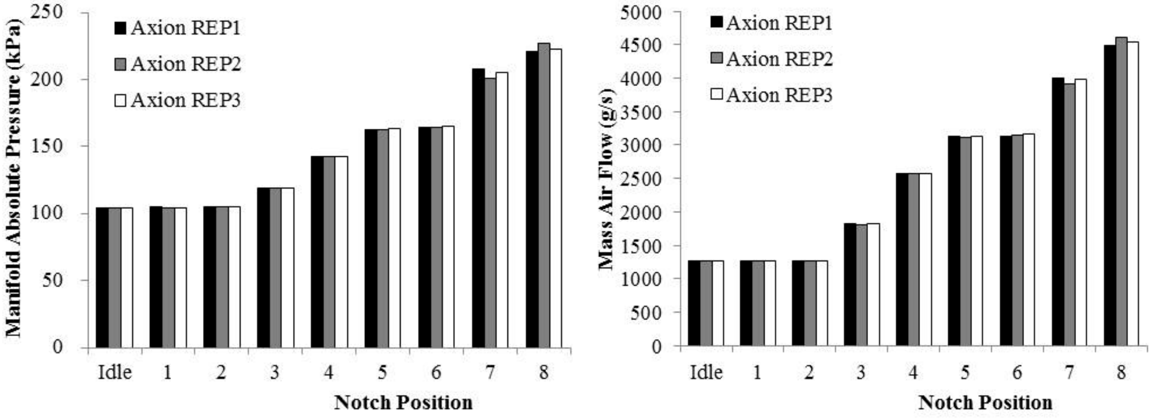
PM emission rates, as shown in Figure D-13, were consistent across the three replicates, with inter-replicate coefficients of variation less than 0.07 for all notch positions. All of the NO, CO, HC, and PM concentrations measured were of the same magnitude as previous rail yard measurements of the same engine operating on ULSD and B10.

Figure D-8. Measured Engine Activity Data during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on B20 Biodiesel



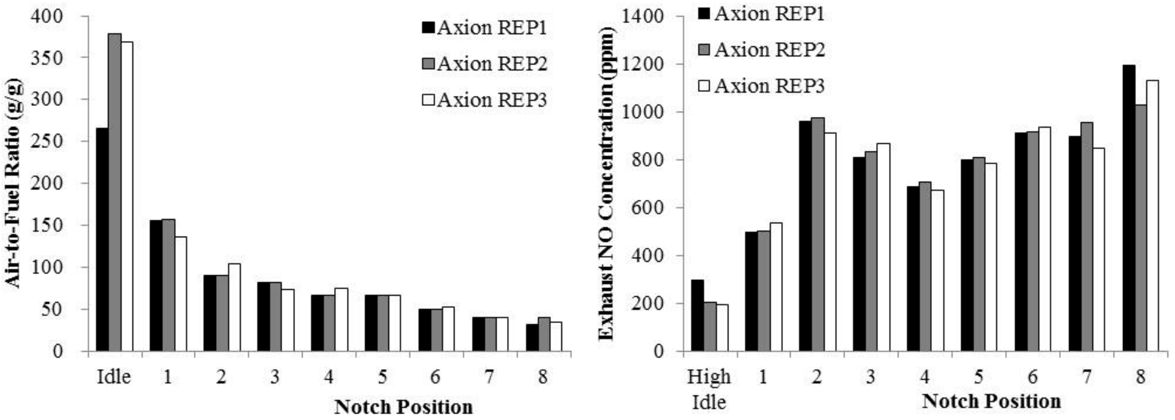
(a) Engine Speed

(b) Intake Air Temperature



(c) Manifold Absolute Pressure

(d) Mass Air Flow



(e) Air-to-Fuel Ratio

(f) Exhaust NO Concentration

Figure D-9. Estimated Fuel Use Rates during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on B20 Biodiesel

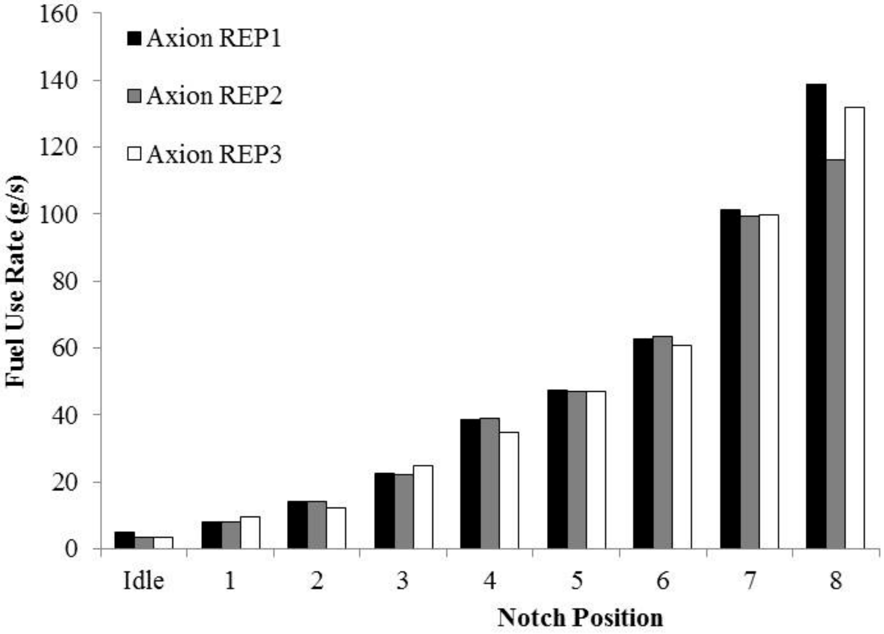


Figure D-10. Estimated NO$_x$ Emission Rates during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on B20 Biodiesel

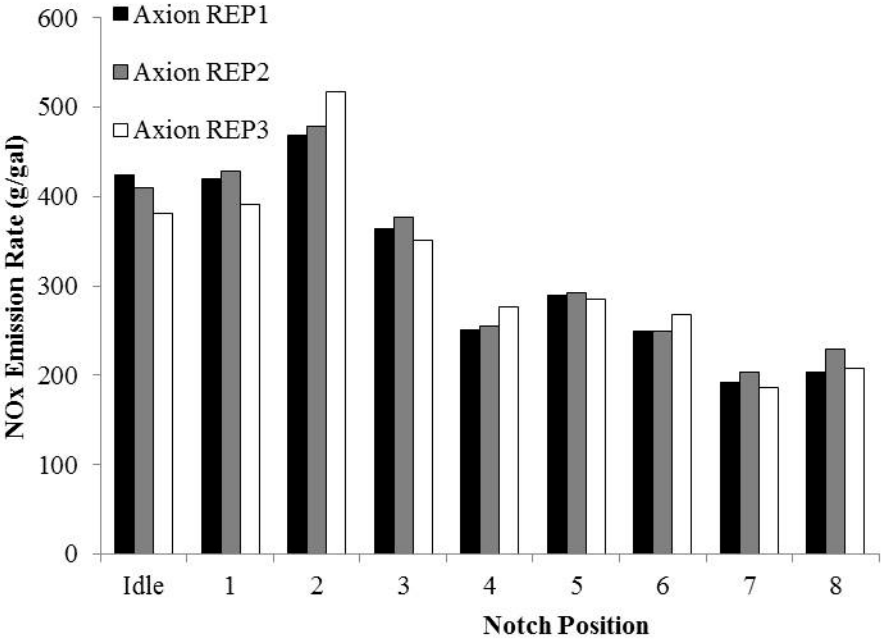
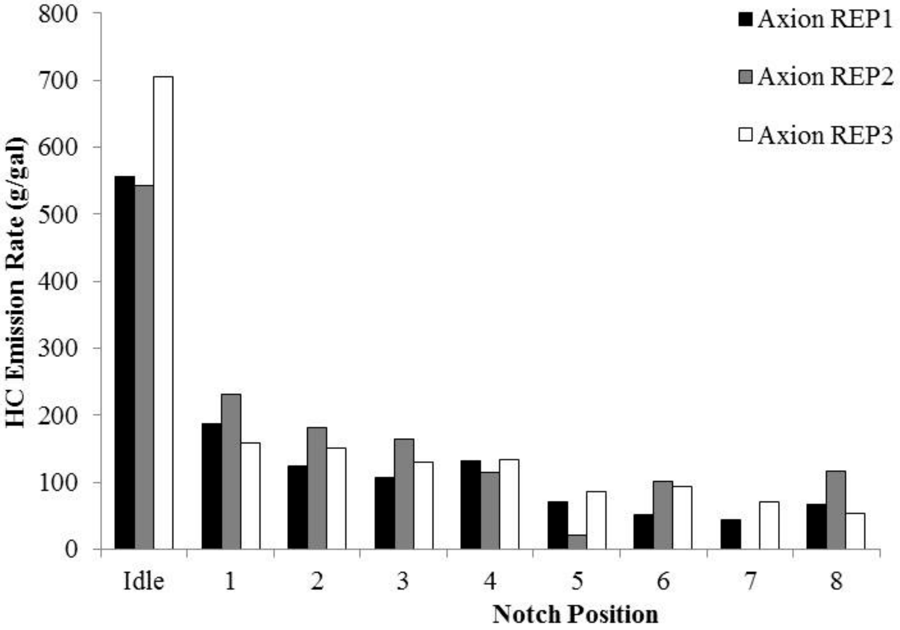


Figure D-11. Estimated HC Emission Rates during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on B20 Biodiesel[a]



[a] No valid data were collected for Notch 7 during replicate 2.

Figure D-12. Estimated CO Emission Rates during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on B20 Biodiesel

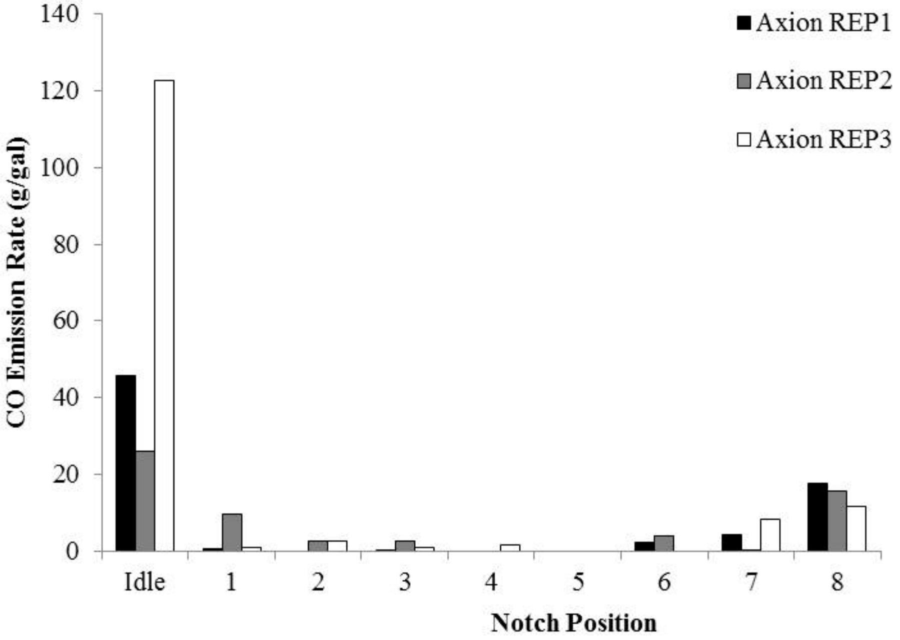
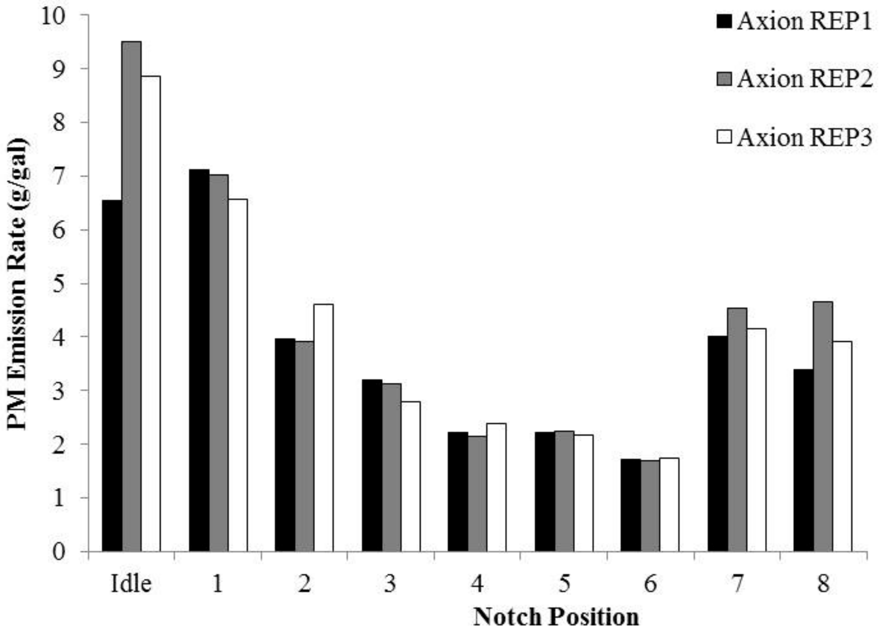


Figure D-13. Measured PM Emission Rate during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on B20 Biodiesel



Estimated EPA line-haul cycle average emission rates for each of the three replicate rail yard measurements are given in Table D-14. The NO_x, HC, and PM cycle average emission rates were consistent among the replicates, with coefficients of variation less than 0.07. The coefficient of variation for CO emission rates was 0.20. Differences in emission rates are attributable to differences in measured exhaust concentrations. Values for engine activity parameters (i.e., RPM, IAT, MAP) were similar across all measurements and thus are not significant factors in inter-replicate variation in emission rates.

Table D-14. Estimated EPA Line-Haul Cycle Average Emission Rates for Rail Yard Replicate Measurements of NC-1797 Prime Mover Engine Operated on B20 Biodiesel

	NO_x (g/bhp-hr)	**HC (g/bhp-hr)**	**CO (g/bhp-hr)**	**Opacity-based PM (g/bhp-hr)**
Replicate 1	12.4	5.34	0.7	0.13
Replicate 2	11.7	5.69	0.5	0.15
Replicate 3	11.7	4.99	0.7	0.14
Average of 3 Replicates	**11.9**	**5.34**	**0.7**	**0.14**
Coefficient of Variation	**0.03**	**0.07**	**0.20**	**0.01**

NO_x, HC, and PM are adjusted with multipliers of 1.053, 2.5, and 5, respectively, as bias correction.

Cycle average emission rates are based on EPA Line-Haul duty cycle.

Over-the-Rail Measurements

Three days of over-the-rail measurements on the NC-1797 prime mover engine operating on B20 biodiesel were conducted on April 15-17, 2014. Measurements of exhaust concentrations for the April 16 Train 73 were invalid because of a loose connection in exhaust line; however, the duty cycle of that train was observed. Thus, five one-way trips were used for cycle average emissions rates analysis, and observed duty cycles for all six one-way trips were quantified.

Based on over-the-rail measurements, steady state notch average emission rates were estimated for idle, dynamic braking, and notches 1 to 8. To enable comparisons with other data, the notch average emission rates were weighted based on the EPA line-haul duty cycle. The EPA line-haul cycle average emission rates for the over-the-rail measurements of the NC-1797 prime mover engine operating on B20 biodiesel are shown in Table D-15. These cycle average emission rates are based on measured engine activity data (RPM, MAP, and IAT) and measured exhaust concentrations. The cycle average estimate was based on measured notch-based emission rates and time fraction for each notch for the EPA line-haul duty cycle. For each set of measurements, there was little variability between measured engine activity data during both days of measurements. The inter-run CVs were typically less than 0.04 for RPM, MAP, and absolute IAT. This indicates that the prime mover engine was operating consistently during over-the-rail measurements. Measured engine activity data during over-the-rail measurements were similar in magnitude to the same data collected during rail yard measurements.

For notch average NO_x rates, the coefficient of variation was less than 0.14 for each notch position amongst the five one-way trips. The coefficients of variation for HC and CO are relatively high for each notch position. The coefficients of variation for HC typically ranged from 0.27 to 0.78 except Notch 7, for which the coefficient of variation was 1.17. For CO, the coefficients of variation tanged from 0.88 to 1.76 except for Notch 8, for which the coefficient of variation was 0.30. However, 20 and 98 percent of the notch-specific HC and CO concentrations, respectively, were below the detection limit. For example, HC concentrations were below the detection limit for Notch 7 for 3 out of 5 runs. CO concentrations were below the detection limit for approximately all notch positions during all runs. These concentrations led to imprecision that contributes to large inter-run variability. For PM, the coefficients of variation were typically less than 0.10 for all notch positions except for Notch 7 and 8, for which the coefficients of variations were 0.16 and 0.21, respectively. Differences in measured exhaust pollutant concentrations were one of the key reasons for the variability.

The EPA line-haul duty cycle average over-the-rail emission rates are quantitatively similar to the EPA line-haul duty cycle average rail yard emission rates. The over-the-rail cycle average NO_x emission rates were higher than the rail yard cycle average emission rate by 17 percent. The over-the-rail cycle average CO and HC emission rates were lower than the rail yard cycle average emission rate by 60 to 76 percent. The cycle average over-the-rail PM emission rate were 8 percent lower than the cycle average rail yard emission rates.

Differences in cycle average emission rates between rail yard and over-the-rail measurements can be attributed to various factors. RPM and MAP were essentially the same for rail yard and over-the-rail measurements. IAT differed on an absolute basis by less than 6 percent from run-to-run during over-the-rail measurements, indicating little to no inter-run differences. At notch 8, the engine output during rail yard measurements was 2,700 horsepower, while engine output was 3,000 horsepower during over-the-rail measurements. With notch 8 accounting for 16 percent of the EPA line-haul duty cycle, higher engine output decreases engine output based emission rates and, therefore, cycle average emission rates. Finally, differences in measured exhaust concentrations between rail yard and over-the-rail measurements lead to differences in fuel use and emission rates. For example, for notches 3 through 7, the over-the-rail average NO_x concentrations for each of these notches were approximately 40 percent higher than for the rail yard. The over-the-rail average HC concentrations were all notch positions were approximately 50 percent lower than for the rail yard. CO concentrations were typically below the detection limit for all notch positions for both the rail yard and over-the-rail measurements, which leads to imprecision.

Table D-15. EPA Line-Haul Cycle Average Emission Rates for Over-the-Rail Measurements of NC-1797 Prime Mover Engine Operated on B20 Biodiesel

	NO_x **(g/bhp-hr)**	**HC** **(g/bhp-hr)**	**CO** **(g/bhp-hr)**	**Opacity-based PM** **(g/bhp-hr)**
Apr. 15, 2014 – Train 73	13.5	2.04	0.2	0.14
Apr. 15, 2014 – Train 74	13.4	2.87	0.1	0.15
Apr. 16, 2014 – Train 74	14.6	2.11	0.3	0.11
Apr. 17, 2014 – Train 73	14.3	2.64	0.2	0.11
Apr. 17, 2014 – Train 74	13.7	0.99	0.1	0.13
Average	**13.9**	**2.13**	**0.2**	**0.13**
Coefficient of Variation	**0.04**	**0.34**	**0.50**	**0.12**

NO_x, HC, and PM are adjusted with multipliers of 1.05, 2.5, and 5, respectively, as bias correction.

Cycle average emission rates are based on EPA Line-Haul driving cycle.

Measurement on exhaust concentrations for April 16 Train 73 was invalid because of loose connection in exhaust line

Throttle notch position data obtained from the locomotive data activity recorder were used to quantify the actual real-world duty cycles for the over-the-rail measurements. The actual observed duty cycle for each one-way trip were quantified. The measured duty cycles are compared to the EPA line-haul duty cycle in Table D-16. The prime mover engine operated in notch 8 during the over-the-rail measurements more than double the percentage of time, on average, than EPA estimates a line-haul locomotive operates in notch 8. For the other notch positions, the observed time was on average less than the EPA line-haul duty cycle. Although not shown here, the real-world duty cycles can be used to estimate inter-cycle variability in cycle average for use and emission rates.

Table D-16. Observed Real-World Over-the-Rail Duty Cycles from Measurement of NC-1797 Operated on B20 Biodiesel

Notch	Percent Time in Each Notch							
	EPA Line-Haul	Measured Over-the-Rail						
		Average	4/15/2014 Train 73	4/15/2014 Train 74	4/16/2014 Train 73	4/16/2014 Train 74	4/17/2014 Train 73	4/17/2014 Train 74
Idle	38.0	33.6	44.5	27.8	42.5	43.7	18.4	24.7
DB	12.5	3.3	1.1	4.5	2.2	5.0	3.6	3.4
1	6.5	6.5	1.2	16.0	2.0	1.4	3.0	15.7
2	6.5	4.0	4.2	4.1	3.0	3.4	6.6	2.6
3	5.2	3.9	1.9	2.6	2.8	4.5	9.2	2.6
4	4.4	3.8	2.5	5.6	2.3	3.4	4.4	4.5
5	3.8	1.6	0.3	2.7	1.5	2.7	0.7	1.6
6	3.9	3.1	0.3	9.0	1.5	1.5	0.6	6.1
7	3.0	0.9	0.1	2.0	1.4	0.3	0.2	1.5
8	16.2	39.3	44.0	25.9	40.7	34.2	53.4	37.4

Train 73 is from Raleigh to Charlotte. Train 74 is from Charlotte to Raleigh.

Details of results of rail yard and over-the-rail measurements of NC-1797 using B20 biodiesel are given in attached supplemental tables.

Table D-17 summarizes the average measured engine speed (RPM), intake air temperature (IAT), manifold absolute pressure (MAP), estimated mass air flow (MAF), and air-to-fuel ratio (AFR) for each throttle notch position and for each replicate of the RY measurement and for each one-way OTR trip. Engine speed ranges from 342 to 903 RPM in both RY and OTR measurements, depending on notch position. For the RY measurements, engine RPM was highly repeatable among replicates for a given notch position, with a standard deviation of less than 0.1 RPM for all notch positions. For the OTR measurements, the RPM was also repeatable among replicates for a given notch position, with coefficient of variation less than 0.01 for all notch positions. For some one-way trips, the sample sizes in these notches are too small to infer a steady-state engine operating speed. The intake air temperature varies with ambient temperature and was generally in the range of 41 to 50 degrees C during all measurements. MAP was highly repeatable in the RY measurements, ranging from 101 to 227 kPa depending on notch position. The inter-replicate standard deviation of measured MAP was less than 4 kPa for each notch position. For OTR measurements, there was slightly more inter-run variability in MAP. However, the coefficient of variation for each notch position was typically 0.04 or less.

Estimated MAF was highly repeatable for both RY and OTR measurements, with the coefficient of variation typically 0.04 or less for all notch position. The MAF ranged from 1,200 to 4,700 g/s, depending on notch position. Estimated AFR was repeatable among replicates for a given notch position in the RY measurements, with coefficient of variation less than 0.11 for all notches, except for idle. For OTR measurements, there was slightly more inter-run variability in AFR for each notch position, but the coefficient of variation was less than 0.23 for all notch positions. Overall, the engine RPM, absolute IAT, MAP, and MAF during the measurements was consistent for the three replicates in the rail yard, and from run to run for the five one-way trips observed between Raleigh and Charlotte.

Table D-18 summarizes the estimated fuel use rates inferred from the engine data of Table D-17. For the RY measurements, fuel use rates range from 3.3 to 139 g/sec depending on notch position, and were highly repeatable among replicates for a given notch position, with a coefficient of variation of 0.09 or less, except for idle. There was more variability in run-to-run estimates of fuel use for the OTR measurements, in part because the amount of time spent in some notch positions was low. The OTR estimated fuel use ranged from 3.2 to 118 g/sec, depending on notch position. The coefficient of variation for all notches was less than 0.19 for all notch positions.

During RY measurements, the maximum engine output was 2,700 hp, whereas during OTR measurements the maximum engine output was 3,000 hp. Furthermore, as shown later in Table D-23, the average CO_2 concentrations for each notch position are lower for OTR than for RY measurements, which implies a lower fuel-to-air ratio. Because the engine activity and engine air flow are approximately the same for OTR versus RY measurements, the combination of higher engine output and lower fuel-to-air ratio lead to higher values of fuel-specific engine output (FSEO) in bhp-hr per gallon of fuel consumed, as shown in Table D-18. The FSEO was highly repeatable for the OTR measurements of each notch position, especially Notch 8, which represents significant portion of the observed duty cycle.

The measured NO exhaust concentration and the estimated NO_x emission rates are shown in Table D-19 for each notch position, each RY replicate, and each OTR one-way run. The average measured concentrations range among notch positions from approximately 190 to 1,190 parts per million (ppm) in the RY measurements, and 230 to 1,400 ppm in the OTR measurements, depending on notch position. The measurements are highly repeatable among replicates for a given notch position for both the RY and OTR measurements, with coefficients of variation typically less than 0.08 except for Idle for the former and less than 0.13 for all notch positions for the latter. The estimated mass emission rates range from 0.4 to 8.7 g/sec for the RY measurements and 0.5 to 9.2 g/sec for the OTR measurements, depending on notch position. Because the observed concentrations tend to be higher for the OTR versus RY measurements, the mass emission rates also tend to be slightly higher for the OTR versus RY measurements.

On a fuel basis, the average NO_x emission rates range from 190 to 520 g/gallon for the RY measurements and 240 to 570 g/gallon for the OTR measurements, depending on notch position. For the RY measurements, the fuel-based emission rates are highly repeatable among replicates for a given notch position, with coefficient of variation typically less than 0.07. For the OTR measurements, the coefficients of variation were typically less than 0.19 for all notch positions. The fuel-based emission rates tend to be lowest at high load.

On an engine output basis, excluding idle and dynamic braking, the notch average NO_x emission rates range from 9.9 g/bhp-hr at Notch 8 to 21.3 g/bhp-hr at Notch 1 in the RY measurements, and range from 9.8 g/bhp-hr at Notch 8 to 22.4 g/bhp-hr at Notch 1 in the OTR measurements. The notch average NO_x emission rates for idle and dynamic braking were higher than the other notch positions. In general, the emission rates on an engine output basis are higher for the OTR measurements than for the RY measurements. This results from a combination of lower exhaust concentration and higher engine output, especially at notch 8.

Results are given for exhaust concentrations and emission rates in Tables D-20, D-21, D-22, and D-23 for CO, HC, PM, and CO_2, respectively. The CO exhaust concentrations during OTR measurements are slightly lower than during RY measurements. Thus, the cycle average CO emission rates are also slightly lower for OTR than RY measurements. On average, the HC exhaust concentrations and average emission rates tend to be lower for OTR than RY. However, CO and HC emission rates are low on an absolute basis, and some of the measured average concentrations for a given notch position and replicate or run are below the gas analyzer detection limit. For PM, the measured exhaust levels for OTR were very close to RY for a given notch position, and thus the cycle average PM emission rates were very close for OTR and RY measurements. The trends in CO_2 emission rates are similar to those for fuel use on a mass per time and mass per engine output basis. CO_2 emission rates are also shown on a g/gallon basis. Since typically over 99 percent of the carbon in the fuel was emitted as CO_2, the fuel-based CO_2 emission rates are approximately constant.

SUMMARY

In this part of the study, a procedure was demonstrated for rail yard and over-the-rail characterization of emission rates for B20 biodiesel. The rail yard engine activity and emission concentration measurements were consistent across the three replicates. For rail yard measurements, NO_x, CO, and HC cycle average emission rates were higher for B20 biodiesel versus ULSD while PM cycle average emission rates were lower for B20 biodiesel versus ULSD.

The cycle average over-the-rail emission rates are of similar magnitude as the cycle average rail yard emission rates. For B20, the cycle average over-the-rail NO_x and PM emission rates were higher than during rail yard measurements, and the cycle average over-the-rail CO and HC emission rates are lower than during rail yard measurements.

Table D-17. Measured Engine Parameters for NC-1797 and B20 Biodiesel

Engine Speed (RPM)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	4/14	4/14	4/14	3 Reps	3 Reps	3 Reps	4/15	4/15	4/16	4/16	4/17	4/17	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	343	343	343	343	0.06	0.00	343	342	--	343	343	343	343	0.11	0.00
Dyn Brake	--	--	--	--	--	--	346	342	--	343	343	342	343	1.33	0.00
1	343	343	343	343	0.05	0.00	344	342	--	345	342	342	343	1.26	0.00
2	343	343	343	343	0.04	0.00	343	343	--	343	343	343	343	0.27	0.00
3	490	490	490	490	0.03	0.00	490	490	--	490	490	490	490	0.20	0.00
4	651	651	651	651	0.04	0.00	651	651	--	651	651	651	651	0.18	0.00
5	750	750	750	750	0.06	0.00	748	749	--	750	750	749	749	0.72	0.00
6	750	750	750	750	0.10	0.00	748	750	--	749	750	750	749	0.57	0.00
7	819	819	819	819	0.03	0.00	--	819	--	824	--	820	821	2.63	0.00
8	903	903	903	903	0.02	0.00	903	903	--	903	903	903	903	0.13	0.00

Intake Air Temeprature (°C)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	4/14	4/14	4/14	3 Reps	3 Reps	3 Reps	4/15	4/15	4/16	4/16	4/17	4/17	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	45	45	43	45	1.07	0.02	47	48	--	43	39	45	44	3.46	0.08
Dyn Brake	--	--	--	--	--	--	48	48	--	44	40	46	45	3.49	0.08
1	45	46	45	45	0.60	0.01	47	48	--	42	42	46	45	2.64	0.06
2	45	47	46	46	0.74	0.02	47	48	--	45	41	45	45	2.69	0.06
3	45	46	45	45	0.72	0.02	49	48	--	44	40	45	45	3.61	0.08
4	44	45	44	45	0.57	0.01	48	49	--	44	42	46	46	3.00	0.07
5	48	49	48	48	0.27	0.01	49	48	--	44	42	46	46	2.70	0.06
6	50	48	48	48	1.20	0.02	49	48	--	42	42	45	45	3.22	0.07
7	49	48	48	48	0.76	0.02	--	47	--	42	--	48	46	3.36	0.07
8	50	47	49	49	1.62	0.03	48	49	--	44	41	46	46	2.90	0.06

Manifold Absolute Pressure (kPa)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	4/14	4/14	4/14	3 Reps	3 Reps	3 Reps	4/15	4/15	4/16	4/16	4/17	4/17	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	104	104	104	104	0.09	0.00	102	101	--	105	106	105	104	2.13	0.02
Dyn Brake	--	--	--	--	--	--	103	102	--	105	105	105	104	1.63	0.02
1	105	105	105	105	0.12	0.00	103	102	--	106	106	105	104	2.08	0.02
2	105	105	105	105	0.11	0.00	102	102	--	105	107	105	104	2.17	0.02
3	119	119	119	119	0.09	0.00	117	115	--	120	121	119	119	2.39	0.02
4	143	143	143	143	0.08	0.00	140	139	--	145	147	144	143	3.65	0.03
5	163	163	163	163	0.07	0.00	159	158	--	166	169	165	163	4.88	0.03
6	164	165	165	165	0.19	0.00	159	159	--	168	169	166	164	4.80	0.03
7	208	201	205	205	3.63	0.02	--	179	--	189	--	191	186	6.22	0.03
8	221	227	223	224	2.82	0.01	205	206	--	215	226	219	214	8.93	0.04

Mass Air Flow (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	4/14	4/14	4/14	3 Reps	3 Reps	3 Reps	4/15	4/15	4/16	4/16	4/17	4/17	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	1263	1262	1269	1265	4.20	0.00	1228	1221	--	1273	1303	1266	1258	34.0	0.03
Dyn Brake	--	--	--	--	--	--	1245	1224	--	1278	1294	1266	1261	27.5	0.02
1	1265	1261	1266	1264	2.95	0.00	1241	1223	--	1292	1292	1266	1263	30.9	0.02
2	1267	1259	1265	1264	4.03	0.00	1234	1225	--	1272	1300	1272	1261	30.8	0.02
3	1818	1809	1816	1814	5.05	0.00	1771	1757	--	1830	1877	1822	1811	48.5	0.03
4	2578	2567	2574	2573	5.69	0.00	2504	2483	--	2610	2663	2586	2569	74.7	0.03
5	3126	3120	3127	3125	3.79	0.00	3050	3050	--	3210	3278	3177	3153	101	0.03
6	3131	3154	3157	3148	14.3	0.00	3058	3070	--	3251	3283	3210	3174	104	0.03
7	4005	3913	3979	3966	47.4	0.01	--	3594	--	3818	--	3764	3725	117	0.03
8	4484	4616	4536	4545	66.36	0.01	4264	4268	--	4472	4688	4505	4440	178	0.04

Air to Fuel Ratio (g/g)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	4/14	4/14	4/14	3 Reps	3 Reps	3 Reps	4/15	4/15	4/16	4/16	4/17	4/17	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	266	379	368	338	62.2	0.18	351	292	--	280	295	346	313	32.8	0.10
Dyn Brake	--	--	--	--	--	--	328	324	--	271	336	398	331	45.4	0.14
1	156	157	136	150	12.0	0.08	216	135	--	142	134	155	156	34.3	0.22
2	89.8	89.8	104	94.4	7.97	0.08	95.6	94.2	--	83.3	83.4	124	96.0	16.5	0.17
3	81.4	81.5	73.8	78.9	4.40	0.06	67.3	75.5	--	64.1	69.0	91.9	73.6	11.1	0.15
4	67.0	66.2	74.5	69.2	4.57	0.07	70.4	68.9	--	63.5	71.5	83.3	71.5	7.26	0.10
5	66.3	66.5	66.7	66.5	0.22	0.00	74.9	62.6	--	58.4	60.3	66.2	64.5	6.51	0.10
6	49.9	49.7	51.9	50.5	1.21	0.02	66.3	53.1	--	52.0	54.9	59.4	57.1	5.86	0.10
7	39.6	39.4	39.8	39.6	0.22	0.01	--	39.3	--	36.2	--	48.3	41.3	6.30	0.15
8	32.3	39.7	34.4	35.5	3.83	0.11	41.7	37.9	--	38.8	39.9	40.5	39.8	1.49	0.04

Table D-18. Estimated Fuel Use Rates for NC-1797 and B20 Biodiesel

Time-Based Fuel Use Rates (g/s)

Throttle Notch Position	Rail Yard Test						Over-The-Rail Test								
	4/14 Axion REP1	4/14 Axion REP2	4/14 Axion REP3	3 Reps Average	3 Reps StDev	3 Reps CV	4/15 Train 73	4/15 Train 74	4/16 Train 73	4/16 Train 74	4/17 Train 73	4/17 Train 73	6 Trains Average	6 Trains StDev	6 Trains CV
Idle	4.74	3.33	3.45	3.84	0.78	0.20	3.50	4.18	--	4.54	4.41	3.66	4.06	0.46	0.11
Dyn Brake	--	--	--	--	--	--	3.80	3.77	--	4.72	3.85	3.18	3.86	0.55	0.14
1	8.10	8.02	9.31	8.48	0.72	0.09	5.75	9.09	--	9.10	9.62	8.17	8.35	1.54	0.19
2	14.1	14.0	12.2	13.5	1.07	0.08	12.9	13.0	--	15.3	15.6	10.3	13.4	2.14	0.16
3	22.3	22.2	24.6	23.0	1.35	0.06	26.3	23.3	--	28.6	27.2	19.8	25.0	3.50	0.14
4	38.5	38.8	34.6	37.3	2.36	0.06	35.6	36.0	--	41.1	37.2	31.0	36.2	3.61	0.10
5	47.1	47.0	46.9	47.0	0.15	0.00	40.7	48.7	--	55.0	54.4	48.0	49.4	5.78	0.12
6	62.7	63.4	60.8	62.3	1.36	0.02	46.1	57.9	--	62.5	59.8	54.0	56.1	6.36	0.11
7	101	99.3	99.9	100	1.00	0.01	--	91.4	--	106	--	77.9	91.6	13.8	0.15
8	139	116	132	129	11.6	0.09	102	113	--	115	117	111	112	5.87	0.05

Engine Output-Based Fuel Use Rates (g/bhp-hr)

Throttle Notch Position	Rail Yard Test						Over-The-Rail Test								
	4/14 Axion REP1	4/14 Axion REP2	4/14 Axion REP3	3 Reps Average	3 Reps StDev	3 Reps CV	4/15 Train 73	4/15 Train 74	4/16 Train 73	4/16 Train 74	4/17 Train 73	4/17 Train 73	6 Trains Average	6 Trains StDev	6 Trains CV
Idle	1.71	2.44	2.36	2.17	0.40	0.18	2.32	1.95	--	1.79	1.84	2.22	2.02	0.24	0.12
Dyn Brake	--	--	--	--	--	--	2.14	2.15	--	1.72	2.11	2.56	2.14	0.30	0.14
1	19.1	19.2	16.6	18.3	1.49	0.08	26.9	17.0	--	17.0	16.0	18.9	19.2	4.43	0.23
2	20.1	20.3	23.3	21.2	1.77	0.08	22.0	21.9	--	18.6	18.2	27.6	21.7	3.77	0.17
3	24.6	24.7	22.3	23.9	1.35	0.06	20.8	23.6	--	19.2	20.2	27.7	22.3	3.41	0.15
4	21.1	20.9	23.5	21.9	1.43	0.07	22.9	22.5	--	19.8	21.8	26.2	22.6	2.32	0.10
5	22.8	22.9	23.0	22.9	0.07	0.00	26.4	22.1	--	19.6	19.8	22.4	22.1	2.76	0.13
6	20.7	20.5	21.4	20.9	0.46	0.02	28.2	22.5	--	20.8	21.7	24.1	23.5	2.91	0.12
7	19.3	19.6	19.5	19.5	0.19	0.01	--	24.0	--	20.8	--	28.1	24.3	3.70	0.15
8	17.6	21.0	18.5	19.0	1.77	0.09	23.9	21.6	--	21.2	20.8	21.9	21.9	1.20	0.05

Table D-19. Measured NO$_x$ Emission Rates for NC-1797 and B20 Biodiesel

Time-Based NO$_x$ Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	4/14	4/14	4/14	3 Reps	3 Reps	3 Reps	4/15	4/15	4/16	4/16	4/17	4/17	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	0.62	0.42	0.40	0.48	0.12	0.25	0.46	0.52	--	0.56	0.54	0.49	0.51	0.04	0.08
Dyn Brake	--	--	--	--	--	--	0.49	0.48	--	0.54	0.46	0.36	0.47	0.07	0.14
1	1.05	1.06	1.12	1.08	0.04	0.04	0.93	1.17	--	1.07	1.18	1.09	1.09	0.10	0.09
2	2.04	2.07	1.95	2.02	0.06	0.03	1.83	1.82	--	1.98	2.11	1.62	1.87	0.18	0.10
3	2.51	2.58	2.66	2.59	0.07	0.03	3.37	4.08	--	4.20	3.45	3.46	3.71	0.39	0.11
4	2.99	3.06	2.96	3.00	0.05	0.02	5.46	5.51	--	5.83	5.04	4.84	5.34	0.40	0.07
5	4.21	4.23	4.13	4.19	0.05	0.01	6.73	6.13	--	6.68	7.69	7.20	6.89	0.59	0.09
6	4.83	4.88	5.02	4.91	0.10	0.02	7.37	6.55	--	7.25	6.94	6.56	6.93	0.38	0.06
7	6.00	6.24	5.74	5.99	0.25	0.04	--	7.52	--	8.64	--	8.76	8.31	0.68	0.08
8	8.72	8.25	8.47	8.48	0.24	0.03	8.17	8.33	--	9.14	8.70	8.93	8.66	0.40	0.05

Fuel-Based NO$_x$ Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	4/14	4/14	4/14	3 Reps	3 Reps	3 Reps	4/15	4/15	4/16	4/16	4/17	4/17	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	424	410	381	405	22.0	0.05	423	403	--	398	397	432	411	16.0	0.04
Dyn Brake	--	--	--	--	--	--	422	413	--	372	387	371	393	23.3	0.06
1	420	428	391	413	19.5	0.05	525	417	--	382	398	431	431	55.8	0.13
2	468	479	518	488	26.1	0.05	458	454	--	421	437	510	456	33.5	0.07
3	364	376	350	364	13.0	0.04	414	567	--	476	411	566	487	77.3	0.16
4	251	255	277	261	13.8	0.05	497	495	--	459	438	505	479	28.9	0.06
5	289	292	285	289	3.14	0.01	535	408	--	393	458	486	456	57.7	0.13
6	250	249	267	255	10.4	0.04	518	366	--	376	375	393	406	63.5	0.16
7	192	204	186	194	8.92	0.05	--	267	--	265	--	364	298	56.6	0.19
8	203	230	208	214	14.1	0.07	259	240	--	257	240	260	251	10.5	0.04

Engine Output-Based NO$_x$ Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	4/14	4/14	4/14	3 Reps	3 Reps	3 Reps	4/15	4/15	4/16	4/16	4/17	4/17	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	223	152	146	174	43.2	0.25	164	187	--	201	195	176	185	14.6	0.08
Dyn Brake	--	--	--	--	--	--	178	173	--	195	166	131	169	23.6	0.14
1	19.9	20.1	21.3	20.4	0.76	0.04	17.6	22.2	--	20.4	22.4	20.6	20.6	1.90	0.09
2	21.0	21.3	20.1	20.8	0.64	0.03	18.8	18.8	--	20.4	21.7	16.7	19.3	1.90	0.10
3	13.4	13.8	14.2	13.8	0.40	0.03	18.0	21.7	--	22.4	18.4	18.5	19.8	2.10	0.11
4	10.8	11.0	10.6	10.8	0.19	0.02	19.7	19.9	--	21.0	18.1	17.4	19.2	1.42	0.07
5	11.4	11.5	11.2	11.4	0.14	0.01	18.3	16.7	--	18.2	20.9	19.6	18.7	1.60	0.09
6	10.9	11.0	11.3	11.0	0.22	0.02	16.6	14.7	--	16.3	15.6	14.7	15.6	0.86	0.06
7	9.00	9.36	8.60	8.99	0.38	0.04	--	10.0	--	11.5	--	11.7	11.1	0.91	0.08
8	10.5	9.90	10.2	10.2	0.28	0.03	9.81	10.0	--	11.0	10.4	10.7	10.4	0.48	0.05
Duty Cycle Avg (Raw)	11.8	11.1	11.1	11.3	0.38	0.03	12.8	12.7	--	13.8	13.6	13.0	13.2	0.5	0.04
Duty Cycle Avg (Adj)	12.4	11.7	11.7	11.9	0.40	0.03	13.5	13.4	--	14.6	14.3	13.7	13.9	0.5	0.04

Exhaust NO$_x$ Concentrations (ppm)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	4/14	4/14	4/14	3 Reps	3 Reps	3 Reps	4/15	4/15	4/16	4/16	4/17	4/17	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	297	202	193	231	57.4	0.25	226	258	--	267	250	235	247	16.8	0.07
Dyn Brake	--	--	--	--	--	--	242	238	--	260	218	179	227	30.7	0.13
1	495	501	534	510	20.8	0.04	444	574	--	511	554	516	520	49.8	0.10
2	960	976	910	949	34.4	0.04	882	886	--	960	977	757	893	87.0	0.10
3	810	832	864	835	27.4	0.03	1122	1366	--	1396	1100	1119	1221	147	0.12
4	686	707	671	688	18.2	0.03	1282	1312	--	1362	1127	1101	1237	116	0.09
5	799	806	782	796	12.6	0.02	1220	1188	--	1271	1419	1351	1290	94.8	0.07
6	913	916	933	921	10.9	0.01	1405	1250	--	1364	1231	1199	1290	89.3	0.07
7	894	956	845	898	55.9	0.06	--	1214	--	1399	--	1324	1313	93.3	0.07
8	1192	1025	1130	1116	84.4	0.08	1122	1146	--	1269	1141	1162	1168	58.1	0.05

Table D-20. Measured CO Emission Rates for NC-1797 and B20 Biodiesel

Time-Based CO Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	4/14	4/14	4/14	3 Reps	3 Reps	3 Reps	4/15	4/15	4/16	4/16	4/17	4/17	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	0.07	0.03	0.13	0.07	0.05	0.70	0.01	0.01	--	0.04	0.05	0.00	0.02	0.02	0.98
Dyn Brake	--	--	--	--	--	--	0.01	0.00	--	0.09	0.01	0.00	0.02	0.04	1.78
1	0.00	0.02	0.00	0.01	0.01	1.36	0.00	0.00	--	0.01	0.05	0.00	0.01	0.02	1.50
2	0.00	0.01	0.01	0.01	0.01	0.87	0.00	0.00	--	0.02	0.03	0.00	0.01	0.01	1.09
3	0.00	0.02	0.01	0.01	0.01	0.98	0.00	0.00	--	0.04	0.01	0.00	0.01	0.02	1.76
4	0.00	0.00	0.02	0.01	0.01	1.73	0.00	0.00	--	0.06	0.02	0.00	0.02	0.03	1.44
5	0.00	0.00	0.00	0.00	0.00	--	0.00	0.00	--	0.03	0.01	0.00	0.01	0.01	1.20
6	0.05	0.08	0.00	0.04	0.04	0.96	0.00	0.01	--	0.05	0.00	0.00	0.01	0.02	1.70
7	0.13	0.00	0.26	0.13	0.13	0.97	--	0.04	--	0.01	--	0.01	0.02	0.02	0.88
8	0.76	0.56	0.47	0.60	0.15	0.25	0.14	0.16	--	0.15	0.11	0.07	0.13	0.04	0.30

Fuel-Based CO Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	4/14	4/14	4/14	3 Reps	3 Reps	3 Reps	4/15	4/15	4/16	4/16	4/17	4/17	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	45.8	26.0	123	64.8	51.1	0.79	13.4	4.12	--	27.6	37.7	1.01	16.8	15.6	0.93
Dyn Brake	--	--	--	--	--	--	4.80	1.01	--	62.0	8.95	0.67	15.5	26.2	1.69
1	0.49	9.66	0.97	3.71	5.16	1.39	2.04	0.54	--	2.83	16.3	1.84	4.71	6.52	1.39
2	0.00	2.53	2.50	1.67	1.45	0.87	0.90	0.35	--	3.55	5.43	0.76	2.19	2.20	1.00
3	0.15	2.51	0.89	1.18	1.21	1.02	0.03	0.00	--	4.39	1.03	0.00	1.09	1.90	1.74
4	0.00	0.00	1.56	0.52	0.90	1.73	0.00	0.40	--	5.06	2.06	0.20	1.54	2.13	1.38
5	0.00	0.00	0.00	0.00	0.00	--	0.23	0.18	--	1.66	0.75	0.07	0.58	0.66	1.14
6	2.33	4.00	0.00	2.11	2.01	0.95	0.25	0.34	--	2.37	0.00	0.09	0.61	0.99	1.63
7	4.14	0.14	8.37	4.21	4.12	0.98	--	1.34	--	0.21	--	0.50	0.68	0.59	0.86
8	17.8	15.6	11.6	15.0	3.15	0.21	4.59	4.58	--	4.35	3.04	1.98	3.71	1.16	0.31

Engine Output-Based CO Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	4/14	4/14	4/14	3 Reps	3 Reps	3 Reps	4/15	4/15	4/16	4/16	4/17	4/17	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	24.1	9.61	47.0	26.9	18.8	0.70	5.23	1.91	--	14.0	18.5	0.41	8.00	7.87	0.98
Dyn Brake	--	--	--	--	--	--	2.03	0.42	--	32.5	3.83	0.24	7.81	13.9	1.78
1	0.02	0.45	0.05	0.18	0.24	1.36	0.07	0.03	--	0.15	0.92	0.09	0.25	0.37	1.50
2	0.00	0.11	0.10	0.07	0.06	0.87	0.04	0.01	--	0.17	0.27	0.02	0.10	0.11	1.09
3	0.01	0.09	0.04	0.04	0.04	0.98	0.00	0.00	--	0.21	0.05	0.00	0.05	0.09	1.76
4	0.00	0.00	0.06	0.02	0.03	1.73	0.00	0.02	--	0.23	0.09	0.01	0.07	0.10	1.44
5	0.00	0.00	0.00	0.00	0.00	--	0.01	0.01	--	0.08	0.03	0.00	0.03	0.03	1.20
6	0.10	0.18	0.00	0.09	0.09	0.96	0.01	0.01	--	0.10	0.00	0.00	0.03	0.04	1.70
7	0.19	0.01	0.39	0.20	0.19	0.97	--	0.05	--	0.01	--	0.02	0.03	0.02	0.88
8	0.92	0.67	0.57	0.72	0.18	0.25	0.17	0.19	--	0.19	0.13	0.08	0.15	0.05	0.30
Duty Cycle Avg (Raw)	0.74	0.50	0.69	0.65	0.13	0.20	0.15	0.13	--	0.27	0.23	0.06	0.17	0.08	0.50
Duty Cycle Avg (Adj)	0.74	0.50	0.69	0.65	0.13	0.20	0.15	0.13	--	0.27	0.23	0.06	0.17	0.08	0.50

Exhaust CO Concentrations (%)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	4/14	4/14	4/14	3 Reps	3 Reps	3 Reps	4/15	4/15	4/16	4/16	4/17	4/17	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	0.006	0.002	0.011	0.006	0.00	0.70	0.001	0.000	--	0.003	0.004	0.000	0.002	0.00	0.96
Dyn Brake	--	--	--	--	--	--	0.000	0.000	--	0.007	0.001	0.000	0.002	0.00	1.78
1	0.000	0.002	0.000	0.001	0.00	1.36	0.000	0.000	--	0.001	0.004	0.000	0.001	0.00	1.49
2	0.000	0.001	0.001	0.001	0.00	0.87	0.000	0.000	--	0.001	0.002	0.000	0.001	0.00	1.08
3	0.000	0.001	0.000	0.000	0.00	0.98	0.000	0.000	--	0.002	0.000	0.000	0.001	0.00	1.77
4	0.000	0.000	0.001	0.000	0.00	1.73	0.000	0.000	--	0.003	0.001	0.000	0.001	0.00	1.45
5	0.000	0.000	0.000	0.000	0.00	--	0.000	0.000	--	0.001	0.000	0.000	0.000	0.00	1.21
6	0.001	0.003	0.000	0.001	0.00	0.95	0.000	0.000	--	0.001	0.000	0.000	0.000	0.00	1.70
7	0.003	0.000	0.007	0.003	0.00	0.97	--	0.001	--	0.000	--	0.000	0.001	0.00	0.90
8	0.018	0.012	0.011	0.014	0.00	0.28	0.003	0.004	--	0.004	0.002	0.002	0.003	0.00	0.32

Table D-21. Measured Hydrocarbon Emission Rates for NC-1797 and B20 Biodiesel

Time-Based HC Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	4/14	4/14	4/14	3 Reps	3 Reps	3 Reps	4/15	4/15	4/16	4/16	4/17	4/17	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	0.82	0.56	0.75	0.71	0.13	0.19	0.34	0.36	--	0.39	0.52	0.11	0.35	0.15	0.43
Dyn Brake	--	--	--	--	--	--	0.34	0.58	--	0.37	0.30	0.05	0.33	0.19	0.58
1	0.47	0.57	0.45	0.50	0.06	0.13	0.22	0.32	--	0.31	0.44	0.21	0.30	0.10	0.32
2	0.54	0.79	0.57	0.63	0.13	0.21	0.18	0.46	--	0.04	0.37	0.17	0.24	0.17	0.68
3	0.74	1.12	0.99	0.95	0.20	0.21	0.15	0.64	--	0.34	0.54	0.25	0.39	0.20	0.52
4	1.56	1.37	1.43	1.45	0.10	0.07	0.48	0.87	--	0.57	0.47	0.31	0.54	0.21	0.39
5	1.03	0.30	1.25	0.86	0.50	0.58	0.04	1.17	--	0.61	0.74	0.25	0.56	0.44	0.78
6	1.01	1.97	1.76	1.58	0.51	0.32	1.16	0.70	--	0.74	0.22	0.45	0.66	0.35	0.53
7	1.39	0.00	2.16	1.18	1.10	0.92	--	1.19	--	0.20	--	0.12	0.50	0.59	1.17
8	2.89	4.15	2.18	3.08	1.00	0.32	0.82	1.22	--	0.94	0.93	0.54	0.89	0.24	0.27

Fuel-Based HC Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	4/14	4/14	4/14	3 Reps	3 Reps	3 Reps	4/15	4/15	4/16	4/16	4/17	4/17	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	557	542	705	601	90.0	0.15	314	282	--	276	385	100	271	105	0.39
Dyn Brake	--	--	--	--	--	--	287	494	--	251	256	47.9	267	159	0.59
1	187	230	158	192	36.5	0.19	125	115	--	112	150	82.2	117	24.4	0.21
2	124	181	151	152	28.5	0.19	45.7	113	--	9.34	77.5	52.6	59.7	38.7	0.65
3	107	164	130	134	28.7	0.21	19.0	89.3	--	38.6	64.5	40.9	50.5	27.0	0.54
4	131	114	134	126	10.5	0.08	43.4	78.2	--	44.6	40.9	31.8	47.8	17.7	0.37
5	70.6	20.8	86.6	59.3	34.3	0.58	2.83	77.7	--	36.1	43.9	16.9	35.5	28.6	0.81
6	51.9	100	93.7	82.0	26.3	0.32	81.5	39.0	--	38.4	12.1	27.2	39.7	25.8	0.65
7	44.5	0.00	70.1	38.2	35.5	0.93	--	42.0	--	6.27	--	5.11	17.8	21.0	1.18
8	67.5	116	53.6	78.9	32.6	0.41	26.1	35.0	--	26.5	25.7	15.8	25.8	6.79	0.26

Engine Output-Based HC Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	4/14	4/14	4/14	3 Reps	3 Reps	3 Reps	4/15	4/15	4/16	4/16	4/17	4/17	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	293	200	270	255	48.3	0.19	122	131	--	139	189	40.9	124	53.4	0.43
Dyn Brake	--	--	--	--	--	--	121	207	--	132	110	16.9	117	68.0	0.58
1	8.86	10.8	8.60	9.43	1.21	0.13	4.21	6.11	--	5.95	8.43	3.93	5.73	1.80	0.32
2	5.58	8.08	5.87	6.51	1.37	0.21	1.87	4.69	--	0.45	3.84	1.72	2.51	1.72	0.68
3	3.93	5.99	5.28	5.07	1.05	0.21	0.83	3.42	--	1.82	2.89	1.34	2.06	1.08	0.52
4	5.61	4.93	5.15	5.23	0.34	0.07	1.72	3.13	--	2.04	1.69	1.10	1.94	0.75	0.39
5	2.79	0.82	3.40	2.34	1.35	0.58	0.10	3.18	--	1.67	2.00	0.68	1.52	1.20	0.78
6	2.26	4.43	3.96	3.55	1.14	0.32	2.61	1.57	--	1.67	0.50	1.02	1.47	0.79	0.53
7	2.09	0.00	3.24	1.78	1.64	0.92	--	1.58	--	0.27	--	0.16	0.67	0.79	1.17
8	3.47	4.98	2.62	3.69	1.20	0.32	0.99	1.46	--	1.13	1.12	0.65	1.07	0.29	0.27
Duty Cycle Avg (Raw)	2.14	2.28	2.00	2.14	0.14	0.07	0.81	1.15	--	0.85	1.06	0.39	0.85	0.29	0.34
Duty Cycle Avg (Adj)	5.34	5.69	4.99	5.34	0.35	0.07	2.04	2.87	--	2.11	2.64	0.99	2.13	0.73	0.34

Exhaust HC Concentrations (ppm)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	4/14	4/14	4/14	3 Reps	3 Reps	3 Reps	4/15	4/15	4/16	4/16	4/17	4/17	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	88	60	81	76	14.4	0.19	38	41	--	42	55	12	37	15.5	0.41
Dyn Brake	--	--	--	--	--	--	37	64	--	39	33	5	36	21.0	0.59
1	50	61	49	53	6.71	0.13	24	36	--	34	47	22	32	10.0	0.31
2	57	83	60	67	14.3	0.21	20	50	--	5	39	18	26	18.0	0.69
3	54	82	72	69	14.3	0.21	12	48	--	26	39	18	29	15.0	0.53
4	81	71	73	75	4.91	0.07	25	47	--	30	24	16	28	11.5	0.41
5	44	13	53	37	21.2	0.58	1	51	--	26	31	11	24	19.2	0.80
6	43	83	74	67	21.2	0.32	50	30	--	31	9	19	28	15.3	0.55
7	47	0	72	39	36.4	0.92	--	43	--	7	--	4	18	21.6	1.18
8	89	116	66	90	25.3	0.28	25	38	--	29	27	16	27	7.84	0.29

Table D-22. Measured Particulate Matter Emission Rates for NC-1797 and B20 Biodiesel

Time-Based PM Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	4/14	4/14	4/14	3 Reps	3 Reps	3 Reps	4/15	4/15	4/16	4/16	4/17	4/17	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	0.01	0.01	0.01	0.01	0.00	0.02	0.01	0.01	--	0.01	0.01	0.01	0.01	0.00	0.09
Dyn Brake	--	--	--	--	--	--	0.01	0.01	--	0.01	0.01	0.01	0.01	0.00	0.08
1	0.01	0.01	0.01	0.01	0.00	0.04	0.01	0.01	--	0.01	0.01	0.01	0.01	0.00	0.07
2	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	--	0.01	0.02	0.01	0.01	0.00	0.07
3	0.02	0.02	0.01	0.02	0.00	0.02	0.02	0.01	--	0.02	0.02	0.02	0.02	0.00	0.07
4	0.02	0.02	0.02	0.02	0.00	0.02	0.02	0.02	--	0.02	0.02	0.02	0.02	0.00	0.05
5	0.02	0.02	0.02	0.02	0.00	0.02	0.02	0.02	--	0.02	0.02	0.02	0.02	0.00	0.10
6	0.02	0.02	0.02	0.02	0.00	0.01	0.03	0.02	--	0.02	0.03	0.03	0.02	0.00	0.06
7	0.09	0.10	0.10	0.10	0.01	0.06	--	0.10	--	0.08	--	0.08	0.09	0.01	0.16
8	0.10	0.12	0.11	0.11	0.01	0.07	0.12	0.13	--	0.08	0.08	0.10	0.10	0.02	0.21

Fuel-Based PM Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	4/14	4/14	4/14	3 Reps	3 Reps	3 Reps	4/15	4/15	4/16	4/16	4/17	4/17	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	6.55	9.51	8.87	8.31	1.56	0.19	8.46	7.30	--	8.17	7.61	8.85	8.08	0.63	0.08
Dyn Brake	--	--	--	--	--	--	10.1	9.40	--	8.58	9.35	10.4	9.55	0.69	0.07
1	7.12	7.02	6.57	6.90	0.29	0.04	9.15	6.00	--	6.68	6.36	7.55	7.15	1.26	0.18
2	3.97	3.92	4.60	4.16	0.38	0.09	5.06	4.43	--	4.35	4.56	6.32	4.94	0.82	0.16
3	3.21	3.13	2.80	3.04	0.22	0.07	3.00	2.98	--	2.47	3.02	3.81	3.06	0.48	0.16
4	2.23	2.15	2.37	2.25	0.11	0.05	2.44	2.40	--	2.12	2.54	3.10	2.52	0.36	0.14
5	2.22	2.25	2.17	2.21	0.04	0.02	2.91	2.08	--	1.85	1.75	2.47	2.21	0.48	0.22
6	1.72	1.69	1.75	1.72	0.03	0.02	2.51	1.86	--	1.60	1.91	2.11	2.00	0.34	0.17
7	4.00	4.53	4.15	4.23	0.27	0.06	--	4.79	--	3.30	--	4.20	4.10	0.75	0.18
8	3.40	4.66	3.92	3.99	0.63	0.16	5.13	5.06	--	3.15	3.02	4.17	4.11	1.01	0.24

Engine Output-Based PM Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	4/14	4/14	4/14	3 Reps	3 Reps	3 Reps	4/15	4/15	4/16	4/16	4/17	4/17	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	3.10	3.17	3.06	3.11	0.06	0.02	2.96	3.05	--	3.71	3.36	3.24	3.26	0.30	0.09
Dyn Brake	--	--	--	--	--	--	3.00	2.79	--	3.18	2.83	2.59	2.88	0.22	0.08
1	0.21	0.21	0.22	0.21	0.01	0.04	0.19	0.20	--	0.22	0.22	0.22	0.21	0.02	0.07
2	0.13	0.12	0.13	0.13	0.00	0.01	0.15	0.13	--	0.15	0.16	0.15	0.15	0.01	0.07
3	0.08	0.08	0.08	0.08	0.00	0.02	0.09	0.08	--	0.08	0.09	0.09	0.09	0.01	0.07
4	0.07	0.07	0.07	0.07	0.00	0.02	0.07	0.07	--	0.07	0.08	0.08	0.07	0.00	0.05
5	0.06	0.06	0.06	0.06	0.00	0.02	0.07	0.06	--	0.06	0.05	0.07	0.06	0.01	0.10
6	0.05	0.05	0.05	0.05	0.00	0.01	0.06	0.05	--	0.05	0.06	0.06	0.05	0.00	0.06
7	0.14	0.16	0.14	0.15	0.01	0.06	--	0.13	--	0.11	--	0.10	0.11	0.02	0.16
8	0.13	0.14	0.14	0.14	0.01	0.07	0.14	0.15	--	0.10	0.09	0.12	0.12	0.03	0.21
Duty Cycle Avg (Raw)	0.03	0.03	0.03	0.03	0.00	0.05	0.03	0.03	--	0.02	0.02	0.03	0.03	0.00	0.12
Duty Cycle Avg (Adj)	0.13	0.15	0.14	0.14	0.01	0.05	0.14	0.15	--	0.11	0.11	0.13	0.13	0.02	0.12

Exhaust PM Concentrations (mg/m^3)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	4/14	4/14	4/14	3 Reps	3 Reps	3 Reps	4/15	4/15	4/16	4/16	4/17	4/17	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	1.6	1.6	1.5	1.6	0.03	0.02	1.5	1.6	--	1.9	1.6	1.6	1.7	0.13	0.08
Dyn Brake	--	--	--	--	--	--	1.6	1.5	--	1.7	1.5	1.4	1.5	0.11	0.07
1	2.1	2.1	2.2	2.1	0.10	0.05	1.9	2.1	--	2.2	2.2	2.3	2.1	0.14	0.06
2	2.3	2.3	2.3	2.3	0.02	0.01	2.7	2.4	--	2.8	2.9	2.6	2.7	0.17	0.06
3	2.0	1.9	1.9	2.0	0.04	0.02	2.3	2.0	--	2.0	2.3	2.1	2.1	0.13	0.06
4	1.8	1.8	1.7	1.8	0.05	0.03	1.9	1.9	--	1.9	1.9	2.0	1.9	0.06	0.03
5	1.7	1.7	1.6	1.7	0.04	0.02	1.8	1.7	--	1.6	1.5	1.9	1.7	0.16	0.09
6	1.8	1.8	1.8	1.8	0.03	0.02	2.0	1.8	--	1.7	1.8	1.9	1.8	0.10	0.06
7	5.4	6.1	5.4	5.6	0.42	0.08	--	6.3	--	5.0	--	4.4	5.2	0.96	0.18
8	5.6	5.9	6.0	5.8	0.20	0.03	6.3	6.8	--	4.4	4.1	5.3	5.4	1.19	0.22

Table D-23. Measured CO_2 Emission Rates for NC-1797 and B20 Biodiesel

Time-Based CO_2 Emission Rates (g/s)

Throttle Notch Position	Rail Yard Test						Over-The-Rail Test								
	4/14	4/14	4/14	3 Reps	3 Reps	3 Reps	4/15	4/15	4/16	4/16	4/17	4/17	6 Trains	6 Trains	6 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	14.1	10.0	10.1	11.4	2.38	0.21	10.7	12.8	--	13.8	13.3	11.3	12.4	1.34	0.11
Dyn Brake	--	--	--	--	--	--	11.6	11.4	--	14.3	11.8	9.9	11.8	1.61	0.14
1	24.9	24.6	28.7	26.0	2.28	0.09	17.7	28.1	--	28.1	29.6	25.3	25.8	4.75	0.18
2	43.6	43.2	37.6	41.5	3.31	0.08	40.1	40.2	--	47.4	48.3	31.9	41.6	6.65	0.16
3	69.0	68.3	75.9	71.1	4.19	0.06	81.8	72.0	--	88.6	84.3	61.5	77.6	10.9	0.14
4	119	120	107	115	7.34	0.06	110	112	--	127	115	96	112	11.1	0.10
5	146	146	145	146	0.56	0.00	127	151	--	171	169	149	153	17.8	0.12
6	194	196	188	193	4.20	0.02	143	180	--	194	186	168	174	19.9	0.11
7	314	309	309	311	2.88	0.01	--	283	--	328	--	242	285	43.0	0.15
8	429	358	408	398	36.4	0.09	317	349	--	358	365	345	347	18.2	0.05

Fuel-Based CO_2 Emission Rates (g/gal)

Throttle Notch Position	Rail Yard Test						Over-The-Rail Test								
	4/14	4/14	4/14	3 Reps	3 Reps	3 Reps	4/15	4/15	4/16	4/16	4/17	4/17	6 Trains	6 Trains	6 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	9660	9701	9449	9603	135	0.01	9861	9895	--	9861	9779	10011	9881	84.1	0.01
Dyn Brake	--	--	--	--	--	--	9890	9769	--	9823	9903	10044	9886	103	0.01
1	9959	9918	9976	9951	29.9	0.00	9994	10003	--	10001	9957	10021	9995	23.6	0.00
2	9998	9959	9977	9978	19.5	0.00	10045	10004	--	10063	10018	10041	10034	23.2	0.00
3	10008	9970	9993	9990	19.5	0.00	10062	10019	--	10044	10033	10049	10042	16.3	0.00
4	9994	10004	9990	9996	7.41	0.00	10048	10026	--	10039	10046	10054	10042	10.9	0.00
5	10031	10061	10021	10038	21.1	0.00	10072	10026	--	10049	10046	10064	10052	17.7	0.00
6	10039	10006	10017	10021	16.5	0.00	10024	10050	--	10047	10067	10057	10049	16.0	0.00
7	10040	10074	10018	10044	28.2	0.00	--	10046	--	10070	--	10070	10062	13.8	0.00
8	10005	9979	10023	10002	22.3	0.00	10051	10046	--	10051	10054	10061	10053	5.77	0.00

Engine Output-Based CO_2 Emission Rates (g/bhp-hr)

Throttle Notch Position	Rail Yard Test						Over-The-Rail Test								
	4/14	4/14	4/14	3 Reps	3 Reps	3 Reps	4/15	4/15	4/16	4/16	4/17	4/17	6 Trains	6 Trains	6 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	5091	3591	3619	4101	858	0.21	3835	4594	--	4978	4799	4078	4457	484	0.11
Dyn Brake	--	--	--	--	--	--	4175	4098	--	5154	4241	3549	4244	578	0.14
1	472	466	543	494	43.2	0.09	336	532	--	533	561	479	488	89.9	0.18
2	448	444	387	426	34.1	0.08	412	413	--	488	496	328	428	68.4	0.16
3	368	364	405	379	22.4	0.06	436	384	--	472	450	328	414	57.9	0.14
4	428	431	384	414	26.4	0.06	397	402	--	459	416	347	404	40.1	0.10
5	397	396	394	396	1.52	0.00	344	410	--	464	458	405	416	48.4	0.12
6	437	441	423	434	9.45	0.02	321	404	--	436	419	377	391	44.8	0.11
7	471	463	463	466	4.31	0.01	--	378	--	438	--	323	380	57.4	0.15
8	515	430	490	478	43.7	0.09	380	419	--	429	438	414	416	21.9	0.05

Exhaust CO_2 Concentrations (%)

Throttle Notch Position	Rail Yard Test						Over-The-Rail Test								
	4/14	4/14	4/14	3 Reps	3 Reps	3 Reps	4/15	4/15	4/16	4/16	4/17	4/17	6 Trains	6 Trains	6 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	0.74	0.53	0.53	0.60	0.13	0.21	0.58	0.70	--	0.73	0.68	0.60	0.66	0.06	0.10
Dyn Brake	--	--	--	--	--	--	0.62	0.62	--	0.76	0.61	0.53	0.63	0.08	0.13
1	1.29	1.28	1.50	1.36	0.12	0.09	0.93	1.51	--	1.47	1.53	1.32	1.35	0.25	0.18
2	2.26	2.24	1.93	2.14	0.18	0.09	2.13	2.15	--	2.53	2.46	1.64	2.18	0.35	0.16
3	2.45	2.43	2.71	2.53	0.16	0.06	3.00	2.65	--	3.24	2.96	2.19	2.81	0.41	0.14
4	3.00	3.05	2.66	2.90	0.21	0.07	2.85	2.92	--	3.28	2.85	2.41	2.86	0.31	0.11
5	3.05	3.06	3.02	3.04	0.02	0.01	2.53	3.22	--	3.57	3.43	3.08	3.17	0.40	0.13
6	4.04	4.05	3.85	3.98	0.12	0.03	2.99	3.77	--	4.01	3.64	3.38	3.56	0.39	0.11
7	5.15	5.21	5.01	5.12	0.10	0.02	--	5.04	--	5.86	--	4.04	4.98	0.91	0.18
8	6.45	4.90	6.00	5.78	0.80	0.14	4.79	5.29	--	5.46	5.26	4.94	5.15	0.27	0.05

D.3 Summary of Results for NC-1797 on B10

This section discusses the results of the rail yard and over-the-rail measurements of the NC-1797 prime mover engine operated on B10 biodiesel, and includes a comparison to previously reported measurements on ULSD.

Rail Yard Measurements

Three rail yard emissions measurement replicates on the prime mover engine of NC-1797 on B10 biodiesel were conducted on March 10, 2014. In the rail yard, emissions measurements were taken when the engine reached steady state at two idle settings and each of eight notch positions. The idle and notch average emission rates were weighted by the EPA line-haul cycle to estimate cycle average rates.

The EPA line-haul cycle average emission rates are shown in Table 2. These cycle average emission rates are based on the measured engine activity data (RPM, MAP, and IAT), inferred engine activity data (MAF, AFR, and VE), and measured exhaust concentrations. There was little variability between replicate measured engine activity data and exhaust NO concentration, given in Figure D-14. This indicates that the prime mover engine was operating consistently during all three replicate measurements.

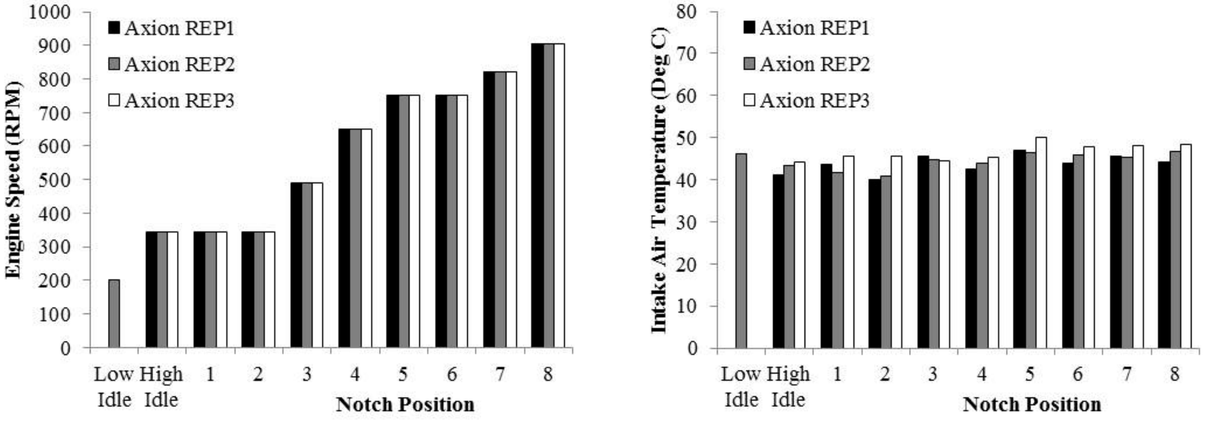
An increasing trend in fuel use rate was apparent with increasing notch position, as shown in Figure D-15. The NO emission rates among the three replicates were consistent, as shown in Figure D-16. The inter-replicate ratios of the standard deviation to the mean (coefficient of variation) for each notch position for the mass per gallon of fuel NO emission rates range from 0.01 to 0.04, which indicates small variability between replicates.

Approximately 4 percent of the notch-specific HC concentrations measured were below the detection limit. These concentrations are not significantly different than zero. However, because of imprecision in the measurements at or below the detection limit, there was large variability in estimated average concentrations. For exhaust HC concentrations across the three replicates, the coefficient of variation varied from 0.13 to 0.61, depending on the notch position. Differences in measured exhaust HC concentrations are the primary reason for inter-replicate variability in the notch-specific HC emission rates, as shown in Figure D-17. The inter-replicate coefficient of variation in the estimated HC emission rates were 35 percent, on average for each notch position.

There was also variability in the estimated notch-specific CO emission rates between the three replicate measurements, as shown in Figure D-18. Approximately 83 percent of the notch-specific CO concentrations measured were below the detection limit. The inter-replicate coefficient of variation in the estimated HC emission rates were 43 percent, on average, for each notch position. However, on an absolute basis, the exhaust CO concentrations were typically less than 0.010 volume percent.

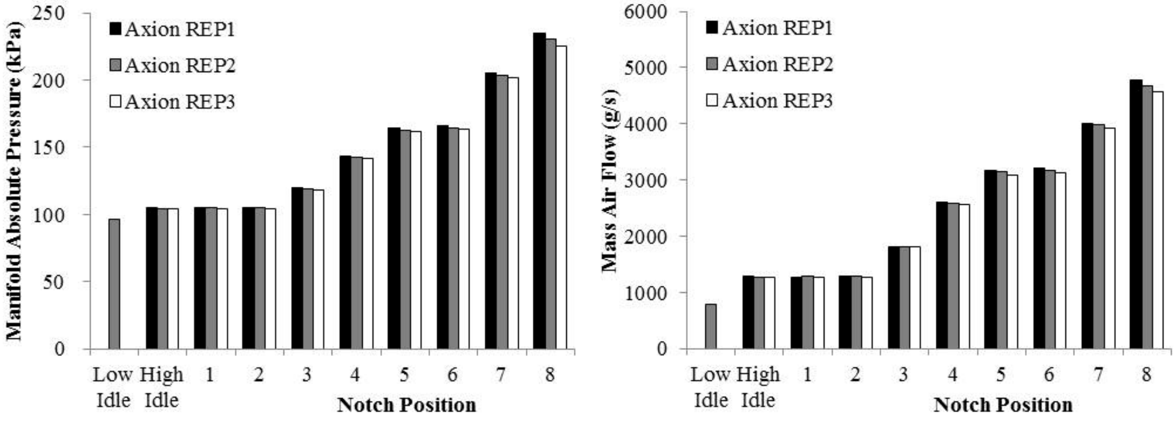
PM emission rates, as shown in Figure D-19, were consistent across the three replicates, with inter-replicate coefficients of variation less than 0.08 for all notch positions except for notch 8. All of the NO, CO, HC, and PM concentrations measured were of the same magnitude as previous rail yard measurements of the same engine operating on ULSD.

Figure D-14. Measured Engine Activity Data during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on B10 Biodiesel



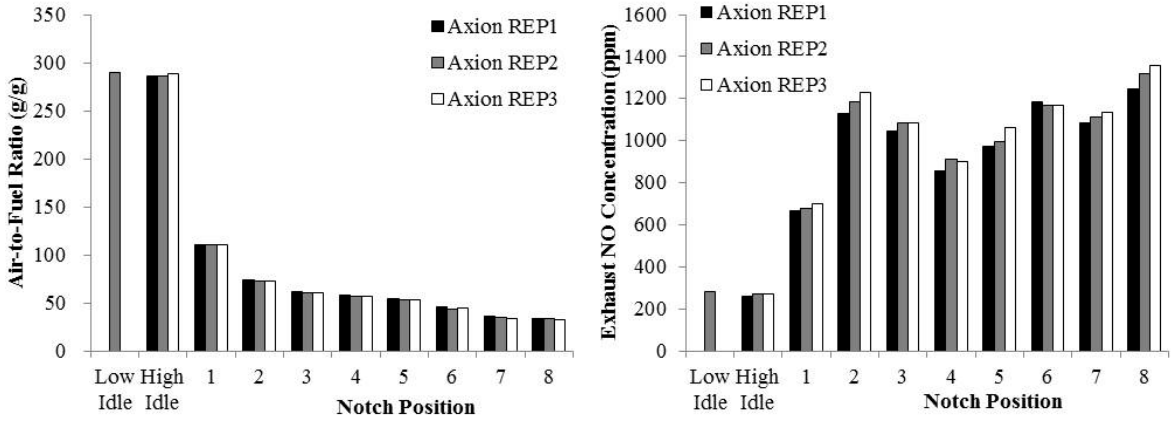
(a) Engine Speed

(b) Intake Air Temperature



(c) Manifold Absolute Pressure

(d) Mass Air Flow



(e) Air-to-Fuel Ratio

(f) Exhaust NO Concentration

Figure D-15. Estimated Fuel Use Rates during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on B10 Biodiesel

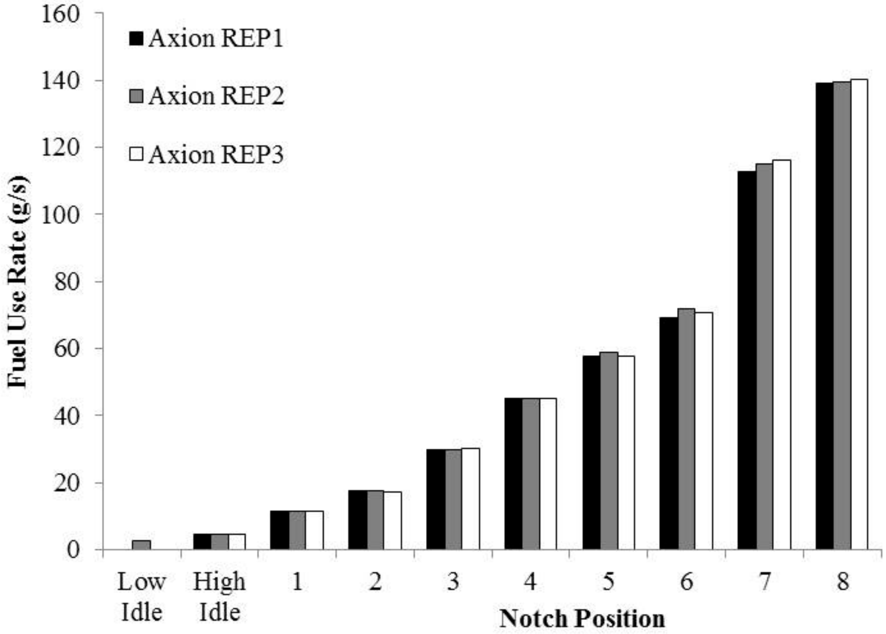


Figure D-16. Estimated NO_x Emission Rates during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on B10 Biodiesel

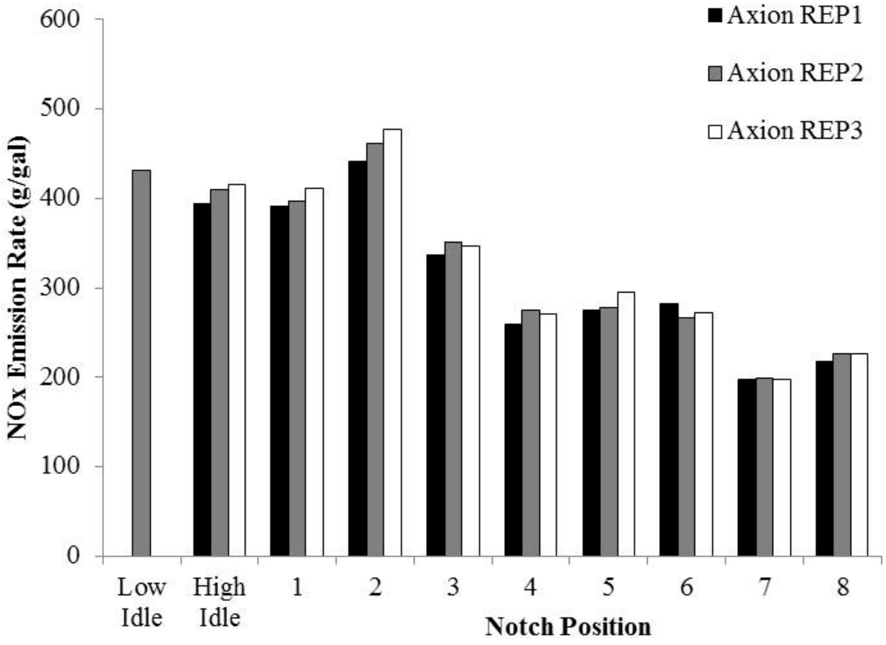


Figure D-17. Estimated HC Emission Rates during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on B10 Biodiesel

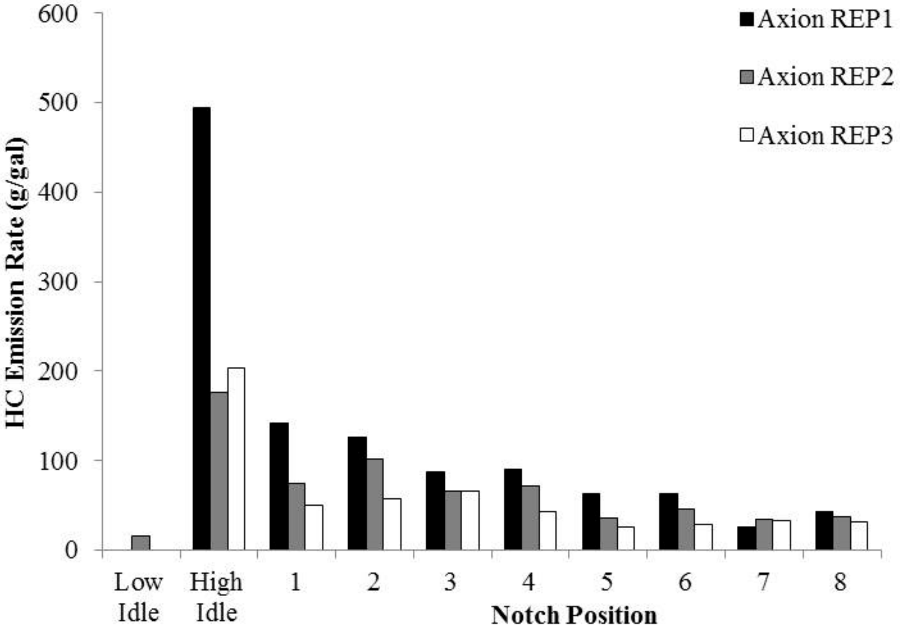


Figure D-18. Estimated CO Emission Rates during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on B10 Biodiesel

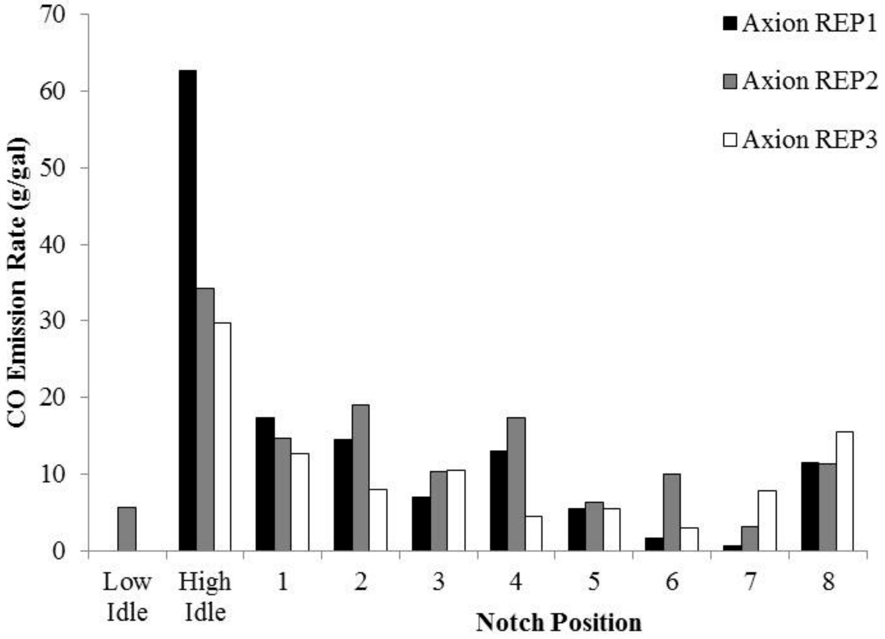
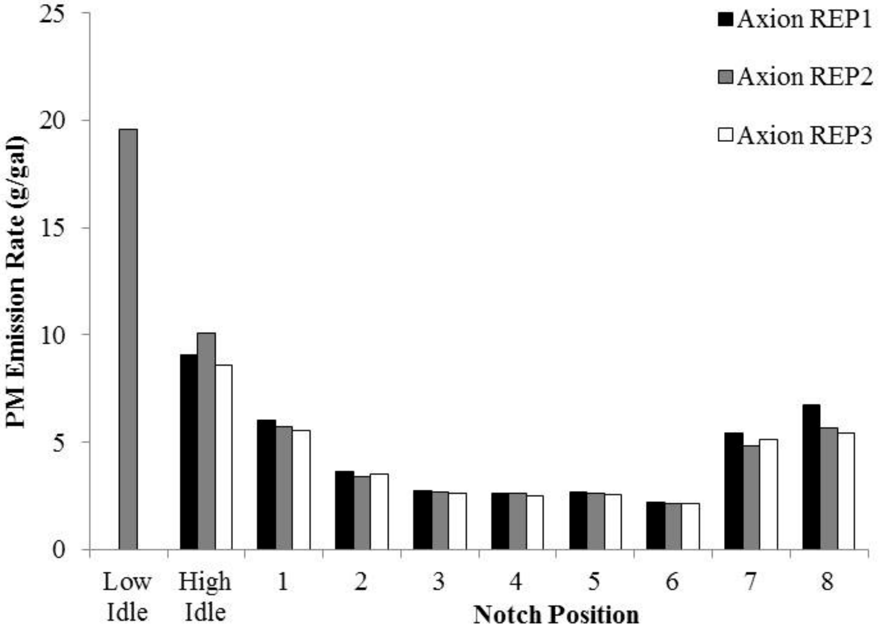


Figure D-19. Measured PM Emission Rate during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on B10 Biodiesel



Estimated EPA line-haul cycle average emission rates for each of the three replicate rail yard measurements are given in Table D-24. The NO_x, CO, and PM cycle average emission rates were consistent among the replicates, with coefficient of variation less than 0.08. The coefficient of variation for HC emission rates are 32 percent. Differences in emission rates are attributable to differences in measured exhaust concentrations. Values for engine activity parameters (i.e., RPM, IAT, MAP) were similar across all measurements, as given in Figure D-14, and thus are not the cause of inter-replicate variation in emission rates.

Table D-24. Estimated EPA Line-Haul Cycle Average Emission Rates for Rail Yard Replicate Measurements of NC-1797 Prime Mover Engine Operated on B10 Biodiesel

	NO_x (g/bhp-hr)	**HC** (g/bhp-hr)	**CO** (g/bhp-hr)	**Opacity-based PM** (g/bhp-hr)
Replicate 1	13.6	4.30	0.7	0.23
Replicate 2	14.1	2.76	0.7	0.20
Replicate 3	14.2	2.40	0.7	0.19
Average of 3 Replicates	**14.0**	**3.16**	**0.7**	**0.21**
Coefficient of Variation	**0.02**	**0.32**	**0.04**	**0.08**

NO_x, HC, and PM are adjusted with multipliers of 1.053, 2.5, and 5, respectively, as bias correction.

Cycle average emission rates are based on EPA Line-Haul duty cycle.

Over-the-Rail Measurements

Two days of over-the-rail measurements on the NC-1797 prime mover engine operating on B10 biodiesel were conducted from March 11-13, 2014.

Based on over-the-rail measurements, notch average emission rates were estimated for low and high idle, dynamic brake, and notches 1 to 8. To enable comparisons with other data, the notch average emission rates were weighted based on the EPA line-haul duty cycle. However, we also quantified the actual observed duty cycle for each one-way trip. The EPA line-haul cycle average emission rates for the over-the-rail measurements of the NC-1797 prime mover engine operating on B10 biodiesel are shown in Table D-25. These cycle average emission rates are based on measured engine activity data (RPM, MAP, and IAT) and measured exhaust concentrations. The cycle average estimate was based on measured notch-based emission rates and time fraction for each notch for the EPA line-haul duty cycle. For each set of measurements, there was little variability between measured engine activity data during both days of measurements. This indicates that the prime mover engine was operating consistently during over-the-rail measurements. Measured engine activity data during over-the-rail measurements were similar to the measured engine activity data during rail yard measurements.

For notch average cycle average NO_x rates, the coefficient of variation was less than 20 percent for each notch position, amongst the six one-way trips. The coefficient of variation for HC and CO was 32 and 48 percent, respectively. However, 30 and 92 percent of the notch-specific HC and CO concentrations, respectively, were below the detection limit, which leads to imprecision that contributes to large inter-run variability. For PM, the coefficient of variation was 10 percent for the six one-way trips. Differences in measured exhaust pollutant concentrations were one of the key reasons for the variability.

The EPA line-haul duty cycle average over-the-rail emission rates are quantitatively similar to the EPA line-haul duty cycle average rail yard emission rates. The cycle averages over-the-rail NO_x emission rate over six one-way trips were within 8 percent of the cycle average rail yard emission rates. The over-the-rail cycle average CO, HC, and PM emission rates were lower than the rail yard cycle average emission rate by 13 to 36 percent.

Differences in cycle average emission rates between rail yard and over-the-rail measurements can be attributed to various factors. RPM and MAP were essentially the same for rail yard and over-the-rail measurements. IAT differed on an absolute basis by less than 6 percent from run-to-run during over-the-rail measurements. At Notch 8, the engine output during rail yard measurements was 2,700 horsepower, while engine output was 3,000 horsepower during over-the-rail measurements. With notch 8 accounting for 16 percent of the EPA line-haul duty cycle, higher engine output decreases engine output based emission rates and, therefore, cycle average emission rates. Finally, differences in measured exhaust concentrations between rail yard and over-the-rail measurements lead to differences in fuel use and emission rates.

Table D-25. EPA Line-Haul Cycle Average Emission Rates for Over-the-Rail Measurements of NC-1797 Prime Mover Engine Operated on B10 Biodiesel

	NO_x **(g/bhp-hr)**	**HC** **(g/bhp-hr)**	**CO** **(g/bhp-hr)**	**Opacity-based PM** **(g/bhp-hr)**
Mar. 11, 2014 – Train 73	14.8	2.00	0.4	0.16
Mar. 11, 2014 – Train 74	15.3	4.10	0.8	0.20
Mar. 12, 2014 – Train 73	13.7	3.23	0.5	0.17
Mar. 12, 2014 – Train 74	13.9	3.01	0.6	0.17
Mar. 13, 2014 – Train 73	15.1	1.72	0.2	0.15
Mar. 13, 2014 – Train 74	14.6	2.36	0.3	0.15
Average	**14.5**	**2.74**	**0.5**	**0.17**
Coefficient of Variation	**0.04**	**0.32**	**0.48**	**0.10**

NO_x, HC, and PM are adjusted with multipliers of 1.05, 2.5, and 5, respectively, as bias correction.

Cycle average emission rates are based on EPA Line-Haul driving cycle.

Throttle notch position data obtained from the locomotive data activity recorder was used to quantify the actual real-world duty cycles for the over-the-rail measurements. The measured duty cycles are compared to the EPA line-haul duty cycle in Table D-26. The prime mover engine operated in notch 8 during the over-the-rail measurements more than double the percentage of time, on average, than EPA estimates a line-haul locomotive operates in Notch 8. For the other notch positions, the observed time was on average less than the EPA line-haul duty cycle. Although not shown here, the real-world duty cycles can be used to estimate inter-cycle variability in cycle averages for use and in emission rates.

Table D-26. Observed Real-World Over-the-Rail Duty Cycles from Measurement of NC-1797 Operated on B10 Biodiesel

Notch	Percent Time in Each Notch							
	EPA Line-Haul	Measured Over-the-Rail						
		Average	3/11/2014 Train 73	3/11/2014 Train 74	3/12/2014 Train 73	3/12/2014 Train 74	3/13/2014 Train 73	3/13/2014 Train 74
Idle	38.0	38.2	42.6	31.6	47.1	42.4	35.9	29.5
DB	12.5	3.8	2.4	2.8	2.4	5.1	5.8	4.1
1	6.5	6.2	2.9	12.1	4.2	4.5	3.7	9.7
2	6.5	3.5	1.2	5.6	1.9	4.3	2.7	4.9
3	5.2	2.9	2.5	3.4	0.9	3.0	2.5	5.0
4	4.4	3.9	1.5	5.8	2.7	5.6	1.3	6.9
5	3.8	2.1	0.7	4.1	1.9	3.8	0.8	1.3
6	3.9	3.8	0.6	9.7	2.7	2.3	0.9	6.4
7	3.0	1.3	0.3	1.6	0.9	1.8	0.5	2.7
8	16.2	34.5	45.3	23.3	35.2	27.2	45.9	29.7

Train 73 is from Raleigh to Charlotte. Train 74 is from Charlotte to Raleigh.

Comparison of Emission Rates from B10 Biodiesel and Ultra-Low Sulfur Diesel

A comparison of the cycle average emission rates measured during RY and OTR measurements of the prime mover engine on ULSD and B10 biodiesel is shown in Table D-27. All of the comparisons are based on the EPA line-haul duty cycle.

For B10 biodiesel versus ULSD, during rail yard and over-the-rail measurements, cycle average NO_x and PM emission rates were moderately higher, from 3 to 25 percent. Cycle average HC emission rates were 213 percent higher for B10 compared to ULSD during rail yard measurements, but 22 percent lower during over-the-rail measurements. Cycle average CO emission rates were 17 percent higher during rail yard measurements, but 45 percent lower during over-the-rail measurements for B10 versus ULSD.

Table D-27. Comparison of EPA Line-Haul Cycle Average Emission Rates for Rail Yard and Over-the-Rail Measurements of NC-1797 Prime Mover Engine Operating for B10 Biodiesel versus Ultra-Low Sulfur Diesel

	NO_x	HC[a]	CO	Opacity-based PM
	(g/bhp-hr)	(g/bhp-hr)	(g/bhp-hr)	(g/bhp-hr)
B10 vs. ULSD				
Rail Yard	+25%	+213%	+17%	+11%
Over-the-Rail	+7%	-22%	-45%	+3%

Table D-28 summarizes the average measured engine speed (RPM), intake air temperature (IAT), manifold absolute pressure (MAP), estimated mass air flow (MAF), and air-to-fuel ratio (AFR) for each throttle notch position and for each replicate of the RY measurement and for each one-way OTR trip. Engine speed ranges from 200 to 903 RPM in both RY and OTR measurements, depending on notch position. For the RY measurements, engine RPM was highly repeatable among replicates for a given notch position, with a standard deviation of less than 1 RPM for all notch positions. For the OTR measurements, the RPM was also repeatable among replicates for a given notch position, with coefficient of variation less than 0.02 for all notch positions. For some one-way trips, the sample sizes in these notches are too small to infer a steady-state engine operating speed. The intake air temperature varies with ambient temperature and was generally in the range of 41 to 50 degrees C during all measurements. MAP was highly repeatable in the RY measurements, ranging from 97 to 235 kPa depending on notch position. The inter-replicate standard deviation of measured MAP was less than 5 kPa for each notch position. For OTR measurements, there was slightly more inter-run variability in MAP. However, the coefficient of variation for each notch position was typically 0.04 or less.

Estimated MAF was highly repeatable for both RY and OTR measurements, with the coefficient of variation typically 0.04 or less for all notch position. The MAF ranged from 800 to 4,800 g/s, depending on notch position. Estimated AFR was highly repeatable among replicates for a given notch position in the RY measurements, with coefficient of variation less than 0.03 for all notches. For OTR measurements, there was slightly more inter-run variability in AFR for each notch position, but the coefficient of variation was less than 0.22. Overall, the engine activity during the measurements was consistent for the three replicates in the rail yard, and from run to run for the six one-way trips observed between Raleigh and Charlotte.

Table D-29 summarizes the estimated fuel use rates inferred from the engine data of Table D-28. For the RY measurements, fuel use rates range from 2.8 to 140 g/sec depending on notch position, and were highly repeatable among replicates for a given notch position, with a coefficient of variation of 0.02 or less. There was more variability in run-to-run estimates of fuel use for the OTR measurements, in part because the amount of time spent in some notch positions was low. The OTR estimated fuel use ranged from 3.9 to 129 g/sec, depending on notch position. The coefficient of variation for all notches was less than 0.19 for all notch positions.

During RY measurements, the maximum engine output was 2,700 hp, whereas during OTR measurements the maximum engine output was 3,000 hp. Furthermore, as shown later in Table D-34, the average CO_2 concentrations for each notch position are lower for OTR than for RY measurements, which implies a lower fuel-to-air ratio. Because the engine activity and, therefore, engine air flow, are approximately the same for OTR versus RY measurements, the combination of higher engine output and lower fuel-to-air ratio lead to higher values of fuel-specific engine output (FSEO) in bhp-hr per gallon of fuel consumed, as shown in Table D-29. The FSEO was highly repeatable for the OTR measurements of each notch position, especially Notch 8, which represents significant portion of the observed duty cycle.

The measured NO exhaust concentration and the estimated NO_x emission rates are shown in Table D-30 for each notch position, each RY replicate, and each OTR one-way run. The average measured concentrations range among notch positions from approximately 260 to 1,360 parts per million (ppm) in the RY measurements, and 270 to 1,600 ppm in the OTR measurements, depending on notch position. The measurements are highly repeatable among replicates for a given notch position for both the RY and OTR measurements, with coefficients of variation typically less than 0.05 for the former and less than 0.18 for the latter. The estimated mass emission rates range from 0.4 to 9.8 g/sec for the RY measurements and 0.4 to 9.5 g/sec for the OTR measurements, depending on notch position. Because the observed concentrations tend to be higher for the OTR versus RY measurements, the mass emission rates also tend to be slightly higher for the OTR versus RY measurements.

On a fuel basis, the average NO_x emission rates range from 200 to 480 g/gallon for the RY measurements and 220 to 510 g/gallon for the OTR measurements, depending on notch position. For both the RY and OTR measurements, the fuel-based emission rates are highly repeatable among replicates for a given notch position, with coefficient of variation typically less than 0.04 for the RY measurements and less than 0.26 for the OTR measurements. The fuel-based emission rates tend to be lowest at high load.

On an engine output basis, excluding idle and dynamic braking, the notch average NO_x emission rates range from 11.3 g/bhp-hr at Notch 8 to 27.4 g/bhp-hr at notch 1 in the RY measurements, and range from 10.3 g/bhp-hr at Notch 8 to 29.6 g/bhp-hr at notch 1 in the OTR measurements. The notch average NO_x emission rates for Idle and Dynamic Braking were higher than the other notch positions. In general, the emission rates on an engine output basis are higher for the OTR measurements than for the RY measurements. This results from a combination of lower exhaust concentration and higher engine output, especially at notch 8.

Results are given for exhaust concentrations and emission rates in Tables D-31, D-32, D-33, and D-34 for CO, HC, PM, and CO_2, respectively. The CO exhaust concentrations during OTR measurements are slightly lower than during RY measurements. Thus, the cycle average CO emission rates are also slightly lower for OTR than RY measurements. On average, the HC exhaust concentrations and average emission rates tend to be lower for OTR than RY. However, CO and HC emission rates are low on an absolute basis, and some of the measured average concentrations for a given notch position and replicate or run are below the gas analyzer detection limit. For PM, the measured exhaust levels for OTR were very close to RY for a given notch position, and thus the cycle average PM emission rates were very close for OTR and RY measurements. The trends in CO_2 emission rates are similar to those for fuel use on a mass per time and mass per engine output basis. CO_2 emission rates are also shown on a g/gallon basis. Since typically over 99 percent of the carbon in the fuel was emitted as CO_2, the fuel-based CO_2 emission rates are approximately constant.

SUMMARY

In these measurements, a procedure was demonstrated for rail yard and over-the-rail characterization of emission rates for B10 biodiesel. The rail yard engine activity and emission concentration measurements were consistent across the three replicates. For rail yard measurements, NO_x, CO, HC, and PM cycle average emission rates were higher for B10 biodiesel versus ULSD.

The cycle average over-the-rail emission rates are in the same magnitude to the cycle average rail yard emission rates. Cycle average over-the-rail NO_x and PM emission rates are higher than during rail yard measurements, and cycle average over-the-rail CO and HC emission rates are lower than during rail yard measurements.

Table D-28. Measured Engine Parameters for NC-1797 and B10 Biodiesel

Engine Speed (RPM)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/10	3/10	3/10	3 Reps	3 Reps	3 Reps	3/11	3/11	3/12	3/12	3/13	3/13	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	343	343	343	343	0.00	0.00	343	343	343	342	343	343	343	0.13	0.00
Dyn Brake	--	--	--	--	--	--	345	342	326	344	343	342	340	7.32	0.02
1	343	343	343	343	0.03	0.00	343	342	343	343	343	342	343	0.49	0.00
2	343	343	343	343	0.02	0.00	344	343	343	343	343	343	343	0.66	0.00
3	490	490	490	490	0.00	0.00	490	490	490	490	490	490	490	0.22	0.00
4	651	651	651	651	0.01	0.00	650	651	651	651	652	651	651	0.72	0.00
5	750	750	750	750	0.04	0.00	749	749	749	750	750	750	749	0.27	0.00
6	750	750	750	750	0.09	0.00	748	750	749	750	749	750	749	0.63	0.00
7	820	819	819	820	0.27	0.00	819	819	819	820	816	820	819	1.59	0.00
8	903	903	903	903	0.02	0.00	903	903	903	903	903	903	903	0.09	0.00

Intake Air Temepratური (°C)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/10	3/10	3/10	3 Reps	3 Reps	3 Reps	3/11	3/11	3/12	3/12	3/13	3/13	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	41	43	44	43	1.56	0.04	42	49	46	46	39	41	44	3.77	0.09
Dyn Brake	--	--	--	--	--	--	42	50	47	46	40	41	44	3.88	0.09
1	44	42	46	44	2.01	0.05	44	50	45	46	39	42	44	3.63	0.08
2	40	41	46	42	2.94	0.07	42	49	47	45	40	42	44	3.32	0.08
3	46	45	44	45	0.68	0.02	42	49	43	46	40	41	44	3.38	0.08
4	43	44	45	44	1.32	0.03	43	49	48	46	40	41	45	3.60	0.08
5	47	46	50	48	2.05	0.04	45	50	46	46	40	41	45	3.78	0.08
6	44	46	48	46	1.88	0.04	43	50	45	47	40	41	44	3.71	0.08
7	46	45	48	46	1.59	0.03	42	49	44	49	39	42	44	4.01	0.09
8	44	47	49	47	2.19	0.05	43	50	48	47	42	43	45	3.24	0.07

Manifold Absolute Pressure (kPa)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/10	3/10	3/10	3 Reps	3 Reps	3 Reps	3/11	3/11	3/12	3/12	3/13	3/13	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	105	104	104	105	0.57	0.01	105	103	104	103	106	106	104	1.37	0.01
Dyn Brake	--	--	--	--	--	--	105	104	103	103	106	106	105	1.48	0.01
1	105	105	104	105	0.45	0.00	105	103	104	103	107	107	105	1.50	0.01
2	105	105	105	105	0.45	0.00	105	104	105	103	106	107	105	1.48	0.01
3	120	119	118	119	0.66	0.01	119	117	119	117	122	122	119	2.03	0.02
4	144	143	142	143	0.93	0.01	145	140	141	140	148	146	143	3.32	0.02
5	164	163	162	163	1.24	0.01	165	160	162	160	169	168	164	4.14	0.03
6	166	164	163	165	1.31	0.01	163	161	162	162	170	169	164	3.97	0.02
7	205	204	202	204	1.72	0.01	180	184	180	184	184	199	185	7.03	0.04
8	235	230	225	230	4.58	0.02	217	208	211	209	227	228	217	8.94	0.04

Mass Air Flow (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/10	3/10	3/10	3 Reps	3 Reps	3 Reps	3/11	3/11	3/12	3/12	3/13	3/13	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	1287	1271	1264	1274	11.9	0.01	1275	1231	1251	1243	1300	1293	1266	27.9	0.02
Dyn Brake	--	--	--	--	--	--	1289	1235	1201	1251	1301	1300	1263	40.6	0.03
1	1277	1280	1260	1272	10.8	0.01	1277	1232	1260	1249	1308	1295	1270	28.5	0.02
2	1293	1286	1263	1280	15.9	0.01	1283	1242	1262	1251	1305	1301	1274	26.7	0.02
3	1820	1817	1812	1816	4.08	0.00	1835	1772	1819	1785	1876	1870	1826	43.0	0.02
4	2607	2580	2559	2582	23.9	0.01	2612	2507	2528	2526	2688	2653	2586	75.6	0.03
5	3160	3143	3092	3132	35.4	0.01	3180	3059	3133	3106	3308	3281	3178	98.6	0.03
6	3211	3168	3135	3172	37.9	0.01	3174	3085	3134	3121	3308	3290	3185	92.6	0.03
7	4012	3990	3928	3977	43.6	0.01	3673	3656	3650	3648	3751	3958	3723	122	0.03
8	4783	4674	4579	4679	102	0.02	4515	4289	4371	4345	4702	4702	4487	182	0.04

Air to Fuel Ratio (g/g)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/10	3/10	3/10	3 Reps	3 Reps	3 Reps	3/11	3/11	3/12	3/12	3/13	3/13	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	286	287	289	287	1.41	0.00	241	237	245	248	296	330	266	38.0	0.14
Dyn Brake	--	--	--	--	--	--	244	236	235	264	280	302	260	27.2	0.10
1	111	111	111	111	0.10	0.00	110	99.3	112	112	145	145	120	19.4	0.16
2	74.1	73.3	73.1	73.5	0.53	0.01	85.6	71.3	111.0	78.7	90.0	103	89.9	14.8	0.16
3	61.3	60.9	60.4	60.9	0.45	0.01	59.6	58.9	63.4	58.3	68.4	75.5	64.0	6.75	0.11
4	57.8	57.2	56.9	57.3	0.45	0.01	61.0	56.5	55.1	56.2	64.1	69.3	60.4	5.53	0.09
5	55.0	53.6	53.5	54.0	0.84	0.02	67.7	50.7	55.3	52.3	57.1	58.8	57.0	6.05	0.11
6	46.4	44.2	44.4	45.0	1.20	0.03	68.3	44.0	46.5	46.5	56.0	51.9	52.2	9.01	0.17
7	35.6	34.7	33.8	34.7	0.90	0.03	49.9	33.7	40.7	35.0	58.0	39.9	42.9	9.36	0.22
8	34.4	33.5	32.7	33.5	0.87	0.03	37.0	33.2	35.4	34.7	39.0	38.7	36.3	2.28	0.06

Table D-29. Estimated Fuel Use Rates for NC-1797 and B10 Biodiesel

Time-Based Fuel Use Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/10	3/10	3/10	3 Reps	3 Reps	3 Reps	3/11	3/11	3/12	3/12	3/13	3/13	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	4.50	4.43	4.38	4.44	0.06	0.01	5.29	5.20	5.11	5.01	4.39	3.92	4.82	0.54	0.11
Dyn Brake	--	--	--	--	--	--	5.29	5.24	5.12	4.75	4.65	4.30	4.89	0.39	0.08
1	11.5	11.5	11.3	11.4	0.10	0.01	11.6	12.4	11.3	11.2	9.05	8.95	10.8	1.43	0.13
2	17.5	17.5	17.3	17.4	0.13	0.01	15.0	17.4	11.4	15.9	14.5	12.7	14.5	2.18	0.15
3	29.7	29.8	30.0	29.8	0.15	0.01	30.8	30.1	28.7	30.6	27.4	24.8	28.7	2.32	0.08
4	45.1	45.1	44.9	45.0	0.08	0.00	42.8	44.4	45.8	45.0	41.9	38.3	43.0	2.72	0.06
5	57.5	58.6	57.8	58.0	0.59	0.01	47.0	60.4	56.7	59.3	58.0	55.8	56.2	4.82	0.09
6	69.3	71.7	70.6	70.5	1.24	0.02	46.5	70.2	67.5	67.1	59.1	63.4	62.3	8.64	0.14
7	113	115	116	114	1.79	0.02	73.6	108	89.8	104	64.7	99.1	90.0	17.5	0.19
8	139	139	140	140	0.59	0.00	122	129	124	125	121	122	124	3.08	0.02

Engine Output-Based Fuel Use Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/10	3/10	3/10	3 Reps	3 Reps	3 Reps	3/11	3/11	3/12	3/12	3/13	3/13	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	1.80	1.83	1.85	1.83	0.03	0.01	1.53	1.56	1.59	1.62	1.85	2.07	1.70	0.21	0.12
Dyn Brake	--	--	--	--	--	--	1.53	1.55	1.58	1.71	1.74	1.89	1.67	0.14	0.08
1	13.4	13.4	13.6	13.4	0.12	0.01	13.2	12.4	13.6	13.8	17.0	17.2	14.5	2.04	0.14
2	16.2	16.2	16.4	16.3	0.13	0.01	18.9	16.3	24.9	17.8	19.5	22.4	20.0	3.16	0.16
3	18.4	18.3	18.2	18.3	0.09	0.01	17.8	18.2	19.1	17.9	19.9	22.1	19.1	1.65	0.09
4	18.0	18.0	18.0	18.0	0.03	0.00	18.9	18.3	17.7	18.0	19.3	21.2	18.9	1.26	0.07
5	18.7	18.3	18.6	18.5	0.19	0.01	22.9	17.8	18.9	18.1	18.5	19.2	19.2	1.85	0.10
6	18.7	18.1	18.4	18.4	0.32	0.02	27.9	18.5	19.2	19.3	22.0	20.5	21.2	3.48	0.16
7	17.3	16.9	16.8	17.0	0.27	0.02	29.7	20.2	24.4	21.0	33.8	22.1	25.2	5.45	0.22
8	17.5	17.4	17.3	17.4	0.07	0.00	19.9	18.8	19.7	19.4	20.2	20.0	19.7	0.48	0.02

Table D-30. Measured NO_x Emission Rates for NC-1797 and B10 Biodiesel

Time-Based NO_x Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/10	3/10	3/10	3 Reps	3 Reps	3 Reps	3/11	3/11	3/12	3/12	3/13	3/13	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	0.55	0.56	0.56	0.56	0.01	0.01	0.61	0.62	0.58	0.54	0.58	0.52	0.57	0.04	0.07
Dyn Brake	--	--	--	--	--	--	0.64	0.63	0.59	0.51	0.59	0.55	0.59	0.05	0.09
1	1.39	1.42	1.45	1.42	0.03	0.02	1.44	1.56	1.31	1.21	1.12	1.16	1.30	0.17	0.13
2	2.39	2.51	2.56	2.48	0.09	0.03	1.74	2.40	1.40	1.85	1.96	1.83	1.86	0.33	0.18
3	3.10	3.24	3.23	3.19	0.08	0.02	4.58	4.55	3.79	4.16	4.52	3.84	4.24	0.36	0.09
4	3.61	3.83	3.76	3.73	0.11	0.03	6.03	6.96	4.82	5.33	6.21	5.23	5.76	0.78	0.14
5	4.88	5.05	5.29	5.07	0.21	0.04	7.38	6.75	7.10	6.17	7.24	7.48	7.02	0.49	0.07
6	6.04	5.93	5.94	5.97	0.06	0.01	7.37	7.04	6.88	7.83	8.20	7.03	7.39	0.52	0.07
7	6.87	7.09	7.12	7.03	0.14	0.02	8.61	7.90	7.50	7.79	8.62	8.29	8.12	0.46	0.06
8	9.39	9.74	9.82	9.65	0.23	0.02	8.86	9.29	8.58	8.54	9.21	9.51	9.00	0.40	0.04

Fuel-Based NO_x Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/10	3/10	3/10	3 Reps	3 Reps	3 Reps	3/11	3/11	3/12	3/12	3/13	3/13	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	394	410	415	407	10.7	0.03	374	384	364	347	427	428	387	33.5	0.09
Dyn Brake	--	--	--	--	--	--	391	390	375	347	411	413	388	24.7	0.06
1	391	397	412	400	10.5	0.03	399	406	375	349	399	417	391	24.7	0.06
2	442	461	478	460	18.0	0.04	374	446	397	377	436	467	416	38.8	0.09
3	337	351	347	345	7.32	0.02	480	489	427	439	531	500	478	39.0	0.08
4	259	274	270	268	8.18	0.03	455	506	339	383	478	441	434	62.1	0.14
5	274	278	295	283	11.2	0.04	507	361	404	335	403	433	407	60.0	0.15
6	281	267	272	273	7.34	0.03	512	324	329	376	448	358	391	74.1	0.19
7	197	199	198	198	1.05	0.01	378	235	270	241	430	270	304	80.4	0.26
8	218	226	226	223	4.51	0.02	234	232	224	221	247	252	235	12.4	0.05

Engine Output-Based NO_x Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/10	3/10	3/10	3 Reps	3 Reps	3 Reps	3/11	3/11	3/12	3/12	3/13	3/13	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	198	203	203	201	2.72	0.01	221	223	207	194	209	187	207	14.1	0.07
Dyn Brake	--	--	--	--	--	--	231	228	214	184	213	198	211	18.0	0.09
1	26.4	26.9	27.4	26.9	0.51	0.02	27.2	29.6	24.8	22.9	21.2	21.9	24.6	3.27	0.13
2	24.6	25.8	26.3	25.6	0.89	0.03	17.9	24.7	14.4	19.1	20.1	18.9	19.2	3.37	0.18
3	16.5	17.3	17.2	17.0	0.42	0.02	24.4	24.3	20.2	22.2	24.1	20.5	22.6	1.94	0.09
4	13.0	13.8	13.5	13.4	0.40	0.03	21.7	25.0	17.3	19.2	22.4	18.8	20.7	2.82	0.14
5	13.3	13.7	14.4	13.8	0.56	0.04	20.0	18.3	19.3	16.8	19.7	20.3	19.1	1.33	0.07
6	13.6	13.4	13.4	13.4	0.13	0.01	16.6	15.8	15.5	17.6	18.4	15.8	16.6	1.17	0.07
7	10.3	10.6	10.7	10.5	0.20	0.02	11.5	10.5	10.0	10.4	11.5	11.1	10.8	0.61	0.06
8	11.3	11.7	11.8	11.6	0.27	0.02	10.6	11.2	10.3	10.3	11.1	11.4	10.8	0.48	0.04
Duty Cycle Avg (Raw)	12.9	13.4	13.5	13.3	0.28	0.02	14.0	14.5	13.0	13.2	14.3	13.9	13.8	0.6	0.04
Duty Cycle Avg (Adj)	13.6	14.1	14.2	14.0	0.30	0.02	14.8	15.3	13.7	13.9	15.1	14.6	14.5	0.7	0.04

Exhaust NO_x Concentrations (ppm)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/10	3/10	3/10	3 Reps	3 Reps	3 Reps	3/11	3/11	3/12	3/12	3/13	3/13	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	261	271	271	268	5.80	0.02	295	305	283	266	273	246	278	21.2	0.08
Dyn Brake	--	--	--	--	--	--	306	311	303	251	279	259	285	25.7	0.09
1	666	677	701	681	17.6	0.03	691	772	640	596	522	543	627	94.1	0.15
2	1130	1188	1232	1183	51.0	0.04	831	1185	680	914	916	855	897	166	0.18
3	1044	1088	1086	1072	25.0	0.02	1538	1584	1278	1446	1463	1241	1425	138	0.10
4	858	911	901	890	28.3	0.03	1426	1705	1180	1306	1412	1193	1370	194	0.14
5	973	997	1061	1010	45.6	0.05	1422	1362	1409	1229	1350	1394	1361	70.0	0.05
6	1186	1169	1171	1176	9.34	0.01	1398	1423	1357	1552	1535	1295	1426	100	0.07
7	1085	1115	1134	1111	24.7	0.02	1433	1347	1268	1338	1411	1272	1345	68.5	0.05
8	1244	1318	1356	1306	56.9	0.04	1248	1372	1249	1247	1217	1232	1261	56.0	0.04

Table D-31. Measured CO Emission Rates for NC-1797 and B10 Biodiesel

Time-Based CO Emission Rates (g/s)

Throttle Notch Position	Rail Yard Test						Over-The-Rail Test								
	3/10	3/10	3/10	3 Reps	3 Reps	3 Reps	3/11	3/11	3/12	3/12	3/13	3/13	6 Trains	6 Trains	6 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	0.09	0.05	0.04	0.06	0.03	0.44	0.06	0.09	0.07	0.07	0.04	0.05	0.06	0.02	0.29
Dyn Brake	--	--	--	--	--	--	0.08	0.10	0.07	0.08	0.05	0.07	0.08	0.02	0.21
1	0.06	0.05	0.04	0.05	0.01	0.16	0.04	0.09	0.03	0.08	0.03	0.03	0.05	0.03	0.52
2	0.08	0.10	0.04	0.07	0.03	0.41	0.01	0.07	0.09	0.07	0.02	0.02	0.05	0.04	0.72
3	0.06	0.10	0.10	0.09	0.02	0.22	0.05	0.07	0.04	0.06	0.02	0.02	0.04	0.02	0.46
4	0.18	0.24	0.06	0.16	0.09	0.57	0.06	0.14	0.05	0.08	0.02	0.02	0.06	0.05	0.73
5	0.10	0.11	0.10	0.10	0.01	0.09	0.04	0.18	0.10	0.13	0.00	0.07	0.09	0.06	0.74
6	0.04	0.22	0.07	0.11	0.10	0.92	0.04	0.15	0.11	0.08	0.01	0.02	0.07	0.06	0.85
7	0.02	0.11	0.28	0.14	0.13	0.94	0.11	0.48	0.10	0.24	0.16	0.06	0.19	0.15	0.81
8	0.50	0.49	0.68	0.55	0.11	0.19	0.23	0.45	0.37	0.37	0.07	0.10	0.26	0.16	0.59

Fuel-Based CO Emission Rates (g/gal)

Throttle Notch Position	Rail Yard Test						Over-The-Rail Test								
	3/10	3/10	3/10	3 Reps	3 Reps	3 Reps	3/11	3/11	3/12	3/12	3/13	3/13	6 Trains	6 Trains	6 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	62.6	34.2	29.8	42.2	17.8	0.42	39.1	56.3	44.0	47.0	28.0	40.8	42.5	9.36	0.22
Dyn Brake	--	--	--	--	--	--	50.9	61.1	45.8	53.2	34.8	54.0	50.0	8.94	0.18
1	17.3	14.6	12.7	14.9	2.32	0.16	11.2	24.4	9.74	21.8	11.1	11.8	15.0	6.35	0.42
2	14.5	19.1	7.99	13.9	5.58	0.40	2.79	13.7	26.6	15.0	4.49	5.05	11.3	9.07	0.80
3	7.02	10.3	10.6	9.30	1.98	0.21	4.74	7.01	4.55	6.56	1.95	3.15	4.66	1.94	0.42
4	13.0	17.4	4.43	11.6	6.58	0.57	4.69	10.4	3.35	5.90	1.56	1.76	4.61	3.28	0.71
5	5.49	6.32	5.51	5.77	0.47	0.08	2.83	9.66	5.60	7.33	0.18	3.87	4.91	3.37	0.69
6	1.72	9.93	3.01	4.89	4.42	0.90	2.60	6.72	5.49	3.61	0.31	0.91	3.27	2.52	0.77
7	0.64	3.23	7.81	3.89	3.63	0.93	4.86	14.2	3.61	7.39	7.79	1.90	6.63	4.35	0.66
8	11.6	11.3	15.6	12.8	2.39	0.19	5.98	11.2	9.64	9.58	1.94	2.63	6.83	3.92	0.57

Engine Output-Based CO Emission Rates (g/bhp-hr)

Throttle Notch Position	Rail Yard Test						Over-The-Rail Test								
	3/10	3/10	3/10	3 Reps	3 Reps	3 Reps	3/11	3/11	3/12	3/12	3/13	3/13	6 Trains	6 Trains	6 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	31.4	16.9	14.6	20.9	9.13	0.44	23.1	32.6	25.1	26.3	13.7	17.8	23.1	6.65	0.29
Dyn Brake	--	--	--	--	--	--	30.1	35.7	26.1	28.2	18.0	25.9	27.3	5.79	0.21
1	1.17	0.99	0.85	1.00	0.16	0.16	0.76	1.78	0.65	1.43	0.59	0.62	0.97	0.51	0.52
2	0.81	1.07	0.44	0.77	0.31	0.41	0.13	0.76	0.96	0.76	0.21	0.20	0.50	0.36	0.72
3	0.34	0.51	0.52	0.46	0.10	0.22	0.24	0.35	0.22	0.33	0.09	0.13	0.23	0.10	0.46
4	0.65	0.87	0.22	0.58	0.33	0.57	0.22	0.51	0.17	0.30	0.07	0.08	0.23	0.17	0.73
5	0.27	0.31	0.27	0.28	0.03	0.09	0.11	0.49	0.27	0.37	0.01	0.18	0.24	0.17	0.74
6	0.08	0.50	0.15	0.24	0.22	0.92	0.08	0.33	0.26	0.17	0.01	0.04	0.15	0.13	0.85
7	0.03	0.17	0.42	0.21	0.20	0.94	0.15	0.64	0.13	0.32	0.21	0.08	0.25	0.21	0.81
8	0.60	0.58	0.81	0.66	0.13	0.19	0.27	0.54	0.44	0.45	0.09	0.12	0.32	0.19	0.59
Duty Cycle Avg (Raw)	0.69	0.66	0.72	0.69	0.03	0.04	0.39	0.75	0.54	0.58	0.19	0.25	0.45	0.21	0.48
Duty Cycle Avg (Adj)	0.69	0.66	0.72	0.69	0.03	0.04	0.39	0.75	0.54	0.58	0.19	0.25	0.45	0.21	0.48

Exhaust CO Concentrations (%)

Throttle Notch Position	Rail Yard Test						Over-The-Rail Test								
	3/10	3/10	3/10	3 Reps	3 Reps	3 Reps	3/11	3/11	3/12	3/12	3/13	3/13	6 Trains	6 Trains	6 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	0.007	0.004	0.003	0.005	0.00	0.43	0.005	0.008	0.006	0.006	0.003	0.004	0.005	0.00	0.31
Dyn Brake	--	--	--	--	--	--	0.007	0.008	0.006	0.007	0.004	0.006	0.006	0.00	0.22
1	0.005	0.004	0.004	0.004	0.00	0.16	0.003	0.008	0.003	0.006	0.003	0.003	0.004	0.00	0.54
2	0.006	0.009	0.004	0.006	0.00	0.40	0.001	0.006	0.008	0.006	0.002	0.002	0.004	0.00	0.73
3	0.004	0.006	0.006	0.005	0.00	0.22	0.003	0.004	0.002	0.004	0.001	0.001	0.002	0.00	0.49
4	0.007	0.010	0.003	0.007	0.00	0.57	0.003	0.006	0.002	0.003	0.001	0.001	0.003	0.00	0.75
5	0.003	0.004	0.003	0.004	0.00	0.08	0.001	0.006	0.003	0.005	0.000	0.002	0.003	0.00	0.76
6	0.001	0.008	0.002	0.004	0.00	0.92	0.001	0.005	0.004	0.003	0.000	0.001	0.002	0.00	0.87
7	0.001	0.003	0.008	0.004	0.00	0.95	0.003	0.014	0.003	0.007	0.004	0.002	0.006	0.00	0.83
8	0.011	0.011	0.016	0.013	0.00	0.21	0.006	0.011	0.009	0.009	0.002	0.002	0.007	0.00	0.62

Table D-32. Measured Hydrocarbon Emission Rates for NC-1797 and B10 Biodiesel

Time-Based HC Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/10	3/10	3/10	3 Reps	3 Reps	3 Reps	3/11	3/11	3/12	3/12	3/13	3/13	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	0.69	0.24	0.28	0.40	0.25	0.62	0.39	0.67	0.59	0.57	0.32	0.47	0.50	0.13	0.26
Dyn Brake	--	--	--	--	--	--	0.30	0.73	0.58	0.60	0.32	0.60	0.52	0.17	0.33
1	0.50	0.26	0.17	0.31	0.17	0.54	0.27	0.71	0.44	0.62	0.27	0.36	0.45	0.18	0.41
2	0.68	0.56	0.31	0.52	0.19	0.37	0.46	0.69	0.56	0.70	0.28	0.28	0.50	0.19	0.38
3	0.80	0.61	0.61	0.67	0.11	0.16	0.59	0.74	0.90	0.60	0.35	0.47	0.61	0.19	0.32
4	1.26	1.00	0.59	0.95	0.34	0.35	0.39	1.25	0.74	1.00	0.25	0.66	0.72	0.37	0.52
5	1.13	0.64	0.47	0.74	0.34	0.46	0.51	1.67	0.99	1.23	0.55	1.14	1.01	0.44	0.43
6	1.34	1.01	0.62	0.99	0.36	0.36	0.59	1.31	1.29	0.89	0.28	0.69	0.84	0.40	0.48
7	0.91	1.20	1.20	1.10	0.16	0.15	1.25	2.27	1.50	1.06	1.79	0.74	1.43	0.54	0.38
8	1.86	1.58	1.36	1.60	0.25	0.16	0.52	1.22	0.88	0.64	0.42	0.51	0.70	0.30	0.43

Fuel-Based HC Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/10	3/10	3/10	3 Reps	3 Reps	3 Reps	3/11	3/11	3/12	3/12	3/13	3/13	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	494	175	204	291	176	0.61	237	417	373	366	238	386	336	78.3	0.23
Dyn Brake	--	--	--	--	--	--	183	449	367	407	221	452	347	117	0.34
1	141	74.0	49.5	88.3	47.6	0.54	76.1	186	127	179	95.2	131	132	43.8	0.33
2	127	102	57.8	95.5	34.9	0.36	99.2	127	160	142	63.3	71.1	110	39.1	0.35
3	86.6	65.9	65.6	72.7	12.0	0.17	61.6	79.6	101	63.7	41.4	60.8	68.1	20.3	0.30
4	90.3	71.8	42.7	68.3	24.0	0.35	29.7	91.0	52.1	71.9	19.4	55.6	53.3	26.4	0.50
5	63.3	35.2	26.1	41.5	19.4	0.47	34.8	89.2	56.6	66.9	30.4	65.8	57.3	22.0	0.38
6	62.3	45.3	28.5	45.3	16.9	0.37	41.2	60.2	61.6	42.8	15.5	35.4	42.8	17.1	0.40
7	26.2	33.8	33.3	31.1	4.23	0.14	54.8	67.5	53.8	32.8	89.4	24.3	53.8	23.5	0.44
8	43.1	36.7	31.3	37.1	5.90	0.16	13.7	30.5	22.9	16.5	11.3	13.6	18.1	7.27	0.40

Engine Output-Based HC Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/10	3/10	3/10	3 Reps	3 Reps	3 Reps	3/11	3/11	3/12	3/12	3/13	3/13	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	248	86.7	99.5	145	89.5	0.62	140	242	213	205	116	169	181	47.4	0.26
Dyn Brake	--	--	--	--	--	--	108	262	210	215	114	217	188	62.3	0.33
1	9.53	5.01	3.29	5.94	3.22	0.54	5.19	13.5	8.40	11.7	5.06	6.90	8.46	3.49	0.41
2	7.04	5.71	3.18	5.31	1.96	0.37	4.74	7.05	5.81	7.17	2.92	2.87	5.09	1.92	0.38
3	4.25	3.25	3.25	3.58	0.58	0.16	3.14	3.95	4.80	3.22	1.88	2.49	3.25	1.04	0.32
4	4.54	3.61	2.14	3.43	1.21	0.35	1.42	4.50	2.66	3.60	0.91	2.37	2.58	1.34	0.52
5	3.06	1.74	1.27	2.02	0.93	0.46	1.37	4.53	2.70	3.34	1.48	3.09	2.75	1.20	0.43
6	3.01	2.26	1.40	2.22	0.80	0.36	1.34	2.94	2.90	2.00	0.64	1.56	1.90	0.91	0.48
7	1.37	1.80	1.80	1.66	0.25	0.15	1.67	3.02	1.99	1.41	2.39	0.99	1.91	0.72	0.38
8	2.23	1.90	1.63	1.92	0.30	0.16	0.62	1.46	1.05	0.77	0.51	0.62	0.84	0.36	0.43
Duty Cycle Avg (Raw)	1.72	1.11	0.96	1.26	0.40	0.32	0.80	1.64	1.29	1.21	0.69	0.94	1.10	0.35	0.32
Duty Cycle Avg (Adj)	4.30	2.76	2.40	3.16	1.01	0.32	2.00	4.10	3.23	3.01	1.72	2.36	2.74	0.88	0.32

Exhaust HC Concentrations (ppm)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/10	3/10	3/10	3 Reps	3 Reps	3 Reps	3/11	3/11	3/12	3/12	3/13	3/13	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	74	26	30	43	26.3	0.61	42	75	65	63	34	50	55	15.4	0.28
Dyn Brake	--	--	--	--	--	--	32	81	67	66	34	64	57	19.7	0.34
1	54	28	19	34	18.3	0.54	30	80	49	69	28	39	49	21.2	0.43
2	73	59	34	55	20.0	0.36	50	76	62	77	30	29	54	21.5	0.40
3	60	46	46	51	8.28	0.16	45	58	68	47	26	34	46	15.5	0.34
4	67	54	32	51	17.8	0.35	21	69	41	55	13	34	39	21.0	0.54
5	51	28	21	33	15.3	0.46	22	76	44	55	23	48	45	20.4	0.46
6	59	45	28	44	15.8	0.36	25	60	57	40	12	29	37	18.7	0.50
7	33	43	43	39	5.91	0.15	47	87	57	41	66	26	54	21.3	0.39
8	55	48	42	49	6.55	0.13	16	41	29	21	13	15	22	10.6	0.47

Table D-33. Measured Particulate Matter Emission Rates for NC-1797 and B10 Biodiesel

Time-Based PM Emission Rates (g/s)															
Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/10	3/10	3/10	3 Reps	3 Reps	3 Reps	3/11	3/11	3/12	3/12	3/13	3/13	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	0.01	0.01	0.01	0.01	0.00	0.09	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.04
Dyn Brake	--	--	--	--	--	--	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.05
1	0.01	0.01	0.01	0.01	0.00	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.04
2	0.01	0.01	0.01	0.01	0.00	0.03	0.02	0.02	0.01	0.01	0.02	0.01	0.02	0.00	0.08
3	0.02	0.02	0.02	0.02	0.00	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.04
4	0.03	0.03	0.03	0.03	0.00	0.03	0.03	0.03	0.03	0.02	0.03	0.03	0.03	0.00	0.12
5	0.03	0.03	0.03	0.03	0.00	0.02	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.00	0.07
6	0.03	0.03	0.03	0.03	0.00	0.01	0.03	0.04	0.03	0.03	0.04	0.03	0.03	0.00	0.09
7	0.14	0.13	0.14	0.13	0.01	0.05	0.06	0.15	0.10	0.11	0.05	0.10	0.09	0.04	0.38
8	0.21	0.17	0.17	0.18	0.02	0.12	0.14	0.17	0.15	0.14	0.12	0.12	0.14	0.02	0.13

Fuel-Based PM Emission Rates (g/gal)															
Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/10	3/10	3/10	3 Reps	3 Reps	3 Reps	3/11	3/11	3/12	3/12	3/13	3/13	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	9.08	10.1	8.59	9.25	0.77	0.08	7.77	7.27	7.54	7.47	8.90	9.52	8.08	0.91	0.11
Dyn Brake	--	--	--	--	--	--	8.80	8.04	8.86	8.86	9.47	9.61	8.94	0.56	0.06
1	6.00	5.71	5.57	5.76	0.22	0.04	6.01	5.14	5.78	5.57	7.47	7.10	6.18	0.91	0.15
2	3.61	3.42	3.51	3.51	0.09	0.03	4.83	4.06	5.60	4.23	5.54	5.43	4.95	0.68	0.14
3	2.73	2.70	2.64	2.69	0.05	0.02	2.59	2.70	2.86	2.45	2.99	3.08	2.78	0.24	0.09
4	2.63	2.59	2.50	2.57	0.07	0.03	3.09	2.56	2.71	2.38	3.53	3.10	2.90	0.42	0.15
5	2.68	2.62	2.57	2.63	0.05	0.02	3.77	2.60	2.77	2.52	2.66	2.61	2.82	0.47	0.17
6	2.20	2.15	2.14	2.16	0.03	0.01	3.28	2.31	2.29	2.21	3.16	2.32	2.59	0.49	0.19
7	5.43	4.84	5.13	5.13	0.30	0.06	3.57	5.87	4.96	4.78	3.22	4.32	4.45	0.97	0.22
8	6.74	5.67	5.40	5.94	0.71	0.12	5.09	5.92	5.31	5.09	4.38	4.54	5.06	0.55	0.11

Engine Output-Based PM Emission Rates (g/bhp-hr)															
Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/10	3/10	3/10	3 Reps	3 Reps	3 Reps	3/11	3/11	3/12	3/12	3/13	3/13	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	4.08	4.46	3.75	4.10	0.36	0.09	4.10	3.77	3.84	3.73	3.89	3.72	3.84	0.14	0.04
Dyn Brake	--	--	--	--	--	--	3.65	3.30	3.56	3.30	3.45	3.24	3.42	0.17	0.05
1	0.25	0.24	0.23	0.24	0.01	0.04	0.25	0.23	0.24	0.23	0.25	0.23	0.24	0.01	0.04
2	0.14	0.13	0.14	0.14	0.00	0.03	0.16	0.16	0.14	0.15	0.18	0.15	0.16	0.01	0.08
3	0.09	0.09	0.09	0.09	0.00	0.01	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.00	0.04
4	0.10	0.10	0.09	0.09	0.00	0.03	0.11	0.09	0.10	0.09	0.12	0.10	0.10	0.01	0.12
5	0.09	0.09	0.08	0.09	0.00	0.02	0.10	0.09	0.09	0.09	0.09	0.08	0.09	0.01	0.07
6	0.08	0.08	0.07	0.08	0.00	0.01	0.08	0.08	0.08	0.07	0.09	0.07	0.08	0.01	0.09
7	0.21	0.19	0.21	0.20	0.01	0.05	0.08	0.19	0.14	0.15	0.06	0.13	0.13	0.05	0.38
8	0.25	0.21	0.20	0.22	0.03	0.12	0.16	0.20	0.17	0.17	0.14	0.15	0.17	0.02	0.13
Duty Cycle Avg (Raw)	0.05	0.04	0.04	0.04	0.00	0.08	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.00	0.10
Duty Cycle Avg (Adj)	0.23	0.20	0.19	0.21	0.02	0.08	0.16	0.20	0.17	0.17	0.15	0.15	0.17	0.02	0.10

Exhaust PM Concentrations (mg/m^3)															
Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/10	3/10	3/10	3 Reps	3 Reps	3 Reps	3/11	3/11	3/12	3/12	3/13	3/13	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Idle	2.0	2.2	1.9	2.0	0.18	0.09	2.1	1.9	2.0	1.9	1.9	1.8	1.9	0.07	0.04
Dyn Brake	--	--	--	--	--	--	1.9	1.7	1.9	1.7	1.7	1.6	1.8	0.11	0.06
1	2.5	2.4	2.3	2.4	0.09	0.04	2.6	2.4	2.4	2.3	2.4	2.3	2.4	0.10	0.04
2	2.6	2.4	2.5	2.5	0.06	0.02	3.0	3.0	2.7	2.8	3.2	2.8	2.9	0.20	0.07
3	2.3	2.3	2.3	2.3	0.03	0.01	2.3	2.4	2.4	2.2	2.3	2.1	2.3	0.11	0.05
4	2.5	2.5	2.4	2.5	0.06	0.02	2.8	2.5	2.7	2.4	3.0	2.4	2.7	0.26	0.10
5	2.6	2.5	2.5	2.5	0.04	0.01	2.8	2.6	2.6	2.5	2.4	2.3	2.5	0.20	0.08
6	2.6	2.7	2.6	2.6	0.03	0.01	2.5	2.9	2.7	2.6	3.1	2.4	2.7	0.25	0.09
7	8.5	7.7	8.3	8.2	0.43	0.05	3.8	9.5	6.6	7.5	3.0	5.8	6.0	2.40	0.40
8	10.7	9.2	9.0	9.7	0.92	0.10	7.6	9.7	8.3	8.0	6.0	6.2	7.6	1.39	0.18

Table D-34. Measured CO$_2$ Emission Rates for NC-1797 and B10 Biodiesel

Time-Based CO$_2$ Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	**3/10**	**3/10**	**3/10**	**3 Reps**	**3 Reps**	**3 Reps**	**3/11**	**3/11**	**3/12**	**3/12**	**3/13**	**3/13**	**6 Trains**	**6 Trains**	**6 Trains**
Position	**Axion REP1**	**Axion REP2**	**Axion REP3**	**Average**	**StDev**	**CV**	**Train 73**	**Train 74**	**Train 73**	**Train 74**	**Train 73**	**Train 73**	**Average**	**StDev**	**CV**
Idle	13.5	13.6	13.4	13.5	0.09	0.01	16.2	15.7	15.5	15.2	13.4	11.9	14.6	1.64	0.11
Dyn Brake	--	--	--	--	--	--	16.2	15.7	15.5	14.3	14.2	12.9	14.8	1.22	0.08
1	35.4	35.7	35.2	35.4	0.27	0.01	36.1	38.1	34.9	34.4	28.0	27.6	33.2	4.35	0.13
2	53.9	54.2	53.7	53.9	0.29	0.01	46.5	53.8	35.0	49.0	45.0	39.3	44.8	6.76	0.15
3	92.1	92.5	93.1	92.5	0.51	0.01	95.7	93.2	88.9	95.0	85.4	77.0	89.2	7.15	0.08
4	140	140	140	140	0.09	0.00	133	137	142	140	131	119	134	8.36	0.06
5	178	182	180	180	1.96	0.01	146	187	176	184	181	173	175	14.8	0.08
6	215	223	220	219	3.84	0.02	145	218	209	209	184	197	194	26.7	0.14
7	351	357	361	356	5.31	0.01	229	336	279	324	200	309	280	54.6	0.20
8	432	433	435	433	1.84	0.00	380	401	384	389	376	379	385	9.24	0.02

Fuel-Based CO$_2$ Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	**3/10**	**3/10**	**3/10**	**3 Reps**	**3 Reps**	**3 Reps**	**3/11**	**3/11**	**3/12**	**3/12**	**3/13**	**3/13**	**6 Trains**	**6 Trains**	**6 Trains**
Position	**Axion REP1**	**Axion REP2**	**Axion REP3**	**Average**	**StDev**	**CV**	**Train 73**	**Train 74**	**Train 73**	**Train 74**	**Train 73**	**Train 73**	**Average**	**StDev**	**CV**
Idle	9673	9913	9902	9829	136	0.01	9867	9730	9776	9775	9884	9773	9801	60.7	0.01
Dyn Brake	--	--	--	--	--	--	9882	9702	9777	9741	9884	9712	9783	81.7	0.01
1	9960	10006	10024	9997	32.8	0.00	10010	9922	9981	9930	9998	9975	9969	35.9	0.00
2	9974	9982	10026	9994	28.3	0.00	10009	9975	9934	9964	10028	10023	9989	37.3	0.00
3	10010	10018	10017	10015	4.28	0.00	10029	10014	10005	10025	10046	10032	10025	14.2	0.00
4	9998	10003	10041	10014	23.4	0.00	10049	10002	10037	10021	10060	10037	10034	20.5	0.00
5	10027	10043	10050	10040	11.7	0.00	10048	10004	10031	10022	10055	10028	10031	18.5	0.00
6	10033	10031	10052	10039	11.6	0.00	10045	10027	10028	10042	10064	10051	10043	14.3	0.00
7	10057	10048	10042	10049	7.82	0.00	10033	10010	10036	10042	10007	10056	10031	19.0	0.00
8	10030	10034	10031	10031	2.32	0.00	10056	10038	10045	10049	10064	10062	10052	10.2	0.00

Engine Output-Based CO$_2$ Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	**3/10**	**3/10**	**3/10**	**3 Reps**	**3 Reps**	**3 Reps**	**3/11**	**3/11**	**3/12**	**3/12**	**3/13**	**3/13**	**6 Trains**	**6 Trains**	**6 Trains**
Position	**Axion REP1**	**Axion REP2**	**Axion REP3**	**Average**	**StDev**	**CV**	**Train 73**	**Train 74**	**Train 73**	**Train 74**	**Train 73**	**Train 73**	**Average**	**StDev**	**CV**
Idle	4852	4899	4833	4861	34.1	0.01	5824	5636	5570	5463	4834	4273	5267	592	0.11
Dyn Brake	--	--	--	--	--	--	5833	5665	5580	5156	5122	4652	5335	438	0.08
1	671	677	667	671	5.11	0.01	683	723	661	652	531	524	629	82.4	0.13
2	555	558	552	555	2.95	0.01	478	553	360	504	463	405	461	69.5	0.15
3	491	493	496	494	2.72	0.01	510	497	474	507	455	411	476	38.1	0.08
4	503	503	503	503	0.32	0.00	480	495	513	502	470	429	481	30.1	0.06
5	485	495	489	490	5.31	0.01	397	508	479	500	490	471	474	40.3	0.08
6	484	501	494	493	8.65	0.02	325	490	471	470	414	444	436	60.2	0.14
7	526	536	541	534	7.96	0.01	305	448	372	432	267	412	373	72.8	0.20
8	518	520	523	520	2.21	0.00	456	482	461	467	451	455	462	11.1	0.02

Exhaust CO$_2$ Concentrations (%)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	**3/10**	**3/10**	**3/10**	**3 Reps**	**3 Reps**	**3 Reps**	**3/11**	**3/11**	**3/12**	**3/12**	**3/13**	**3/13**	**6 Trains**	**6 Trains**	**6 Trains**
Position	**Axion REP1**	**Axion REP2**	**Axion REP3**	**Average**	**StDev**	**CV**	**Train 73**	**Train 74**	**Train 73**	**Train 74**	**Train 73**	**Train 73**	**Average**	**StDev**	**CV**
Idle	0.70	0.72	0.71	0.71	0.01	0.01	0.86	0.85	0.83	0.83	0.70	0.62	0.78	0.10	0.13
Dyn Brake	--	--	--	--	--	--	0.85	0.85	0.87	0.77	0.74	0.67	0.79	0.08	0.10
1	1.87	1.88	1.88	1.87	0.01	0.00	1.91	2.08	1.88	1.87	1.44	1.43	1.77	0.27	0.15
2	2.81	2.83	2.85	2.83	0.02	0.01	2.45	2.92	1.87	2.66	2.32	2.02	2.37	0.39	0.16
3	3.42	3.42	3.45	3.43	0.02	0.01	3.54	3.57	3.30	3.63	3.04	2.74	3.30	0.35	0.11
4	3.65	3.66	3.69	3.66	0.02	0.01	3.47	3.71	3.84	3.76	3.27	2.99	3.51	0.33	0.09
5	3.91	3.96	3.98	3.95	0.03	0.01	3.10	4.15	3.85	4.04	3.71	3.55	3.73	0.38	0.10
6	4.65	4.83	4.77	4.75	0.09	0.02	3.02	4.85	4.55	4.56	3.79	4.00	4.13	0.67	0.16
7	6.09	6.19	6.33	6.20	0.12	0.02	4.19	6.31	5.19	6.13	3.61	5.21	5.11	1.06	0.21
8	6.30	6.45	6.62	6.46	0.16	0.03	5.90	6.52	6.16	6.25	5.47	5.40	5.95	0.45	0.08

D.4 Summary of Results for NC-1797 on ULSD

This section discusses the results of the rail yard and over-the-rail measurements of the NC-1797 prime mover engine.

Rail Yard Measurements

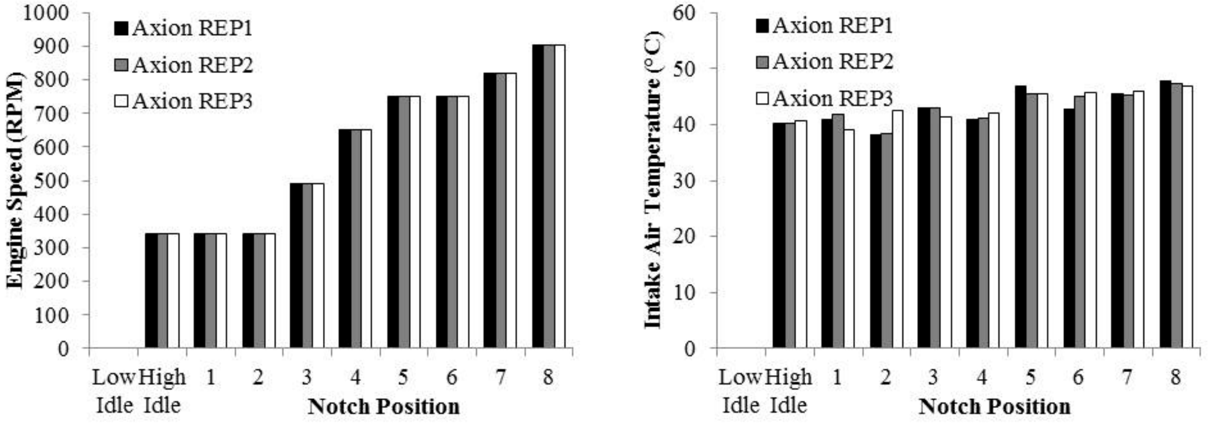
Three rail yard emissions measurement replicates on the prime mover engine of NC-1797 were conducted on October 22, 2013. Results for the rail yard measurements are presented and discussed in this section. The most recent results are compared to previous measurements of the prime mover engine of NC-1797.

The cycle average emission rates for the rail yard measurements of the NC-1797 prime mover engine are shown in Table D-35. These cycle average emission rates are based on the measured engine activity data (RPM, MAP, and IAT), inferred engine activity data (MAF, AFR, and VE), and measured exhaust concentrations. Low idle was not observed during the rail yard measurements. When in idle, the locomotive was in high idle for all time during the rail yard measurements. There was little variability between replicate measured engine activity data, given in Figure D-20. This indicates that the prime mover engine was operating consistently during all three replicate measurements.

An increase in fuel use rates was apparent as notch position increased during the rail yard measurements, as shown in Figure D-21. Higher inter-replicate variability was observed at notches 7 and 8. The NO emission rates estimated with the Axion during the three replicates were consistent, as shown in Figure D-22. The inter-replicate ratios of the standard deviation to the mean (coefficient of variation) for each notch position for the mass per gallon of fuel NO emission rates range from 0.01 to 0.04, which indicates small variability between replicates. There was variability in the estimated HC emission rates between the three replicate measurements, as shown in Figure D-23. On average for each notch position, inter-replicate coefficient of variation in the estimated HC emission rates were 50 percent. Differences in measured exhaust HC concentrations were the primary reason for the inter-replicate variability. Across the three replicates, the coefficient of variation varied from 0.14 to 0.92, depending on the notch position.

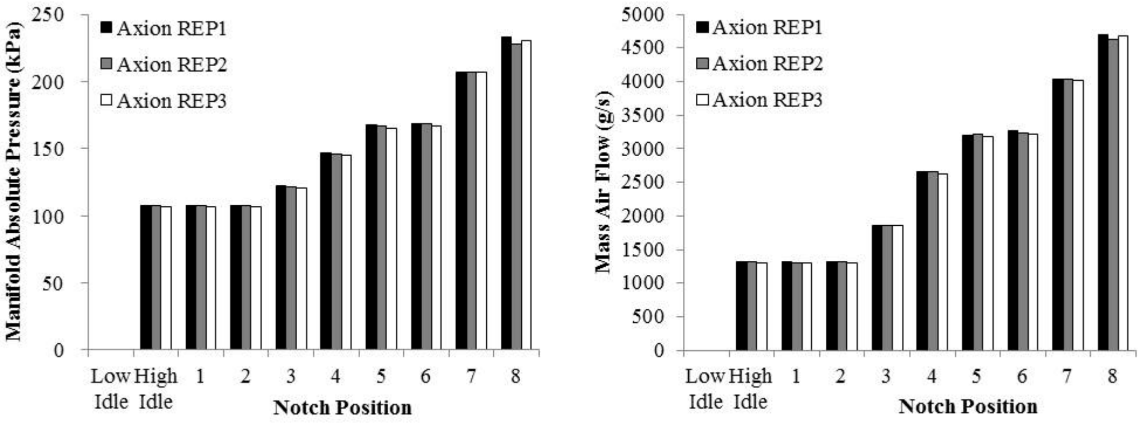
There was also variability in the estimated CO emission rates between the three replicate measurements, as shown in Figure D-24. Inter-replicate coefficient of variation in the estimated CO emission rates were, on average for each notch position, 93 percent. For CO exhaust concentrations, the coefficient of variation varied from 0.57 to 1.63, depending on the notch position. Thus, when replicates were compared, differences in measured exhaust concentrations primarily contributed to the variability in mass emission rates. However, on an absolute basis, the exhaust CO concentrations were very low. PM emission rates, as shown in Figure D-25, were consistent across the three replicates, with inter-replicate coefficient of variation of less than 0.05 for all notch positions.

Figure D-20. Measured and Inferred Engine Activity Data during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on Ultra-Low Sulfur Diesel



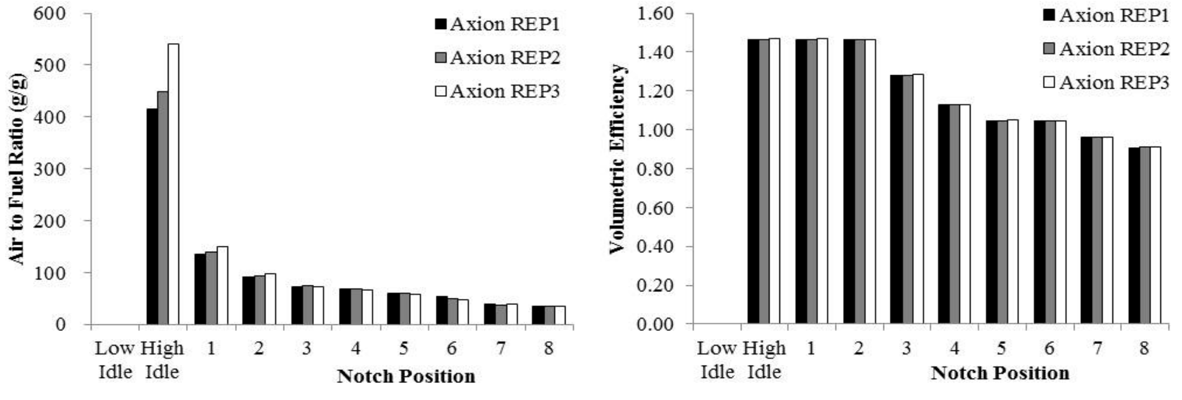
(a) Engine Speed

(b) Intake Air Temperature



(c) Manifold Absolute Pressure

(d) Mass Air Flow



(e) Air-to-Fuel Ratio

(f) Volumetric Efficiency

Figure D-21. Estimated Fuel Use Rates during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on Ultra-Low Sulfur Diesel

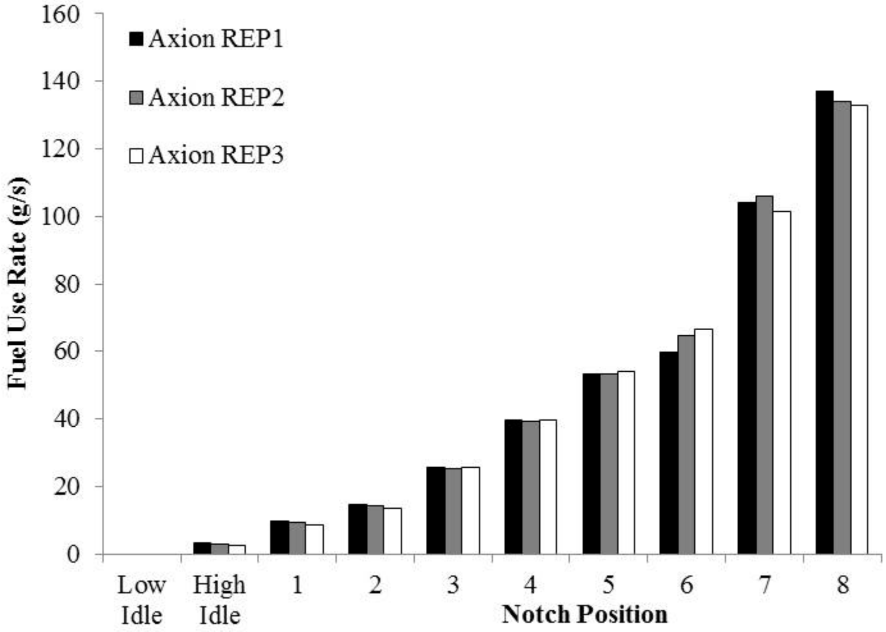


Figure D-22. Estimated NO_x Emission Rates during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on Ultra-Low Sulfur Diesel

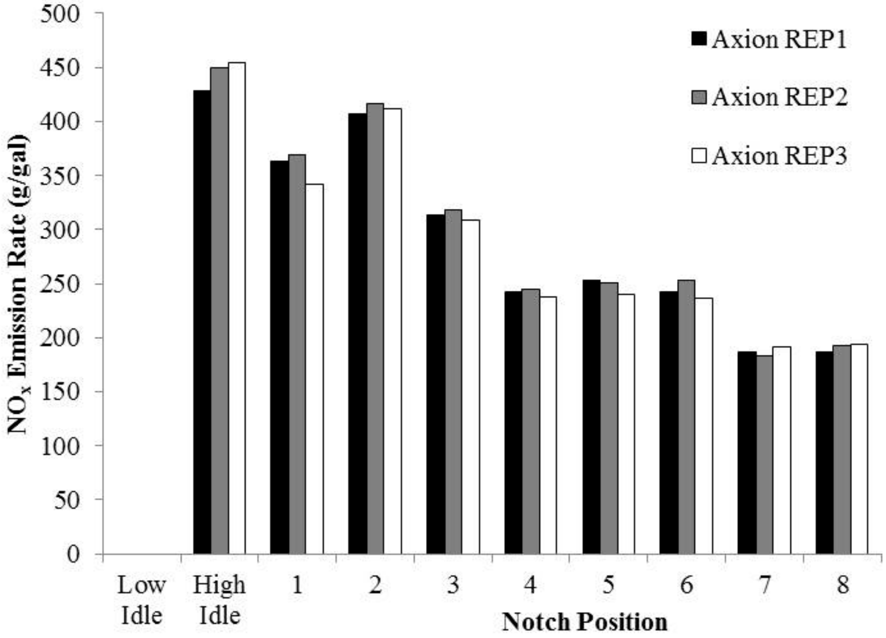


Figure D-23. Estimated HC Emission Rates during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on Ultra-Low Sulfur Diesel

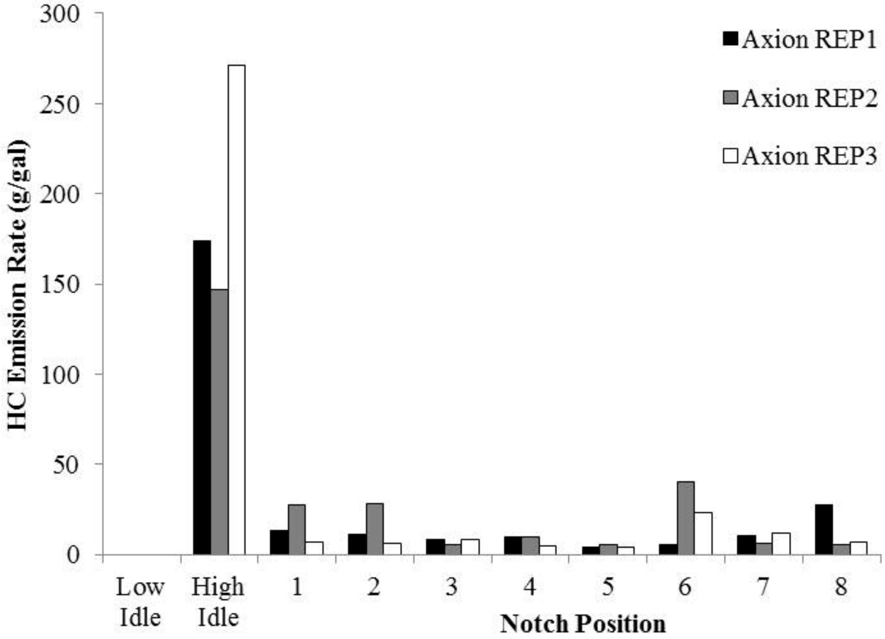


Figure D-24. Estimated CO Emission Rates during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on Ultra-Low Sulfur Diesel

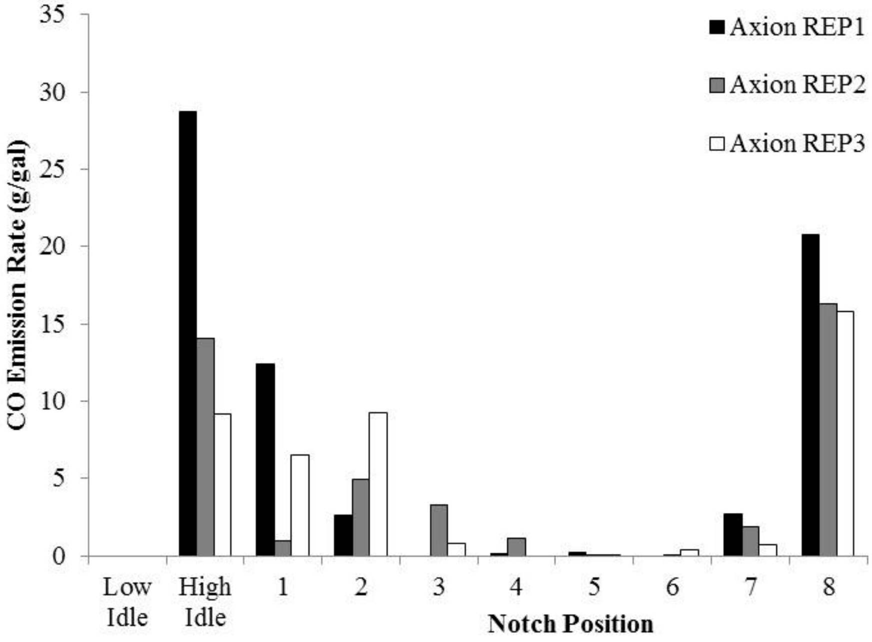
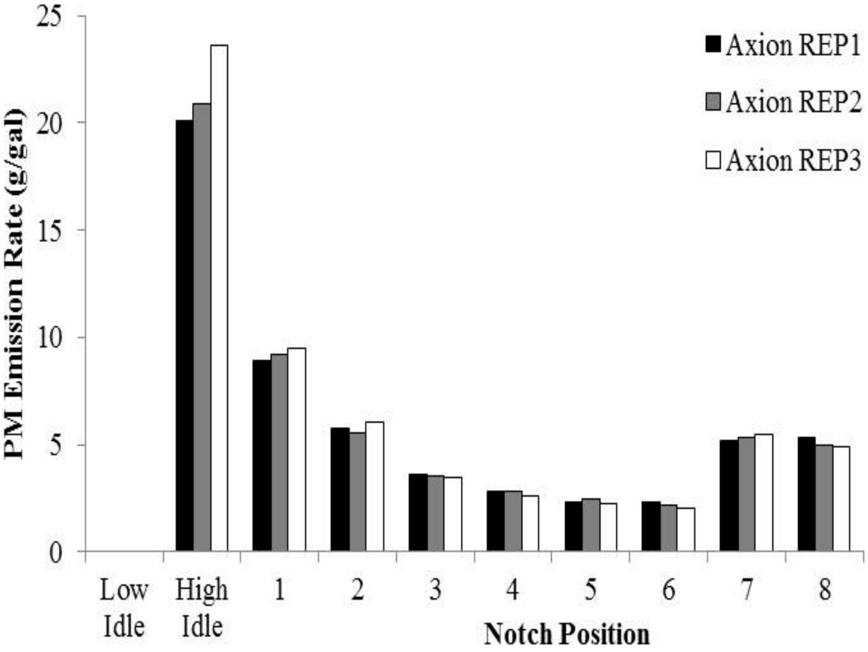


Figure D-25. Measured PM Concentrations during Rail Yard Measurements of the NC-1797 Prime Mover Engine Operated on Ultra-Low Sulfur Diesel



Estimated cycle average emission rates for the three replicate rail yard measurements are given in Table D-35. There was little variability in the NO_x and PM cycle average emission rates among the replicates. Amongst the three replicates, the average coefficient of variation for each notch position averages for CO and HC are 20 and 33 percent, respectively. Differences in emission rates are attributable to differences in measured exhaust concentrations. Values for engine activity parameters (RPM, IAT, MAP) were similar across all measurements, as given in Figure D-20.

Table D-35. Cycle Average Emission Rates for Rail Yard Replicate Measurements of NC-1797 Prime Mover Engine Operated on Ultra-Low Sulfur Diesel

	NO_x (g/bhp-hr)	HC (g/bhp-hr)	CO (g/bhp-hr)	Opacity-based PM (g/bhp-hr)
Replicate 1	11.2	1.39	0.75	0.20
Replicate 2	11.3	0.76	0.55	0.19
Replicate 3	11.0	0.87	0.52	0.19
Sept. 1, 2013	**11.2**	**1.01**	**0.61**	**0.19**
EPA Tier 0+	**8.0**	**1.00**	**5.0**	**0.22**
EPA Tier 1+	7.4	0.55	2.2	0.22

† NO_x, HC, and PM are adjusted with multipliers of 1.05, 2.5, and 5, respectively, as bias correction.

†† Cycle average emission rates are based on EPA Line-Haul driving cycle.

OTR Measurements

Three days of OTR measurements on the NC-1797 prime mover engine were conducted from October 9-11, 2013. Results for these measurements are presented and discussed in this section.

The cycle average emission rates from the OTR measurements of the NC-1797 prime mover engine are shown in Table D-36. These cycle average emission rates are based on the measured engine activity data (RPM, MAP, and IAT) and measured exhaust concentrations. There was little variability between measured engine activity data during all three days of measurements. This indicates that the prime mover engine was operating consistently during over-the-rail measurements. Measured engine activity data during OTR measurements were similar to the measured engine activity data during rail yard measurements.

The cycle average over-the-rail emission rates are quantitatively similar to the cycle average rail yard emission rates measured in October 2013. There was less than three percent variability amongst the six one way trips with regard to cycle average NO_x emission rates. The average cycle average over-the-rail NO_x emission rate over six one-way trips was 21 percent higher than the cycle average rail yard NO_x emission rates. There was higher variability amongst the six one-way cycle average PM (eight percent), CO (33 percent), and HC (44 percent) emission rates. Differences in measured exhaust pollutant concentrations were one of the key reasons for the variability. Amongst the six one way trips, the average coefficient of variation for each notch position, averaged over all notch positions, for the exhaust concentrations were 15 percent, 59 percent, and 52 percent for PM, CO, and HC, respectively.

The average cycle average OTR CO emission rate was 35 percent higher than the cycle average CO emission rates estimated from rail yard measurements. The average cycle average over-the-rail PM emission rate was 16 percent lower than the cycle average PM emission rate estimated from rail yard measurements. The average cycle average over-the-rail HC emission rate was more than three times the cycle average rail yard HC emission rate.

Table D-36. Cycle Average Emission Rates for Over-the-Rail Measurements of NC-1797 Prime Mover Engine Operated on Ultra-Low Sulfur Diesel

	NO_x (g/bhp-hr)	HC (g/bhp-hr)	CO (g/bhp-hr)	Opacity-based PM (g/bhp-hr)
Oct. 9, 2013 – Train 75	13.3	2.76	0.59	0.19
Oct. 9, 2013 – Train 76	13.0	5.01	1.11	0.17
Oct. 10, 2013 – Train 75	13.8	1.97	0.57	0.15
Oct. 10, 2013 – Train 76	14.2	5.03	1.15	0.15
Oct. 11, 2013 – Train 75	13.7	1.68	0.58	0.16
Oct. 11, 2013 – Train 76	13.6	4.62	0.92	0.15
Average	**13.6**	**3.51**	**0.82**	**0.16**
EPA Tier 0+	**8.0**	**1.00**	**5.0**	**0.22**
EPA Tier 1+	7.4	0.55	2.2	0.22

† NO_x, HC, and PM are adjusted with multipliers of 1.05, 2.5, and 5, respectively, as bias correction.

†† Cycle average emission rates are based on EPA Line-Haul driving cycle.

Differences in cycle average emission rates between rail yard and over-the-rail measurements can be attributed to various factors. RPM and MAP was essentially the same for rail yard and over-the-rail measurements. IAT differed on an absolute basis by less than 6 percent from run-to-run during over-the-rail measurements. At notch 8, the engine output during rail yard measurements was 2700 horsepower, while engine output was 3000 horsepower during over-the-rail measurements. With notch 8 accounting for 16 percent of the EPA line-haul duty cycle used to estimate cycle average emission rates, higher engine output decreases engine output based emission rates and, therefore, cycle average emission rates. Finally, differences in measured exhaust concentrations between rail yard and over-the-rail measurements lead to differences in fuel use and emission rates.

Throttle notch position data was obtained from the locomotive data activity recorder to measure the duty cycles for the over-the-rail measurements. The measured duty cycles are compared to the EPA line-haul duty cycle in Table D-37. The prime mover engine operated in notch 8 during the over-the-rail tests more than double the percentage of time, on average, the EPA estimates a line-haul locomotive is operating in notch 8. The average percentage of time the prime mover engine operated in idle through notch 7 during the over-the-rail tests was lower than the percentage of time the EPA estimates a line-haul locomotive is operating in those throttle notch settings, with the exception of dynamic braking, where the amount of time spent during the six one-way trips was similar to the percentage of time allocated in the line-haul duty cycle.

Table D-37. Over-the-Rail Duty Cycles during Measurement of NC-1797 Operated on Ultra-Low Sulfur Diesel

Notch	Percent Time in Each Notch							
	EPA Line-Haul	Measured Over-the-Rail						
		Average	10/9/2013 Train 75	10/9/2013 Train 76	10/10/2013 Train 75	10/10/2013 Train 76	10/11/2013 Train 75	10/11/2013 Train 76
Idle	38.0	39.0	42.1	45.1	33.4	26.6	41.8	44.8
DB	12.5	4.0	2.8	4.5	3.0	3.4	3.1	7.0
1	6.5	3.0	2.2	3.3	1.0	7.9	1.9	1.7
2	6.5	4.6	1.9	2.0	9.3	9.9	1.9	2.5
3	5.2	2.7	2.5	1.9	3.0	5.1	0.7	2.7
4	4.4	3.0	2.4	3.0	5.6	4.4	1.6	1.2
5	3.8	2.1	2.6	3.1	1.8	2.1	1.7	1.0
6	3.9	2.1	2.1	3.2	2.0	1.6	1.5	2.1
7	3.0	1.2	1.1	3.7	0.1	0.2	0.9	1.4
8	16.2	42.4	43.2	34.7	43.8	42.1	48.0	42.6

Details of results of the field measurements and of the fuel use and emission rates for rail yard and over-the-rail measurements of NC-1797 using ULSD are given in attached supplemental tables.

Table D-38 summarizes the average measured engine speed (RPM), intake air temperature (IAT), manifold absolute pressure (MAP), estimated mass air flow (MAF), air-to-fuel ratio (AFR), and volumetric efficiency (VE) for each throttle notch position and for each replicate of the RY test and for each one-way OTR trip. Engine speed ranges from 343 to 903 RPM in both RY and OTR measurements. For the RY measurements, engine RPM was highly repeatable, with a standard deviation of less than 1 RPM for all notch positions. For the OTR measurements, the RPM was also repeatable, with a standard deviation of 2 RPM or less for all notch positions. The intake air temperature varies with ambient temperature and was generally in the range of 38 to 50 degrees C during all measurements. MAP was highly repeatable in the RY tests, ranging from 107 to 233 kPa among notch positions with an inter-test standard deviation of less than 3 kPa for each notch position. For OTR measurements, there was slightly more inter-run variability. However, the ratio of the standard deviation to the mean of the run average MAP values for each notch position was typically 0.04 or less.

Estimated MAF was highly repeatable for both RY and OTR measurements, ranging from 1,300 to 4,700 g/s, with the ratio of the standard deviation to the mean of 0.05 or less for all notches. Estimated AFR was highly repeatable in the RY tests, with standard deviations less than 8 for all notches except for high idle. For OTR measurements, there was slightly more inter-run variability. But the ratio of the standard deviation to the mean was typically less than 0.2, except for Notch 1 and 7. Overall, the engine activity during the measurements was consistent from test to test for the three replicates in the rail yard, and from run to run for the six one-way trips observed between Raleigh and Charlotte.

Table D-39 summarizes the estimated fuel use rates inferred from the engine data of Table D-38 and volumetric efficiency measured in dynamometer tests of a similar engine. For the RY tests, fuel use rates from 2.4 to 137 g/sec depending on notch position, and was highly repeatable, with a coefficient of variation (CV, which was standard deviation divided by the mean) of typically 0.06 or less except for Idle. There was more variability in run-to-run estimates of fuel use for the OTR measurements, in part because the amount of time spent in some notch positions was low. The OTR estimated fuel use ranged from 3.4 to 123 g/sec, depending on notch position. The CV for all notches was less than 0.3.

During RY measurements, the maximum engine output was 2,700 hp, whereas during OTR measurements the maximum engine output was 3,000 hp. Furthermore, as shown later in Table D-44, the average CO_2 concentrations for each notch position are lower for OTR than for RY measurements, which implies a lower fuel-to-air ratio. Because the engine activity and, therefore, engine air flow, are approximately the same for OTR versus RY measurements, the combination of higher engine output and lower fuel-to-air ratio lead to higher values of fuel-specific engine output (FSEO) in bhp-hr per gallon of fuel consumed, as shown in Table D-39. The FSEO was highly repeatable for the OTR measurements of Notch 8, which represents significant portion of the observed duty cycle. In contrast, there was large inter-run variation for some notches, such as Notches 3 and 7. However, these notches were rarely used compared to other notches, and thus the apparent variation was an artifact of small sample sizes.

The measured NO exhaust concentration and the estimated NO_x emission rates are shown in Table D-40 for each notch position, each RY test replicate, and each OTR one-way run. The average measured concentrations range among notch positions from approximately 160 to 1,100 ppm in the RY tests, and 200 to 1,500 ppm in the OTR measurements. The measurements are highly repeatable for the RY and OTR measurements, with CVs typically less than 0.1 for the former and less than 0.2 for the latter. The estimated mass emission rates range from 0.3 to 8.0 g/sec for the RY measurements and 0.4 to 8.6 g/sec for the OTR measurements. Because the observed concentrations tend to be higher for the OTR versus RY measurements, the mass emission rates also tend to be slightly higher for the OTR versus RY measurements.

On a fuel basis, the average NO_x emission rates range from 180 to 450 g/gallon among notch positions for the RY measurements and 210 to 660 g/gallon for the OTR measurements. For the RY measurements, the fuel-based emission rates are highly repeatable, with CV typically less than 0.04. The OTR measurements have more run-to-run variability but are nonetheless consistent, with CVs ranging from 0.06 to 0.24. The fuel-based emission rates tend to be lowest at high load.

On an engine output basis, the notch average NO_x emission rates range from 9.6 g/bhp-hr at Notch 8 to 19.6 g/bhp-hr at Notch 1 in the RY measurements, with very high values at idle during which engine output was very low. For the OTR measurements, the notch average emission rates range from 9.9 g/bhp-hr at Notch 8 to 22.0 g/bhp-hr at Notch 1, with much higher values during idle and dynamic braking. In general, the emission rates on an engine output basis are higher for the OTR measurements than for the RY measurements. This results from a combination of lower exhaust concentration and higher engine output, especially at Notch 8.

Results are given for exhaust concentrations and emission rates in Tables D-41, D-42, D-43, and D-44 for CO, HC, PM, and CO_2, respectively. The CO exhaust concentrations during OTR measurements tend to be higher than during RY measurements. Thus, the cycle average CO emission rates also tend to be higher for OTR than RY measurements. On average, the HC exhaust concentrations and average emission rates tend to be higher for OTR than RY. However, both the CO and HC emission rates are low on an absolute basis, and some of the measured average concentrations for a given notch position and replicate or run are below the gas analyzer detection limit. For PM, the measured exhaust levels tend to be lower for OTR than RY for a given notch position, and thus the cycle average PM emission rate tends to also be lower. The trends in CO_2 emission rates are similar to those for fuel use on a mass per time and mass per engine output basis. CO_2 emission rates are also shown on a g/gallon basis. Since typically over 99 percent of the carbon in the fuel was emitted as CO_2, the fuel-based CO_2 emission rates are approximately constant.

Differences in emission rates are attributable to differences in measured exhaust concentrations. Values for engine activity parameters (RPM, IAT, MAP) were similar across all rail yard and over-the-rail measurements.

Table D-38. Measured Engine Parameters for NC-1797 and ULSD

Engine Speed (RPM)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	10/9	10/9	10/10	10/10	10/11	10/11	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Idle	343	343	343	343	0.02	0.00	343	343	342	343	343	343	343	0.05	0.00
Dyn Brake	--	--	--	--	--	--	343	343	342	342	343	344	343	0.46	0.00
1	343	343	343	343	0.04	0.00	343	343	343	343	344	344	343	0.40	0.00
2	343	343	343	343	0.04	0.00	344	343	343	343	344	343	343	0.81	0.00
3	490	490	490	490	0.08	0.00	489	489	490	490	494	490	490	1.73	0.00
4	651	651	651	651	0.01	0.00	651	651	651	651	651	651	651	0.22	0.00
5	750	750	750	750	0.03	0.00	750	749	749	750	749	750	750	0.40	0.00
6	750	750	750	750	0.01	0.00	750	750	750	750	750	750	750	0.21	0.00
7	820	820	820	820	0.04	0.00	819	819	--	819	820	819	819	0.43	0.00
8	903	903	903	903	0.09	0.00	903	903	903	903	903	903	903	0.06	0.00

Intake Air Temeprature (°C)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	10/9	10/9	10/10	10/10	10/11	10/11	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Idle	40	40	41	40	0.29	0.01	47	47	46	47	49	49	47	1.17	0.02
Dyn Brake	--	--	--	--	--	--	47	45	46	47	50	49	47	1.74	0.04
1	41	42	39	41	1.36	0.03	49	47	45	47	49	49	48	1.52	0.03
2	38	38	43	40	2.46	0.06	48	47	46	47	50	49	48	1.57	0.03
3	43	43	41	42	0.86	0.02	49	49	45	47	51	49	48	1.98	0.04
4	41	41	42	41	0.64	0.02	48	48	46	48	49	47	48	1.06	0.02
5	47	45	46	46	0.75	0.02	47	48	45	48	48	50	48	1.73	0.04
6	43	45	46	45	1.52	0.03	48	48	47	48	51	49	48	1.37	0.03
7	46	45	46	46	0.34	0.01	49	48	--	48	48	49	48	0.48	0.01
8	48	47	47	47	0.50	0.01	48	48	47	49	50	50	49	1.14	0.02

Manifold Absolute Pressure (kPa)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	10/9	10/9	10/10	10/10	10/11	10/11	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Idle	108	107	107	107	0.55	0.01	106	106	107	106	105	105	106	0.58	0.01
Dyn Brake	--	--	--	--	--	--	108	107	107	107	106	106	106	0.64	0.01
1	108	107	106	107	0.66	0.01	107	107	107	106	106	106	106	0.51	0.00
2	108	108	107	107	0.64	0.01	107	106	107	106	105	106	106	0.71	0.01
3	122	122	121	122	0.79	0.01	120	120	121	120	121	119	120	0.71	0.01
4	147	146	145	146	0.84	0.01	144	144	145	143	143	142	144	1.19	0.01
5	167	167	165	166	1.01	0.01	166	164	166	163	163	161	164	1.93	0.01
6	169	168	167	168	0.98	0.01	165	166	166	164	163	166	165	1.10	0.01
7	207	207	207	207	0.31	0.00	183	187	--	183	186	185	185	2.01	0.01
8	233	227	230	230	2.68	0.01	215	214	218	215	218	215	216	1.60	0.01

Mass Air Flow (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	10/9	10/9	10/10	10/10	10/11	10/11	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Idle	1315	1311	1302	1309	6.48	0.00	1274	1273	1281	1267	1258	1256	1268	9.70	0.01
Dyn Brake	--	--	--	--	--	--	1286	1285	1277	1277	1259	1263	1275	10.9	0.01
1	1312	1306	1307	1309	3.03	0.00	1271	1276	1284	1270	1261	1263	1271	8.46	0.01
2	1326	1322	1296	1315	16.5	0.01	1278	1274	1287	1273	1255	1260	1271	11.6	0.01
3	1866	1863	1857	1862	4.60	0.00	1807	1797	1834	1814	1812	1790	1809	15.3	0.01
4	2660	2654	2628	2647	17.1	0.01	2566	2572	2600	2560	2545	2539	2564	21.8	0.01
5	3204	3209	3188	3201	10.7	0.00	3182	3137	3207	3135	3130	3081	3145	44.1	0.01
6	3264	3237	3208	3237	27.8	0.01	3167	3170	3176	3147	3102	3160	3154	27.3	0.01
7	4039	4039	4024	4034	8.36	0.00	3629	3713	--	3643	3690	3665	3668	34.3	0.01
8	4702	4625	4673	4667	39.1	0.01	4423	4397	4479	4410	4437	4397	4424	31.1	0.01

Air to Fuel Ratio (g/g)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	10/9	10/9	10/10	10/10	10/11	10/11	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Idle	416	448	541	469	64.8	0.14	361	373	248	256	278	317	305	53.3	0.17
Dyn Brake	--	--	--	--	--	--	313	360	270	247	262	303	292	41.3	0.14
1	135	138	150	141	7.70	0.05	145	190	111	129	155	177	151	29.3	0.19
2	90.4	93.5	96.8	93.6	3.24	0.03	129	135	73.8	72.9	90.4	102	100	26.8	0.27
3	72.6	74.3	73.0	73.3	0.87	0.01	82.0	82.9	65.5	61.2	74.3	86.4	75.4	10.2	0.14
4	67.4	67.4	66.5	67.1	0.52	0.01	71.9	70.2	59.4	59.2	62.3	71.1	65.7	6.00	0.09
5	60.3	60.4	58.9	59.9	0.81	0.01	65.4	66.4	57.7	54.4	57.9	62.4	60.7	4.76	0.08
6	54.8	50.2	48.2	51.1	3.38	0.07	54.8	59.0	50.1	46.7	47.1	53.0	51.8	4.76	0.09
7	38.8	38.1	39.7	38.9	0.81	0.02	79.8	47.6	--	35.5	37.9	46.1	49.4	17.8	0.36
8	34.3	34.5	35.1	34.7	0.43	0.01	41.5	41.4	36.8	36.3	36.2	39.1	38.5	2.47	0.06

Table D-39. Estimated Fuel Use Rates for NC-1797 and ULSD

Time-Based Fuel Use Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	10/9	10/9	10/10	10/10	10/11	10/11	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Idle	3.16	2.92	2.41	2.83	0.38	0.14	3.53	3.41	5.17	4.95	4.53	3.96	4.26	0.73	0.17
Dyn Brake	--	--	--	--	--	--	4.11	3.57	4.74	5.16	4.81	4.17	4.43	0.58	0.13
1	9.69	9.43	8.71	9.28	0.50	0.05	8.74	6.72	11.6	9.86	8.16	7.14	8.70	1.80	0.21
2	14.7	14.1	13.4	14.1	0.65	0.05	9.93	9.42	17.4	17.5	13.9	12.4	13.4	3.52	0.26
3	25.7	25.1	25.4	25.4	0.30	0.01	22.0	21.7	28.0	29.6	24.4	20.7	24.4	3.66	0.15
4	39.5	39.4	39.5	39.5	0.07	0.00	35.7	36.7	43.7	43.2	40.9	35.7	39.3	3.75	0.10
5	53.1	53.2	54.1	53.5	0.55	0.01	48.7	47.2	55.6	57.6	54.1	49.4	52.1	4.21	0.08
6	59.6	64.5	66.6	63.5	3.59	0.06	57.8	53.7	63.4	67.3	65.9	59.6	61.3	5.18	0.08
7	104	106	101	104	2.35	0.02	45.5	77.9	--	103	97.4	79.6	80.6	22.4	0.28
8	137	134	133	135	2.06	0.02	107	106	122	122	123	113	115	7.71	0.07

Engine Output-Based Fuel Use Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	10/9	10/9	10/10	10/10	10/11	10/11	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Idle	2.56	2.76	3.36	2.89	0.41	0.14	2.29	2.37	1.56	1.63	1.78	2.04	1.95	0.34	0.17
Dyn Brake	--	--	--	--	--	--	1.97	2.26	1.71	1.57	1.68	1.94	1.85	0.25	0.14
1	15.8	16.3	17.6	16.6	0.92	0.06	17.6	22.8	13.3	15.6	18.8	21.5	18.3	3.58	0.20
2	19.3	20.0	21.1	20.1	0.94	0.05	28.5	30.0	16.2	16.2	20.4	22.8	22.4	5.93	0.27
3	21.1	21.6	21.3	21.3	0.26	0.01	24.7	25.2	19.5	18.4	22.4	26.3	22.7	3.23	0.14
4	20.5	20.5	20.4	20.5	0.04	0.00	22.6	22.0	18.5	18.7	19.8	22.6	20.7	1.95	0.09
5	19.8	19.8	19.4	19.6	0.20	0.01	21.6	22.2	18.9	18.2	19.4	21.3	20.3	1.63	0.08
6	21.7	20.0	19.4	20.4	1.18	0.06	22.4	24.1	20.4	19.2	19.6	21.7	21.2	1.84	0.09
7	18.6	18.3	19.1	18.7	0.42	0.02	48.0	28.0	--	21.2	22.4	27.4	29.4	10.8	0.37
8	17.7	18.1	18.2	18.0	0.27	0.02	22.7	22.8	19.9	19.9	19.8	21.5	21.1	1.43	0.07

Table D-40. Measured NO_x Emission Rates for NC-1797 and ULSD

Time-Based NO_x Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	10/9	10/9	10/10	10/10	10/11	10/11	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Idle	0.42	0.41	0.34	0.39	0.04	0.11	0.53	0.46	0.58	0.61	0.59	0.54	0.55	0.05	0.10
Dyn Brake	--	--	--	--	--	--	0.56	0.42	0.54	0.61	0.62	0.57	0.55	0.07	0.13
1	1.09	1.08	0.92	1.03	0.09	0.09	1.37	0.91	1.33	1.21	1.08	1.08	1.16	0.18	0.15
2	1.85	1.83	1.71	1.80	0.08	0.04	1.47	1.36	2.17	2.40	1.86	1.88	1.86	0.40	0.21
3	2.50	2.48	2.44	2.47	0.03	0.01	4.06	4.15	3.68	3.92	4.30	4.25	4.06	0.23	0.06
4	2.96	2.99	2.92	2.96	0.03	0.01	5.76	5.68	5.15	5.75	5.98	6.08	5.73	0.32	0.06
5	4.17	4.14	4.03	4.11	0.07	0.02	6.17	6.58	6.96	7.09	7.27	7.54	6.93	0.49	0.07
6	4.47	5.07	4.89	4.81	0.30	0.06	6.42	5.60	6.79	6.57	6.36	5.88	6.27	0.45	0.07
7	6.03	6.02	6.03	6.03	0.00	0.00	5.90	6.31	--	8.97	6.79	7.11	7.01	1.19	0.17
8	7.93	7.99	8.01	7.98	0.04	0.01	8.38	8.55	7.96	8.33	8.14	8.20	8.26	0.21	0.03

Fuel-Based NO_x Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	10/9	10/9	10/10	10/10	10/11	10/11	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Idle	428	449	454	444	13.9	0.03	485	431	362	395	419	442	422	42.2	0.10
Dyn Brake	--	--	--	--	--	--	441	375	367	382	414	438	403	32.6	0.08
1	364	369	342	358	14.5	0.04	505	435	371	395	425	486	436	51.6	0.12
2	407	417	412	412	4.88	0.01	476	464	402	442	432	488	451	31.9	0.07
3	314	318	308	313	4.75	0.02	593	617	424	426	568	660	548	100	0.18
4	242	244	238	241	3.16	0.01	520	499	379	428	471	548	474	62.1	0.13
5	253	251	240	248	6.83	0.03	408	448	403	397	433	491	430	35.9	0.08
6	242	253	237	244	8.40	0.03	358	336	345	314	311	317	330	18.9	0.06
7	187	183	191	187	4.28	0.02	417	261	--	281	224	288	294	73.1	0.25
8	186	192	194	191	3.90	0.02	253	259	210	221	214	235	232	20.5	0.09

Engine Output-Based NO_x Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	10/9	10/9	10/10	10/10	10/11	10/11	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Idle	151	147	122	140	15.7	0.11	192	165	209	218	212	196	199	19.5	0.10
Dyn Brake	--	--	--	--	--	--	203	150	194	221	223	204	199	26.5	0.13
1	20.7	20.5	17.5	19.6	1.79	0.09	26.0	17.2	25.2	23.0	20.4	20.4	22.0	3.32	0.15
2	19.1	18.8	17.6	18.5	0.77	0.04	15.1	14.0	22.4	24.7	19.1	19.3	19.1	4.10	0.21
3	13.4	13.3	13.1	13.3	0.18	0.01	21.7	22.2	19.6	20.9	22.9	22.7	21.7	1.23	0.06
4	10.7	10.8	10.5	10.6	0.12	0.01	20.7	20.5	18.5	20.7	21.5	21.9	20.6	1.17	0.06
5	11.5	11.5	11.2	11.4	0.20	0.02	17.1	18.2	19.3	19.6	20.1	20.9	19.2	1.36	0.07
6	10.1	11.4	11.0	10.8	0.69	0.06	14.4	12.6	15.3	14.8	14.3	13.2	14.1	1.00	0.07
7	9.04	9.04	9.04	9.04	0.00	0.00	7.86	8.41	--	12.0	9.05	9.48	9.35	1.58	0.17
8	9.52	9.59	9.61	9.57	0.05	0.01	10.1	10.3	9.55	10.0	9.77	9.84	9.91	0.25	0.03
Duty Cycle Avg (Raw)	10.7	10.8	10.5	10.6	0.14	0.01	12.6	12.3	13.1	13.5	13.0	12.9	12.9	0.4	0.03
Duty Cycle Avg (Adj)	11.2	11.3	11.0	11.2	0.15	0.01	13.3	13.0	13.8	14.2	13.7	13.6	13.6	0.4	0.03

Exhaust NO_x Concentrations (ppm)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	10/9	10/9	10/10	10/10	10/11	10/11	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Idle	198	193	162	184	19.4	0.11	257	221	282	292	290	264	268	26.8	0.10
Dyn Brake	--	--	--	--	--	--	271	201	264	295	306	273	268	36.6	0.14
1	518	513	439	490	44.2	0.09	659	437	645	582	526	520	562	84.0	0.15
2	864	854	822	847	21.9	0.03	700	653	1056	1152	912	890	894	194	0.22
3	827	819	809	818	8.83	0.01	1347	1395	1250	1326	1445	1399	1360	68.5	0.05
4	685	693	685	688	4.45	0.01	1359	1322	1244	1383	1438	1444	1365	75.4	0.06
5	809	802	789	800	10.1	0.01	1193	1263	1364	1407	1428	1466	1353	105	0.08
6	839	953	939	910	62.0	0.07	1214	1080	1337	1285	1261	1105	1213	102	0.08
7	905	910	894	903	8.25	0.01	1002	1049	--	1539	1124	1129	1169	214	0.18
8	1061	1087	1076	1075	13.2	0.01	1141	1173	1139	1192	1151	1113	1151	27.9	0.02

Table D-41. Measured CO Emission Rates for NC-1797 and ULSD

Time-Based CO Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	10/9	10/9	10/10	10/10	10/11	10/11	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Idle	0.03	0.01	0.01	0.02	0.01	0.69	0.06	0.16	0.04	0.16	0.04	0.11	0.09	0.06	0.59
Dyn Brake	--	--	--	--	--	--	0.02	0.20	0.05	0.34	0.02	0.12	0.12	0.12	1.00
1	0.04	0.00	0.02	0.02	0.02	0.90	0.07	0.09	0.01	0.11	0.03	0.07	0.06	0.04	0.58
2	0.01	0.02	0.04	0.02	0.01	0.56	0.13	0.08	0.04	0.08	0.02	0.08	0.07	0.04	0.54
3	0.00	0.03	0.01	0.01	0.01	1.24	0.18	0.07	0.05	0.11	0.02	0.08	0.09	0.06	0.65
4	0.00	0.01	0.00	0.01	0.01	1.48	0.21	0.21	0.08	0.16	0.06	0.15	0.14	0.06	0.43
5	0.00	0.00	0.00	0.00	0.00	1.23	0.09	0.16	0.15	0.24	0.13	0.16	0.16	0.05	0.31
6	0.00	0.00	0.01	0.00	0.00	1.63	0.25	0.46	0.11	0.20	0.03	0.08	0.19	0.16	0.84
7	0.09	0.06	0.02	0.06	0.03	0.57	0.00	0.67	--	0.19	0.35	0.33	0.31	0.25	0.79
8	0.88	0.68	0.65	0.74	0.13	0.17	0.38	0.56	0.44	0.65	0.53	0.67	0.54	0.12	0.21

Fuel-Based CO Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	10/9	10/9	10/10	10/10	10/11	10/11	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Idle	28.8	14.1	9.19	17.3	10.2	0.59	56.5	151	25.0	104	29.8	85.3	75.3	48.1	0.64
Dyn Brake	--	--	--	--	--	--	14.2	179	35.8	210	16.6	90.7	91.2	85.5	0.94
1	12.4	0.95	6.50	6.63	5.74	0.87	24.6	43.9	2.45	35.1	13.7	30.3	25.0	15.0	0.60
2	2.65	4.94	9.28	5.62	3.37	0.60	43.1	27.6	7.69	15.6	4.19	20.3	19.7	14.2	0.72
3	0.00	3.29	0.83	1.38	1.71	1.24	26.0	9.85	5.90	12.5	2.56	13.1	11.7	8.10	0.70
4	0.12	1.15	0.00	0.42	0.63	1.48	18.5	18.1	5.78	12.0	4.89	13.4	12.1	5.85	0.48
5	0.22	0.05	0.00	0.09	0.12	1.23	6.05	11.2	8.77	13.3	7.64	10.5	9.58	2.61	0.27
6	0.00	0.01	0.35	0.12	0.20	1.63	13.9	27.7	5.61	9.66	1.38	4.07	10.4	9.55	0.92
7	2.68	1.83	0.71	1.74	0.98	0.57	0.21	27.6	--	5.81	11.7	13.4	11.8	10.3	0.87
8	20.8	16.3	15.8	17.6	2.75	0.16	11.4	17.1	11.7	17.1	14.0	19.3	15.1	3.25	0.22

Engine Output-Based CO Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	10/9	10/9	10/10	10/10	10/11	10/11	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Idle	10.2	4.60	2.47	5.74	3.97	0.69	22.3	57.5	14.5	57.8	15.1	37.8	34.1	20.0	0.59
Dyn Brake	--	--	--	--	--	--	6.53	71.7	18.9	121	8.91	42.3	44.9	44.7	1.00
1	0.71	0.05	0.33	0.36	0.33	0.90	1.26	1.73	0.17	2.04	0.66	1.27	1.19	0.69	0.58
2	0.12	0.22	0.40	0.25	0.14	0.56	1.37	0.83	0.43	0.87	0.19	0.80	0.75	0.41	0.54
3	0.00	0.14	0.04	0.06	0.07	1.24	0.95	0.35	0.27	0.61	0.10	0.45	0.46	0.30	0.65
4	0.01	0.05	0.00	0.02	0.03	1.48	0.74	0.74	0.28	0.58	0.22	0.54	0.52	0.22	0.43
5	0.01	0.00	0.00	0.00	0.01	1.23	0.25	0.46	0.42	0.66	0.36	0.45	0.43	0.13	0.31
6	0.00	0.00	0.02	0.01	0.01	1.63	0.56	1.04	0.25	0.45	0.06	0.17	0.42	0.35	0.84
7	0.13	0.09	0.03	0.08	0.05	0.57	0.00	0.89	--	0.25	0.47	0.44	0.41	0.33	0.79
8	1.06	0.81	0.78	0.89	0.15	0.17	0.45	0.68	0.53	0.77	0.64	0.81	0.65	0.14	0.21
Duty Cycle Avg (Raw)	0.75	0.55	0.52	0.61	0.12	0.20	0.59	1.11	0.57	1.15	0.58	0.92	0.82	0.27	0.33
Duty Cycle Avg (Adj)	0.75	0.55	0.52	0.61	0.12	0.20	0.59	1.11	0.57	1.15	0.58	0.92	0.82	0.27	0.33

Exhaust CO Concentrations (%)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	10/9	10/9	10/10	10/10	10/11	10/11	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Idle	0.002	0.001	0.001	0.001	0.00	0.69	0.005	0.013	0.003	0.013	0.004	0.009	0.008	0.00	0.58
Dyn Brake	--	--	--	--	--	--	0.002	0.017	0.004	0.028	0.002	0.010	0.010	0.01	0.99
1	0.003	0.000	0.001	0.002	0.00	0.90	0.006	0.008	0.001	0.009	0.003	0.006	0.005	0.00	0.58
2	0.001	0.002	0.003	0.002	0.00	0.57	0.011	0.007	0.003	0.007	0.002	0.006	0.006	0.00	0.54
3	0.000	0.001	0.000	0.001	0.00	1.24	0.010	0.004	0.003	0.007	0.001	0.005	0.005	0.00	0.64
4	0.000	0.001	0.000	0.000	0.00	1.48	0.008	0.008	0.003	0.007	0.003	0.006	0.006	0.00	0.42
5	0.000	0.000	0.000	0.000	0.00	1.23	0.003	0.005	0.005	0.008	0.004	0.005	0.005	0.00	0.32
6	0.000	0.000	0.000	0.000	0.00	1.63	0.008	0.015	0.004	0.007	0.001	0.002	0.006	0.01	0.83
7	0.002	0.002	0.001	0.001	0.00	0.57	0.000	0.019	--	0.006	0.010	0.009	0.009	0.01	0.80
8	0.020	0.016	0.015	0.017	0.00	0.17	0.009	0.013	0.011	0.016	0.013	0.016	0.013	0.00	0.21

Table D-42. Measured Hydrocarbon Emission Rates for NC-1797 and ULSD

Time-Based HC Emission Rates (g/s)

Throttle Notch Position	Rail Yard Test						Over-The-Rail Test								
	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	10/9	10/9	10/10	10/10	10/11	10/11	6 Trains	6 Trains	6 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Idle	0.17	0.13	0.20	0.17	0.03	0.21	0.42	1.02	0.27	0.86	0.28	0.92	0.63	0.34	0.54
Dyn Brake	--	--	--	--	--	--	0.32	0.64	0.26	1.30	0.14	1.04	0.62	0.47	0.76
1	0.04	0.08	0.02	0.05	0.03	0.68	0.54	0.61	0.01	0.75	0.27	0.75	0.49	0.29	0.60
2	0.05	0.12	0.03	0.07	0.05	0.77	0.82	0.83	0.37	0.67	0.19	0.77	0.61	0.27	0.44
3	0.07	0.04	0.06	0.06	0.01	0.25	0.92	0.75	0.27	1.01	0.07	1.21	0.70	0.44	0.63
4	0.12	0.12	0.06	0.10	0.04	0.36	1.22	1.84	0.68	1.42	0.76	1.56	1.25	0.45	0.37
5	0.07	0.09	0.07	0.08	0.01	0.14	0.84	2.03	1.27	1.85	0.90	1.22	1.35	0.49	0.36
6	0.10	0.81	0.48	0.46	0.36	0.77	1.42	1.24	1.11	1.87	0.27	0.53	1.07	0.58	0.54
7	0.34	0.19	0.38	0.30	0.10	0.33	0.22	1.91	--	2.05	0.64	1.35	1.23	0.79	0.64
8	1.16	0.23	0.29	0.56	0.52	0.93	0.80	1.54	0.59	1.32	0.72	1.29	1.04	0.39	0.37

Fuel-Based HC Emission Rates (g/gal)

Throttle Notch Position	Rail Yard Test						Over-The-Rail Test								
	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	10/9	10/9	10/10	10/10	10/11	10/11	6 Trains	6 Trains	6 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Idle	174	147	271	197	65.5	0.33	385	958	171	558	200	743	502	311	0.62
Dyn Brake	--	--	--	--	--	--	247	581	180	812	93	800	452	320	0.71
1	14	28	7	16	10.6	0.66	199	290	3	245	108	337	197	123	0.63
2	11	28	6	15	11.6	0.77	265	282	68	124	44	200	164	101	0.61
3	8	5	8	7	1.75	0.24	134	112	32	109	9	188	97	66.4	0.68
4	10	10	5	8	2.92	0.36	110	161	50	105	60	141	105	43.6	0.42
5	4	5	4	5	0.68	0.14	56	139	73	104	54	79	84	32.3	0.38
6	5	40	23	23	17.6	0.77	79	74	57	89	13	29	57	30.0	0.53
7	11	6	12	9	3.24	0.34	16	79	--	64	21	55	47	27.5	0.59
8	27	5	7	13	12.1	0.91	24	47	16	35	19	37	29	11.9	0.40

Engine Output-Based HC Emission Rates (g/bhp-hr)

Throttle Notch Position	Rail Yard Test						Over-The-Rail Test								
	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	10/9	10/9	10/10	10/10	10/11	10/11	6 Trains	6 Trains	6 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Idle	61.3	48.0	73.0	60.8	12.5	0.21	152	366	98.5	309	101	329	226	122	0.54
Dyn Brake	--	--	--	--	--	--	113	232	95.3	468	50.0	373	222	168	0.76
1	0.77	1.54	0.36	0.89	0.60	0.68	10.2	11.5	0.22	14.2	5.16	14.1	9.25	5.53	0.60
2	0.50	1.28	0.27	0.68	0.53	0.77	8.41	8.49	3.80	6.93	1.95	7.90	6.25	2.73	0.44
3	0.36	0.22	0.35	0.31	0.08	0.25	4.89	4.01	1.46	5.37	0.35	6.45	3.76	2.37	0.63
4	0.43	0.42	0.20	0.35	0.13	0.36	4.38	6.61	2.45	5.09	2.74	5.63	4.48	1.64	0.37
5	0.20	0.25	0.20	0.21	0.03	0.14	2.34	5.63	3.51	5.13	2.50	3.36	3.75	1.36	0.36
6	0.22	1.82	1.08	1.04	0.80	0.77	3.19	2.78	2.50	4.20	0.62	1.20	2.41	1.31	0.54
7	0.51	0.29	0.57	0.46	0.15	0.33	0.30	2.55	--	2.73	0.85	1.80	1.64	1.06	0.64
8	1.39	0.27	0.35	0.67	0.62	0.93	0.96	1.85	0.71	1.59	0.87	1.54	1.25	0.47	0.37
Duty Cycle Avg (Raw)	0.56	0.30	0.35	0.40	0.13	0.33	1.10	2.01	0.79	2.01	0.67	1.85	1.40	0.62	0.44
Duty Cycle Avg (Adj)	1.39	0.76	0.87	1.01	0.34	0.33	2.76	5.01	1.97	5.03	1.68	4.62	3.51	1.55	0.44

Exhaust HC Concentrations (ppm)

Throttle Notch Position	Rail Yard Test						Over-The-Rail Test								
	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	10/9	10/9	10/10	10/10	10/11	10/11	6 Trains	6 Trains	6 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Idle	18	14	22	18	3.81	0.21	46	111	30	93	31	100	68	36.7	0.54
Dyn Brake	--	--	--	--	--	--	34	70	29	141	15	112	67	50.5	0.75
1	4	9	2	5	3.39	0.68	58	66	1	81	30	81	53	31.6	0.60
2	5	13	3	7	5.35	0.76	88	89	40	73	21	82	66	28.3	0.43
3	5	3	5	4	1.07	0.25	68	57	21	77	5	90	53	33.2	0.63
4	6	6	3	5	1.84	0.36	65	96	37	77	41	84	67	23.6	0.36
5	3	4	3	3	0.46	0.14	37	88	56	83	40	53	59	21.4	0.36
6	4	34	21	20	15.2	0.77	60	54	49	82	12	23	47	25.6	0.55
7	11	7	13	10	3.26	0.32	8	72	--	79	24	48	46	30.2	0.65
8	35	7	9	17	15.6	0.92	24	48	19	43	23	39	33	12.0	0.37

Table D-43. Measured Particulate Matter Emission Rates for NC-1797 and ULSD

Time-Based PM Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	10/9	10/9	10/10	10/10	10/11	10/11	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Idle	0.01	0.01	0.01	0.01	0.00	0.06	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.08
Dyn Brake	--	--	--	--	--	--	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.17
1	0.02	0.02	0.02	0.02	0.00	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.11
2	0.02	0.02	0.02	0.02	0.00	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.05
3	0.02	0.02	0.02	0.02	0.00	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.14
4	0.02	0.03	0.02	0.02	0.00	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.00	0.13
5	0.03	0.03	0.03	0.03	0.00	0.03	0.04	0.03	0.03	0.02	0.02	0.02	0.03	0.01	0.26
6	0.03	0.03	0.03	0.03	0.00	0.02	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.00	0.15
7	0.12	0.13	0.12	0.12	0.00	0.02	0.06	0.08	--	0.10	0.14	0.09	0.09	0.03	0.31
8	0.16	0.15	0.15	0.15	0.01	0.06	0.14	0.12	0.12	0.11	0.12	0.11	0.12	0.01	0.10

Fuel-Based PM Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	10/9	10/9	10/10	10/10	10/11	10/11	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Idle	20.1	20.9	23.6	21.5	1.82	0.08	18.0	18.6	11.6	10.7	11.9	13.7	14.1	3.42	0.24
Dyn Brake	--	--	--	--	--	--	19.5	21.3	13.1	10.8	12.0	12.8	14.9	4.35	0.29
1	8.93	9.19	9.49	9.20	0.28	0.03	11.0	12.6	6.97	7.63	8.74	10.7	9.61	2.18	0.23
2	5.77	5.52	6.04	5.77	0.26	0.04	9.20	10.3	6.00	5.49	6.77	7.79	7.58	1.86	0.25
3	3.65	3.54	3.51	3.56	0.08	0.02	5.02	4.91	3.56	2.93	3.89	3.64	3.99	0.82	0.21
4	2.81	2.83	2.62	2.75	0.11	0.04	3.41	3.05	2.62	2.16	2.41	2.47	2.69	0.46	0.17
5	2.35	2.44	2.25	2.34	0.09	0.04	4.00	2.77	2.65	1.88	2.00	2.19	2.58	0.78	0.30
6	2.35	2.20	2.04	2.20	0.16	0.07	3.21	2.95	2.15	2.00	2.33	2.06	2.45	0.51	0.21
7	5.22	5.30	5.45	5.32	0.11	0.02	6.11	4.36	--	4.15	6.35	5.16	5.23	0.99	0.19
8	5.34	5.00	4.93	5.09	0.22	0.04	5.92	5.00	4.29	3.87	4.26	4.38	4.62	0.73	0.16

Engine Output-Based PM Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	10/9	10/9	10/10	10/10	10/11	10/11	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Idle	5.13	4.94	4.58	4.89	0.28	0.06	5.15	5.13	4.83	4.29	4.35	4.39	4.69	0.40	0.08
Dyn Brake	--	--	--	--	--	--	6.47	6.14	5.01	4.52	4.65	4.30	5.18	0.91	0.17
1	0.37	0.37	0.35	0.36	0.01	0.03	0.41	0.36	0.34	0.32	0.30	0.33	0.34	0.04	0.11
2	0.20	0.18	0.19	0.19	0.01	0.04	0.21	0.22	0.24	0.22	0.22	0.22	0.22	0.01	0.05
3	0.11	0.11	0.11	0.11	0.00	0.03	0.13	0.13	0.12	0.10	0.11	0.09	0.11	0.02	0.14
4	0.09	0.09	0.08	0.09	0.00	0.04	0.10	0.09	0.09	0.08	0.08	0.07	0.08	0.01	0.13
5	0.08	0.08	0.08	0.08	0.00	0.03	0.12	0.08	0.09	0.07	0.07	0.07	0.08	0.02	0.26
6	0.07	0.07	0.07	0.07	0.00	0.02	0.09	0.08	0.07	0.07	0.08	0.06	0.08	0.01	0.15
7	0.18	0.19	0.19	0.19	0.00	0.02	0.08	0.10	--	0.13	0.19	0.12	0.12	0.04	0.31
8	0.20	0.18	0.18	0.18	0.01	0.06	0.17	0.14	0.14	0.13	0.14	0.13	0.14	0.01	0.10
Duty Cycle Avg (Raw)	0.04	0.04	0.04	0.04	0.00	0.05	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.00	0.08
Duty Cycle Avg (Adj)	0.20	0.19	0.19	0.19	0.01	0.05	0.19	0.17	0.17	0.15	0.16	0.15	0.16	0.01	0.08

Exhaust PM Concentrations (mg/m^3)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	10/9	10/9	10/10	10/10	10/11	10/11	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Idle	2.6	2.5	2.4	2.5	0.13	0.05	2.7	2.7	2.5	2.2	2.3	2.3	2.5	0.20	0.08
Dyn Brake	--	--	--	--	--	--	3.4	3.2	2.6	2.3	2.5	2.2	2.7	0.46	0.17
1	3.6	3.6	3.4	3.5	0.09	0.03	4.0	3.6	3.4	3.2	3.0	3.2	3.4	0.36	0.11
2	3.4	3.2	3.4	3.3	0.14	0.04	3.8	4.0	4.4	4.0	4.0	4.0	4.0	0.21	0.05
3	2.7	2.6	2.6	2.6	0.08	0.03	3.2	3.1	3.0	2.6	2.8	2.2	2.8	0.39	0.14
4	2.2	2.3	2.1	2.2	0.07	0.03	2.5	2.3	2.4	2.0	2.1	1.8	2.2	0.27	0.12
5	2.1	2.2	2.1	2.1	0.06	0.03	3.3	2.2	2.5	1.9	1.8	1.8	2.3	0.57	0.25
6	2.3	2.3	2.3	2.3	0.02	0.01	3.1	2.7	2.3	2.3	2.7	2.0	2.5	0.36	0.15
7	7.1	7.4	7.1	7.2	0.16	0.02	4.1	4.9	--	6.4	8.9	5.7	6.0	1.84	0.31
8	8.5	7.9	7.7	8.1	0.44	0.05	7.5	6.4	6.5	5.9	6.4	5.8	6.4	0.60	0.09

Table D-44. Measured CO_2 Emission Rates for NC-1797 and ULSD

Time-Based CO_2 Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	10/9	10/9	10/10	10/10	10/11	10/11	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Idle	9.73	9.05	7.40	8.73	1.20	0.14	10.7	9.8	15.9	14.7	13.9	11.7	12.8	2.42	0.19
Dyn Brake	--	--	--	--	--	--	12.6	10.5	14.6	14.8	14.9	12.2	13.3	1.80	0.14
1	30.2	29.5	27.2	29.0	1.56	0.05	26.9	20.5	36.1	30.2	25.3	21.8	26.8	5.76	0.21
2	45.9	44.1	41.8	43.9	2.05	0.05	30.3	28.8	54.3	54.1	43.3	38.1	41.5	11.1	0.27
3	80.3	78.4	79.5	79.4	0.97	0.01	68.1	67.2	87.3	91.9	76.2	64.0	75.8	11.5	0.15
4	123	123	124	123	0.25	0.00	111	113	136	134	127	111	122	12.0	0.10
5	166	166	169	167	1.72	0.01	152	146	173	179	168	153	162	13.1	0.08
6	186	201	208	198	11.1	0.06	180	167	197	209	206	186	191	16.4	0.09
7	325	332	317	324	7.38	0.02	142	242	--	320	304	248	251	69.8	0.28
8	426	418	415	420	5.94	0.01	333	331	380	378	383	350	359	24.2	0.07

Fuel-Based CO_2 Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	10/9	10/9	10/10	10/10	10/11	10/11	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Idle	9922	9962	9893	9926	34.5	0.00	9749	9249	9930	9568	9905	9484	9648	264	0.03
Dyn Brake	--	--	--	--	--	--	9900	9436	9908	9245	9991	9441	9653	316	0.03
1	10046	10056	10060	10054	6.84	0.00	9914	9827	10068	9868	9987	9820	9914	97.6	0.01
2	10063	10049	10056	10056	7.18	0.00	9844	9858	10020	9973	10041	9920	9943	82.6	0.01
3	10069	10066	10068	10068	1.66	0.00	9951	9990	10046	9987	10065	9938	9996	50.3	0.01
4	10068	10067	10071	10069	2.49	0.00	9978	9947	10034	9991	10030	9967	9991	35.0	0.00
5	10071	10071	10072	10071	0.40	0.00	10030	9972	10015	9990	10029	10009	10008	23.1	0.00
6	10071	10049	10059	10060	10.8	0.00	10004	9985	10031	10004	10064	10050	10023	30.3	0.00
7	10064	10068	10066	10066	2.10	0.00	10064	9982	--	10026	10043	10020	10027	30.4	0.00
8	10025	10045	10045	10038	11.7	0.00	10042	10019	10046	10026	10041	10021	10032	11.8	0.00

Engine Output-Based CO_2 Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	10/9	10/9	10/10	10/10	10/11	10/11	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Idle	3503	3257	2662	3141	433	0.14	3850	3530	5734	5292	5018	4203	4605	872	0.19
Dyn Brake	--	--	--	--	--	--	4549	3768	5245	5334	5371	4404	4779	647	0.14
1	573	558	516	549	29.5	0.05	510	389	685	573	479	413	508	109	0.21
2	472	454	430	452	21.1	0.05	312	297	558	557	445	392	427	115	0.27
3	432	421	427	427	5.19	0.01	363	359	466	490	407	341	404	61.5	0.15
4	444	443	445	444	0.90	0.00	398	408	491	483	458	398	439	43.1	0.10
5	460	460	469	463	4.78	0.01	420	405	479	495	466	425	448	36.4	0.08
6	419	453	468	447	24.9	0.06	404	375	444	471	463	419	429	36.9	0.09
7	488	497	475	487	11.1	0.02	190	322	--	427	405	330	335	93.1	0.28
8	512	502	498	504	7.13	0.01	399	397	456	454	459	420	431	29.0	0.07

Exhaust CO_2 Concentrations (%)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	10/9	10/9	10/10	10/10	10/11	10/11	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 76	Average	StDev	CV
Idle	0.50	0.47	0.39	0.45	0.06	0.13	0.57	0.52	0.85	0.78	0.75	0.62	0.68	0.13	0.19
Dyn Brake	--	--	--	--	--	--	0.67	0.56	0.78	0.79	0.81	0.65	0.71	0.10	0.14
1	1.57	1.54	1.42	1.51	0.08	0.05	1.42	1.09	1.93	1.60	1.36	1.16	1.43	0.31	0.22
2	2.35	2.27	2.21	2.28	0.07	0.03	1.59	1.53	2.90	2.86	2.33	1.99	2.20	0.60	0.27
3	2.92	2.86	2.91	2.90	0.04	0.01	2.49	2.49	3.26	3.42	2.82	2.32	2.80	0.45	0.16
4	3.14	3.14	3.19	3.16	0.03	0.01	2.87	2.90	3.62	3.56	3.37	2.89	3.20	0.35	0.11
5	3.55	3.55	3.65	3.58	0.06	0.02	3.23	3.09	3.73	3.90	3.64	3.29	3.48	0.32	0.09
6	3.85	4.17	4.39	4.14	0.28	0.07	3.74	3.54	4.28	4.50	4.49	3.85	4.07	0.41	0.10
7	5.37	5.51	5.17	5.35	0.17	0.03	2.66	4.42	--	6.04	5.54	4.33	4.60	1.31	0.28
8	6.28	6.26	6.13	6.23	0.08	0.01	4.98	5.00	5.98	5.96	5.95	5.23	5.52	0.50	0.09

Appendix E.
Results of Rail Yard and Over the Rail Measurements for NC-1810

E.1 Summary of Results for NC-1810 on B100

These rail yard and over-the-rail emissions measurements of a locomotive prime mover engine were conducted to compare fuel use and emission rates for an ultra-low sulfur diesel (ULSD) baseline and multiple biodiesel fuel blends. These measurements were conducted as part of a Federal Railroad Administration (FRA) research project to evaluate the emissions implications of locomotive biodiesel use compared to ULSD.

RY and OTR measurements were conducted in February 2014 on the prime mover engine of locomotive NC-1810 operating on soy-based biodiesel (B100). Rail yard and over-the-rail measurements were previously conducted on the same engine using other fuel blends, including ULSD, 10 percent soy-based biodiesel and 90 percent ULSD blend (B10), 20 percent soy-based biodiesel and 80 percent ULSD blend (B20), 40 percent soy-based biodiesel and 60 percent ULSD blend (B40), 60 percent soy-based biodiesel and 40 percent ULSD blend (B60), and 80 percent soy-based biodiesel and 20 percent ULSD blend (B80). The dates of the measurements of the NC-1810 prime mover engine in the rail yard and over the rail are given in Table E-1. Each rail yard test involved three replicates of a test cycle. Each over the rail test involved typically three days comprised of six one way trips between Raleigh and Charlotte, NC.

Table E-1. Fuel Characteristics and Dates Measured on NC-1810 Prime Mover Engine

Fuel Name	Percent Petrodiesel	Percent Biodiesel	Dates of Measurements	
			Rail Yard	Over-The-Rail
ULSD	100	0	March 27, 2014	March 20-22, 2014
B10	90	10	Sept. 14, 2012	Aug. 29-31, 2012
B20	80	20	Oct. 24, 2012	Oct. 18-20, 2012
B40	60	40	Nov. 19, 2012	Nov. 16, 19, 21, 2012
B60	40	60	Oct. 26, 2013	Aug. 9-10, Oct. 27, 2013
B80	20	80	Dec. 22, 2013	Dec. 19-21, 2013
B100	0	100	Feb. 10, 2014	Feb. 2-9, 2014

The prime mover engine was an EMD 12-710G3B. The engine was originally manufactured in 1988 and was rebuilt by AMTRAK in 2012. The 140-liter engine has a peak engine output of 3000 horsepower (hp) at an engine speed of 900 revolutions per minute (rpm).

The fuel use and emission rates are inferred based on measurements made with a Portable Emissions Measurement System (PEMS). The PEMS utilized for measurements was the Axion system manufactured by Clean Air Technologies International, Inc. (CATI). Prior to each set of measurements, each PEMS was calibrated with a California Bureau of Automotive Repair (BAR) certified calibration gas (BAR-97 Low).

BRIEF RESULTS

The cycle average emission rates for the RY and OTR measurements are shown in Table E-2. The cycle average emission rates are based on the line-haul duty cycle used by the U.S. Environmental Protection Agency (EPA) for its regulations. The EPA line haul duty cycle specifies the percentage of operating time spent in idle, all eight throttle notch positions, and dynamic braking. Three replicates of each rail yard measurement were conducted. Dynamic braking takes place during over-the-rail operation, but cannot be simulated in the rail yard. During dynamic braking, the traction motors act as generators, and the resulting electrical current is dissipated in a resistor grid. Thus, the time apportioned for dynamic braking in the line-haul duty cycle (12.5 percent) was combined with the time apportioned for idling in the line-haul duty cycle (38.0 percent). Therefore, idling accounts for 50.5 percent of the duty cycle used to calculate rail yard cycle average emission rates. Over-the-rail measurements were made during six one-way trips between Raleigh and Charlotte, NC. During over-the-rail measurements, dynamic braking was observed. The results shown in Table E-2 are based on the average of the three rail yard replicates for the rail yard measurements, and the average of typically six one way runs, except as noted, for the over the rail measurements.

Table E-2 summarizes cycle average results for each fuel that has been evaluated. The results are described in more detail in subsequent parts of this report. The NO_x emission rates range from 7.0 to 9.5 g/bhp-hr from the over-the-rail results. Similarly, the results for HC, CO, and PM are of similar magnitude when comparing the two types of measurements.

Table E-2. Preliminary EPA Line Haul Cycle Average Emission Rates for the NC-1810 Prime Mover Engine Operated on Multiple Fuels in the Rail Yard and Over-the-Rail[a,b,c]

(a) Rail Yard Measurements

Measurement	NO_x (g/bhp-hr)	HC (g/bhp-hr)	CO (g/bhp-hr)	Opacity-based PM (g/bhp-hr)
ULSD	7.9	3.81	1.2	0.32
B10	7.0	0.17	1.3	0.33
B20	7.7	0.34	0.7	0.28
B40	8.5	0.15	0.6	0.30
B60	8.9	1.14	1.2	0.24
B80	7.1	0.25	0.7	0.32
B100	9.5	1.79	0.4	0.31

(b) Over-the-Rail Measurements

Measurement	NO_x (g/bhp-hr)	HC (g/bhp-hr)	CO (g/bhp-hr)	Opacity-based PM (g/bhp-hr)
ULSD	7.0	3.57	1.5	0.28
B10	6.4	0.85	1.5	0.53
B20	7.2	0.64	1.3	0.33
B40	8.0	0.20	1.2	0.37
B60	7.8	1.47	1.6	0.45
B80	6.8	1.93	0.5	0.27
B100[d]	8.2	2.49	0.6	0.27

[a] *The cycle average emission rates are based on the U.S. EPA line-haul duty cycle used for regulatory purposes.*

[b] *NO_x, HC, and opacity-based PM emission rates from the Axion are adjusted with multipliers of 1.053, 2.5, and 5, respectively, as bias correction.*

[c] *Dynamic braking not observed during rail yard measurements. Therefore, idling accounts for 50.5 percent of the duty cycle used to calculate rail yard cycle average emission rates.*

[d] *The cycle average emission rates are based on four one way runs.*

METHODS

A PEMS was used to quantify the fuel use and emission rates of the NC-1810 prime mover engine for rail yard measurements conducted at the NCDOT Capital Yard Maintenance Facility in Raleigh, NC and for over-the-rail measurements conducted during real-world passenger rail service.

Instruments

Instruments used for data collection included a PEMS with engine sensor array and a locomotive activity data recorder.

Portable Emissions Measurement System

The Axion PEMS includes two parallel five-gas analyzers; a laser light scattering, real-time PM detection system; an engine sensor array; and an on-board computer. The engine sensor array was used to measure manifold absolute pressure (MAP), intake air temperature (IAT), and engine speed (RPM). To measure MAP and IAT, a pressure sensor and thermistor were attached to barb fittings installed on an engine cylinder cover. The RPM optical sensor was used in combination with reflective tape to measure the time interval of revolutions of the flywheel, which rotates at the same speed as the engine crankshaft. Emission concentrations and engine activity data were recorded on a second-by-second basis.

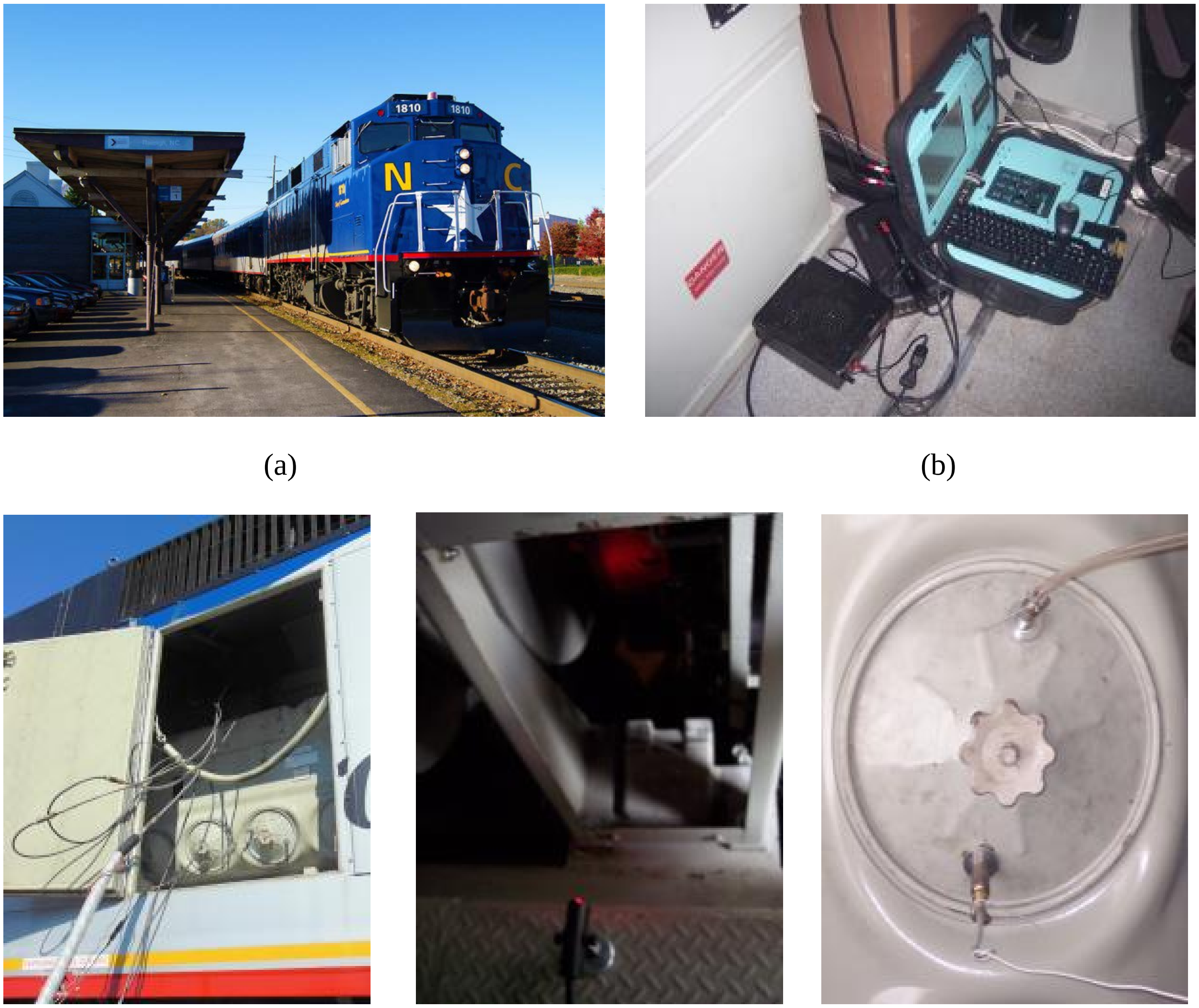
The Axion measures NO using an electrochemical cell. Diesel engine NO_x emissions typically include approximately 95 vol-% NO and 5 vol-% NO_2. Therefore, a multiplicative correction factor of 1.053 was included to approximate for total NO_x. CO and HC are measured using non-dispersive infrared (NDIR). NDIR responds well to straight chain hydrocarbons, but on average it detects or responds to only about half of the actual HC concentrations. Based on literature review, we applied a multiplicative correction factor of 2.5 to approximate for total HC. As reported in Appendix E, we are conducting supplemental measurements in the rail yard with an additional PEMS that is able to measure NO and NO_2, and to measure HC using both NDIR and Flame Ionization Detection (FID). Based on these supplemental measurements, we will verify or adjust these correction factors. In previous work, we compared average PM emission rates estimated based on the PEMS measurements to average emission rates reported for similar engines based on Federal Reference Measurement (FRM) measurements. Based on this comparison, a multiplicative correction factor or 5 was inferred to approximate for total PM.

Photographs of the PEMS setup during rail yard and over-the-rail measurements of NC-1810 are given in Figure E-1.

Locomotive Activity Data Recorder

The NC-1810 locomotive has an EMD EM2000 Locomotive Computer System that records locomotive activity data. Real-time engine RPM and horsepower output data are displayed in the locomotive cab; they were also combined with other recorded data, including throttle (notch) position, to estimate mass per time fuel use and emission rates. At idle, the on-board readout does not display a value for engine output. Therefore, the engine load at idle was estimated at 10 hp based on measurements of the EMD12-710 prime mover engine of NC-1810 on an engine dynamometer. A similar EMD12-710 prime mover, from NC-1869, was also measured on the dynamometer and had an idle engine output of 9 hp, which was not substantially different than that of NC-1810.

Figure E-1. Photographs from Prime Mover Engine Measurement of NC-1810



(a) (b)

(c) (d) (e)

(a) Locomotive NC-1810 at the Raleigh AMTRAK station;

(b) Axion Portable Emissions Measurement System unit in locomotive cab for use during over-the-rail measurements;

(c) Sample lines connecting prime mover engine exhaust pipe to PEMS units;

(d) Engine speed sensor placed at prime mover engine flywheel;

(e) Intake air temperature and manifold absolute pressure sensor ports on prime mover engine

Fuel Use and Emissions

Fuel-based emission rates, in g/gal, are estimated based on exhaust gas and fuel composition. Fuel-based emission rates are estimated independently of data for fuel flow, and are subsequently multiplied by measured fuel flow rate per unit engine output, in gal/bhp-hr, to estimate mass per unit engine output emission rates (in g/bhp-hr). However, there was not a feasible way to directly measure fuel use during RY and OTR measurements, since fuel was taken from an on-board tank and locomotive engines continuously return unspent fuel to the tank. Instead, exhaust flow rate was estimated based on the mass air flow (MAF) through the engine and inference of the air-to-fuel ratio (AFR) from the measured exhaust composition. MAF was estimated based upon the "speed density" method, which depends on engine displacement, compression ratio, IAT, MAP, RPM, and volumetric efficiency (VE). VE is the ratio of the actual volume of air that flows through the engine cylinder versus the physical cylinder volume. VE has been reported to range up to 1.90 for turbocharged 2-stroke diesel engines. VE was estimated based on the product of measured RPM and MAP observed during dynamometer measurements of similar EMD 12-710G3B prime mover engines.

For each second, mass emission rates, in g/s, are estimated based upon the mole fraction of each pollutant on a dry basis, dry exhaust molar flow rate, and average molecular weight of exhaust gas. Engine output-based emission rates, in g/bhp-hr, are estimated based on the mass emission rate, in g/hr, divided by the engine output observed from the locomotive activity data recorder.

For particulate matter, the PEMS reports milligrams per cubic meter concentration on a dry basis. The dry exhaust flow per gallon of fuel consumed was estimated by inferring the air-to-fuel ratio from the exhaust composition based on the volume percent of carbon in the exhaust. The volume of exhaust produced per gallon of fuel was multiplied by the mass per volume concentration of PM to estimate the PM emission rate (in g/gal). The latter was multiplied by fuel flow per unit engine output to estimate the engine output-based PM emission rate (in g/bhp-hr).

RESULTS

This section discusses the results of the RY and OTR measurements of the NC-1810 prime mover engine operated on B100 biodiesel, and comparison to previously reported measurements on ULSD, B10, B20, B40, B60, and B80 biodiesel blends.

Rail Yard Measurements

Three rail yard emissions measurement replicates on the prime mover engine of NC-1810 with B100 biodiesel were conducted on February 10, 2014. In the rail yard, emissions measurements were taken when the engine reached steady state at two idle settings and at all eight notch positions. The idle and notch average emission rates were weighted by the EPA line-haul duty cycle to estimate cycle average rates.

The EPA line-haul duty cycle average emission rates are shown in Table E-2. These cycle average emission rates are based on the measured engine activity data (RPM, MAP, and IAT), inferred engine activity data (MAF, AFR, and VE), and measured exhaust concentrations. There was little variability between replicate measured engine activity data and exhaust NO concentration (see Figure E-2). This indicates that the prime mover engine was operating consistently as all three replicates were being measured.

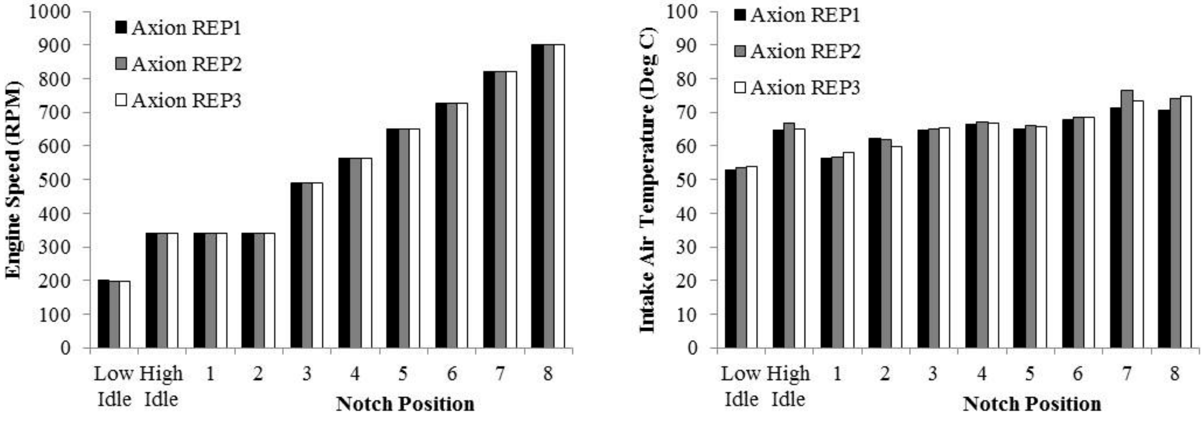
An increasing trend in fuel use rate with increasing notch position was apparent, as shown in Figure E-3. The NO emission rates among the three replicates were consistent, as shown in Figure E-4. The inter-replicate ratios of the standard deviation to the mean (coefficient of variation) for each notch position for the mass per gallon of fuel NO emission rates range from 0.02 to 0.06, which indicates small variability between replicates.

Approximately 30 percent of the notch-specific HC concentrations measured were below the detection limit. These concentrations are not significantly different than zero. However, because of imprecision in the measurements at or below the detection limit, there was large variability in estimated average concentrations. For exhaust HC concentrations across the three replicates, the coefficient of variation varied from 0.33 to 0.96, depending on the notch position. For notches 6 and 7, where the average HC concentrations were below the detection limit for two out of three replicates, the coefficients of variation were 0.96 and 0.93, respectively. For idle and notches 1 through 5, where the average HC concentrations were typically above the detection limit, the coefficients of variation were typically 0.50. Average HC concentrations were below the detection limit for all three replicates for notch 8. Variability in measured concentrations result in variability in the estimated notch-specific HC emission rates between the three replicate measurements, as shown in Figure E-5. The inter-replicate coefficient of variation in the estimated HC emission rates were 60 percent, on average, for each notch position.

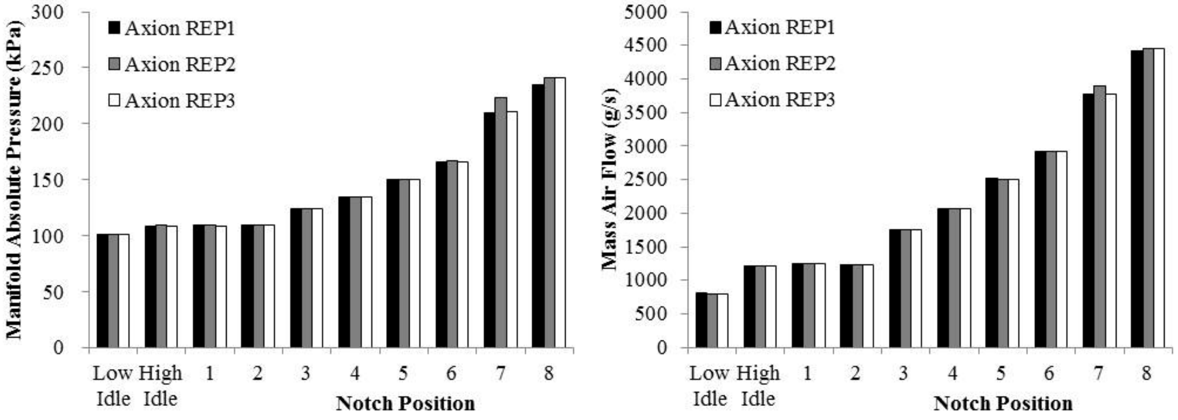
There was also variability in the estimated notch-specific CO concentrations and emission rates between the three replicate measurements, as shown in Figure E-6. Approximately 83 percent of the notch-specific CO concentrations were below the detection limit. The inter-replicate coefficient of variation in the estimated CO emission rates was 76 percent, on average, for each notch position. However, on an absolute basis, the exhaust CO concentrations were typically less than 0.010 volume percent.

PM emission rates, as shown in Figure E-7, were consistent across the three replicates, with inter-replicate coefficients of variation less than 0.11 for all notch positions, except for Notch 8. All of the NO, CO, HC, and PM concentrations measured were of the same magnitude as previous rail yard measurements of the same engine operating on ULSD, B10, B20, B40, B60, and B80 biodiesel.

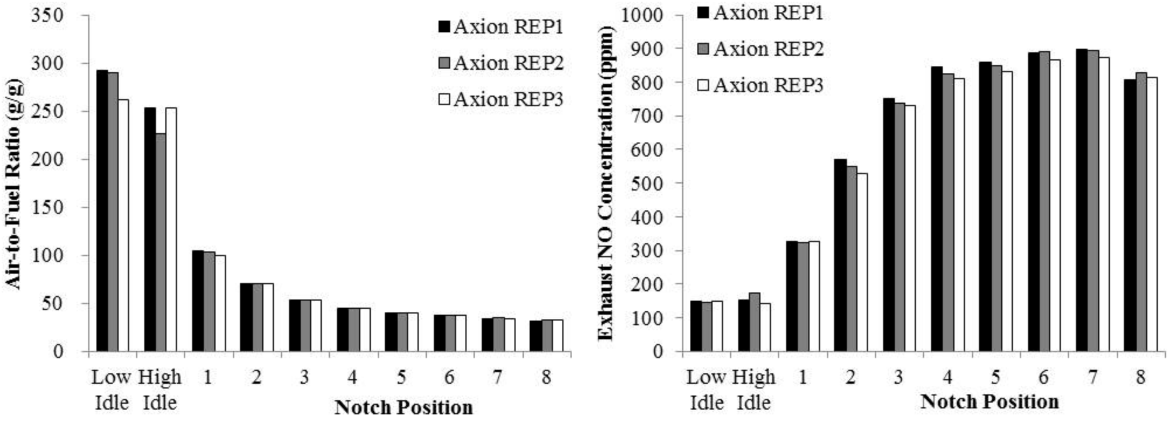
Figure E-2. Measured Engine Activity Data during Rail Yard Measurements of the NC-1810 Prime Mover Engine Operated on B100 Biodiesel



(a) Engine Speed (b) Intake Air Temperature



(c) Manifold Absolute Pressure (d) Mass Air Flow



(e) Air-to-Fuel Ratio (f) Exhaust NO Concentration

Figure E-3. Estimated Fuel Use Rates during Rail Yard Measurements of the NC-1810 Prime Mover Engine Operated on B100 Biodiesel

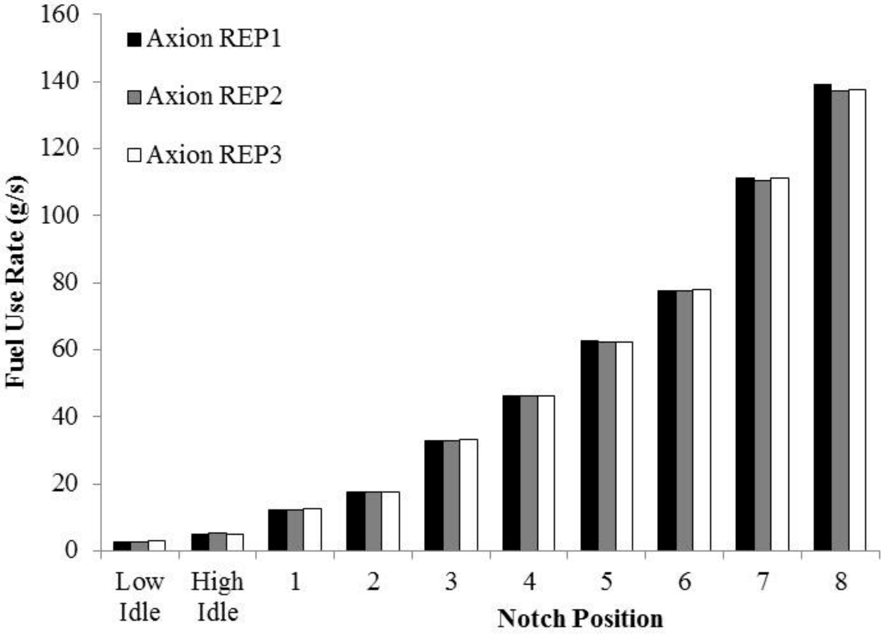


Figure E-4. Estimated NO_x Emission Rates during Rail Yard Measurements of the NC-1810 Prime Mover Engine Operated on B100 Biodiesel

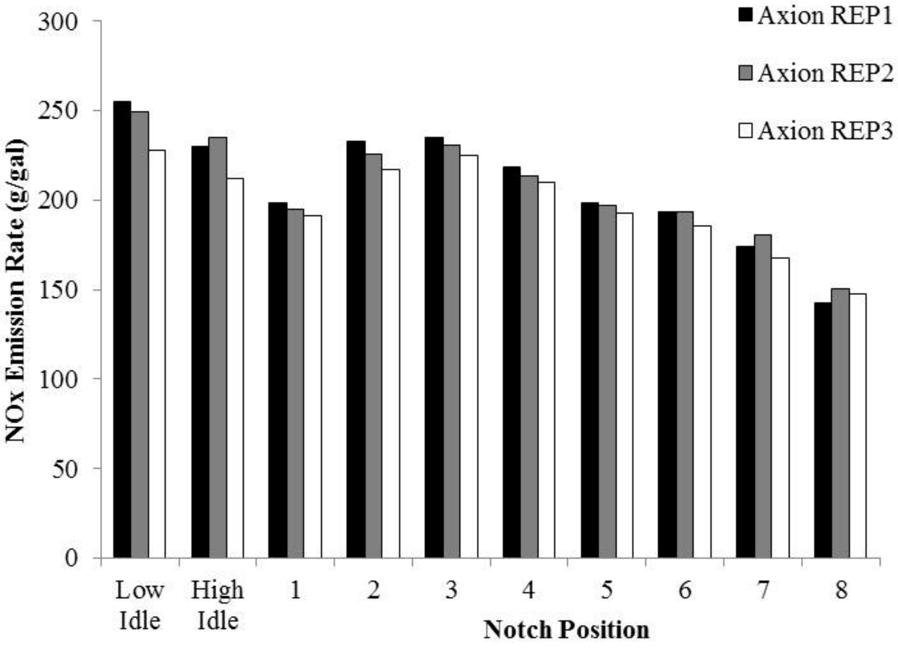


Figure E-5. Estimated HC Emission Rates during Rail Yard Measurements of the NC-1810 Prime Mover Engine Operated on B100 Biodiesel

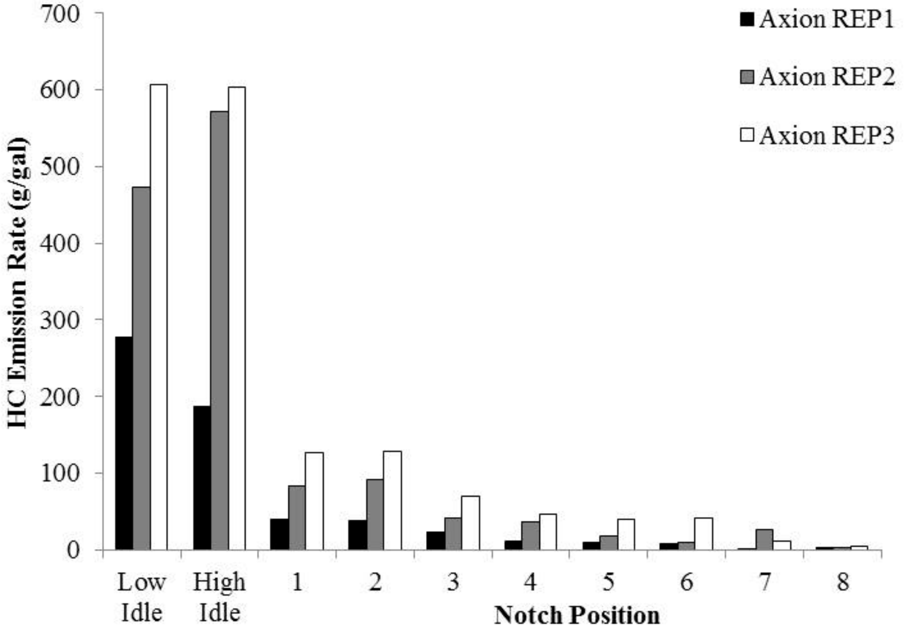


Figure E-6. Estimated CO Emission Rates during Rail Yard Measurements of the NC-1810 Prime Mover Engine Operated on B100 Biodiesel

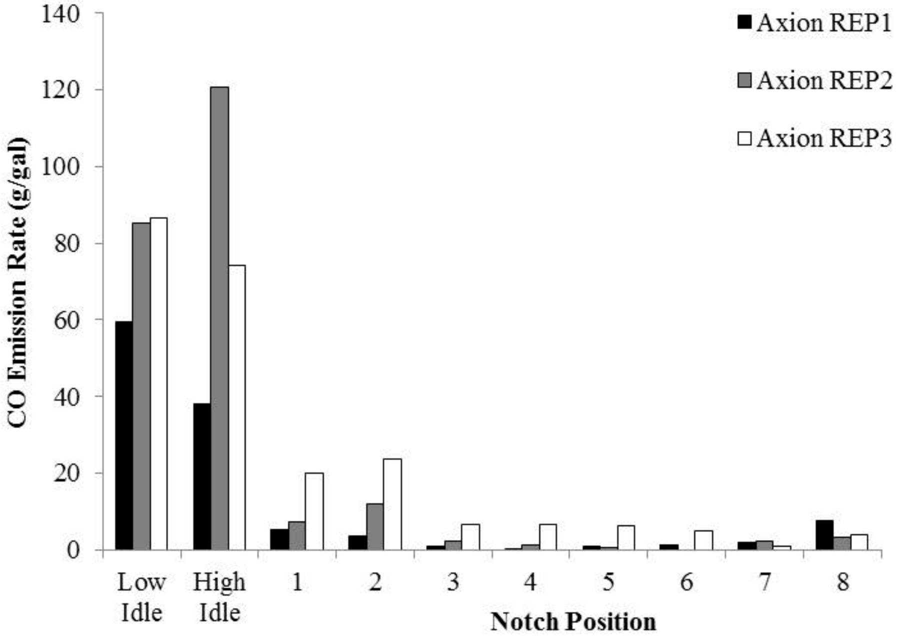
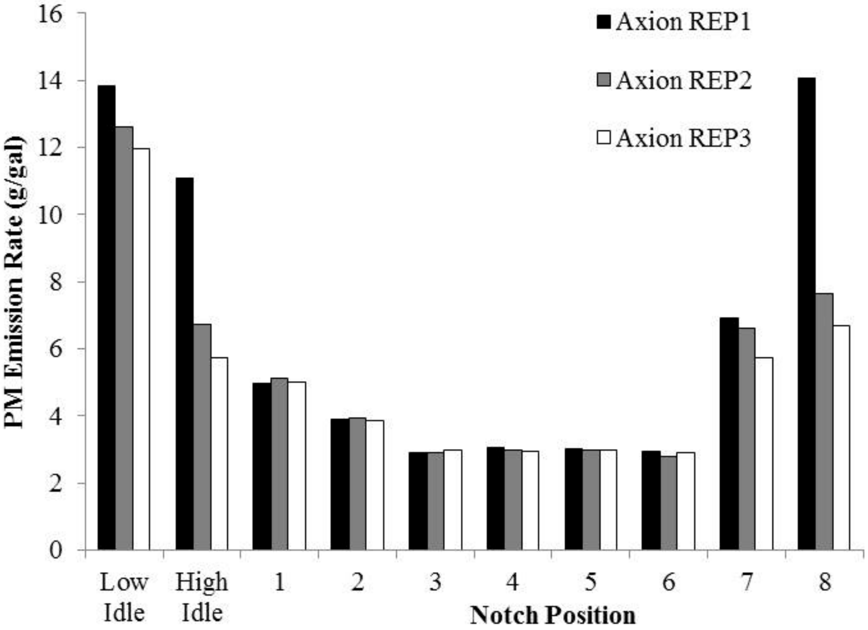


Figure E-7. Measured PM Emission Rate during Rail Yard Measurements of the NC-1810 Prime Mover Engine Operated on B100 Biodiesel



Estimated EPA line-haul cycle average emission rates for each of the three replicate rail yard measurements are given in Table E-3. The cycle average NO_x emission rates were within 3 percent of each other among the replicates. The inter-replicate coefficient of variation for cycle average HC emission rates was 47 percent. Differences in emission rates are attributable to differences in measured exhaust concentrations. Because a substantial number of the HC concentration measurements were near or below the detection limit, the HC measurements are imprecise and, thus, subject to variability. Although most of the CO concentration measurements were below the detection limit, the coefficient of variation for the inter-replicate variability in CO emission rate was only 0.17. The inter-replicate coefficient of variation for cycle average PM emission rates was 33 percent. The relatively high coefficient of variation for PM was influenced by one replicate that was much higher than the other two replicates. Values for engine activity parameters (i.e., RPM, IAT, MAP) were similar across all measurements, as given in Figure E-2, and thus are not the cause of inter-replicate variation in emission rates. The inter-replicate variation in emission rates for a given pollutant was mainly a result of the variation in measured exhaust concentration.

Table E-3. Estimated EPA Line-Haul Cycle Average Emission Rates for Rail Yard Replicate Measurements of NC-1810 Prime Mover Engine Operated on B100 Biodiesel

	NO_x (g/bhp-hr)	HC (g/bhp-hr)	CO (g/bhp-hr)	Opacity-based PM (g/bhp-hr)
Replicate 1	9.5	0.95	0.4	0.43
Replicate 2	9.6	1.79	0.3	0.27
Replicate 3	9.4	2.63	0.5	0.24
Average of 3 Replicates	**9.5**	**1.79**	**0.4**	**0.31**
Coefficient of Variation	**0.01**	**0.47**	**0.17**	**0.33**

NO_x, HC, and PM are adjusted with multipliers of 1.053, 2.5, and 5, respectively, as bias correction.

Cycle average emission rates are based on EPA Line-Haul duty cycle.

Over-the-Rail Measurements

Two days of OTR measurements on the NC-1810 prime mover engine operating on B100 biodiesel were conducted on February 8-9, 2014. Typically, three days of OTR measurements are completed on each locomotive. However, the NC-1810 prime mover engine had mechanical difficulties that resulted in canceling a third day of measurements.

Based on the over-the-rail measurements, notch average emission rates were estimated for low and high idle, dynamic brake, and notches 1 to 8. To enable comparisons with other data, the notch average emission rates are weighted based on the EPA line-haul duty cycle. However, we also quantified the actual observed duty cycle for each one-way trip. The EPA line-haul cycle average emission rates for B100 biodiesel are shown in Table E-4. These cycle average emission rates are based on measured engine activity data (RPM, MAP, and IAT) and measured exhaust concentrations. The cycle average estimate was based on measured notch-based emission rates and time fraction for each notch for the EPA line-haul duty cycle. For each set of measurements, there was little variability between measured engine activity data during both days of measurements. This indicates that the prime mover engine was operating consistently during over-the-rail measurements. Measured engine activity data during over-the-rail measurements were similar to the measured engine activity data during rail yard measurements.

For the average NO_x emission rate per notch position, the coefficient of variation was less than 23 percent for each notch position, except for low idle, amongst the four one-way trips. The coefficients of variation for HC and CO are 30 and 29 percent, respectively. Approximately 20 and 70 percent of the notch-specific HC and CO concentrations, respectively, were below the detection limit, which leads to imprecision that contributes to large inter-run variability. For PM, the coefficient of variation was 13 percent for the four one-way trips. Differences in measured exhaust pollutant concentrations were the key reason for the variability.

The EPA line-haul duty cycle average over-the-rail emission rates are quantitatively similar to the EPA line-haul duty cycle average rail yard emission rates. The cycle average over-the-rail NO_x and PM emission rates over the four one-way trips were within 13 percent of the cycle average rail yard emission rates. The over-the-rail cycle average HC and CO emission rates were approximately 39 and 48 percent higher than the rail yard cycle average emission rates, respectively.

Differences in cycle average emission rates between rail yard and over-the-rail measurements can be attributed to various factors. RPM and MAP were essentially the same for rail yard and over-the-rail measurements. IAT differed on an absolute basis by less than 6 percent from run-to-run during over-the-rail measurements. At notch 8, the engine output during rail yard measurements was 2,700 horsepower, while engine output was 3,000 horsepower during over-the-rail measurements. With notch 8 accounting for 16 percent of the EPA line-haul duty cycle, higher engine output decreases engine output based emission rates and, therefore, cycle average emission rates. Finally, differences in measured exhaust concentrations between rail yard and over-the-rail measurements lead to differences in fuel use and emission rates.

Throttle notch position data obtained from the locomotive data activity recorder were used to quantify the actual real-world duty cycles for the over-the-rail measurements. The measured duty cycles are compared to the EPA line-haul duty cycle in Table E-5. The prime mover engine operated in notch 8 during the over-the-rail measurements more than double the percentage of time, on average, than EPA estimates a line-haul locomotive operates in notch 8. For the other notch positions, the observed time was, on average, less than the EPA line-haul duty cycle. Although not shown here, the real-world duty cycles can be used to estimate inter-cycle variability in cycle average fuel use and emission rates.

Table E-4. EPA Line-Haul Cycle Average Emission Rates for Over-the-Rail Measurements of NC-1810 Prime Mover Engine Operated on B100 Biodiesel

	NO_x **(g/bhp-hr)**	**HC** **(g/bhp-hr)**	**CO** **(g/bhp-hr)**	**Opacity-based PM** **(g/bhp-hr)**
Feb. 8, 2014 – Train 73	8.4	2.92	0.6	0.32
Feb. 8, 2014 – Train 74	8.4	2.02	0.6	0.25
Feb. 9, 2014 – Train 73	8.6	1.74	0.4	0.24
Feb. 9, 2014 – Train 74	7.6	3.30	0.8	0.28
Average	**8.2**	**2.49**	**0.6**	**0.27**
Coefficient of Variation	**0.05**	**0.30**	**0.29**	**0.13**

NO_x, HC, and PM are adjusted with multipliers of 1.05, 2.5, and 5, respectively, as bias correction.

Cycle average emission rates are based on EPA Line-Haul duty cycle.

Table E-5. Observed Real-World Over-the-Rail Duty Cycles from Measurement of NC-1810 Operated on B100 Biodiesel

Notch	Percent Time in Each Notch					
	EPA Line-Haul	Measured Over-the-Rail				
		Average	2/8/2014 Train 73	2/8/2014 Train 74	2/9/2014 Train 73	2/9/2014 Train 74
Idle	38.0	26.9	21.9	35.4	22.8	27.6
DB	12.5	15.5	10.6	15.2	17.4	18.9
1	6.5	4.3	7.8	3.1	3.7	2.7
2	6.5	2.7	3.3	1.7	3.1	2.6
3	5.2	2.3	2.6	2.1	2.6	1.9
4	4.4	2.5	2.2	2.8	3.2	1.9
5	3.8	2.1	2.0	2.2	3.1	1.1
6	3.9	2.9	1.2	3.9	5.3	1.4
7	3.0	1.1	0.4	1.7	2.3	0.1
8	16.2	39.7	48.1	32.0	36.7	41.9

Train 73 is from Raleigh to Charlotte. Train 74 is from Charlotte to Raleigh

Table E-6. Comparison of EPA Line-Haul Cycle Average Emission Rates for Rail Yard and Over-the-Rail Measurements of NC-1810 Prime Mover Engine Operating on Multiple Biodiesel Blends versus Ultra-low Sulfur Diesel

	NO_x	HC^a	CO	Opacity-based PM
	(g/bhp-hr)	(g/bhp-hr)	(g/bhp-hr)	(g/bhp-hr)
B10 vs. ULSD				
Rail Yard	-11%	-96%	+8%	+3%
Over-the-Rail	-9%	-76%	+3%	+86%
B20 vs. ULSD				
Rail Yard	-3%	-91%	-42%	-13%
Over-the-Rail	+2%	--82%	-10%	+16%
B40 vs. ULSD				
Rail Yard	+8%	-96%	-50%	-6%
Over-the-Rail	+14%	-94%	-17%	+30%
B60 vs. ULSD				
Rail Yard	+13%	-70%	0%	-25%
Over-the-Rail	+11%	-59%	+10%	+58%
B80 vs. ULSD				
Rail Yard	-10%	-93%	-42%	0%
Over-the-Rail	-3%	-46%	-66%	-5%
B100 vs. ULSD				
Rail Yard	+20%	-53%	-67%	+3%
Over-the-Rail	+17%	-30%	-59%	-3%

Comparison of Emission Rates for Ultra-Low Sulfur Diesel and Multiple Biodiesel Blends

A comparison of the cycle average emission rates measured during rail yard and over-the-rail measurements of the prime mover engine on different biodiesel blends versus ULSD is shown in Table E-6. All of the comparisons are based on the EPA line-haul duty cycle.

For cycle average NO_x emission rates, B10 biodiesel blends have a small decrease compared to ULSD, by approximately 9percent. For B20 and B80, the relative differences are small, indicating little to no difference. For B40 and B60, the NO_x emission rates are slightly higher than ULSD, by approximately 11 to 14 percent. For B100, there was a moderate increase compared to ULSD, by approximately 17 percent. Thus, there was not a clear trend for these comparisons, which indicate that B10 and B80 may lead to lower NO_x emissions than ULSD.

For HC, much lower cycle average emission rates were observed in the rail yard and over-the-rail for the biofuels compared to ULSD. However, these results are influenced by a relatively large ULSD HC emission rate, and the percentage reductions for the biofuels are much higher than expected.

For CO, little to no difference in cycle average emission rates was observed for B10 and B60 compared to ULSD. For B20 and B40, decreases were observed for CO rates compared to ULSD, but the trends for rail yard and over-the-rail were inconsistent, with approximately 50 percent reduction for rail yard and 20 percent reduction for over-the-rail measurements. For B80 and B100, large decreases were observed compared to ULSD, by approximately 60 percent. Thus, CO emission rates were found to be lower for B20, B40, B80, and B100 compared to ULSD.

For PM, higher cycle average emission rates were observed for B10 than ULSD. For B80, decreased rates were observed versus ULSD. For B100, there was little to no change compared to ULSD. For B20, B40, and B60, the PM emission rate comparison to ULSD was inconclusive; rail yard results were 6 to 25 percent lower, but over-the-rail emission rates were 16 to 58 percent higher. The evidence supporting lower emission rates for biofuels versus ULSD was strongest for B80.

Details on the results of rail yard and over-the-rail measurements of NC-1810 using B100 biodiesel are given in supplemental tables.

Table E-7 summarizes the average measured engine speed (RPM), intake air temperature (IAT), manifold absolute pressure (MAP), estimated mass air flow (MAF), and air-to-fuel ratio (AFR) for each throttle notch position and for each replicate of the RY measurement and for each one-way OTR trip. Engine speed ranges from 198 to 901 RPM in both RY and OTR measurements, depending on notch position. For the RY measurements, engine RPM was highly repeatable among replicates for a given notch position, with a standard deviation of less than 1 RPM for all notch positions. For the OTR measurements, the RPM was also repeatable among replicates for a given notch position, with coefficient of variation less than 0.07 for all notch positions. For some one-way trips, the sample sizes in these notches are too small to infer a steady-state engine operating speed. The intake air temperature varies with ambient temperature and was generally in the range of 53 to 75 degrees C during all measurements. MAP was highly repeatable in the RY measurements, ranging from 99 to 241 kPa depending on notch position. The inter-measurement standard deviation of measured MAP was less than 3 kPa for each notch position.

For OTR measurements, there was slightly more inter-run variability in MAP. However, the coefficient of variation for each notch position was typically 0.04 or less.

Estimated MAF was highly repeatable for both RY and OTR measurements, with the coefficient of variation typically 0.07 or less for all notch position. The MAF ranged from 760 to 4500 g/s, depending on notch position. Estimated AFR was highly repeatable among replicates for a given notch position in the RY measurements, with coefficient of variation less than 0.06 for all notches. For OTR measurements, there was slightly more inter-run variability in AFR for each notch position, but the coefficient of variation was less than 0.11, with the exception of Notch 2. Overall, the engine activity was consistent from test-to-test for the three replicates in the rail yard, and from run-to run-for the four one-way trips between Raleigh and Charlotte.

Table E-8 summarizes the estimated fuel use rates inferred from the engine data in Table E-1. For the RY measurements, fuel use rates range from 2.8 to 139 g/sec depending on notch position, and were highly repeatable among replicates for a given notch position, with a coefficient of variation of 0.06 or less. There was more variability in run-to-run estimates of fuel use for the OTR measurements, in part because the amount of time spent in some notch positions was low. The OTR estimated fuel use ranged from 2.6 to 135 g/sec, depending on notch position. The coefficient of variation was less than 0.10 for all notch positions, except for dynamic braking and notch 2.

During RY measurements, the maximum engine output was 2700 horsepower, whereas during OTR measurements the maximum engine output was 3000 horsepower. Furthermore, as shown later in Table E-7, the average CO_2 concentrations for each notch position are lower for OTR than for RY measurements, which implies a lower fuel-to-air ratio. Because the engine activity and, therefore, engine air flow, are approximately the same for OTR versus RY measurements, the combination of higher engine output and lower fuel-to-air ratio lead to higher values of fuel-specific engine output (FSEO), in bhp-hr per gallon of fuel consumed, as shown in Table E-2. The FSEO was highly repeatable for the OTR measurements of each notch position, especially Notch 8, which represents a significant portion of the observed duty cycle.

The measured NO exhaust concentrations and the estimated NO_x emission rates are shown in Table E-3 for each notch position, each RY replicate, and each OTR one-way run. The average measured concentrations range among notch positions from approximately 140 to 900 parts per million (ppm) in the RY measurements, and 130 to 890 ppm in the OTR measurements, depending on notch position. The measurements are highly repeatable among replicates for a given notch position for both the RY and OTR measurements, with coefficients of variation typically less than 0.04 for the former and less than 0.23 for the latter. The estimated mass emission rates range from 0.2 to 6.2 g/sec for the RY measurements and 0.2 to 6.0 g/sec for the OTR measurements, depending on notch position. Because the observed concentrations tend to be higher for the OTR versus RY measurements, the mass emission rates also tend to be slightly higher for the OTR versus RY measurements.

On a fuel basis, the average NO_x emission rates range from 140 to 260 g/gallon for the RY measurements and 130 to 260 g/gallon for the OTR measurements, depending on notch position. For both the RY and OTR measurements, the fuel-based emission rates are highly repeatable among replicates for a given notch position, with coefficients of variation typically less than 0.08. The fuel-based emission rates tend to be lowest at high load.

On an engine output basis, excluding idle and dynamic brake, the notch average NO_x emission rates range from 8.0 g/bhp-hr at notch 8 to 13.6 g/bhp-hr at notch 1 in the RY measurements, and range from 6.3 g/bhp-hr at notch 8 to 15.4 g/bhp-hr at notch 1 in the OTR measurements. The notch average NO_x emission rates for idle and dynamic brake were higher than the other notch positions. In general, the emission rates on an engine output basis are higher for the OTR measurements than for the RY measurements. This results from a combination of lower exhaust concentration and higher engine output, especially at notch 8.

Results are given for exhaust concentrations and emission rates in Tables E-4, E-5, E-6, and E-7 for CO, HC, PM, and CO_2, respectively. The CO exhaust concentrations during OTR measurements are within 0.004 percentage points of RY concentrations. The cycle average CO emission rates are within 0.3 g/bhp-hr for OTR and RY measurements. On average, the HC exhaust concentrations and average emission rates tend to be higher for OTR than RY. However, HC emission rates are low on an absolute basis, and some of the measured average concentrations for a given notch position and replicate or run are below the gas analyzer detection limit. For PM, the measured exhaust levels tend to be lower for OTR than RY for a given notch position, and, thus, the cycle average PM emission rate also tends to be lower. The trends in CO_2 emission rates are similar to those for fuel use on a mass per time and mass per engine output basis. CO_2 emission rates are also shown on a g/gallon basis. Since over 99 percent of the carbon in the fuel was typically emitted as CO_2, the fuel-based CO_2 emission rates are approximately constant.

In these measurements, a procedure was demonstrated for rail yard and over-the-rail characterization of emission rates for B100 biodiesel. The rail yard engine activity and emission concentration measurements were consistent across the three replicates. Compared to ULSD based on rail yard measurements, cycle average NO_x emission rates were slightly lower for B10 and B80, similar for B20, slightly higher for B40 and B60, and moderately higher for B100. Cycle average HC emission rates were lower for all of the biodiesel blends versus ULSD. Compared to ULSD, cycle average CO emission rates were significantly lower for B20, B40, B80, and B100, and similar for B10 and B60. Cycle average PM emission rates were slightly lower for B20, B40, and B60, with little to no difference for B10, B80, and B100.

The cycle average over-the-rail emission rates are of the same magnitude as the cycle average rail yard emission rates. Cycle average NO_x, HC, and CO emission rates followed the same trend as the RY measurements for the biodiesel blends compared to ULSD. Compared to ULSD, cycle average PM emission rates were significantly higher for B10, B20, B40, and B60, but lower for B80, with little to no difference for B100. These observed differences are mostly attributable to measured exhaust concentrations, rather than engine activity, and may result in part from differences associated with transient operation for over-the-rail operation versus steady-state operation in the rail yard.

Table E-7. Measured Engine Parameters for NC-1810 and B100

Engine Speed (RPM)													
Throttle	Rail Yard Test						Over-The-Rail Test						
Notch	2/10	2/10	2/10	3 Reps	3 Reps	3 Reps	2/8	2/8	2/9	2/9	4 Trains	4 Trains	4 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	199	198	198	199	0.78	0.00	197	197	198	197	197	0.24	0.00
High Idle	340	340	339	339	0.44	0.00	339	338	338	338	338	0.57	0.00
Dyn Brake	--	--	--	--	--	--	384	337	358	325	351	25.8	0.07
1	340	339	339	339	0.52	0.00	339	338	338	338	338	0.51	0.00
2	340	339	339	339	0.49	0.00	338	337	339	337	338	0.77	0.00
3	489	489	489	489	0.10	0.00	488	487	488	487	488	0.84	0.00
4	563	562	562	562	0.42	0.00	562	562	562	561	562	0.49	0.00
5	651	651	650	651	0.32	0.00	650	648	650	648	649	0.97	0.00
6	728	728	727	728	0.37	0.00	726	721	727	726	725	2.55	0.00
7	822	822	821	821	0.33	0.00	821	821	820	--	820	0.19	0.00
8	901	901	901	901	0.23	0.00	901	900	901	901	901	0.17	0.00

Intake Air Temeprature (°C)													
Throttle	Rail Yard Test						Over-The-Rail Test						
Notch	2/10	2/10	2/10	3 Reps	3 Reps	3 Reps	2/8	2/8	2/9	2/9	4 Trains	4 Trains	4 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	53	54	54	53	0.47	0.01	63	64	63	65	64	0.68	0.01
High Idle	65	67	65	66	1.13	0.02	68	66	66	67	67	0.79	0.01
Dyn Brake	--	--	--	--	--	--	67	67	66	68	67	0.82	0.01
1	56	57	58	57	0.95	0.02	68	64	67	66	66	1.82	0.03
2	62	62	60	61	1.30	0.02	65	64	66	66	65	1.09	0.02
3	65	65	65	65	0.30	0.00	67	66	66	69	67	1.29	0.02
4	67	67	67	67	0.38	0.01	65	66	64	69	66	2.10	0.03
5	65	66	66	66	0.60	0.01	67	68	68	71	69	1.71	0.02
6	68	68	69	68	0.47	0.01	67	71	69	73	70	2.43	0.03
7	71	77	73	74	2.59	0.04	68	74	70	--	71	3.10	0.04
8	71	74	75	73	2.22	0.03	72	72	72	73	72	0.34	0.00

Manifold Absolute Pressure (kPa)													
Throttle	Rail Yard Test						Over-The-Rail Test						
Notch	2/10	2/10	2/10	3 Reps	3 Reps	3 Reps	2/8	2/8	2/9	2/9	4 Trains	4 Trains	4 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	101	101	101	101	0.03	0.00	99	98	99	99	99	0.34	0.00
High Idle	109	109	109	109	0.06	0.00	107	106	107	106	107	0.62	0.01
Dyn Brake	--	--	--	--	--	--	111	107	110	107	109	2.20	0.02
1	109	109	109	109	0.03	0.00	108	106	107	106	107	0.87	0.01
2	109	109	109	109	0.02	0.00	108	106	107	107	107	0.69	0.01
3	124	124	124	124	0.01	0.00	122	120	122	120	121	1.08	0.01
4	134	134	134	134	0.06	0.00	132	130	132	130	131	1.12	0.01
5	150	150	150	150	0.15	0.00	146	145	148	147	146	0.95	0.01
6	166	166	166	166	0.14	0.00	164	161	163	160	162	1.82	0.01
7	210	223	211	215	7.50	0.03	190	194	188	--	191	2.80	0.01
8	235	241	241	239	3.56	0.01	231	222	236	218	227	8.39	0.04

Mass Air Flow (g/s)													
Throttle	Rail Yard Test						Over-The-Rail Test						
Notch	2/10	2/10	2/10	3 Reps	3 Reps	3 Reps	2/8	2/8	2/9	2/9	4 Trains	4 Trains	4 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	808	803	801	804	3.32	0.00	766	762	770	763	765	3.46	0.00
High Idle	1221	1214	1218	1218	3.18	0.00	1197	1190	1198	1186	1193	5.59	0.00
Dyn Brake	--	--	--	--	--	--	1350	1193	1276	1153	1243	87.7	0.07
1	1253	1250	1244	1249	4.90	0.00	1198	1195	1195	1188	1194	3.90	0.00
2	1233	1232	1239	1235	3.81	0.00	1206	1196	1197	1190	1197	6.86	0.01
3	1762	1760	1758	1760	1.72	0.00	1729	1709	1731	1694	1716	17.5	0.01
4	2069	2064	2065	2066	2.39	0.00	2048	2021	2059	2002	2032	26.0	0.01
5	2513	2505	2503	2507	5.12	0.00	2448	2419	2458	2418	2435	20.4	0.01
6	2929	2924	2916	2923	6.22	0.00	2894	2806	2869	2796	2841	48.1	0.02
7	3776	3901	3768	3815	74.5	0.02	3538	3522	3481	--	3514	29.5	0.01
8	4409	4449	4445	4434	21.8	0.00	4337	4199	4410	4141	4272	123	0.03

Air to Fuel Ratio (g/g)													
Throttle	Rail Yard Test						Over-The-Rail Test						
Notch	2/10	2/10	2/10	3 Reps	3 Reps	3 Reps	2/8	2/8	2/9	2/9	4 Trains	4 Trains	4 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	292	290	262	281	17.0	0.06	252	264	250	299	266	22.5	0.08
High Idle	253	226	253	244	15.6	0.06	218	231	206	239	224	14.4	0.06
Dyn Brake	--	--	--	--	--	--	201	231	206	247	221	21.6	0.10
1	104	103	100	102	2.06	0.02	121	108	96	120	111	11.9	0.11
2	69.8	70.3	70.0	70.0	0.24	0.00	77.0	115	70.5	85.9	87.0	19.5	0.22
3	53.7	53.7	52.8	53.4	0.55	0.01	54.3	52.3	58.7	61.0	56.6	3.98	0.07
4	44.6	44.6	44.8	44.7	0.08	0.00	47.8	46.3	48.7	46.6	47.4	1.12	0.02
5	40.0	40.1	40.2	40.1	0.10	0.00	41.6	40.9	41.5	41.0	41.2	0.34	0.01
6	37.7	37.8	37.4	37.6	0.20	0.01	39.3	36.7	38.7	36.9	37.9	1.31	0.03
7	33.9	35.3	33.9	34.4	0.80	0.02	40.3	33.2	34.2	--	35.9	3.87	0.11
8	31.7	32.5	32.3	32.2	0.40	0.01	32.1	31.9	33.0	31.3	32.1	0.71	0.02

Table E-8. Estimated Fuel Use Rates for NC-1810 and B100

Time-Based Fuel Use Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test						
Notch	2/10	2/10	2/10	3 Reps	3 Reps	3 Reps	2/8	2/8	2/9	2/9	4 Trains	4 Trains	4 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	2.77	2.77	3.06	2.87	0.17	0.06	3.03	2.89	3.08	2.55	2.89	0.24	0.08
High Idle	4.83	5.38	4.82	5.01	0.32	0.06	5.50	5.16	5.80	4.95	5.35	0.37	0.07
Dyn Brake	--	--	--	--	--	--	6.70	5.16	6.20	4.67	5.68	0.93	0.16
1	12.0	12.1	12.4	12.2	0.20	0.02	9.86	11.1	12.5	9.91	10.8	1.22	0.11
2	17.7	17.5	17.7	17.6	0.08	0.00	15.7	10.4	17.0	13.9	14.2	2.84	0.20
3	32.8	32.8	33.3	33.0	0.31	0.01	31.8	32.7	29.5	27.8	30.5	2.24	0.07
4	46.4	46.2	46.2	46.3	0.12	0.00	42.8	43.6	42.3	42.9	42.9	0.57	0.01
5	62.8	62.4	62.2	62.5	0.28	0.00	58.9	59.2	59.3	58.9	59.1	0.19	0.00
6	77.7	77.3	78.0	77.7	0.30	0.00	73.6	76.5	74.1	75.7	75.0	1.36	0.02
7	111	111	111	111	0.41	0.00	87.8	106	102	--	98.6	9.66	0.10
8	139	137	137	138	1.05	0.01	135	132	133	132	133	1.57	0.01

Engine Output-Based Fuel Use Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test						
Notch	2/10	2/10	2/10	3 Reps	3 Reps	3 Reps	2/8	2/8	2/9	2/9	4 Trains	4 Trains	4 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	3.00	3.00	2.71	2.90	0.17	0.06	2.74	2.88	2.70	3.25	2.89	0.25	0.09
High Idle	1.72	1.55	1.72	1.66	0.10	0.06	1.51	1.61	1.43	1.68	1.56	0.11	0.07
Dyn Brake	--	--	--	--	--	--	1.24	1.61	1.34	1.78	1.49	0.25	0.17
1	13.1	13.0	12.7	12.9	0.21	0.02	16.0	14.2	12.7	15.9	14.7	1.58	0.11
2	16.5	16.6	16.4	16.5	0.08	0.00	18.6	27.9	17.1	21.0	21.1	4.77	0.23
3	17.1	17.1	16.8	17.0	0.16	0.01	17.6	17.1	19.0	20.2	18.5	1.38	0.07
4	17.9	18.0	18.0	18.0	0.05	0.00	19.4	19.0	19.7	19.3	19.4	0.26	0.01
5	17.5	17.6	17.7	17.6	0.08	0.00	18.7	18.6	18.6	18.7	18.6	0.06	0.00
6	17.1	17.2	17.0	17.1	0.07	0.00	18.1	17.4	17.9	17.6	17.7	0.32	0.02
7	17.9	18.0	17.9	18.0	0.07	0.00	25.6	21.1	22.0	--	22.9	2.35	0.10
8	16.1	16.4	16.3	16.3	0.12	0.01	18.4	18.9	18.7	18.8	18.7	0.22	0.01

Table E-9. Measured NO_x Emission Rates for NC-1810 and B100

Time-Based NO_x Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test						
Notch	2/10	2/10	2/10	3 Reps	3 Reps	3 Reps	2/8	2/8	2/9	2/9	4 Trains	4 Trains	4 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	0.21	0.21	0.21	0.21	0.00	0.01	0.24	0.21	0.24	0.18	0.22	0.03	0.14
High Idle	0.34	0.38	0.31	0.34	0.04	0.11	0.37	0.35	0.41	0.31	0.36	0.04	0.11
Dyn Brake	--	--	--	--	--	--	0.42	0.35	0.41	0.30	0.37	0.06	0.16
1	0.72	0.71	0.72	0.72	0.00	0.01	0.65	0.69	0.81	0.57	0.68	0.10	0.15
2	1.24	1.20	1.16	1.20	0.04	0.03	1.01	0.69	1.17	0.79	0.92	0.21	0.23
3	2.33	2.28	2.27	2.29	0.03	0.01	2.12	2.27	2.04	1.69	2.03	0.25	0.12
4	3.06	2.98	2.93	2.99	0.07	0.02	2.68	2.85	2.63	2.53	2.67	0.13	0.05
5	3.76	3.71	3.62	3.70	0.07	0.02	3.49	3.59	3.50	3.21	3.45	0.16	0.05
6	4.53	4.51	4.37	4.47	0.09	0.02	4.15	4.38	4.19	4.01	4.18	0.15	0.04
7	5.85	6.02	5.62	5.83	0.20	0.03	4.48	5.47	4.98	--	4.98	0.49	0.10
8	5.99	6.24	6.12	6.11	0.12	0.02	5.83	5.73	6.03	5.22	5.70	0.34	0.06

Fuel-Based NO_x Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test						
Notch	2/10	2/10	2/10	3 Reps	3 Reps	3 Reps	2/8	2/8	2/9	2/9	4 Trains	4 Trains	4 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	255	249	228	244	14.1	0.06	263	240	259	231	248	15.0	0.06
High Idle	230	235	212	225	12.1	0.05	223	222	232	208	221	9.94	0.04
Dyn Brake	--	--	--	--	--	--	209	222	220	211	215	6.45	0.03
1	199	195	191	195	3.75	0.02	219	207	216	191	208	12.7	0.06
2	233	226	217	225	7.71	0.03	214	221	228	188	213	17.1	0.08
3	235	230	225	230	4.90	0.02	220	230	229	201	220	13.5	0.06
4	218	214	210	214	4.17	0.02	207	216	206	195	206	8.66	0.04
5	198	197	193	196	3.01	0.02	196	201	196	181	193	8.79	0.05
6	193	193	185	191	4.40	0.02	187	189	187	175	185	6.29	0.03
7	174	180	167	174	6.46	0.04	169	170	162	--	167	4.55	0.03
8	143	151	147	147	4.06	0.03	143	144	149	131	142	7.87	0.06

Engine Output-Based NO_x Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test						
Notch	2/10	2/10	2/10	3 Reps	3 Reps	3 Reps	2/8	2/8	2/9	2/9	4 Trains	4 Trains	4 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	76.6	75.1	75.9	75.9	0.79	0.01	86.7	75.3	86.6	64.3	78.2	10.7	0.14
High Idle	121	137	111	123	13.3	0.11	133	125	146	112	129	14.4	0.11
Dyn Brake	--	--	--	--	--	--	152	124	148	107	133	21.2	0.16
1	13.7	13.5	13.6	13.6	0.08	0.01	12.4	13.2	15.4	10.8	12.9	1.91	0.15
2	12.8	12.3	11.9	12.3	0.41	0.03	10.4	7.14	12.0	8.11	9.41	2.20	0.23
3	12.4	12.2	12.1	12.2	0.17	0.01	11.3	12.1	10.9	8.99	10.8	1.33	0.12
4	11.0	10.7	10.5	10.8	0.24	0.02	9.66	10.3	9.46	9.10	9.62	0.48	0.05
5	10.2	10.1	9.8	10.0	0.20	0.02	9.49	9.76	9.51	8.73	9.37	0.44	0.05
6	10.2	10.2	9.8	10.1	0.20	0.02	9.34	9.85	9.42	9.02	9.41	0.34	0.04
7	8.78	9.03	8.43	8.75	0.30	0.03	5.98	7.29	6.65	--	6.64	0.66	0.10
8	7.98	8.31	8.16	8.15	0.17	0.02	7.00	6.88	7.23	6.27	6.84	0.41	0.06
Duty Cycle Avg (Raw)	9.0	9.2	9.0	9.0	0.10	0.01	7.9	7.9	8.2	7.2	7.8	0.4	0.05
Duty Cycle Avg (Adj)	9.5	9.6	9.4	9.5	0.11	0.01	8.4	8.4	8.6	7.6	8.2	0.4	0.05

Exhaust NO_x Concentrations (ppm)

Throttle	Rail Yard Test						Over-The-Rail Test						
Notch	2/10	2/10	2/10	3 Reps	3 Reps	3 Reps	2/8	2/8	2/9	2/9	4 Trains	4 Trains	4 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	147	145	148	147	1.26	0.01	177	154	174	132	159	20.7	0.13
High Idle	154	175	142	157	16.7	0.11	174	163	190	148	169	17.3	0.10
Dyn Brake	--	--	--	--	--	--	175	162	180	145	166	15.5	0.09
1	325	322	325	324	1.55	0.00	308	326	381	272	322	45.4	0.14
2	569	548	528	549	20.4	0.04	477	325	546	379	432	98.7	0.23
3	751	736	731	739	10.6	0.01	699	755	663	571	672	77.2	0.11
4	844	826	810	826	17.2	0.02	746	801	726	724	749	35.8	0.05
5	859	850	830	846	14.8	0.02	810	844	807	760	805	34.5	0.04
6	888	890	867	882	13.3	0.02	814	892	832	825	841	34.8	0.04
7	897	893	874	888	12.0	0.01	734	884	824	--	814	75.3	0.09
8	807	829	815	817	10.8	0.01	791	793	792	736	778	27.9	0.04

Table E-10. Measured CO Emission Rates for NC-1810 and B100

Time-Based CO Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test						
Notch	2/10	2/10	2/10	3 Reps	3 Reps	3 Reps	2/8	2/8	2/9	2/9	4 Trains	4 Trains	4 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	0.05	0.07	0.08	0.07	0.02	0.23	0.04	0.06	0.04	0.06	0.05	0.01	0.27
High Idle	0.06	0.20	0.11	0.12	0.07	0.59	0.10	0.08	0.06	0.09	0.08	0.02	0.20
Dyn Brake	--	--	--	--	--	--	0.15	0.10	0.06	0.10	0.10	0.03	0.33
1	0.02	0.03	0.08	0.04	0.03	0.75	0.07	0.09	0.09	0.15	0.10	0.03	0.32
2	0.02	0.06	0.13	0.07	0.05	0.77	0.09	0.08	0.05	0.14	0.09	0.04	0.42
3	0.01	0.02	0.07	0.03	0.03	0.90	0.08	0.07	0.08	0.13	0.09	0.03	0.30
4	0.01	0.02	0.09	0.04	0.05	1.18	0.10	0.09	0.07	0.17	0.11	0.04	0.40
5	0.02	0.01	0.12	0.05	0.06	1.26	0.09	0.11	0.07	0.25	0.13	0.08	0.64
6	0.03	0.00	0.11	0.05	0.06	1.22	0.20	0.12	0.11	0.12	0.14	0.04	0.31
7	0.07	0.07	0.03	0.06	0.02	0.36	0.33	0.21	0.16	--	0.24	0.09	0.37
8	0.32	0.13	0.16	0.20	0.10	0.50	0.39	0.39	0.20	0.47	0.36	0.12	0.32

Fuel-Based CO Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test						
Notch	2/10	2/10	2/10	3 Reps	3 Reps	3 Reps	2/8	2/8	2/9	2/9	4 Trains	4 Trains	4 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	59.4	85.3	86.6	77.1	15.3	0.20	39.1	67.7	40.4	76.6	55.9	19.1	0.34
High Idle	38.1	120.7	74.1	77.6	41.4	0.53	60.9	54.5	35.5	61.3	53.0	12.1	0.23
Dyn Brake	--	--	--	--	--	--	72.5	64.8	34.1	70.4	60.5	17.9	0.30
1	5.44	7.25	20.0	10.9	7.96	0.73	24.4	27.1	24.4	49.3	31.3	12.1	0.39
2	3.71	11.9	23.6	13.1	10.0	0.77	18.6	25.1	9.80	33.4	21.7	10.0	0.46
3	1.00	2.34	6.76	3.37	3.01	0.90	8.07	7.21	9.18	15.6	10.0	3.80	0.38
4	0.40	1.40	6.49	2.76	3.27	1.18	7.74	7.18	5.52	13.2	8.40	3.31	0.39
5	0.92	0.51	6.40	2.61	3.29	1.26	4.86	6.42	4.00	14.3	7.40	4.73	0.64
6	1.33	0.00	4.85	2.06	2.51	1.22	8.94	5.13	4.88	5.04	6.00	1.97	0.33
7	2.03	2.13	1.01	1.72	0.62	0.36	12.6	6.69	5.23	--	8.16	3.89	0.48
8	7.68	3.23	3.82	4.91	2.42	0.49	9.53	9.74	4.99	11.9	9.03	2.90	0.32

Engine Output-Based CO Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test						
Notch	2/10	2/10	2/10	3 Reps	3 Reps	3 Reps	2/8	2/8	2/9	2/9	4 Trains	4 Trains	4 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	17.9	25.7	28.8	24.1	5.65	0.23	12.9	21.3	13.5	21.3	17.2	4.66	0.27
High Idle	20.0	70.6	38.8	43.1	25.6	0.59	36.4	30.6	22.4	33.0	30.6	5.98	0.20
Dyn Brake	--	--	--	--	--	--	52.9	36.3	23.0	35.7	37.0	12.2	0.33
1	0.37	0.50	1.42	0.77	0.57	0.75	1.38	1.73	1.74	2.80	1.91	0.61	0.32
2	0.20	0.65	1.30	0.72	0.55	0.77	0.91	0.81	0.52	1.44	0.92	0.38	0.42
3	0.05	0.12	0.36	0.18	0.16	0.90	0.41	0.38	0.44	0.70	0.48	0.15	0.30
4	0.02	0.07	0.33	0.14	0.16	1.18	0.36	0.34	0.25	0.61	0.39	0.16	0.40
5	0.05	0.03	0.33	0.13	0.17	1.26	0.23	0.31	0.19	0.69	0.36	0.23	0.64
6	0.07	0.00	0.26	0.11	0.13	1.22	0.45	0.27	0.25	0.26	0.30	0.10	0.31
7	0.10	0.11	0.05	0.09	0.03	0.36	0.44	0.29	0.21	--	0.32	0.12	0.37
8	0.43	0.18	0.21	0.27	0.14	0.50	0.47	0.46	0.24	0.57	0.44	0.14	0.32
Duty Cycle Avg (Raw)	0.41	0.33	0.47	0.40	0.07	0.17	0.61	0.60	0.38	0.80	0.59	0.17	0.29
Duty Cycle Avg (Adj)	0.41	0.33	0.47	0.40	0.07	0.17	0.61	0.60	0.38	0.80	0.59	0.17	0.29

Exhaust CO Concentrations (%)

Throttle	Rail Yard Test						Over-The-Rail Test						
Notch	2/10	2/10	2/10	3 Reps	3 Reps	3 Reps	2/8	2/8	2/9	2/9	4 Trains	4 Trains	4 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	0.006	0.009	0.010	0.008	0.00	0.24	0.005	0.007	0.005	0.008	0.006	0.00	0.28
High Idle	0.004	0.016	0.009	0.010	0.01	0.59	0.008	0.007	0.005	0.008	0.007	0.00	0.20
Dyn Brake	--	--	--	--	--	--	0.011	0.008	0.005	0.008	0.008	0.00	0.29
1	0.002	0.002	0.006	0.003	0.00	0.75	0.006	0.007	0.007	0.012	0.008	0.00	0.33
2	0.002	0.005	0.010	0.006	0.00	0.76	0.007	0.006	0.004	0.012	0.007	0.00	0.43
3	0.001	0.001	0.004	0.002	0.00	0.90	0.004	0.004	0.005	0.008	0.005	0.00	0.32
4	0.000	0.001	0.004	0.002	0.00	1.18	0.005	0.005	0.003	0.008	0.005	0.00	0.41
5	0.001	0.000	0.005	0.002	0.00	1.26	0.003	0.005	0.003	0.010	0.005	0.00	0.65
6	0.001	0.000	0.004	0.002	0.00	1.22	0.007	0.004	0.004	0.004	0.005	0.00	0.29
7	0.002	0.002	0.001	0.002	0.00	0.34	0.009	0.006	0.005	--	0.007	0.00	0.37
8	0.008	0.003	0.004	0.005	0.00	0.51	0.009	0.009	0.005	0.012	0.009	0.00	0.34

Table E-11. Measured Hydrocarbon Emission Rates for NC-1810 and B100

Time-Based HC Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test						
Notch	2/10	2/10	2/10	3 Reps	3 Reps	3 Reps	2/8	2/8	2/9	2/9	4 Trains	4 Trains	4 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	0.23	0.40	0.56	0.40	0.17	0.42	0.28	0.33	0.20	0.38	0.30	0.08	0.26
High Idle	0.27	0.93	0.88	0.69	0.36	0.53	0.63	0.45	0.37	0.45	0.47	0.11	0.23
Dyn Brake	--	--	--	--	--	--	0.80	0.51	0.40	0.54	0.56	0.17	0.30
1	0.15	0.31	0.48	0.31	0.17	0.53	0.52	0.42	0.49	0.71	0.53	0.12	0.23
2	0.21	0.48	0.69	0.46	0.24	0.53	0.63	0.38	0.51	0.60	0.53	0.11	0.21
3	0.24	0.42	0.71	0.45	0.24	0.52	0.73	0.44	0.58	0.68	0.61	0.13	0.21
4	0.16	0.51	0.66	0.44	0.26	0.58	0.78	0.52	0.61	1.03	0.74	0.23	0.31
5	0.18	0.34	0.74	0.42	0.29	0.69	1.04	0.64	0.63	1.49	0.95	0.41	0.43
6	0.20	0.22	0.99	0.47	0.45	0.95	1.25	0.62	0.80	0.99	0.92	0.27	0.29
7	0.06	0.90	0.38	0.45	0.43	0.95	0.90	0.53	0.84	--	0.75	0.20	0.26
8	0.12	0.15	0.23	0.17	0.06	0.34	1.10	0.60	0.36	1.13	0.80	0.38	0.47

Fuel-Based HC Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test						
Notch	2/10	2/10	2/10	3 Reps	3 Reps	3 Reps	2/8	2/8	2/9	2/9	4 Trains	4 Trains	4 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	278	473	607	453	166	0.37	311	373	216	499	350	119	0.34
High Idle	187	571	603	454	232	0.51	377	287	210	300	294	68.4	0.23
Dyn Brake	--	--	--	--	--	--	393	328	212	381	328	82.8	0.25
1	40.3	84.0	128	84.0	43.6	0.52	175	124	129	236	166	52.0	0.31
2	38.5	91.0	129	86.1	45.3	0.53	134	122	100	143	125	18.3	0.15
3	23.8	42.2	70.3	45.5	23.4	0.52	75.5	44.8	64.9	80.9	66.5	15.9	0.24
4	11.5	36.2	47.4	31.7	18.4	0.58	60.5	39.6	47.4	79.8	56.8	17.6	0.31
5	9.42	18.0	39.6	22.3	15.5	0.70	58.5	35.9	35.3	83.7	53.4	22.9	0.43
6	8.73	9.5	42.2	20.2	19.1	0.95	56.3	26.9	35.7	43.2	40.6	12.4	0.31
7	1.78	27.1	11.2	13.4	12.8	0.96	33.8	16.4	27.1	--	25.8	8.79	0.34
8	2.91	3.56	5.53	4.00	1.37	0.34	27.0	15.2	8.97	28.4	19.9	9.36	0.47

Engine Output-Based HC Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test						
Notch	2/10	2/10	2/10	3 Reps	3 Reps	3 Reps	2/8	2/8	2/9	2/9	4 Trains	4 Trains	4 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	83.5	142	202	143	59.4	0.42	103	117	72.1	138	108	27.9	0.26
High Idle	98.1	334	316	249	131	0.53	226	161	133	162	170	39.2	0.23
Dyn Brake	--	--	--	--	--	--	286	184	143	194	202	60.6	0.30
1	2.78	5.83	9.07	5.89	3.14	0.53	9.86	7.89	9.21	13.4	10.1	2.36	0.23
2	2.11	4.96	7.08	4.72	2.49	0.53	6.52	3.94	5.29	6.14	5.47	1.14	0.21
3	1.26	2.23	3.77	2.42	1.27	0.52	3.87	2.36	3.08	3.62	3.23	0.67	0.21
4	0.58	1.82	2.38	1.59	0.92	0.58	2.82	1.88	2.18	3.73	2.65	0.82	0.31
5	0.49	0.92	2.02	1.14	0.79	0.69	2.83	1.74	1.72	4.05	2.58	1.10	0.43
6	0.46	0.50	2.24	1.07	1.01	0.95	2.82	1.40	1.80	2.22	2.06	0.61	0.29
7	0.09	1.36	0.57	0.67	0.64	0.95	1.20	0.70	1.11	--	1.00	0.26	0.26
8	0.16	0.20	0.31	0.22	0.08	0.34	1.32	0.73	0.43	1.36	0.96	0.46	0.47
Duty Cycle Avg (Raw)	0.38	0.71	1.05	0.72	0.34	0.47	1.17	0.81	0.70	1.32	1.00	0.29	0.29
Duty Cycle Avg (Adj)	0.95	1.79	2.63	1.79	0.84	0.47	2.92	2.02	1.74	3.30	2.49	0.74	0.29

Exhaust HC Concentrations (ppm)

Throttle	Rail Yard Test						Over-The-Rail Test						
Notch	2/10	2/10	2/10	3 Reps	3 Reps	3 Reps	2/8	2/8	2/9	2/9	4 Trains	4 Trains	4 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	36	62	89	62	26.2	0.42	47	54	33	64	49	13.2	0.27
High Idle	28	96	91	72	37.7	0.53	66	47	39	48	50	11.6	0.23
Dyn Brake	--	--	--	--	--	--	74	54	39	59	57	14.5	0.26
1	15	31	49	32	17.0	0.54	55	44	51	76	57	13.7	0.24
2	21	50	71	47	24.8	0.52	67	40	54	65	57	12.2	0.22
3	17	30	51	33	17.3	0.52	54	33	42	52	45	9.6	0.21
4	10	32	41	28	16.0	0.58	49	33	38	67	47	15.0	0.32
5	9	17	38	22	15.1	0.69	54	34	33	79	50	21.8	0.44
6	9	10	44	21	20.2	0.96	55	29	36	46	41	11.7	0.28
7	2	30	13	15	14.2	0.93	33	19	31	--	28	7.53	0.27
8	4	4	7	5	1.67	0.33	34	19	11	36	25	12.1	0.49

Table E-12. Measured Particulate Matter Emission Rates for NC-1810 and B100

Time-Based PM Emission Rates (g/s)

Throttle Notch Position	Rail Yard Test						Over-The-Rail Test						
	2/10	2/10	2/10	3 Reps	3 Reps	3 Reps	2/8	2/8	2/9	2/9	4 Trains	4 Trains	4 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	0.01	0.01	0.01	0.01	0.00	0.05	0.01	0.01	0.01	0.01	0.01	0.00	0.08
High Idle	0.02	0.01	0.01	0.01	0.00	0.34	0.01	0.01	0.01	0.01	0.01	0.00	0.13
Dyn Brake	--	--	--	--	--	--	0.01	0.01	0.01	0.01	0.01	0.00	0.19
1	0.01	0.01	0.01	0.01	0.00	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.17
2	0.02	0.02	0.02	0.02	0.00	0.01	0.02	0.01	0.02	0.01	0.02	0.00	0.20
3	0.02	0.02	0.02	0.02	0.00	0.02	0.04	0.02	0.02	0.02	0.03	0.01	0.27
4	0.03	0.03	0.03	0.03	0.00	0.02	0.05	0.03	0.03	0.04	0.04	0.01	0.18
5	0.04	0.04	0.04	0.04	0.00	0.01	0.05	0.04	0.05	0.05	0.05	0.00	0.05
6	0.05	0.05	0.05	0.05	0.00	0.03	0.07	0.07	0.06	0.07	0.07	0.01	0.08
7	0.18	0.17	0.15	0.17	0.02	0.10	0.15	0.15	0.14	--	0.15	0.01	0.06
8	0.44	0.24	0.21	0.30	0.13	0.43	0.32	0.24	0.23	0.27	0.27	0.04	0.15

Fuel-Based PM Emission Rates (g/gal)

Throttle Notch Position	Rail Yard Test						Over-The-Rail Test						
	2/10	2/10	2/10	3 Reps	3 Reps	3 Reps	2/8	2/8	2/9	2/9	4 Trains	4 Trains	4 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	13.8	12.6	12.0	12.8	0.95	0.07	12.5	12.0	11.0	12.3	11.9	0.65	0.05
High Idle	11.1	6.71	5.72	7.84	2.85	0.36	8.00	6.43	5.98	7.53	6.99	0.94	0.13
Dyn Brake	--	--	--	--	--	--	7.95	6.84	6.77	8.10	7.42	0.70	0.10
1	4.98	5.11	5.02	5.04	0.07	0.01	7.93	5.29	5.07	5.44	5.93	1.34	0.23
2	3.89	3.93	3.85	3.89	0.04	0.01	5.81	5.72	4.17	4.44	5.03	0.85	0.17
3	2.91	2.90	2.98	2.93	0.04	0.01	5.13	3.26	3.36	3.57	3.83	0.88	0.23
4	3.03	2.97	2.94	2.98	0.05	0.02	4.65	3.17	3.33	3.68	3.71	0.66	0.18
5	3.01	2.97	2.96	2.98	0.03	0.01	3.61	3.49	3.78	3.96	3.71	0.20	0.05
6	2.95	2.79	2.90	2.88	0.08	0.03	4.26	3.92	3.57	4.12	3.97	0.30	0.08
7	6.92	6.60	5.73	6.42	0.62	0.10	7.20	6.14	5.70	--	6.34	0.77	0.12
8	14.1	7.64	6.68	9.46	4.01	0.42	10.5	7.94	7.70	9.12	8.80	1.27	0.14

Engine Output-Based PM Emission Rates (g/bhp-hr)

Throttle Notch Position	Rail Yard Test						Over-The-Rail Test						
	2/10	2/10	2/10	3 Reps	3 Reps	3 Reps	2/8	2/8	2/9	2/9	4 Trains	4 Trains	4 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	2.85	2.60	2.73	2.73	0.13	0.05	2.81	2.59	2.52	2.34	2.57	0.20	0.08
High Idle	5.47	3.69	2.82	3.99	1.35	0.34	4.49	3.40	3.55	3.82	3.81	0.49	0.13
Dyn Brake	--	--	--	--	--	--	4.28	2.84	3.38	3.04	3.38	0.64	0.19
1	0.22	0.23	0.23	0.23	0.00	0.02	0.29	0.22	0.24	0.20	0.24	0.04	0.17
2	0.16	0.16	0.16	0.16	0.00	0.01	0.21	0.14	0.16	0.14	0.16	0.03	0.20
3	0.11	0.11	0.12	0.11	0.00	0.02	0.19	0.13	0.12	0.12	0.14	0.04	0.27
4	0.12	0.11	0.11	0.12	0.00	0.02	0.17	0.12	0.12	0.13	0.13	0.02	0.18
5	0.11	0.11	0.11	0.11	0.00	0.01	0.12	0.12	0.13	0.14	0.13	0.01	0.05
6	0.12	0.11	0.11	0.11	0.00	0.03	0.16	0.15	0.13	0.16	0.15	0.01	0.08
7	0.27	0.26	0.22	0.25	0.02	0.10	0.20	0.20	0.18	--	0.20	0.01	0.06
8	0.59	0.32	0.28	0.39	0.17	0.43	0.38	0.28	0.28	0.33	0.32	0.05	0.15
Duty Cycle Avg (Raw)	0.09	0.05	0.05	0.06	0.02	0.33	0.06	0.05	0.05	0.06	0.05	0.01	0.13
Duty Cycle Avg (Adj)	0.43	0.27	0.24	0.31	0.10	0.33	0.32	0.25	0.24	0.28	0.27	0.04	0.13

Exhaust PM Concentrations (mg/m^3)

Throttle Notch Position	Rail Yard Test						Over-The-Rail Test						
	2/10	2/10	2/10	3 Reps	3 Reps	3 Reps	2/8	2/8	2/9	2/9	4 Trains	4 Trains	4 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	2.4	2.2	2.3	2.3	0.10	0.04	2.5	2.3	2.2	2.1	2.3	0.17	0.07
High Idle	2.9	1.9	1.5	2.1	0.70	0.34	2.4	1.8	1.9	2.1	2.0	0.26	0.13
Dyn Brake	--	--	--	--	--	--	2.1	1.6	1.7	1.7	1.8	0.22	0.12
1	2.3	2.4	2.4	2.4	0.06	0.02	3.1	2.3	2.5	2.2	2.6	0.42	0.16
2	3.0	3.0	3.0	3.0	0.03	0.01	4.1	2.7	3.2	2.8	3.2	0.64	0.20
3	3.0	2.9	3.1	3.0	0.07	0.02	5.2	3.4	3.1	3.2	3.7	0.98	0.26
4	3.9	3.8	3.8	3.8	0.07	0.02	5.6	3.9	3.9	4.6	4.5	0.79	0.18
5	4.0	3.9	3.9	4.0	0.05	0.01	4.6	4.5	4.8	5.1	4.8	0.27	0.06
6	4.4	4.2	4.4	4.3	0.13	0.03	6.0	6.0	5.2	6.3	5.9	0.49	0.08
7	11.6	10.6	9.7	10.6	0.93	0.09	10.2	10.3	9.4	--	10.0	0.49	0.05
8	25.4	13.4	11.8	16.9	7.45	0.44	18.5	13.9	13.0	16.4	15.5	2.48	0.16

Table E-13. Measured CO_2 Emission Rates for NC-1810 and B100

Time-Based CO_2 Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test						
Notch	2/10	2/10	2/10	3 Reps	3 Reps	3 Reps	2/8	2/8	2/9	2/9	4 Trains	4 Trains	4 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	8.19	8.08	8.85	8.37	0.42	0.05	9.00	8.49	9.18	7.44	8.53	0.78	0.09
High Idle	14.4	15.5	14.0	14.6	0.78	0.05	16.2	15.3	17.3	14.7	15.9	1.16	0.07
Dyn Brake	--	--	--	--	--	--	19.7	15.2	18.5	13.7	16.8	2.78	0.17
1	36.5	36.6	37.4	36.8	0.46	0.01	29.6	33.4	37.4	29.5	32.5	3.78	0.12
2	53.6	53.0	53.2	53.3	0.31	0.01	47.2	31.4	51.3	41.6	42.8	8.62	0.20
3	100	99.4	101	100	0.78	0.01	96.3	99.2	89.3	83.9	92.2	6.89	0.07
4	141	140	140	140	0.58	0.00	130	132	128	130	130	1.75	0.01
5	191	190	189	190	1.11	0.01	178	180	180	178	179	0.91	0.01
6	236	235	236	236	0.63	0.00	223	232	225	230	227	4.31	0.02
7	339	336	338	337	1.53	0.00	266	323	309	--	299	29.6	0.10
8	422	417	418	419	3.04	0.01	410	399	406	401	404	4.80	0.01

Fuel-Based CO_2 Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test						
Notch	2/10	2/10	2/10	3 Reps	3 Reps	3 Reps	2/8	2/8	2/9	2/9	4 Trains	4 Trains	4 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	9810	9650	9565	9675	124	0.01	9822	9739	9878	9648	9772	101	0.01
High Idle	9900	9534	9588	9674	198	0.02	9747	9812	9889	9794	9810	59.3	0.01
Dyn Brake	--	--	--	--	--	--	9719	9771	9891	9729	9778	78.7	0.01
1	10041	10011	9964	10006	38.6	0.00	9929	9955	9957	9852	9923	49.3	0.00
2	10045	10000	9958	10001	43.4	0.00	9963	9960	9997	9934	9964	25.9	0.00
3	10058	10045	10020	10041	19.1	0.00	10015	10035	10020	10000	10018	14.5	0.00
4	10067	10050	10035	10050	15.8	0.00	10025	10039	10036	10005	10026	15.6	0.00
5	10067	10062	10040	10056	14.5	0.00	10031	10042	10046	10000	10030	20.7	0.00
6	10067	10068	10041	10059	15.5	0.00	10026	10050	10045	10040	10040	10.4	0.00
7	10070	10054	10066	10063	8.12	0.00	10034	10054	10049	--	10046	10.5	0.00
8	10060	10067	10065	10064	3.36	0.00	10043	10050	10061	10038	10048	9.89	0.00

Engine Output-Based CO_2 Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test						
Notch	2/10	2/10	2/10	3 Reps	3 Reps	3 Reps	2/8	2/8	2/9	2/9	4 Trains	4 Trains	4 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	2950	2907	3186	3014	150	0.05	3239	3056	3304	2680	3069	280	0.09
High Idle	5199	5574	5022	5265	281	0.05	5825	5508	6237	5276	5711	416	0.07
Dyn Brake	--	--	--	--	--	--	7083	5480	6672	4941	6044	1001	0.17
1	692	694	708	698	8.77	0.01	561	633	709	559	615	71.6	0.12
2	551	545	547	548	3.20	0.01	485	323	527	428	441	88.6	0.20
3	531	530	538	533	4.14	0.01	514	529	476	448	492	36.7	0.07
4	508	505	504	505	2.07	0.00	467	476	461	467	468	6.29	0.01
5	519	516	513	516	3.02	0.01	485	488	489	483	486	2.47	0.01
6	531	529	532	531	1.42	0.00	501	523	506	517	512	9.70	0.02
7	508	504	507	506	2.29	0.00	355	430	412	--	399	39.5	0.10
8	563	555	557	559	4.06	0.01	492	479	487	481	485	5.75	0.01

Exhaust CO_2 Concentrations (%)

Throttle	Rail Yard Test						Over-The-Rail Test						
Notch	2/10	2/10	2/10	3 Reps	3 Reps	3 Reps	2/8	2/8	2/9	2/9	4 Trains	4 Trains	4 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	0.62	0.62	0.68	0.64	0.03	0.05	0.73	0.69	0.73	0.61	0.69	0.06	0.08
High Idle	0.73	0.78	0.71	0.74	0.04	0.05	0.84	0.79	0.89	0.77	0.82	0.05	0.06
Dyn Brake	--	--	--	--	--	--	0.90	0.78	0.89	0.74	0.83	0.08	0.10
1	1.81	1.82	1.87	1.83	0.03	0.02	1.54	1.72	1.93	1.55	1.69	0.19	0.11
2	2.71	2.68	2.67	2.68	0.02	0.01	2.45	1.62	2.64	2.20	2.23	0.44	0.20
3	3.54	3.53	3.58	3.55	0.03	0.01	3.50	3.62	3.20	3.13	3.36	0.24	0.07
4	4.29	4.27	4.26	4.27	0.01	0.00	3.97	4.10	3.89	4.09	4.01	0.10	0.02
5	4.80	4.78	4.77	4.78	0.02	0.00	4.56	4.64	4.57	4.63	4.60	0.04	0.01
6	5.10	5.11	5.16	5.12	0.03	0.01	4.81	5.21	4.92	5.20	5.04	0.20	0.04
7	5.71	5.48	5.79	5.66	0.16	0.03	4.80	5.74	5.63	--	5.39	0.52	0.10
8	6.27	6.09	6.12	6.16	0.10	0.02	6.13	6.08	5.87	6.22	6.08	0.15	0.02

E.2 Summary of Results for NC-1810 on B80

The purpose of these RY and OTR emissions measurements of the prime mover engine was to compare fuel use and emission rates of one locomotive on ultra-low sulfur diesel (ULSD) baseline and the four biodiesel fuel blends.

RY and OTR measurements were conducted in December 2013 on the prime mover engine of locomotive NC-1810 operating on an 80 percent soy-based biodiesel and 20 percent ULSD blend (B80). Rail yard and over-the-rail measurements were conducted in August, October, and November 2013 on the prime mover engine of locomotive NC-1810 (City of Greensboro) operating on a 60 percent soy-based biodiesel and 40 percent ULSD blend (B60). These measurements were conducted as part of a Federal Railroad Administration (FRA) research project to evaluate the emissions implications of biodiesel use in locomotives compared to several different biodiesel fuel blends.

The prime mover engine was an EMD 12-710G3B. The engine was originally manufactured in 1988 and was rebuilt by AMTRAK in 2012. The 140-Liter engine has a peak engine output of 3000 horsepower (hp) at an engine speed of 900 revolutions per minute (rpm).

The PEMS utilized for measurements was the Axion system manufactured by Clean Air Technologies International, Inc. (CATI). Prior to measurements, the PEMS was calibrated with a California Bureau of Automotive Repair (BAR) certified calibration gas (BAR-97 Low).

The cycle average emission rates for the rail yard and over-the-rail measurements of the NC-1810 prime mover engine with the Axion are shown in Table E-14. The cycle average emission rates are based on the line-haul duty cycle used by the U.S. Environmental Protection Agency (EPA) for regulatory purposes. Three replicates of each rail yard measurement were conducted. During rail yard measurements, dynamic braking is not observed; thus, the time apportioned for dynamic braking in the line-haul duty cycle (12.5 percent) was combined with the time apportioned for idling in the line-haul duty cycle (38.0 percent). Therefore, idling accounts for 50.5 percent of the duty cycle used to calculate rail yard cycle average emission rates. Over-the-rail measurements were made during six one-way trips between Raleigh and Charlotte, NC. During over-the-rail measurements, dynamic braking was observed.

Table E-14. Preliminary Cycle Average Emission Rates for the NC-1810 Prime Mover Engine Operated on B80 Biodiesel in the Rail Yard and Over-the-Rail[a,b,c]

Measurement	NO_x (g/bhp-hr)	HC (g/bhp-hr)	CO (g/bhp-hr)	Opacity-based PM (g/bhp-hr)
Rail Yard	7.1	0.25	0.73	0.32
Over-the-Rail	6.8	1.93	0.49	0.27
EPA Tier 0+	**8.0**	**1.00**	**5.0**	**0.22**
EPA Tier 1+	7.4	0.55	2.2	0.22

[a] The cycle average emission rates are based on the U.S. EPA line-haul duty cycle, which was used for regulatory purposes.

[b] NO_x, HC, and opacity-based PM emission rates from the Axion are adjusted with multipliers of 1.053, 2.5, and 5, respectively, as bias correction. For B80 biodiesel measurements, PM emission rates are corrected based on the correction factors developed from the NC-1859 on B20 biodiesel measurements.

[c] Dynamic braking not observed during rail yard measurements. Therefore, idling accounts for 50.5 percent of the duty cycle used to calculate rail yard cycle average emission rates.

This section discusses the results of the RY and OTR measurements of the NC-1810 prime mover engine operated on B80 biodiesel, and comparison to previously measurements on B60 biodiesel.

Rail Yard Measurements

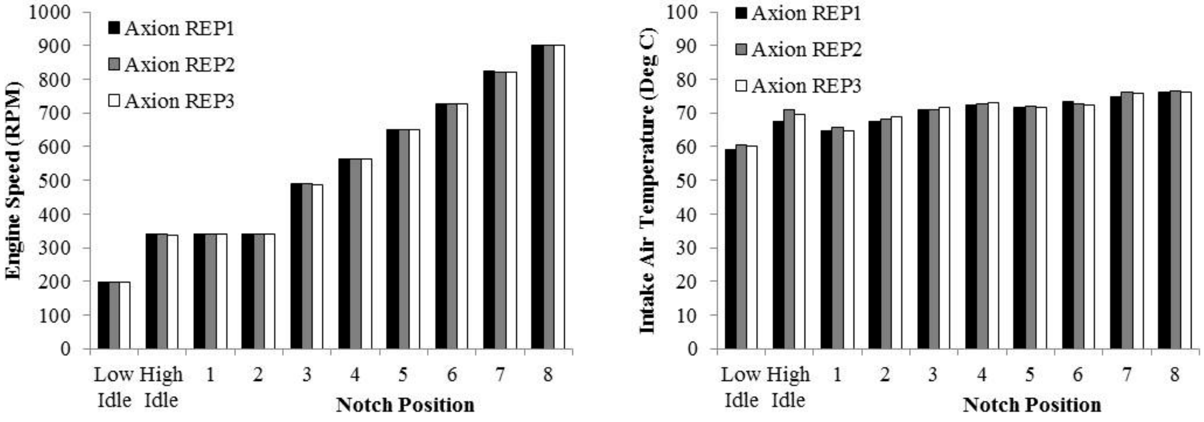
Three RY emissions measurement replicates on the prime mover engine of NC-1810 on B80 biodiesel were conducted on December 22, 2013. Results for these rail yard measurements are presented and discussed in this section.

The cycle average emission rates for the rail yard measurements of the NC-1810 prime mover engine are shown in Table E-15. These cycle average emission rates are based on the measured engine activity data (RPM, MAP, and IAT), inferred engine activity data (MAF, AFR, and VE), and measured exhaust concentrations. For the rail yard measurements of the NC-1810 prime mover engine operated on B80 biodiesel, there was little variability between replicate measured engine activity data, given in Figure E-8. This indicates that the prime mover engine was operating consistently during all three replicate measurements.

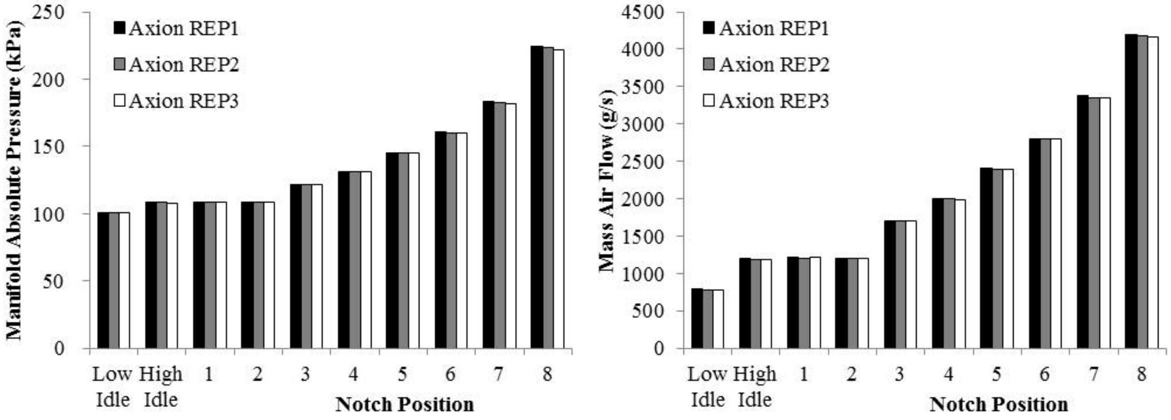
For the rail yard measurements of the NC-1810 prime mover engine operated on B80 biodiesel, an increasing trend in fuel use rates was apparent as notch position increased during the rail yard measurements, as shown in Figure E-9. The standard deviations across the three replicates were less than 1 RPM for all notches. The NO emission rates estimated with the Axion during the three replicates were fairly consistent, as shown in Figure E-10. The inter-replicate ratios of the standard deviation to the mean (coefficient of variation) for each notch position for the mass per gallon of fuel NO emission rates range from 0.01 to 0.04, which indicates small variability between replicates. There was variability in the estimated HC emission rates between the three replicate measurements, as shown in Figure E-11. Inter-replicate coefficient of variation in the estimated HC emission rates were, on average for each notch position, 49 percent. Differences in measured exhaust HC concentrations were the primary reason for the inter-replicate variability. Across the three replicates, the coefficient of variation varied from 0.18 to 1.35, depending on the notch position. Large variability was observed in idle and notches 7 and 8. There was also variability in the estimated CO emission rates between the three replicate measurements, as shown in Figure E-12. Inter-replicate coefficient of variation in the estimated CO emission rates were (on average for each notch position) 45 percent. For CO exhaust concentrations, the coefficient of variation varied from 0.06 to 0.82, depending on the notch position. Therefore, differences in measured exhaust concentrations primarily contributed to the variability in mass emission rates when comparing replicates. However, on an absolute basis, the exhaust CO concentrations were very low. PM emission rates, as shown in Figure E-13, were fairly consistent across the three replicates, with inter-replicate coefficient of variation less than 0.20 for all notch positions. Both the NO, CO, HC, and PM concentrations measured were of the same magnitude as previous rail yard measurements on NC-1810 prime mover engine operating on B60.

Table 3 gives the estimated cycle average emission rates for the three replicate rail yard measurements on the NC-1810 prime mover engine when it was operated on B80. For each set of measurements, there was little variability in the NO_x and PM cycle average emission rates among the replicates. For measurements on B80 biodiesel amongst the three replicates, the average coefficient of variation for each notch position, averaged over all notch positions for CO and HC, are 8 and 47 percent respectively. Differences in emission rates are attributable to differences in measured exhaust concentrations. Values for engine activity parameters (RPM, IAT, MAP) were similar across all measurements, as given in Figure E-8.

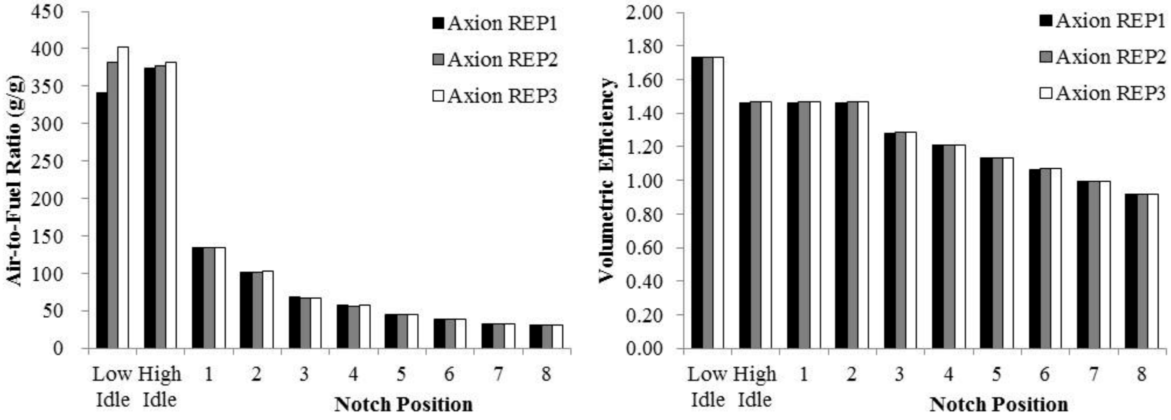
Figure E-8. Measured Engine Activity Data during Rail Yard Measurements of the NC-1810 Prime Mover Engine Operated on B80 Biodiesel



(a) Engine Speed (b) Intake Air Temperature



(c) Manifold Absolute Pressure (d) Mass Air Flow



(e) Air-to-Fuel Ratio (f) Volumetric Efficiency

Figure E-9. Estimated Fuel Use Rates during Rail Yard Measurements of the NC-1810 Prime Mover Engine Operated on B80 Biodiesel

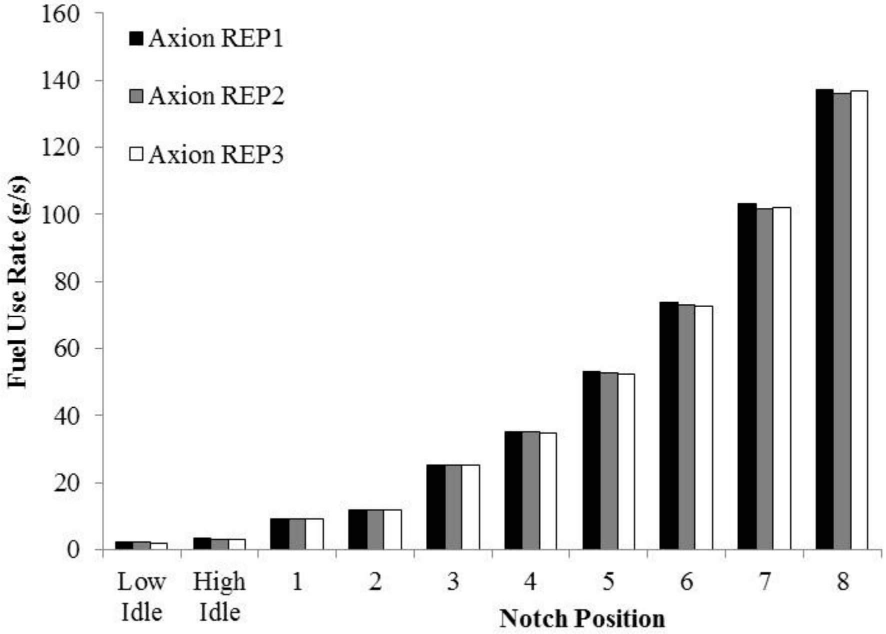


Figure E-10. Estimated NO_x Emission Rates during Rail Yard Measurements of the NC-1810 Prime Mover Engine Operated on B80 Biodiesel

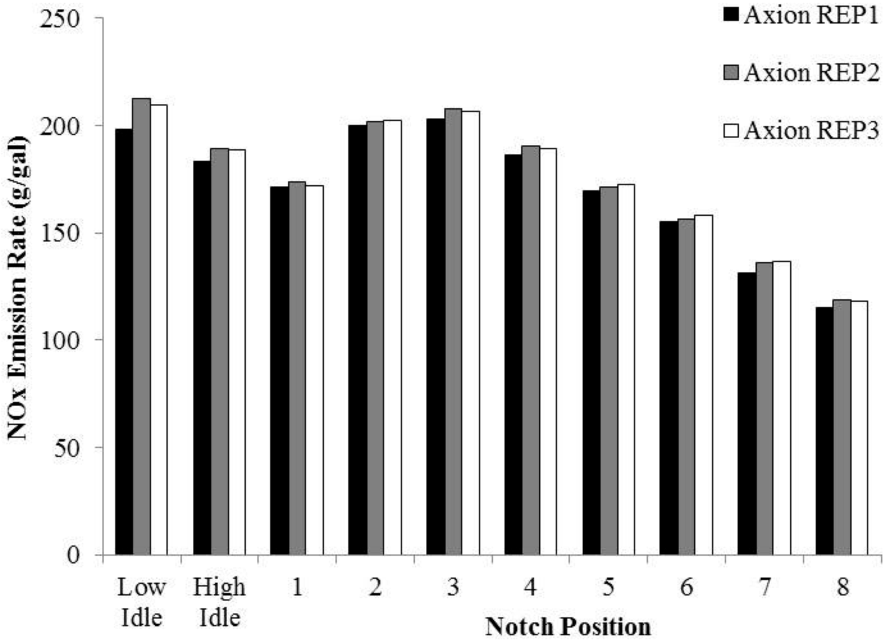


Figure E-11. Estimated HC Emission Rates during Rail Yard Measurements of the NC-1810 Prime Mover Engine Operated on B80 Biodiesel

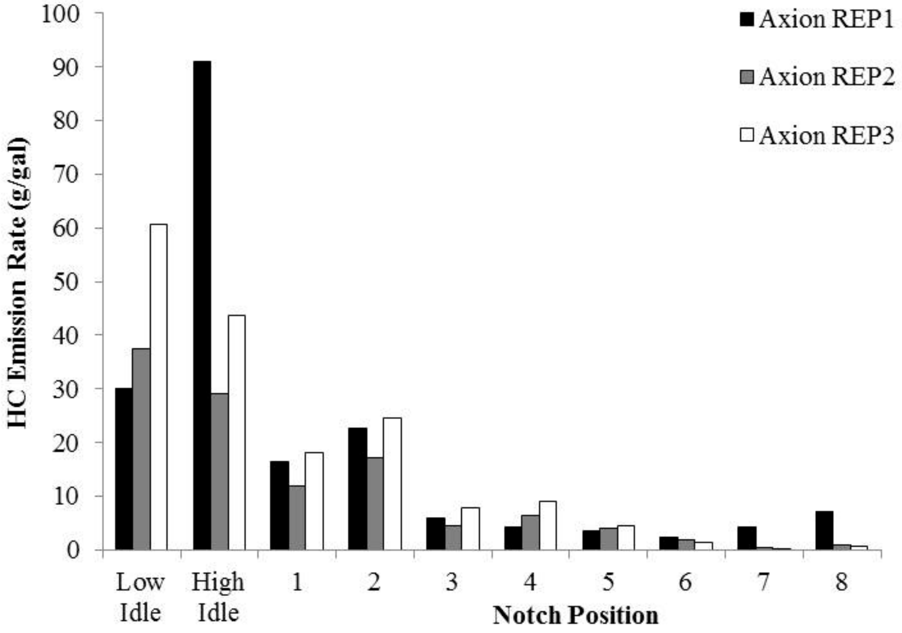


Figure E-12. Estimated CO Emission Rates during Rail Yard Measurements of the NC-1810 Prime Mover Engine Operated on B80 Biodiesel

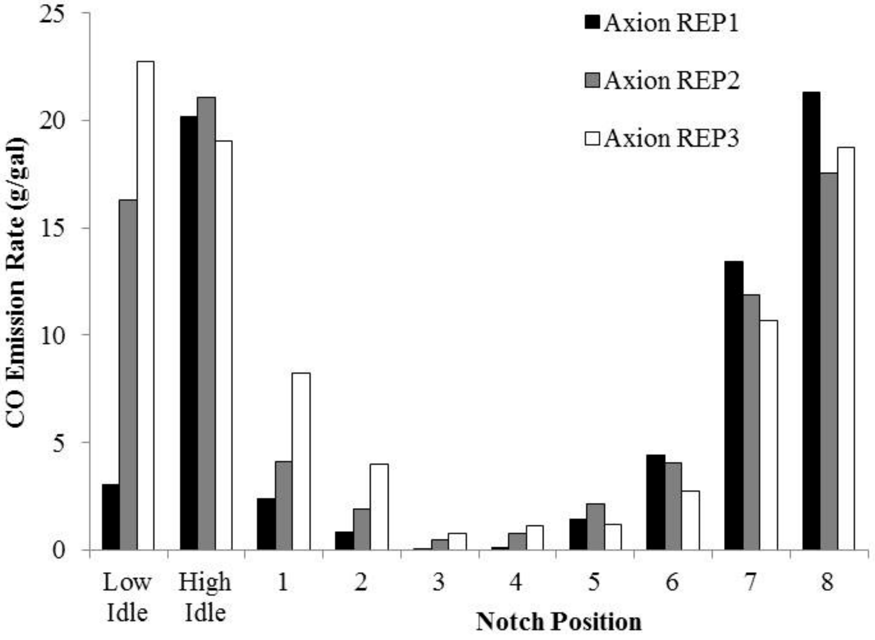


Figure E-13. Measured PM Concentrations during Rail Yard Measurements of the NC-1810 Prime Mover Engine Operated on B80 Biodiesel

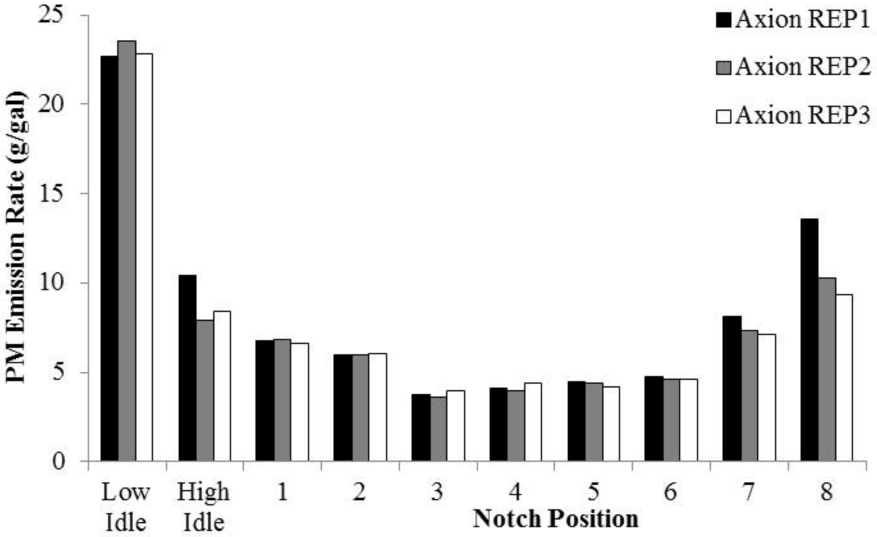


Table E-15. Cycle Average Emission Rates for Rail Yard Replicate Measurements of NC-1810 Prime Mover Engine Operated on B80

	NO_x **(g/bhp-hr)**	**HC** **(g/bhp-hr)**	**CO** **(g/bhp-hr)**	**Opacity-based PM** **(g/bhp-hr)**
Replicate 1	7.1	0.38	0.79	0.38
Replicate 2	7.2	0.16	0.68	0.30
Replicate 3	7.2	0.21	0.73	0.28
Average of 3 Replicates	**7.1**	**0.25**	**0.73**	**0.32**
EPA Tier 0+	**8.0**	**1.00**	**5.0**	**0.22**
EPA Tier 1+	7.4	0.55	2.2	0.22

† NO_x, HC, and PM are adjusted with multipliers of 1.05, 2.5, and 5, respectively, as bias correction. For B80 biodiesel measurements, PM emission rates are corrected based on the correction factors developed from the NC-1859 on B20 biodiesel measurements.

†† Cycle average emission rates are based on EPA Line-Haul driving cycle.

Over-the-Rail Measurements

Three days of over-the-rail measurements on the NC-1810 prime mover engine operating on B80 biodiesel were conducted on December 19 to 21, 2013. Three days of over-the-rail measurements on the NC-1810 prime mover engine operating on B60 biodiesel were conducted on August 9 to 10, and October 26, 2013. Results for the over-the-rail measurements are presented and discussed in this section.

The cycle average emission rates for the over-the-rail measurements of the NC-1810 prime mover engine operating on B80 biodiesel are shown in Table E-16. These cycle average emission rates are based on the measured engine activity data (RPM, MAP, and IAT) and measured exhaust concentrations. For each set of measurements, there was little variability between measured engine activity data during all three days of measurements. This indicates that the prime mover engine was operating consistently during over-the-rail measurements. Measured engine activity data during over-the-rail measurements were similar to the measured engine activity data during rail yard measurements.

For each set of the measurements, there was variability in the NO_x cycle average emission rates among the trips. For train 74 on December 20, 2013, the NO_x emission rates were lower than the other measurements. The NO_x concentrations measured for that train were lower than the average of the other measurements by 82 percent in low idle, and 16 percent in notch 8. The EPA estimated long haul driving cycle for low idle and notch 8 were 50.5 percent and 16.5 percent, respectively. Therefore, the cycle average NO_x emission rates for that train was lower than the others. Amongst the six one way trips, the average coefficient of variation for each notch position, averaged over all notch positions, for CO and HC are 41 and 48 percent, respectively, for B80 biodiesel. For PM cycle average emission rates among the trips, the coefficient of variation were less than 23 percent for all notch positions for the available six one-way trips for B80 biodiesel measurements. Differences in measured exhaust pollutant concentrations were one of the key reasons for the variability. The average coefficient of variation for each notch position, averaged over all notch positions, for the exhaust concentrations across the six one way trips were 41 percent and 47 percent for CO and HC, respectively, for B80 biodiesel. Differences in PM emission rates are partially attributable to different PM photometers used.

For the NC-1810 prime mover engine operating on B80 biodiesel, the cycle average over-the-rail emission rates are quantitatively similar to the cycle average rail yard emission rates. The average cycle averages over-the-rail NO_x emission rate over six one-way trips were very close to the cycle average rail yard emission rates, within 4 percent of differences. The cycle average over-the-rail HC emission rates were approximately more than 6 times higher than the cycle average from rail yard measurements. The cycle average over-the-rail CO emission rates were 30 percent lower than the rail yard cycle average rates. The cycle average over-the-rail PM emission rates were 15 percent lower than the rail yard cycle average rates. However, on an absolute basis, the cycle average HC, CO, and PM emission rates were very close to the cycle average PM emission rate estimated from rail yard measurements.

Differences in cycle average emission rates between rail yard and over-the-rail measurements can be attributed to various factors. RPM and MAP was essentially the same for rail yard and over-the-rail measurements. IAT differed on an absolute basis by less than 6 percent from run-to-run during over-the-rail measurements. At notch 8, the engine output during rail yard measurements was 2700 horsepower, while engine output was 3000 horsepower during over-the-rail measurements. With notch 8 accounting for 16 percent of the EPA line-haul duty cycle used to estimate cycle average emission rates, higher engine output decreases engine output based emission rates and, therefore, cycle average emission rates. Finally, differences in measured exhaust concentrations between rail yard and over-the-rail measurements lead to differences in fuel use and emission rates.

Throttle notch position data was obtained from the locomotive data activity recorder to measure the duty cycles for the over-the-rail measurements. The measured duty cycles are compared to the EPA line-haul duty cycle in Table E-17. The prime mover engine operated in notch 8 during the over-the-rail tests more than double the percentage of time, on average, the EPA estimates a line-haul locomotive is operating in notch 8. The average percentage of time the prime mover engine operated in Idle through notch 7 during the over-the-rail tests was lower than the percentage of time the EPA estimates a line-haul locomotive is operating in those throttle notch settings, with the exception of Dynamic Braking, where the amount of time spent during the six one-way trips was similar to the percentage of time allocated in the line-haul duty cycle.

Table E-16. Cycle Average Emission Rates for Over-the-Rail Measurements of NC-1810 Prime Mover Engine Operated on B80 Biodiesel

	NO_x **(g/bhp-hr)**	**HC** **(g/bhp-hr)**	**CO** **(g/bhp-hr)**	**Opacity-based PM** **(g/bhp-hr)**
Dec. 19, 2013 – Train 73	7.2	3.03	0.41	0.21
Dec. 19, 2013 – Train 74	6.7	1.87	0.44	0.26
Dec. 20, 2013 – Train 73	7.6	1.94	0.40	0.28
Dec. 20, 2013 – Train 74	4.7	2.03	0.39	0.27
Dec. 21, 2013 – Train 73	7.2	1.42	0.47	0.30
Dec. 21, 2013 – Train 74	7.6	1.33	0.85	0.29
Average	**6.8**	**1.93**	**0.49**	**0.27**
EPA Tier 0+	**8.0**	**1.00**	**5.0**	**0.22**
EPA Tier 1+	7.4	0.55	2.2	0.22

† NO_x, HC, and PM are adjusted with multipliers of 1.05, 2.5, and 5, respectively, as bias correction. For B80 biodiesel measurements, PM emission rates are corrected based on the correction factors developed from the NC-1859 on B20 biodiesel measurements.

†† Cycle average emission rates are based on EPA Line-Haul driving cycle.

Table E-17. Over-the-Rail Duty Cycles during Measurement of NC-1810 Operated on B80 Biodiesel

Notch	Percent Time in Each Notch							
	EPA Line-Haul	Measured Over-the-Rail						
		Average	12/19/2013 Train 73	12/19/2013 Train 74	12/20/2013 Train 73	12/20/2013 Train 74	12/21/2013 Train 73	12/21/2013 Train 74
Idle	38.0	27.6	38.4	23.7	24.8	39.5	25.7	13.5
DB	12.5	11.6	7.0	10.4	14.5	12.9	15.5	9.4
1	6.5	4.8	5.5	8.7	3.0	1.3	1.9	8.4
2	6.5	4.9	8.7	6.4	2.0	4.1	1.2	6.8
3	5.2	4.2	5.5	4.2	2.9	3.1	1.4	8.2
4	4.4	3.3	3.5	6.1	1.9	2.8	1.6	4.2
5	3.8	1.9	1.1	2.1	2.4	2.4	1.2	2.2
6	3.9	2.9	0.2	10.1	3.0	2.6	0.5	0.7
7	3.0	0.7	0.0	2.0	1.5	0.3	0.5	0.1
8	16.2	38.1	30.1	26.3	44.0	31.0	50.5	46.6

Details of results of the field measurements and of the fuel use and emission rates for RY and OTR measurements of NC-1810 using B80 biodiesel are given in attached supplemental tables.

Table E-18 summarizes the average measured engine speed (RPM), intake air temperature (IAT), manifold absolute pressure (MAP), estimated mass air flow (MAF), and air-to-fuel ratio (AFR) for each throttle notch position and for each replicate of the rail yard (RY) test and for each one-way over-the-rail (OTR) trip. Engine speed ranges from 197 to 902 RPM in both RY and OTR measurements. For the RY measurements, engine RPM was highly repeatable, with a standard deviation of less than 2 RPM for all notch positions. For the OTR measurements, the RPM was also repeatable, with a standard deviation of 1 RPM or less except for dynamic breaking. For some one-way trips, the sample sizes in notch 6 and 7 are too small to infer a steady-state engine operating speed. For dynamic breading, the ratios of standard deviation to the mean of the six trips were less than 0.10. The intake air temperature varies with ambient temperature and was generally in the range of 58 to 79 degrees C during all measurements. MAP was highly repeatable in the RY tests, ranging from 99 to 234 kPa among notch positions with an inter-test standard deviation of less than 2 kPa for each notch position. For OTR measurements, there was slightly more inter-run variability. However, the ratio of the standard deviation to the mean of the run average MAP values for each notch position was typically 0.03 or less.

Estimated MAF was highly repeatable for both RY and OTR measurements, ranging from 760 to 4,400 g/s, with the ratio of the standard deviation to the mean of 0.08 or less for all notches. Estimated AFR was highly repeatable in the RY tests, with standard deviations less than 4 for all notches except for low idle. For OTR measurements, there was more inter-run variability. The ratio of the standard deviation to the mean was typically less than 0.6. Estimated VE was highly repeatable in both the RY and OTR measurements, ranging from 0.9 to 1.8. For all notches, the standard deviation was less than 0.10. Overall, the engine activity during the measurements was consistent from test to test for the three replicates in the rail yard, and from run to run for the six one-way trips observed between Raleigh and Charlotte.

Table E-19 summarizes the estimated fuel use rates inferred from the engine data of Table E-18. For the RY tests, fuel use rates from 1.9 to 137 g/sec depending on notch position, and was highly repeatable, with a coefficient of variation (CV, which was standard deviation divided by the mean) of typically 0.01 or less at high engine load. The CV was slightly higher at low engine load, but the absolute variability in fuel use rates at low load was small. There was more variability in run-to-run estimates of fuel use for the OTR measurements, in part because the amount of time spent in some notch positions was low. The OTR estimated fuel use ranged from 0.6 to 134 g/sec, depending on notch position. The CV was typically less than 0.3, except for Low Idle and Notch 1.

During RY measurements, the maximum engine output was 2,700 hp, whereas during OTR measurements the maximum engine output was 3,000 hp. Furthermore, as shown later in Table E-24, the average CO_2 concentrations for each notch position are lower for OTR than for RY measurements, which implies a lower fuel-to-air ratio. Because the engine activity and, therefore, engine air flow, are approximately the same for OTR versus RY measurements, the combination of higher engine output and lower fuel-to-air ratio lead to higher values of fuel-specific engine output (FSEO) in bhp-hr per gallon of fuel consumed, as shown in Table E-19. The FSEO was highly repeatable for the OTR measurements of all notches, especially Notch 8, which represents significant portion of the observed duty cycle.

The measured NO exhaust concentration and the estimated NO_x emission rates are shown in Table E-20 for each notch position, each RY test replicate, and each OTR one-way run. The average measured concentrations range among notch positions from approximately 90 to 710 ppm in the RY tests, and 20 to 760 ppm in the OTR measurements. The measurements are highly repeatable for the RY measurements, with CVs typically less than 0.06. For over-the-rail measurements, the NO exhaust concentrations were lower for train 74 on December 20, 2013 compared to the other measurements. Without this train, the CVs for the other measurements for all notches were typically less than 0.2 except low idle. The estimated mass emission rates range from 0.1 to 5.0 g/sec for the RY measurements and 0.1 to 5.7 g/sec for the OTR measurements. Because the observed concentrations tend to be higher for the OTR versus RY measurements, the mass emission rates also tend to be slightly higher for the OTR versus RY measurements.

On a fuel basis, the average NO_x emission rates range from 110 to 220 g/gallon among notch positions for the RY measurements and 120 to 340 g/gallon for the OTR measurements. For the RY measurements, the fuel-based emission rates are highly repeatable, with CV typically less than 0.04. The OTR measurements have slightly more run-to-run variability but are nonetheless consistent, with CVs less than 0.20 except for low idle. The fuel-based emission rates tend to be lowest at high load.

On an engine output basis, the notch average NO_x emission rates range from 6.4 g/bhp-hr at notch 8 to 9.0 g/bhp-hr at notch 1 in the RY measurements, with very high values at idle during which engine output was very low. For the OTR measurements, the notch average emission rates range from 5.1 g/bhp-hr at notch 8 to 11.4 g/bhp-hr at Notch 1, with much higher values during idle and dynamic braking. In general, the emission rates on an engine output basis are higher for the OTR measurements than for the RY measurements. This results from a combination of lower exhaust concentration and higher engine output, especially at Notch 8.

Results are given for exhaust concentrations and emission rates in Tables E-21, E-22, E-23, and E-24 for CO, HC, PM, and CO_2, respectively. The CO exhaust concentrations during OTR measurements tend to be higher than during RY measurements, a result of higher measured exhaust concentrations. Thus, the cycle average CO emission rates also tend to be higher for OTR than RY measurements. On average, the HC exhaust concentrations and average emission rates tend to be higher for OTR than RY. However, both the CO and HC emission rates are low on an absolute basis, and some of the measured average concentrations for a given notch position and replicate or run are below the gas analyzer detection limit. For PM, the measured exhaust levels tend to be lower for OTR than RY for a given notch position, and thus the cycle average PM emission rate tends to also be lower. The trends in CO_2 emission rates are similar to those for fuel use on a mass per time and mass per engine output basis. CO_2 emission rates are also shown on a g/gallon basis. Since typically over 99 percent of the carbon in the fuel is emitted as CO_2, the fuel-based CO_2 emission rates are approximately constant.

SUMMARY

In this study, a procedure was demonstrated for RY characterization of emission rates for B80 biodiesel. The rail yard engine activity and emission concentration measurements were consistent across the three replicates. Six days of over-the-rail emissions measurements on the prime mover engine of NC-1810 were conducted – three days on B80 biodiesel and three days on B60 biodiesel. The cycle average over-the-rail emission rates are quantitatively similar to the cycle average rail yard emission rates measured for each fuel. For all three sets of measurements on different fuels, cycle average over-the-rail NO_x and HC emission rates are higher than during rail yard measurements, and cycle average over-the-rail CO emission rates are lower than during rail yard measurements. These observed differences are mostly attributable to exhaust concentrations rather than engine activity, and are likely a result of differences associated with transient operation for over the rail operation versus steady-state operation in the rail yard. Cycle average PM emission rates were similar for rail yard and over-the-rail measurements.

Differences in emission rates are attributable to differences in measured exhaust concentrations. Values for engine activity parameters (RPM, IAT, MAP) were similar across all rail yard and over-the-rail measurements.

Table E-18. Measured Engine Parameters for NC-1810 and B80

Engine Speed (RPM)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	12/22	12/22	12/22	3 Reps	3 Reps	3 Reps	12/19	12/19	12/20	12/20	12/21	12/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	198	197	197	197	0.73	0.00	198	197	198	197	197	--	197	0.48	0.00
High Idle	340	339	338	339	0.91	0.00	340	338	339	338	339	338	339	0.63	0.00
Dyn Brake	--	--	--	--	--	--	394	346	345	345	341	416	364	32.1	0.09
1	340	339	339	339	0.63	0.00	339	338	339	338	339	338	338	0.75	0.00
2	340	339	339	339	0.60	0.00	339	338	338	338	339	338	338	0.76	0.00
3	489	488	488	488	0.46	0.00	489	488	488	487	489	488	488	0.80	0.00
4	563	563	563	563	0.21	0.00	562	562	562	561	562	562	562	0.51	0.00
5	651	651	651	651	0.14	0.00	650	650	650	649	649	649	650	0.46	0.00
6	728	727	727	728	0.65	0.00	727	726	727	726	727	726	726	0.60	0.00
7	823	821	820	821	1.22	0.00	--	820	822	820	821	--	821	0.83	0.00
8	902	901	901	901	0.43	0.00	901	900	900	900	900	900	900	0.47	0.00

Intake Air Temeprature (°C)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	12/22	12/22	12/22	3 Reps	3 Reps	3 Reps	12/19	12/19	12/20	12/20	12/21	12/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	59	60	60	60	0.72	0.01	58	62	66	64	67	--	63	3.41	0.05
High Idle	67	71	70	69	1.79	0.03	65	69	69	70	69	75	69	3.18	0.05
Dyn Brake	--	--	--	--	--	--	66	70	68	70	69	74	70	2.80	0.04
1	65	66	65	65	0.60	0.01	67	68	70	66	67	75	69	3.09	0.04
2	68	68	69	68	0.56	0.01	68	71	68	70	70	75	70	2.42	0.03
3	71	71	72	71	0.52	0.01	69	70	69	72	65	77	70	3.86	0.06
4	72	73	73	73	0.32	0.00	70	71	69	71	67	78	71	3.49	0.05
5	71	72	72	72	0.24	0.00	71	71	70	71	70	79	72	3.47	0.05
6	73	73	72	73	0.41	0.01	69	74	71	72	68	78	72	3.74	0.05
7	75	76	76	76	0.65	0.01	--	74	70	78	68	--	72	4.56	0.06
8	76	76	76	76	0.21	0.00	71	74	72	74	73	79	74	2.56	0.03

Manifold Absolute Pressure (kPa)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	12/22	12/22	12/22	3 Reps	3 Reps	3 Reps	12/19	12/19	12/20	12/20	12/21	12/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	101	101	101	101	0.06	0.00	101	101	101	99	100	--	100	0.74	0.01
High Idle	108	108	108	108	0.12	0.00	109	108	108	108	108	107	108	0.75	0.01
Dyn Brake	--	--	--	--	--	--	114	109	110	108	109	114	111	2.72	0.02
1	108	108	108	108	0.12	0.00	110	109	110	108	109	108	109	0.97	0.01
2	109	108	108	108	0.12	0.00	110	109	109	108	110	108	109	0.81	0.01
3	122	122	122	122	0.14	0.00	124	122	124	122	124	121	123	1.41	0.01
4	132	131	131	131	0.20	0.00	136	132	134	132	133	131	133	1.66	0.01
5	145	145	145	145	0.21	0.00	150	146	148	145	146	146	147	1.95	0.01
6	161	160	160	160	0.45	0.00	167	162	164	159	163	159	162	3.21	0.02
7	183	182	182	183	0.76	0.00	--	187	192	182	189	--	188	4.06	0.02
8	224	224	222	223	1.34	0.01	235	223	233	219	228	221	226	6.58	0.03

Mass Air Flow (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	12/22	12/22	12/22	3 Reps	3 Reps	3 Reps	12/19	12/19	12/20	12/20	12/21	12/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	791	783	784	786	4.17	0.01	794	780	775	766	767	--	776	11.4	0.01
High Idle	1208	1191	1193	1197	8.91	0.01	1224	1195	1202	1189	1198	1166	1196	18.9	0.02
Dyn Brake	--	--	--	--	--	--	1411	1220	1232	1211	1205	1426	1284	104	0.08
1	1218	1210	1214	1214	3.98	0.00	1220	1205	1214	1202	1211	1172	1204	16.8	0.01
2	1209	1203	1200	1204	4.54	0.00	1217	1198	1204	1192	1212	1174	1200	15.5	0.01
3	1710	1706	1700	1705	4.89	0.00	1744	1717	1739	1699	1766	1669	1722	35.0	0.02
4	2000	1995	1991	1996	4.58	0.00	2059	2011	2044	2007	2048	1961	2022	36.3	0.02
5	2406	2399	2398	2401	4.32	0.00	2477	2424	2448	2399	2426	2363	2423	39.3	0.02
6	2807	2797	2800	2801	5.00	0.00	2929	2817	2868	2795	2881	2734	2837	69.4	0.02
7	3380	3347	3342	3356	20.4	0.01	--	3433	3551	3329	3527	--	3460	101	0.03
8	4198	4182	4156	4179	21.3	0.01	4407	4194	4356	4130	4272	4114	4246	120	0.03

Air to Fuel Ratio (g/g)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	12/22	12/22	12/22	3 Reps	3 Reps	3 Reps	12/19	12/19	12/20	12/20	12/21	12/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	341	382	403	375	31.3	0.08	634	641	297	1213	285	--	614	377	0.61
High Idle	375	377	382	378	3.53	0.01	290	389	273	286	254	276	294	48.0	0.16
Dyn Brake	--	--	--	--	--	--	242	407	259	351	238	216	285	75.9	0.27
1	134	134	135	134	0.49	0.00	155	193	136	443	173	121	203	120	0.59
2	101	102	102	102	0.48	0.00	87.6	121	101	207	88.0	87.6	116	46.8	0.40
3	67.9	67.5	67.7	67.7	0.21	0.00	63.6	73.8	64.4	155	68.2	59.6	80.8	36.7	0.45
4	56.9	56.7	57.2	56.9	0.26	0.00	50.8	55.4	53.3	99.2	55.5	49.4	60.6	19.1	0.31
5	45.3	45.7	45.8	45.6	0.23	0.01	42.3	46.1	45.4	78.1	43.3	40.9	49.4	14.2	0.29
6	38.1	38.4	38.5	38.3	0.20	0.01	38.5	42.9	41.5	66.6	38.2	36.7	44.1	11.3	0.26
7	32.8	32.9	32.8	32.8	0.07	0.00	--	33.5	33.5	40.1	33.1	--	35.0	3.37	0.10
8	30.6	30.8	30.4	30.6	0.19	0.01	34.0	32.9	33.8	35.0	32.7	30.8	33.2	1.44	0.04

Table E-19. Estimated Fuel Use Rates for NC-1810 and B80

Time-Based Fuel Use Rates (g/s)

Throttle Notch Position	Rail Yard Test						Over-The-Rail Test								
	12/22 Axion REP1	12/22 Axion REP2	12/22 Axion REP3	3 Reps Average	3 Reps StDev	3 Reps CV	12/19 Train 73	12/19 Train 74	12/20 Train 73	12/20 Train 74	12/21 Train 73	12/21 Train 74	6 Trains Average	6 Trains StDev	6 Trains CV
Low Idle	2.32	2.05	1.94	2.10	0.19	0.09	1.25	1.22	2.61	0.63	2.69	--	1.68	0.92	0.55
High Idle	3.22	3.16	3.13	3.17	0.05	0.02	4.22	3.07	4.41	4.16	4.72	4.23	4.14	0.56	0.14
Dyn Brake	--	--	--	--	--	--	5.83	2.99	4.76	3.45	5.06	6.61	4.78	1.38	0.29
1	9.10	9.04	9.01	9.05	0.05	0.01	7.89	6.25	8.95	2.71	7.00	9.66	7.08	2.47	0.35
2	11.9	11.8	11.7	11.8	0.10	0.01	13.9	9.87	11.9	5.76	13.8	13.4	11.4	3.17	0.28
3	25.2	25.3	25.1	25.2	0.08	0.00	27.4	23.3	27.0	11.0	25.9	28.0	23.8	6.49	0.27
4	35.2	35.2	34.8	35.0	0.22	0.01	40.5	36.3	38.4	20.2	36.9	39.7	35.3	7.57	0.21
5	53.1	52.5	52.4	52.7	0.36	0.01	58.5	52.6	53.9	30.7	56.0	57.8	51.6	10.5	0.20
6	73.7	72.9	72.7	73.1	0.50	0.01	76.0	65.6	69.1	42.0	75.4	74.5	67.1	13.0	0.19
7	103	102	102	102	0.71	0.01	--	102	106	83.1	107	--	99.6	11.2	0.11
8	137	136	137	137	0.70	0.01	130	127	129	118	131	134	128	5.31	0.04

Engine Output-Based Fuel Use Rates (g/bhp-hr)

Throttle Notch Position	Rail Yard Test						Over-The-Rail Test								
	12/22 Axion REP1	12/22 Axion REP2	12/22 Axion REP3	3 Reps Average	3 Reps StDev	3 Reps CV	12/19 Train 73	12/19 Train 74	12/20 Train 73	12/20 Train 74	12/21 Train 73	12/21 Train 74	6 Trains Average	6 Trains StDev	6 Trains CV
Low Idle	3.57	4.03	4.25	3.95	0.35	0.09	6.60	6.79	3.17	13.09	3.07	--	6.54	4.07	0.62
High Idle	2.56	2.62	2.64	2.61	0.04	0.02	1.96	2.69	1.87	1.99	1.75	1.95	2.03	0.33	0.16
Dyn Brake	--	--	--	--	--	--	1.42	2.76	1.74	2.39	1.63	1.25	1.86	0.59	0.32
1	17.2	17.4	17.4	17.3	0.09	0.01	19.9	25.1	17.5	57.9	22.4	16.3	26.5	15.7	0.59
2	24.3	24.5	24.7	24.5	0.20	0.01	20.8	29.3	24.4	50.2	21.0	21.6	27.9	11.4	0.41
3	22.2	22.1	22.2	22.1	0.07	0.00	20.3	24.0	20.6	50.9	21.5	19.9	26.2	12.2	0.46
4	23.5	23.5	23.7	23.6	0.15	0.01	20.4	22.8	21.5	40.8	22.4	20.8	24.8	7.91	0.32
5	20.6	20.8	20.9	20.8	0.14	0.01	18.7	20.8	20.3	35.6	19.5	18.9	22.3	6.57	0.29
6	17.9	18.1	18.2	18.1	0.12	0.01	17.4	20.1	19.1	31.5	17.5	17.8	20.6	5.45	0.27
7	19.2	19.5	19.4	19.4	0.13	0.01	--	21.8	21.0	26.8	20.9	--	22.6	2.83	0.13
8	16.2	16.4	16.3	16.3	0.08	0.01	19.1	19.4	19.2	21.0	18.9	18.5	19.4	0.84	0.04

Table E-20. Measured NO_x Emission Rates for NC-1810 and B80

Time-Based NO_x Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	12/22	12/22	12/22	3 Reps	3 Reps	3 Reps	12/19	12/19	12/20	12/20	12/21	12/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	0.14	0.13	0.12	0.13	0.01	0.06	0.09	0.12	0.18	0.03	0.18	--	0.12	0.07	0.55
High Idle	0.18	0.18	0.18	0.18	0.00	0.01	0.28	0.23	0.28	0.18	0.27	0.24	0.25	0.04	0.15
Dyn Brake	--	--	--	--	--	--	0.34	0.22	0.31	0.15	0.29	0.32	0.27	0.07	0.28
1	0.47	0.48	0.47	0.47	0.00	0.01	0.52	0.43	0.60	0.17	0.43	0.57	0.45	0.16	0.35
2	0.72	0.73	0.72	0.72	0.00	0.00	0.96	0.65	0.77	0.28	0.85	0.84	0.72	0.24	0.33
3	1.55	1.59	1.58	1.57	0.02	0.01	1.91	1.69	1.78	0.56	1.58	1.77	1.55	0.50	0.32
4	1.99	2.03	2.00	2.01	0.02	0.01	2.65	2.44	2.27	0.85	2.13	2.35	2.11	0.64	0.30
5	2.73	2.74	2.75	2.74	0.01	0.00	3.44	3.20	3.07	1.43	3.03	3.19	2.90	0.73	0.25
6	3.47	3.47	3.49	3.47	0.01	0.00	4.13	3.98	3.77	1.99	3.49	3.78	3.52	0.78	0.22
7	4.11	4.21	4.23	4.18	0.06	0.02	--	4.88	4.86	3.34	4.76	--	4.46	0.75	0.17
8	4.79	4.90	4.91	4.87	0.07	0.01	5.71	5.39	5.44	4.25	5.19	5.04	5.17	0.51	0.10

Fuel-Based NO_x Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	12/22	12/22	12/22	3 Reps	3 Reps	3 Reps	12/19	12/19	12/20	12/20	12/21	12/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	198	213	209	207	7.64	0.04	229	333	230	131	216	--	228	71.6	0.31
High Idle	183	189	188	187	3.11	0.02	216	249	212	145	188	190	200	35.1	0.18
Dyn Brake	--	--	--	--	--	--	193	238	212	139	187	160	188	35.5	0.19
1	171	174	172	172	1.19	0.01	216	227	222	201	204	195	211	12.7	0.06
2	200	202	202	201	1.27	0.01	228	215	214	160	202	207	205	23.4	0.11
3	203	207	207	206	2.28	0.01	230	240	217	169	201	209	211	24.9	0.12
4	186	190	189	188	2.14	0.01	215	221	195	139	190	195	193	29.0	0.15
5	170	172	173	171	1.57	0.01	194	200	188	154	178	182	183	16.3	0.09
6	155	156	158	156	1.56	0.01	179	200	180	156	152	167	172	17.5	0.10
7	131	136	136	135	2.97	0.02	--	157	151	132	147	--	147	10.3	0.07
8	115	119	118	117	2.08	0.02	145	139	139	118	131	124	133	10.1	0.08

Engine Output-Based NO_x Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	12/22	12/22	12/22	3 Reps	3 Reps	3 Reps	12/19	12/19	12/20	12/20	12/21	12/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	50.2	47.7	44.5	47.5	2.84	0.06	31.3	44.2	65.6	9.04	63.6	--	42.8	23.6	0.55
High Idle	64.6	65.3	64.4	64.7	0.47	0.01	99.8	83.8	102	65.8	97.0	88.0	89.4	13.6	0.15
Dyn Brake	--	--	--	--	--	--	123	78.0	110	52.3	103	116	97.2	26.9	0.28
1	8.98	9.03	8.92	8.98	0.06	0.01	9.83	8.16	11.4	3.13	8.22	10.8	8.60	2.99	0.35
2	7.45	7.46	7.41	7.44	0.03	0.00	9.90	6.64	7.95	2.88	8.70	8.65	7.46	2.48	0.33
3	8.28	8.49	8.40	8.39	0.11	0.01	10.2	9.04	9.49	3.00	8.44	9.46	8.27	2.65	0.32
4	7.16	7.31	7.19	7.22	0.08	0.01	9.54	8.77	8.16	3.08	7.66	8.47	7.61	2.31	0.30
5	7.43	7.44	7.46	7.44	0.02	0.00	9.36	8.70	8.35	3.90	8.24	8.66	7.87	1.98	0.25
6	7.80	7.80	7.85	7.82	0.03	0.00	9.29	8.95	8.49	4.47	7.86	8.50	7.93	1.76	0.22
7	6.16	6.31	6.34	6.27	0.10	0.02	--	6.50	6.47	4.46	6.35	--	5.95	1.00	0.17
8	6.39	6.54	6.55	6.49	0.09	0.01	6.85	6.47	6.53	5.10	6.23	6.05	6.21	0.61	0.10
Duty Cycle Avg (Raw)	6.7	6.8	6.8	6.8	0.05	0.01	6.9	6.4	7.2	4.5	6.8	7.2	6.5	1.0	0.16
Duty Cycle Avg (Adj)	7.1	7.2	7.2	7.1	0.06	0.01	7.2	6.7	7.6	4.7	7.2	7.6	6.8	1.1	0.16

Exhaust NO_x Concentrations (ppm)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	12/22	12/22	12/22	3 Reps	3 Reps	3 Reps	12/19	12/19	12/20	12/20	12/21	12/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	102	98	91	97	5.45	0.06	63	92	135	19	133	--	88	48.9	0.55
High Idle	86	88	86	87	1.03	0.01	130	114	136	92	130	121	120	15.9	0.13
Dyn Brake	--	--	--	--	--	--	140	104	142	74	137	130	121	26.9	0.22
1	225	228	224	226	1.96	0.01	245	212	285	81	206	283	219	75.2	0.34
2	348	350	348	348	1.12	0.00	458	323	369	144	407	418	353	112	0.32
3	530	543	539	537	6.90	0.01	635	567	590	197	524	621	522	164	0.31
4	582	594	586	587	6.11	0.01	748	693	643	267	610	704	611	175	0.29
5	665	668	670	668	2.54	0.00	808	754	724	383	731	792	699	158	0.23
6	727	727	732	729	2.77	0.00	835	789	760	437	717	810	725	147	0.20
7	714	737	745	732	16.5	0.02	--	815	788	592	802	--	749	106	0.14
8	678	698	704	693	13.7	0.02	763	734	730	615	715	726	714	51.0	0.07

Table E-21. Measured CO Emission Rates for NC-1810 and B80

Time-Based CO Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	12/22	12/22	12/22	3 Reps	3 Reps	3 Reps	12/19	12/19	12/20	12/20	12/21	12/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	0.00	0.01	0.01	0.01	0.01	0.68	0.03	0.04	0.02	0.00	0.02	--	0.02	0.01	0.58
High Idle	0.02	0.02	0.02	0.02	0.00	0.06	0.05	0.06	0.06	0.02	0.03	0.06	0.05	0.02	0.34
Dyn Brake	--	--	--	--	--	--	0.06	0.04	0.06	0.02	0.03	0.07	0.05	0.02	0.40
1	0.01	0.01	0.02	0.01	0.01	0.61	0.05	0.04	0.03	0.01	0.05	0.06	0.04	0.02	0.49
2	0.00	0.01	0.01	0.01	0.01	0.71	0.04	0.06	0.05	0.04	0.02	0.06	0.04	0.01	0.28
3	0.00	0.00	0.01	0.00	0.00	0.82	0.08	0.03	0.03	0.02	0.05	0.08	0.05	0.03	0.52
4	0.00	0.01	0.01	0.01	0.01	0.77	0.09	0.06	0.07	0.08	0.06	0.10	0.07	0.02	0.21
5	0.02	0.03	0.02	0.03	0.01	0.31	0.13	0.03	0.09	0.04	0.03	0.16	0.08	0.06	0.72
6	0.10	0.09	0.06	0.08	0.02	0.24	0.24	0.13	0.08	0.05	0.24	0.27	0.17	0.09	0.55
7	0.42	0.37	0.33	0.37	0.04	0.12	--	0.24	0.30	0.28	0.31	--	0.28	0.03	0.11
8	0.89	0.72	0.78	0.80	0.08	0.11	0.28	0.37	0.29	0.39	0.39	0.64	0.39	0.13	0.34

Fuel-Based CO Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	12/22	12/22	12/22	3 Reps	3 Reps	3 Reps	12/19	12/19	12/20	12/20	12/21	12/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	3.06	16.3	22.7	14.0	10.0	0.72	69.9	114	30.3	17.3	27.3	--	51.7	40.0	0.77
High Idle	20.2	21.0	19.0	20.1	1.02	0.05	40.2	60.3	41.9	19.5	20.5	49.6	38.7	16.1	0.42
Dyn Brake	--	--	--	--	--	--	31.5	42.0	41.2	21.3	19.1	34.5	31.6	9.69	0.31
1	2.39	4.10	8.25	4.91	3.02	0.61	22.4	23.3	12.2	6.82	21.6	21.6	18.0	6.81	0.38
2	0.84	1.88	3.99	2.24	1.60	0.72	9.71	18.8	12.7	22.7	5.75	14.3	14.0	6.10	0.44
3	0.06	0.49	0.79	0.45	0.37	0.82	10.1	4.25	3.89	7.42	5.89	9.06	6.77	2.55	0.38
4	0.12	0.76	1.15	0.67	0.52	0.77	7.05	5.01	6.08	12.9	5.45	7.95	7.41	2.91	0.39
5	1.40	2.15	1.20	1.58	0.50	0.32	7.19	1.58	5.34	4.01	2.03	9.39	4.92	3.02	0.61
6	4.40	4.05	2.71	3.72	0.89	0.24	10.4	6.44	3.80	4.17	10.5	11.9	7.86	3.51	0.45
7	13.4	11.9	10.7	12.0	1.36	0.11	--	7.83	9.34	10.9	9.63	--	9.43	1.27	0.13
8	21.3	17.5	18.8	19.2	1.94	0.10	7.00	9.49	7.32	10.8	9.71	15.7	10.0	3.15	0.31

Engine Output-Based CO Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	12/22	12/22	12/22	3 Reps	3 Reps	3 Reps	12/19	12/19	12/20	12/20	12/21	12/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	0.78	3.65	4.84	3.09	2.09	0.68	9.56	15.1	8.65	1.19	8.03	--	8.51	4.96	0.58
High Idle	7.12	7.27	6.50	6.96	0.41	0.06	18.6	20.3	20.2	8.86	10.6	22.9	16.9	5.76	0.34
Dyn Brake	--	--	--	--	--	--	20.1	13.7	21.4	8.06	10.5	24.9	16.5	6.67	0.40
1	0.12	0.21	0.43	0.26	0.16	0.61	1.02	0.84	0.63	0.11	0.87	1.20	0.78	0.38	0.49
2	0.03	0.07	0.15	0.08	0.06	0.71	0.42	0.58	0.47	0.41	0.25	0.60	0.45	0.13	0.28
3	0.00	0.02	0.03	0.02	0.01	0.82	0.45	0.16	0.17	0.13	0.25	0.41	0.26	0.14	0.52
4	0.00	0.03	0.04	0.03	0.02	0.77	0.31	0.20	0.26	0.29	0.22	0.34	0.27	0.06	0.21
5	0.06	0.09	0.05	0.07	0.02	0.31	0.35	0.07	0.24	0.10	0.09	0.45	0.22	0.16	0.72
6	0.22	0.20	0.13	0.19	0.05	0.24	0.54	0.29	0.18	0.12	0.54	0.60	0.38	0.21	0.55
7	0.63	0.55	0.50	0.56	0.07	0.12	--	0.32	0.40	0.37	0.42	--	0.38	0.04	0.11
8	1.19	0.96	1.04	1.06	0.11	0.11	0.33	0.44	0.34	0.46	0.46	0.76	0.47	0.16	0.34
Duty Cycle Avg (Raw)	0.79	0.68	0.73	0.73	0.06	0.08	0.41	0.44	0.40	0.39	0.47	0.85	0.49	0.18	0.36
Duty Cycle Avg (Adj)	0.79	0.68	0.73	0.73	0.06	0.08	0.41	0.44	0.40	0.39	0.47	0.85	0.49	0.18	0.36

Exhaust CO Concentrations (%)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	12/22	12/22	12/22	3 Reps	3 Reps	3 Reps	12/19	12/19	12/20	12/20	12/21	12/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	0.000	0.001	0.002	0.001	0.00	0.68	0.003	0.005	0.003	0.000	0.003	--	0.003	0.00	0.58
High Idle	0.002	0.002	0.002	0.002	0.00	0.06	0.004	0.005	0.005	0.002	0.002	0.005	0.004	0.00	0.34
Dyn Brake	--	--	--	--	--	--	0.004	0.003	0.005	0.002	0.002	0.005	0.004	0.00	0.34
1	0.001	0.001	0.002	0.001	0.00	0.61	0.004	0.004	0.003	0.000	0.004	0.005	0.003	0.00	0.50
2	0.000	0.001	0.001	0.001	0.00	0.71	0.003	0.005	0.004	0.004	0.002	0.005	0.004	0.00	0.29
3	0.000	0.000	0.000	0.000	0.00	0.82	0.005	0.002	0.002	0.001	0.003	0.005	0.003	0.00	0.53
4	0.000	0.000	0.001	0.000	0.00	0.77	0.004	0.003	0.003	0.004	0.003	0.005	0.004	0.00	0.23
5	0.001	0.001	0.001	0.001	0.00	0.32	0.005	0.001	0.004	0.002	0.001	0.007	0.003	0.00	0.72
6	0.004	0.003	0.002	0.003	0.00	0.24	0.008	0.004	0.003	0.002	0.009	0.010	0.006	0.00	0.56
7	0.013	0.011	0.010	0.011	0.00	0.11	--	0.007	0.008	0.008	0.009	--	0.008	0.00	0.10
8	0.022	0.018	0.019	0.020	0.00	0.10	0.006	0.009	0.007	0.010	0.009	0.016	0.009	0.00	0.37

Table E-22. Measured Hydrocarbon Emission Rates for NC-1810 and B80

Time-Based HC Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	12/22	12/22	12/22	3 Reps	3 Reps	3 Reps	12/19	12/19	12/20	12/20	12/21	12/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	0.02	0.02	0.04	0.03	0.01	0.29	0.05	0.13	0.25	0.06	0.16	--	0.13	0.08	0.63
High Idle	0.09	0.03	0.04	0.05	0.03	0.61	0.54	0.25	0.34	0.25	0.24	0.22	0.31	0.12	0.39
Dyn Brake	--	--	--	--	--	--	0.74	0.26	0.34	0.18	0.24	0.32	0.35	0.20	0.59
1	0.05	0.03	0.05	0.04	0.01	0.21	0.43	0.44	0.19	0.24	0.28	0.20	0.30	0.12	0.39
2	0.08	0.06	0.09	0.08	0.01	0.18	0.63	0.26	0.40	0.38	0.37	0.22	0.38	0.14	0.38
3	0.04	0.03	0.06	0.05	0.01	0.27	0.73	0.28	0.34	0.38	0.35	0.27	0.39	0.17	0.44
4	0.05	0.07	0.09	0.07	0.02	0.35	0.96	0.60	0.64	0.55	0.48	0.27	0.58	0.23	0.39
5	0.06	0.06	0.07	0.06	0.01	0.10	1.29	0.36	0.63	0.89	0.52	0.28	0.66	0.38	0.57
6	0.05	0.04	0.03	0.04	0.01	0.25	0.55	0.63	0.57	1.22	0.35	0.41	0.62	0.31	0.50
7	0.13	0.01	0.01	0.05	0.07	1.35	--	1.29	1.06	1.33	0.36	--	1.01	0.45	0.44
8	0.29	0.03	0.03	0.12	0.15	1.26	2.09	1.29	0.76	1.24	0.61	0.38	1.06	0.62	0.58

Fuel-Based HC Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	12/22	12/22	12/22	3 Reps	3 Reps	3 Reps	12/19	12/19	12/20	12/20	12/21	12/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	30.0	37.6	60.6	42.7	15.9	0.37	141	346	318	304	198	--	261	87.7	0.34
High Idle	90.9	29.2	43.7	54.6	32.3	0.59	419	269	252	195	169	173	246	94.0	0.38
Dyn Brake	--	--	--	--	--	--	419	282	236	169	157	157	237	103	0.43
1	16.4	11.9	18.2	15.5	3.24	0.21	181	233	68.2	289	132	67.2	162	89.8	0.56
2	22.7	17.1	24.6	21.5	3.90	0.18	150	88.0	110	216	88.9	53.7	118	57.6	0.49
3	5.83	4.54	7.80	6.06	1.64	0.27	88.1	40.2	41.4	113	44.1	31.2	59.7	32.9	0.55
4	4.23	6.43	8.93	6.53	2.35	0.36	78.2	54.0	54.6	89.7	42.5	22.8	57.0	24.1	0.42
5	3.57	3.93	4.43	3.98	0.43	0.11	72.8	22.6	38.4	95.0	30.5	15.7	45.8	31.3	0.68
6	2.43	1.95	1.48	1.95	0.48	0.24	23.9	31.8	27.1	95.4	15.2	18.2	35.3	30.1	0.85
7	4.18	0.45	0.28	1.64	2.21	1.35	--	41.3	32.9	52.9	11.2	--	34.6	17.6	0.51
8	7.04	0.81	0.75	2.87	3.61	1.26	53.0	33.4	19.4	34.6	15.4	9.32	27.5	16.0	0.58

Engine Output-Based HC Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	12/22	12/22	12/22	3 Reps	3 Reps	3 Reps	12/19	12/19	12/20	12/20	12/21	12/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	7.60	8.43	12.9	9.64	2.84	0.29	19.2	46.0	90.7	21.0	58.4	--	47.1	29.5	0.63
High Idle	32.0	10.1	14.9	19.0	11.5	0.61	193	90.3	121	88.8	87.2	80.2	110	43.1	0.39
Dyn Brake	--	--	--	--	--	--	267	92.4	123	63.9	86.6	114	124	72.9	0.59
1	0.86	0.62	0.94	0.81	0.17	0.21	8.23	8.40	3.51	4.51	5.30	3.74	5.62	2.18	0.39
2	0.85	0.63	0.90	0.79	0.14	0.18	6.50	2.71	4.07	3.89	3.82	2.25	3.87	1.48	0.38
3	0.24	0.19	0.32	0.25	0.07	0.27	3.92	1.51	1.81	2.01	1.85	1.41	2.09	0.92	0.44
4	0.16	0.25	0.34	0.25	0.09	0.35	3.46	2.14	2.29	1.98	1.72	0.99	2.10	0.81	0.39
5	0.16	0.17	0.19	0.17	0.02	0.10	3.51	0.98	1.71	2.41	1.41	0.75	1.79	1.02	0.57
6	0.12	0.10	0.07	0.10	0.02	0.25	1.24	1.43	1.28	2.74	0.78	0.92	1.40	0.70	0.50
7	0.20	0.02	0.01	0.08	0.10	1.35	--	1.71	1.41	1.78	0.48	--	1.35	0.60	0.44
8	0.39	0.04	0.04	0.16	0.20	1.26	2.51	1.55	0.91	1.49	0.73	0.45	1.27	0.74	0.58
Duty Cycle Avg (Raw)	0.15	0.06	0.08	0.10	0.05	0.47	1.21	0.75	0.76	0.81	0.57	0.53	0.77	0.24	0.31
Duty Cycle Avg (Adj)	0.38	0.16	0.21	0.25	0.12	0.47	3.03	1.87	1.91	2.03	1.42	1.33	1.93	0.61	0.31

Exhaust HC Concentrations (ppm)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	12/22	12/22	12/22	3 Reps	3 Reps	3 Reps	12/19	12/19	12/20	12/20	12/21	12/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	3	4	6	4	1.32	0.30	9	22	42	10	27	--	22	13.7	0.62
High Idle	10	3	5	6	3.42	0.60	57	28	36	28	26	25	33	12.2	0.37
Dyn Brake	--	--	--	--	--	--	68	28	36	20	26	29	34	17.2	0.50
1	5	4	5	5	0.95	0.21	46	49	20	26	30	22	32	12.5	0.39
2	9	7	10	8	1.50	0.18	68	30	43	44	40	24	41	15.0	0.36
3	3	3	5	4	0.96	0.27	55	21	25	30	26	21	30	12.7	0.43
4	3	5	6	5	1.63	0.36	61	38	41	39	31	18	38	14.0	0.37
5	3	3	4	3	0.36	0.10	68	19	33	53	28	15	36	20.6	0.57
6	3	2	2	2	0.52	0.25	25	28	26	60	16	20	29	15.8	0.54
7	5	1	0	2	2.70	1.35	--	48	39	53	14	--	39	17.6	0.46
8	9	1	1	4	4.80	1.26	63	40	23	40	19	12	33	18.5	0.56

Table E-23. Measured Particulate Matter Emission Rates for NC-1810 and B80

Time-Based PM Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	12/22	12/22	12/22	3 Reps	3 Reps	3 Reps	12/19	12/19	12/20	12/20	12/21	12/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	0.03	0.02	0.02	0.02	0.00	0.08	0.01	0.01	0.01	0.01	0.01	--	0.01	0.00	0.17
High Idle	0.02	0.02	0.02	0.02	0.00	0.16	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.09
Dyn Brake	--	--	--	--	--	--	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.13
1	0.03	0.03	0.03	0.03	0.00	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.00	0.13
2	0.04	0.04	0.04	0.04	0.00	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.18
3	0.05	0.05	0.05	0.05	0.00	0.04	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.00	0.10
4	0.07	0.06	0.07	0.07	0.00	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.00	0.06
5	0.11	0.10	0.10	0.10	0.00	0.05	0.06	0.05	0.06	0.04	0.05	0.05	0.05	0.00	0.08
6	0.16	0.15	0.15	0.15	0.00	0.03	0.06	0.08	0.07	0.07	0.11	0.08	0.08	0.02	0.23
7	0.27	0.25	0.24	0.25	0.02	0.08	--	0.18	0.21	0.21	0.27	--	0.22	0.03	0.16
8	0.56	0.42	0.39	0.46	0.09	0.20	0.20	0.27	0.26	0.25	0.27	0.27	0.25	0.03	0.10

Fuel-Based PM Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	12/22	12/22	12/22	3 Reps	3 Reps	3 Reps	12/19	12/19	12/20	12/20	12/21	12/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	47.9	49.7	48.1	48.5	0.99	0.02	41.2	36.0	13.4	70.2	12.8	--	34.7	23.7	0.68
High Idle	30.4	23.1	24.5	26.0	3.88	0.15	7.43	9.89	6.94	7.97	7.62	6.46	7.72	1.19	0.15
Dyn Brake	--	--	--	--	--	--	7.19	10.7	7.79	10.6	8.74	6.85	8.65	1.68	0.19
1	15.1	15.2	14.7	15.0	0.23	0.02	7.95	9.91	9.14	26.8	10.1	6.03	11.7	7.58	0.65
2	13.7	13.8	14.0	13.8	0.13	0.01	5.72	8.05	7.35	12.5	7.96	5.07	7.78	2.62	0.34
3	8.12	7.82	8.59	8.17	0.39	0.05	4.08	4.79	4.32	11.4	5.51	4.20	5.71	2.82	0.49
4	8.27	7.95	8.79	8.34	0.42	0.05	4.34	4.63	4.23	9.27	4.62	4.80	5.32	1.95	0.37
5	8.80	8.60	8.15	8.52	0.33	0.04	4.43	4.69	4.81	6.79	4.37	4.43	4.92	0.93	0.19
6	9.39	9.02	9.05	9.15	0.21	0.02	3.45	5.18	4.60	7.09	6.50	5.09	5.32	1.31	0.25
7	11.6	10.5	10.2	10.8	0.74	0.07	--	7.65	8.38	10.6	10.6	--	9.32	1.54	0.17
8	17.9	13.6	12.3	14.6	2.92	0.20	6.95	9.46	9.02	9.38	9.13	8.97	8.82	0.94	0.11

Engine Output-Based PM Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	12/22	12/22	12/22	3 Reps	3 Reps	3 Reps	12/19	12/19	12/20	12/20	12/21	12/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	9.16	8.42	7.73	8.44	0.72	0.08	3.82	3.25	2.59	3.28	2.55	--	3.10	0.54	0.17
High Idle	8.09	6.02	6.34	6.82	1.12	0.16	3.19	3.09	3.11	3.37	3.66	2.78	3.20	0.30	0.09
Dyn Brake	--	--	--	--	--	--	3.35	2.57	2.96	2.93	3.53	3.62	3.16	0.41	0.13
1	0.60	0.60	0.58	0.59	0.01	0.02	0.23	0.23	0.30	0.27	0.26	0.22	0.25	0.03	0.13
2	0.39	0.39	0.39	0.39	0.00	0.00	0.18	0.18	0.20	0.16	0.25	0.15	0.19	0.03	0.18
3	0.25	0.24	0.26	0.25	0.01	0.04	0.13	0.13	0.14	0.15	0.17	0.14	0.14	0.01	0.10
4	0.24	0.23	0.25	0.24	0.01	0.04	0.15	0.14	0.13	0.16	0.14	0.16	0.15	0.01	0.06
5	0.29	0.28	0.27	0.28	0.01	0.05	0.15	0.14	0.15	0.12	0.14	0.15	0.14	0.01	0.08
6	0.36	0.34	0.34	0.35	0.01	0.03	0.13	0.17	0.16	0.15	0.25	0.19	0.17	0.04	0.23
7	0.41	0.37	0.36	0.38	0.03	0.08	--	0.24	0.28	0.28	0.35	--	0.29	0.05	0.16
8	0.75	0.56	0.52	0.61	0.12	0.20	0.24	0.33	0.31	0.30	0.32	0.32	0.31	0.03	0.10
Duty Cycle Avg (Raw)	0.13	0.10	0.10	0.11	0.02	0.15	0.04	0.05	0.06	0.05	0.06	0.06	0.05	0.01	0.12
Duty Cycle Avg (Adj)	0.64	0.52	0.49	0.55	0.08	0.15	0.21	0.26	0.28	0.27	0.30	0.29	0.27	0.03	0.12

Exhaust PM Concentrations (mg/m^3)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	12/22	12/22	12/22	3 Reps	3 Reps	3 Reps	12/19	12/19	12/20	12/20	12/21	12/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	7.8	7.2	6.6	7.2	0.58	0.08	3.3	2.9	2.3	3.0	2.3	--	2.8	0.46	0.17
High Idle	4.5	3.4	3.6	3.8	0.60	0.16	1.7	1.7	1.7	1.9	2.0	1.5	1.7	0.16	0.09
Dyn Brake	--	--	--	--	--	--	1.6	1.4	1.6	1.7	1.9	1.7	1.6	0.17	0.11
1	6.3	6.3	6.1	6.2	0.12	0.02	2.5	2.5	3.2	3.0	2.8	2.4	2.7	0.32	0.12
2	7.5	7.6	7.6	7.6	0.02	0.00	3.5	3.7	3.9	3.5	4.9	3.2	3.8	0.61	0.16
3	6.7	6.5	7.1	6.7	0.31	0.05	3.5	3.5	3.6	4.1	4.4	3.8	3.8	0.38	0.10
4	8.2	7.9	8.6	8.2	0.38	0.05	4.9	4.7	4.5	5.7	4.8	5.6	5.0	0.51	0.10
5	10.9	10.6	10.0	10.5	0.46	0.04	5.5	5.3	5.5	5.1	5.4	5.8	5.4	0.25	0.05
6	13.9	13.3	13.3	13.5	0.39	0.03	5.1	6.4	6.1	6.3	9.6	7.8	6.9	1.59	0.23
7	20.0	18.0	17.6	18.6	1.27	0.07	--	12.5	13.8	14.9	18.3	--	14.9	2.46	0.17
8	33.4	25.2	23.2	27.3	5.39	0.20	11.3	15.4	14.7	15.1	15.5	16.2	14.7	1.73	0.12

Table E-24. Measured CO_2 Emission Rates for NC-1810 and B80

Time-Based CO_2 Emission Rates (g/s)

Throttle Notch Position	Rail Yard Test						Over-The-Rail Test								
	12/22	12/22	12/22	3 Reps	3 Reps	3 Reps	12/19	12/19	12/20	12/20	12/21	12/21	6 Trains	6 Trains	6 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	7.07	6.25	5.91	6.41	0.60	0.09	3.75	3.58	7.79	1.89	8.11	--	5.02	2.77	0.55
High Idle	9.77	9.62	9.51	9.63	0.13	0.01	12.5	9.16	13.2	12.5	14.3	12.7	12.4	1.71	0.14
Dyn Brake	--	--	--	--	--	--	17.3	8.95	14.3	10.4	15.3	19.9	14.4	4.13	0.29
1	27.8	27.6	27.5	27.6	0.15	0.01	23.8	18.8	27.2	8.14	21.2	29.3	21.4	7.55	0.35
2	36.4	36.1	35.8	36.1	0.31	0.01	42.1	29.9	36.0	17.3	41.9	40.8	34.7	9.68	0.28
3	77.0	77.3	76.8	77.0	0.26	0.00	83.4	71.0	82.4	33.3	78.9	85.4	72.4	19.8	0.27
4	108	108	106	107	0.68	0.01	123	111	117	61.4	113	121	108	23.1	0.21
5	162	161	160	161	1.11	0.01	178	161	164	93.4	171	176	157	32.0	0.20
6	225	223	222	223	1.50	0.01	232	200	211	128	230	227	205	39.7	0.19
7	315	311	312	312	2.06	0.01	--	312	323	253	326	--	304	34.3	0.11
8	419	415	417	417	1.95	0.00	395	389	393	360	399	408	391	16.3	0.04

Fuel-Based CO_2 Emission Rates (g/gal)

Throttle Notch Position	Rail Yard Test						Over-The-Rail Test								
	12/22	12/22	12/22	3 Reps	3 Reps	3 Reps	12/19	12/19	12/20	12/20	12/21	12/21	6 Trains	6 Trains	6 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	10051	10026	10001	10026	24.9	0.00	9878	9683	9831	9860	9910	--	9833	88.2	0.01
High Idle	9987	10023	10018	10009	19.7	0.00	9754	9815	9854	9924	9938	9890	9862	69.9	0.01
Dyn Brake	--	--	--	--	--	--	9768	9835	9865	9937	9948	9924	9879	70.2	0.01
1	10060	10061	10050	10057	5.97	0.00	9928	9894	10013	9886	9960	9999	9947	53.1	0.01
2	10059	10061	10053	10058	4.15	0.00	9967	9991	9987	9906	10011	10019	9980	40.7	0.00
3	10071	10071	10068	10070	1.40	0.00	10004	10043	10043	9993	10038	10041	10027	22.2	0.00
4	10071	10069	10067	10069	2.25	0.00	10015	10033	10031	9999	10040	10048	10028	17.8	0.00
5	10070	10068	10070	10069	0.76	0.00	10018	10058	10042	10010	10052	10050	10038	19.8	0.00
6	10066	10067	10069	10067	1.68	0.00	10043	10045	10052	10009	10048	10044	10040	15.6	0.00
7	10051	10055	10057	10054	3.43	0.00	--	10037	10039	10025	10052	--	10038	11.3	0.00
8	10036	10046	10044	10042	5.19	0.00	10031	10039	10051	10036	10050	10044	10042	7.88	0.00

Engine Output-Based CO_2 Emission Rates (g/bhp-hr)

Throttle Notch Position	Rail Yard Test						Over-The-Rail Test								
	12/22	12/22	12/22	3 Reps	3 Reps	3 Reps	12/19	12/19	12/20	12/20	12/21	12/21	6 Trains	6 Trains	6 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	2546	2250	2126	2307	216	0.09	1351	1288	2805	681	2918	--	1809	997	0.55
High Idle	3518	3462	3424	3468	47.3	0.01	4502	3298	4748	4514	5131	4575	4461	617	0.14
Dyn Brake	--	--	--	--	--	--	6228	3220	5131	3753	5500	7174	5168	1487	0.29
1	527	523	521	524	2.89	0.01	451	356	516	154	401	556	406	143	0.35
2	375	372	368	371	3.21	0.01	433	308	370	178	431	419	357	99.6	0.28
3	411	412	410	411	1.40	0.00	445	379	439	177	421	455	386	106	0.27
4	387	387	383	386	2.45	0.01	444	398	421	221	405	436	387	83.3	0.21
5	441	437	435	438	3.02	0.01	484	437	446	254	465	479	427	87.0	0.20
6	507	502	500	503	3.37	0.01	522	450	475	287	518	511	460	89.4	0.19
7	472	466	467	468	3.09	0.01	--	416	431	337	434	--	405	45.7	0.11
8	558	553	556	556	2.60	0.00	474	466	472	432	479	489	469	19.6	0.04

Exhaust CO_2 Concentrations (%)

Throttle Notch Position	Rail Yard Test						Over-The-Rail Test								
	12/22	12/22	12/22	3 Reps	3 Reps	3 Reps	12/19	12/19	12/20	12/20	12/21	12/21	6 Trains	6 Trains	6 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	0.57	0.51	0.48	0.52	0.05	0.09	0.30	0.29	0.64	0.16	0.67	--	0.41	0.23	0.55
High Idle	0.51	0.51	0.51	0.51	0.00	0.01	0.65	0.50	0.69	0.69	0.76	0.69	0.66	0.09	0.13
Dyn Brake	--	--	--	--	--	--	0.78	0.47	0.73	0.59	0.80	0.89	0.71	0.15	0.22
1	1.46	1.46	1.44	1.45	0.01	0.01	1.24	1.02	1.42	0.44	1.11	1.60	1.14	0.40	0.35
2	1.93	1.92	1.90	1.92	0.01	0.01	2.20	1.65	1.89	0.98	2.22	2.23	1.86	0.49	0.26
3	2.89	2.90	2.89	2.89	0.01	0.00	3.04	2.61	3.01	1.28	2.88	3.29	2.69	0.72	0.27
4	3.47	3.46	3.44	3.46	0.02	0.01	3.83	3.47	3.65	2.11	3.55	3.99	3.43	0.67	0.20
5	4.35	4.32	4.31	4.32	0.02	0.01	4.60	4.17	4.26	2.75	4.54	4.82	4.19	0.75	0.18
6	5.20	5.15	5.13	5.16	0.03	0.01	5.16	4.37	4.68	3.09	5.20	5.36	4.64	0.84	0.18
7	6.02	5.99	6.05	6.02	0.03	0.00	--	5.75	5.78	4.93	6.04	--	5.62	0.48	0.09
8	6.52	6.50	6.58	6.54	0.04	0.01	5.81	5.82	5.81	5.74	6.05	6.46	5.95	0.27	0.05

E.3 Summary of Results for NC-1810 on B60

Rail yard and over-the-rail measurements were conducted on the prime mover engine of locomotive NC-1810 (City of Greensboro) with B60 using a portable emissions measurement system (PEMS). The prime mover engine was an EMD 12-710G3B. The engine was originally manufactured in 1988 and was rebuilt by American Motive Power, Inc. (AMP) in 2010. The 140 L engine has a peak engine output of 3000 horsepower (hp) at an engine speed of 900 revolutions per minute (rpm).

The cycle average emission rates for the rail yard and over-the-rail measurements of the NC-1810 prime mover engine on B60, are shown in Table E-25. The cycle average emission rates are based on the line-haul duty cycle used by the U.S. Environmental Protection Agency (EPA) for regulatory purposes. During rail yard measurements, dynamic braking was not observed; thus, the time apportioned for dynamic braking in the line-haul duty cycle (12.5 percent) was combined with the time apportioned for idling in the line-haul duty cycle (38.0 percent). Therefore, idling accounts for 50.5 percent of the duty cycle used to calculate rail yard cycle average emission rates.

During five replicate rail yard measurements, the inter-replicate Coefficient of Variation (CV), or the ratio of the standard deviation to the mean, in RPM at each notch position was 1 percent or less. Similarly, the coefficient of variation for IAT was 4 percent or less, and for MAP was 3 percent or less except at notch 7, for which the CV was 7 percent. For fuel use rate, the CV was 5 percent or lower for notches 1 through 8, and was 7 to 10 percent at idle. For NOx, the CV ranges from 5 to 12 percent depending on the notch position. The inter-replicate CV for the time-based PM emission rate at each notch position was 18 percent or less, with the exception of High Idle, where the inter-replicate CV was 22 percent. The highest inter-replicate CV value was observed for the time-based CO and HC emission rates, with values as high as 158 percent at each notch position. However, CO and HC emission rates from diesel engines are very low. The absolute variation in these rates was small, even though on a relative basis the variation appears to be high. A majority of the measured CO and HC emission concentrations were below the detection limit of the PEMS, which may not be significantly different than zero.

During over-the-rail measurements, the inter-replicate variability in RPM, IAT, and MAP was 11 percent or less at each notch position. The CV for time-based NO_x emission rates was 8 percent or less at each notch position during the six one-way trips. The inter-run CV in the time-based fuel use and PM emission rate at each notch position was 26 percent and 48 percent or less, respectively. The highest inter-run CV values was observed for the time-based CO and HC emission rates, with values as high as 177 percent at each notch position. The absolute variation in these rates was small, even though on a relative basis the variation appears to be high

Differences in fuel use and cycle average emission rates between rail yard and over-the-rail measurements can be attributed to various factors. RPM and MAP was essentially the same for rail yard and over-the-rail measurements. IAT was as much as 10°C higher during over-the-rail measurements, which has a small effect on intake air flow rates of about 2 percent. At Notch 8, the engine output during rail yard measurements was 2700 horsepower, compared to 3000 horsepower during over-the-rail measurements. With Notch 8 accounting for 16 percent of the EPA line-haul duty cycle used to estimate cycle average emission rates, higher engine output decreases engine output based emission rates and, therefore, cycle average emission rates.

Table E-25. Preliminary Rail Yard and Over-the-Rail Cycle Average Emission Rates for the NC-1810 Prime Mover Engine with B60 Measured in the Rail Yard[a,b]

(a) Rail Yard

Fuel	NO_x (g/bhp-hr)	HC (g/bhp-hr)	CO (g/bhp-hr)	Opacity-based PM (g/bhp-hr)
B60	8.4	0.74	0.9	0.22

(b) Over-the-Rail

Fuel	NO_x (g/bhp-hr)	HC (g/bhp-hr)	CO (g/bhp-hr)	Opacity-based PM (g/bhp-hr)
B60	7.8	1.47	1.6	0.45

[a] Cycle average emission rates are based on U.S. EPA line-haul duty cycle used for regulatory purposes.

[b] NO_x, HC, and opacity-based PM emission rates are adjusted with multipliers of 1.053, 2.5, and 5, respectively, as bias correction.

[c] HC concentrations measured during the ULSD rail yard measurements were erratic and unusually high, and differed substantially between the two gas analyzers. Therefore, the HC emission rate result was deemed not to be valid and was not reported. The rail yard test will be repeated to establish a baseline on ULSD for HC.

[d] HC concentration measured during the ULSD over-the-rail measurement was based on the average HC concentration for two gas analyzers. The difference in concentrations reported by the two analyzers at a given notch was higher than expected. Therefore, the HC emission rate result was deemed not to be valid and was not reported.

Finally, differences in measured exhaust concentrations between rail yard and over-the-rail measurements lead to differences in fuel use and emission rates.

Throttle notch position data was obtained from the locomotive data activity recorder to measure the duty cycles for the over-the-rail measurements. The measured duty cycles are compared to the EPA line-haul duty cycle in Table E-26. The prime mover engine operated at notch 8 during the over-the-rail tests more than double the percentage of time, on average, the EPA estimates a line-haul locomotive is operating at notch 8. The average percentage of time the prime mover engine operated in Idle through notch 7 during the OTR tests was lower than the percentage of time the EPA estimates a line-haul locomotive is operating in those throttle notch settings, with the exception of dynamic braking, where the amount of time spent during the six one-way trips was similar to the percentage of time allocated in the line-haul duty cycle.

Table E-26. Over-the-Rail Duty Cycles During Measurement of NC-1810 on B60 Biodiesel

Notch	Percent Time in Each Notch							
	EPA Line-Haul	Measured Over-the-Rail						
		Average	8/9/2013 Train 75	8/9/2013 Train 76	8/10/2013 Train 75	8/10/2013 Train 76	10/26/2013 Train 73	10/26/2013 Train 74
Idle	38.0	27.4	33.8	29.3	26.2	31.3	27.3	16.5
DB	12.5	12.9	11.7	16.1	10.0	14.0	13.4	12.2
1	6.5	4.1	1.2	1.2	5.6	5.0	4.8	6.5
2	6.5	3.9	3.4	3.2	3.9	2.7	2.1	8.3
3	5.2	3.5	2.9	2.2	3.3	1.5	1.2	9.9
4	4.4	2.4	3.4	3.5	1.5	1.6	1.4	3.1
5	3.8	1.7	2.1	2.2	0.9	1.2	1.9	1.9
6	3.9	1.4	2.6	3.0	0.2	1.1	0.8	0.5
7	3.0	0.5	0.8	1.0	0.4	0.2	0.3	0.1
8	16.2	42.3	38.1	38.4	48.0	41.4	46.7	41.0

Details of results of the field measurements and of the fuel use and emission rates for RY and OTR measurements of NC-1810 using B60 biodiesel are given in attached supplemental tables.

Table E-27 summarizes the average measured engine speed (RPM), intake air temperature (IAT), and manifold absolute pressure (MAP) for each throttle notch position and for each replicate of the RY test and for each OTR trip. Engine speed ranges from 200 to 900 RPM in both RY and OTR measurements. For the RY measurements, engine RPM was highly repeatable, with a standard deviation of less than 2 RPM for all notch positions. For the OTR measurements, the RPM was also repeatable, with a standard deviation of 6 RPM or less except in dynamic braking, which was a transient mode of operation. The intake air temperature varies with ambient temperature and was generally in the range of 60 to 80 degrees C during all measurements. MAP was highly repeatable in the RY tests, ranging from 99 to 243 kPa with an inter-test standard deviation of less than 5 kPa for most notch settings. For OTR measurements, there was slightly more inter-run variability. However, the CV of the run average MAP values was typically 0.05 or less. Overall, the engine activity during the measurements was consistent from test to test for the five replicates in the rail yard, and from run to run for the six one-way trips observed between Raleigh and Charlotte.

Table E-28 summarizes the estimated fuel use rates inferred from the engine data of Table E-27 and volumetric efficiency measured in dynamometer tests of a similar engine. For the RY tests, fuel use rates from 2.4 to 139 g/sec depending on notch position, and was highly repeatable, with a CV of typically 0.05 or less at high engine load. The CV was slightly higher at low engine load, but the absolute variability in fuel use rates at low load was small. There was more variability in run-to-run estimates of fuel use for the OTR measurements, in part because the amount of time spent in some notch positions was low. The OTR estimated fuel use ranged from 2.2 to 124 g/sec, with CV of only 0.05 for Notch 8.

During RY measurements, the maximum engine output was 2,700 hp, whereas during OTR measurements the maximum engine output was 3,000 hp. Furthermore, as shown later in Table E-33, the average CO_2 concentrations for each notch position are lower for OTR than for RY measurements, which implies a lower fuel-to-air ratio. Because the engine activity and, therefore, engine air flow, are approximately the same for OTR versus RY measurements, the combination of higher engine output and lower fuel-to-air ratio lead to higher values of fuel-specific engine output (FSEO) in bhp-hr per gallon of fuel consumed, as shown in Table E-28. The FSEO was highly repeatable for the OTR measurements of notch 8, which represents significant portion of the observed duty cycle. In contrast, there was large inter-run variation for some notches, such as notches 3 and 7. However, these notches were rarely used compared to other notches, and thus the apparent variation was an artifact of small sample sizes.

The measured NO exhaust concentration and the estimated NO_x emission rates are shown in Table E-29 for each notch position, each RY test replicate, and each OTR one-way run. The average measured concentrations range among notch positions from approximately 130 to 830 ppm in the RY tests, and 140 to 830 ppm in the OTR measurements. The measurements are highly repeatable for the RY and OTR measurements, with CVs typically less than 0.11 for each of the RY and OTR measurements. The estimated mass emission rates range from 0.2 to 5.3 g/sec for the RY measurements and 0.2 to 5.3 g/sec for the OTR measurements. Because the observed concentrations tend to be lower for the OTR versus RY measurements, the mass emission rates also tend to be slightly lower for the OTR versus RY measurements.

On a fuel basis, the average NO_x emission rates range from 130 to 240 g/gallon among notch positions for the RY measurements and 140 to 250 g/gallon for the OTR measurements. For the RY measurements, the fuel-based emission rates are highly repeatable, with CV typically less than 0.11. The OTR measurements have more run-to-run variability but are nonetheless consistent, with CVs ranging from 0.05 to 0.15 in most cases, except for notch 7 for which the sample size was small. The fuel-based emission rates tend to be lowest at high load.

On an engine output basis, the notch average NO_x emission rates range from 7.1 g/bhp-hr at Notch 8 to 12.2 g/bhp-hr at Notch 1 in the RY measurements, with very high values at idle during which engine output was very low. For the OTR measurements, the notch average emission rates range from 6.4 g/bhp-hr at Notch 8 to 11.6 g/bhp-hr at notch 1, while much higher values occur at idle and while dynamic braking. In general, the emission rates on an engine output basis are lower for the OTR measurements than for the RY measurements. This results from a combination of lower exhaust concentration and higher engine output, especially at Notch 8.

Results are given for exhaust concentrations and emission rates in Tables E-30, E-31, E-32, and E-33 for CO, HC, PM, and CO_2, respectively. The CO exhaust concentrations during OTR measurements tend to be higher than during RY measurements, most likely as a result of more transient operation of the engine for the former. Thus, the cycle average CO emission rates also tend to be higher for OTR than RY measurements. Similarly, the HC exhaust concentrations and average emission rates tend to be higher for OTR than RY. However, both the CO and HC emission rates are low on an absolute basis, and some of the measured average concentrations for a given notch position and replicate or run are below the gas analyzer detection limit. For PM, the measured exhaust levels tend to be higher for OTR than RY for a given notch position, and thus the cycle average PM emission rate tends to also be higher. The trends in CO_2 emission rates are similar to those for fuel use on a mass per time and mass per engine output basis. CO_2 emission rates are also shown on a g/gallon basis. Since typically over 99 percent of the carbon in the fuel is emitted as CO_2, the fuel-based CO_2 emission rates are approximately constant.

Table E-27. Measured Engine Parameters for NC-1810 and B60

Throttle	Engine Speed (RPM)																
Notch	10/27	10/27	10/27	11/24	11/24	5 Reps	5 Reps	5 Reps	8/9	8/9	8/10	8/10	10/26	10/26	6 Trains	6 Trains	6 Trains
Position	RY Rep1	RY Rep2	RY Rep3	RY Rep4	RY Rep5	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 73	Train 74	Average	StDev	CV
Low Idle	200	198	197	202	200	199	1.66	0.01	201	198	202	200	199	196	199	2.32	0.01
High Idle	340	339	339	341	340	340	1.05	0.00	352	351	350	350	340	338	347	5.90	0.02
Dyn Brake	--	--	--	--	--	--	--	--	353	359	410	361	348	424	376	32.6	0.09
1	340	339	339	341	341	340	0.90	0.00	349	351	350	352	340	338	347	5.95	0.02
2	340	339	339	341	340	340	0.81	0.00	347	344	351	354	339	339	346	6.04	0.02
3	489	488	488	491	489	489	1.02	0.00	490	494	484	497	489	488	490	4.52	0.01
4	562	561	561	564	562	562	1.15	0.00	568	568	---	576	563	562	567	5.59	0.01
5	650	650	650	652	651	651	0.92	0.00	649	652	652	650	650	649	650	1.25	0.00
6	728	727	728	729	729	728	0.71	0.00	727	729	---	734	727	727	729	2.89	0.00
7	822	821	821	823	823	822	1.25	0.00	822	825	---	812	823	821	820	5.07	0.01
8	902	902	901	902	902	902	0.66	0.00	905	905	904	902	902	900	903	1.93	0.00

Throttle	Intake Air Temperature (deg C)																
Notch	10/27	10/27	10/27	11/24	11/24	5 Reps	5 Reps	5 Reps	8/9	8/9	8/10	8/10	10/26	10/26	6 Trains	6 Trains	6 Trains
Position	RY Rep1	RY Rep2	RY Rep3	RY Rep4	RY Rep5	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 73	Train 74	Average	StDev	CV
Low Idle	57	60	58	54	54	57	2.33	0.04	70	72	70	68	63	66	68	3.24	0.05
High Idle	67	66	67	67	68	67	0.77	0.01	74	74	76	72	63	69	71	4.59	0.06
Dyn Brake	--	--	--	--	--	--	--	--	74	75	76	72	65	70	72	4.20	0.06
1	59	60	61	58	59	59	1.39	0.02	74	71	79	74	65	70	72	4.69	0.06
2	64	63	63	61	61	63	1.25	0.02	76	72	78	75	66	72	73	4.40	0.06
3	66	67	68	64	66	66	1.56	0.02	75	74	76	74	64	73	73	4.31	0.06
4	67	68	68	65	67	67	1.48	0.02	75	75	---	72	65	74	72	4.50	0.06
5	65	68	69	65	65	66	1.86	0.03	75	80	80	74	69	75	75	4.25	0.06
6	69	70	69	67	66	68	1.68	0.02	78	81	---	71	68	78	75	5.10	0.07
7	72	72	71	71	70	71	0.84	0.01	76	86	---	80	62	78	76	8.55	0.11
8	70	74	75	72	72	73	1.83	0.03	78	78	80	77	71	75	76	3.23	0.04

Throttle	Manifold Absolute Pressure (kPa)																
Notch	10/27	10/27	10/27	11/24	11/24	5 Reps	5 Reps	5 Reps	8/9	8/9	8/10	8/10	10/26	10/26	6 Trains	6 Trains	6 Trains
Position	RY Rep1	RY Rep2	RY Rep3	RY Rep4	RY Rep5	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 73	Train 74	Average	StDev	CV
Low Idle	99	99	99	102	102	100	1.73	0.02	98	99	100	99	99	97	99	0.89	0.01
High Idle	107	106	106	110	110	108	2.09	0.02	106	106	106	107	107	106	106	0.54	0.01
Dyn Brake	--	--	--	--	--	--	--	--	106	107	114	108	108	113	109	3.52	0.03
1	107	106	106	110	110	108	2.15	0.02	107	107	107	108	109	106	107	0.94	0.01
2	107	106	106	110	110	108	2.14	0.02	108	106	107	110	109	107	108	1.24	0.01
3	121	120	120	125	125	122	2.76	0.02	119	120	125	123	125	121	122	2.61	0.02
4	131	130	130	136	136	132	3.30	0.02	128	129	---	132	135	132	131	2.78	0.02
5	145	144	144	152	151	147	4.01	0.03	140	141	145	147	151	147	145	3.94	0.03
6	161	159	159	168	168	163	4.51	0.03	154	157	---	160	163	166	160	5.09	0.03
7	194	190	182	214	213	199	14.23	0.07	176	210	---	183	189	217	195	17.7	0.09
8	226	228	226	243	240	233	8.06	0.03	210	216	210	215	237	225	219	10.3	0.05

Table E-28. Estimated Fuel Use Rates for NC-1810 and B60

Throttle	Time-Based Fuel Use Rates (g/s)																
Notch	10/27	10/27	10/27	11/24	11/24	5 Reps	5 Reps	5 Reps	8/9	8/9	8/10	8/10	10/26	10/26	6 Trains	6 Trains	6 Trains
Position	RY AX1	RY AX2	RY AX3	RY Rep4	RY Rep5	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 73	Train 74	Average	StDev	CV
Low Idle	2.73	2.62	2.40	3.12	2.99	2.77	0.29	0.10	2.66	2.20	2.28	1.50	2.55	1.88	2.18	0.43	0.20
High Idle	4.52	4.12	4.19	4.53	4.86	4.44	0.30	0.07	4.73	4.49	3.76	3.28	4.54	3.78	4.10	0.57	0.14
Dyn Brake	---	---	---	--	--	--	--	--	4.81	5.35	6.20	3.31	4.81	6.27	5.12	1.09	0.21
1	12.1	12.0	10.9	12.3	12.1	11.9	0.54	0.05	10.6	9.4	6.17	7.12	7.80	9.29	8.39	1.64	0.20
2	17.5	17.4	15.7	17.9	17.6	17.2	0.88	0.05	14.7	12.8	6.05	11.2	13.4	14.1	12.0	3.16	0.26
3	31.6	31.6	30.1	31.0	30.8	31.0	0.64	0.02	26.2	25.7	20.4	22.9	28.7	28.9	25.5	3.31	0.13
4	44.4	43.8	43.5	44.7	44.3	44.1	0.46	0.01	38.7	38.6	---	36.2	40.7	41.5	39.1	2.09	0.05
5	60.3	58.8	58.9	59.8	59.6	59.5	0.61	0.01	56.0	51.9	39.2	51.4	55.5	55.9	51.6	6.41	0.12
6	74.7	73.9	76.9	72.9	73.9	74.5	1.51	0.02	70.0	70.3	---	63.1	73.2	71.7	69.7	3.89	0.06
7	109	105	106	107	108	107	1.64	0.02	90.7	103	---	53.3	107	101	91.0	21.9	0.24
8	139	135	135	134	128	134	4.13	0.03	133	126	124	114	123	126	124	6.43	0.05

Throttle	Engine Output-Based Fuel Use Rates (bhp-hr/gal)																
Notch	10/27	10/27	10/27	11/24	11/24	5 Reps	5 Reps	3 Reps	8/9	8/9	8/10	8/10	10/26	10/26	6 Trains	6 Trains	6 Trains
Position	RY AX1	RY AX2	RY AX3	RY Rep4	RY Rep5	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 73	Train 74	Average	StDev	CV
Low Idle	3.04	3.17	3.46	2.66	2.77	3.02	0.32	0.11	3.12	3.77	3.63	5.55	3.25	4.41	3.96	0.90	0.23
High Idle	1.84	2.01	1.98	1.83	1.71	1.87	0.12	0.07	1.75	1.85	2.21	2.53	1.83	2.20	2.06	0.30	0.15
Dyn Brake	---	---	---	--	--	--	--	---	1.73	1.55	1.34	2.51	1.72	1.32	1.70	0.43	0.26
1	13.0	13.1	14.4	12.8	13.1	13.3	0.64	0.05	14.9	16.7	25.6	22.2	20.2	17.0	19.4	3.98	0.20
2	15.9	15.3	17.5	15.8	16.0	16.1	0.82	0.05	19.8	22.6	48.0	25.9	21.7	20.6	26.5	10.8	0.41
3	17.6	17.7	18.5	18.1	18.2	18.0	0.36	0.02	21.4	21.8	27.4	24.5	19.5	19.4	22.3	3.10	0.14
4	18.3	18.5	18.7	18.6	18.7	18.6	0.17	0.01	21.5	21.5	---	23.0	20.4	20.0	21.3	1.15	0.05
5	18.2	18.4	18.3	18.4	18.4	18.3	0.10	0.01	19.3	20.8	27.5	21.0	19.5	19.3	21.2	3.17	0.15
6	17.8	17.9	17.3	18.2	18.0	17.8	0.35	0.02	19.0	18.9	---	21.1	18.2	18.5	19.1	1.13	0.06
7	16.8	16.6	16.5	18.6	18.4	17.4	1.02	0.06	22.0	19.4	---	37.4	18.6	19.8	23.4	7.90	0.34
8	16.1	16.3	16.6	16.7	17.5	16.7	0.55	0.03	18.7	19.7	20.1	21.9	20.3	19.7	20.1	1.07	0.05

Table E-29. Measured NO_x Emission Rates for NC-1810 and B60

Throttle	Time-Based NOx Emission Rates (g/s)																
Notch	10/27	10/27	10/27	11/24	11/24	5 Reps	5 Reps	5 Reps	8/9	8/9	8/10	8/10	10/26	10/26	6 Trains	6 Trains	6 Trains
Position	RY AX1	RY AX2	RY AX3	RY Rep4	RY Rep5	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 73	Train 74	Average	StDev	CV
Low Idle	0.21	0.21	0.18	0.20	0.18	0.20	0.02	0.08	0.22	0.14	0.22	0.16	0.19	0.14	0.18	0.04	0.21
High Idle	0.29	0.29	0.26	0.26	0.25	0.27	0.02	0.07	0.33	0.30	0.27	0.27	0.30	0.24	0.29	0.03	0.12
Dyn Brake	---	---	---	--	--	---	---	---	0.34	0.33	0.29	0.27	0.32	0.34	0.32	0.03	0.09
1	0.70	0.71	0.64	0.60	0.56	0.64	0.07	0.10	0.65	0.70	0.63	0.60	0.51	0.57	0.61	0.07	0.11
2	1.22	1.21	1.07	1.01	0.96	1.10	0.12	0.11	1.04	1.00	0.99	1.08	0.93	0.96	1.00	0.05	0.05
3	2.25	2.20	2.11	1.80	1.72	2.02	0.24	0.12	1.75	2.38	2.00	1.90	1.98	1.97	2.00	0.21	0.11
4	2.89	2.83	2.83	2.44	2.33	2.66	0.26	0.10	2.55	2.77	2.21	2.55	2.57	2.64	2.55	0.19	0.07
5	3.55	3.48	3.51	3.03	2.91	3.30	0.30	0.09	3.32	3.40	3.15	3.66	3.34	3.31	3.36	0.17	0.05
6	4.22	4.21	4.11	3.61	3.46	3.92	0.36	0.09	4.11	4.41	2.51	4.05	4.00	4.15	3.87	0.68	0.18
7	5.06	5.01	4.77	4.69	4.48	4.80	0.24	0.05	4.20	5.37	---	4.14	4.53	5.44	4.73	0.63	0.13
8	5.44	5.59	5.58	5.11	4.87	5.32	0.32	0.06	4.78	5.15	5.41	5.78	5.41	5.23	5.29	0.33	0.06

Throttle	Fuel-Based NOx Emission Rates (g/gal)																
Notch	10/27	10/27	10/27	11/24	11/24	5 Reps	5 Reps	5 Reps	8/9	8/9	8/10	8/10	10/26	10/26	6 Trains	6 Trains	6 Trains
Position	RY AX1	RY AX2	RY AX3	RY Rep4	RY Rep5	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 73	Train 74	Average	StDev	CV
Low Idle	257	268	255	209	199	238	31.2	0.13	276	211	291	219	251	251	250	31.2	0.12
High Idle	212	231	202	187	174	201	22.3	0.11	234	224	243	202	221	212	223	14.7	0.07
Dyn Brake	---	---	---	--	--	---	---	---	236	206	242	200	219	180	214	23.2	0.11
1	193	196	195	162	153	180	20.7	0.12	205	245	245	251	216	203	228	21.9	0.10
2	231	231	226	187	181	211	24.8	0.12	235	257	280	323	230	224	258	37.9	0.15
3	235	231	232	192	184	215	24.7	0.11	221	306	271	273	228	226	254	34.3	0.14
4	215	214	215	180	174	200	20.6	0.10	218	237	217	226	209	211	220	10.4	0.05
5	195	196	197	168	162	183	17.3	0.09	196	217	246	240	199	196	216	22.6	0.10
6	187	189	177	164	155	174	14.7	0.08	195	207	189	210	181	191	195	11.1	0.06
7	154	158	149	144	137	149	8.39	0.06	153	173	---	285	140	179	186	57.5	0.31
8	129	138	137	126	126	131	5.80	0.04	119	135	155	166	146	137	143	16.5	0.12

Throttle	Engine Output-Based NOx Emission Rates (g/bhp-hr)																
Notch	10/27	10/27	10/27	11/24	11/24	5 Reps	5 Reps	5 Reps	8/9	8/9	8/10	8/10	10/26	10/26	6 Trains	6 Trains	6 Trains
Position	RY AX1	RY AX2	RY AX3	RY Rep4	RY Rep5	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 73	Train 74	Average	StDev	CV
Low Idle	76.4	76.4	66.5	71.2	64.8	71.1	5.41	0.08	79.9	50.6	87.4	63.0	69.8	51.5	67.0	14.9	0.22
High Idle	104	104	92.0	92.1	91.8	96.8	6.63	0.07	120	110	107	106	109	87.3	107	10.8	0.10
Dyn Brake	---	---	---	--	--	---	---	---	123	120	116	109	115	123	118	5.49	0.05
1	13.4	13.5	12.2	11.4	10.5	12.2	1.26	0.10	12.4	13.2	11.9	11.4	9.66	10.8	11.6	1.25	0.11
2	13.1	13.6	11.7	10.7	10.2	11.9	1.48	0.12	10.7	10.2	10.4	11.2	9.56	9.82	10.3	0.60	0.06
3	12.1	11.8	11.3	9.58	9.16	10.8	1.32	0.12	9.32	12.7	10.7	10.1	10.6	10.5	10.6	1.12	0.11
4	10.6	10.4	10.4	8.77	8.38	9.72	1.05	0.11	9.16	9.97	7.96	9.17	9.27	9.51	9.17	0.67	0.07
5	9.67	9.63	9.73	8.22	7.91	9.03	0.89	0.10	9.19	9.41	8.56	9.94	9.24	9.18	9.25	0.44	0.05
6	9.50	9.54	9.26	8.12	7.79	8.84	0.82	0.09	9.26	9.92	5.65	9.10	9.01	9.33	8.71	1.53	0.18
7	8.29	8.59	8.18	7.03	6.72	7.76	0.83	0.11	6.29	8.05	---	6.21	6.80	8.16	7.10	0.94	0.13
8	7.25	7.60	7.44	6.81	6.49	7.12	0.46	0.06	5.73	6.18	6.49	6.93	6.50	6.27	6.35	0.40	0.06
Duty Cycle Avg (Raw)	8.4	8.7	8.3	7.5	7.2	8.0	0.65	0.08	7.0	7.6	7.2	7.7	7.4	7.4	7.4	0.23	0.03
Duty Cycle Avg (Adjusted)	8.9	9.1	8.8	7.9	7.5	8.4	0.68	0.08	7.4	8.0	7.6	8.1	7.8	7.8	7.8	0.24	0.03

Throttle	Exhaust NOx Concentrations (ppm)																
Notch	10/27	10/27	10/27	11/24	11/24	5 Reps	5 Reps	5 Reps	8/9	8/9	8/10	8/10	10/26	10/26	6 Trains	6 Trains	6 Trains
Position	RY AX1	RY AX2	RY AX3	RY Rep4	RY Rep5	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 73	Train 74	Average	StDev	CV
Low Idle	158	160	140	144	132	147	12	0.08	175	113	169	125	148	114	140	28	0.20
High Idle	143	142	127	124	124	132	9	0.07	167	151	134	131	147	123	142	16	0.11
Dyn Brake	---	---	---	--	--	---	---	---	170	163	142	131	152	139	150	15	0.10
1	342	347	314	286	266	311	35	0.11	328	341	310	290	248	290	301	33	0.11
2	599	595	525	488	466	535	61	0.11	525	486	474	496	455	485	487	23	0.05
3	776	769	736	607	587	695	91	0.13	631	804	688	640	672	702	689	62	0.09
4	858	844	845	703	682	786	86	0.11	783	821	683	734	741	801	760	51	0.07
5	869	869	872	728	704	808	85	0.10	870	867	768	853	798	830	831	41	0.05
6	894	896	889	749	717	829	88	0.11	927	952	549	821	834	870	825	145	0.18
7	867	863	853	758	724	813	67	0.08	782	864	---	692	762	871	794	75	0.09
8	784	807	802	707	687	757	56	0.07	744	748	790	806	749	760	766	26	0.03

Table E-30. Measured CO Emission Rates for NC-1810 and B60

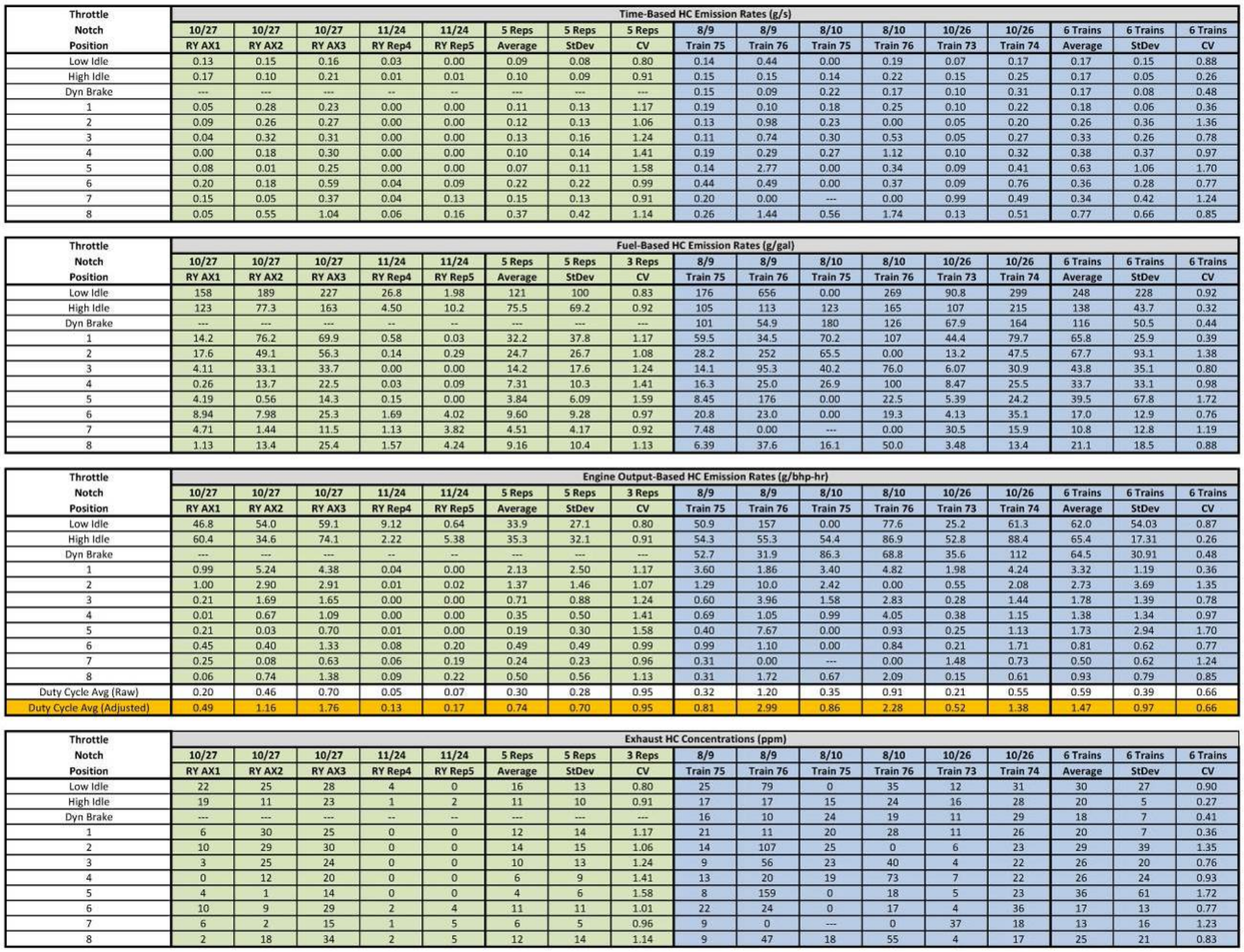
Throttle	Time-Based CO Emission Rates (g/s)																	
Notch	10/27	10/27	10/27	11/24	11/24	5 Reps	5 Reps	5 Reps	8/9	8/9	8/10	8/10	10/26	10/26	6 Trains	6 Trains	6 Trains
Position	RY AX1	RY AX2	RY AX3	RY Rep4	RY Rep5	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 73	Train 74	Average	StDev	CV
Low Idle	0.11	0.03	0.11	0.03	0.04	0.07	0.04	0.61	0.03	0.77	0.11	0.21	0.09	0.09	0.22	0.28	1.27
High Idle	0.15	0.00	0.11	0.09	0.01	0.07	0.07	0.88	0.03	0.57	0.17	0.27	0.12	0.14	0.22	0.19	0.88
Dyn Brake	---	---	---	--	--	---	---	---	0.03	0.78	0.11	0.22	0.11	0.18	0.24	0.27	1.14
1	0.08	0.14	0.08	0.05	0.03	0.08	0.04	0.59	0.02	0.28	0.18	0.13	0.10	0.15	0.14	0.08	0.59
2	0.13	0.08	0.12	0.02	0.03	0.08	0.05	0.67	0.04	0.23	0.06	0.27	0.08	0.12	0.13	0.10	0.73
3	0.10	0.17	0.11	0.01	0.00	0.08	0.07	0.90	0.04	0.00	0.11	0.29	0.14	0.16	0.12	0.10	0.82
4	0.18	0.07	0.22	0.02	0.00	0.10	0.10	0.99	0.06	1.05	0.62	0.54	0.10	0.17	0.42	0.39	0.91
5	0.14	0.01	0.16	0.04	0.00	0.07	0.08	1.09	0.12	2.55	0.40	0.21	0.16	0.26	0.62	0.95	1.54
6	0.17	0.08	0.50	0.01	0.00	0.15	0.21	1.35	0.14	2.33	0.11	0.09	0.08	0.54	0.55	0.89	1.62
7	0.63	0.35	0.65	0.21	0.18	0.40	0.23	0.57	0.14	1.34	---	0.00	0.12	0.47	0.41	0.55	1.32
8	0.74	0.74	1.08	0.37	0.20	0.63	0.35	0.55	1.05	0.45	1.15	1.45	0.47	0.65	0.87	0.41	0.47

Throttle	Fuel-Based CO Emission Rates (g/gal)																	
Notch	10/27	10/27	10/27	11/24	11/24	5 Reps	5 Reps	3 Reps	8/9	8/9	8/10	8/10	10/26	10/26	6 Trains	6 Trains	6 Trains
Position	RY AX1	RY AX2	RY AX3	RY Rep4	RY Rep5	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 73	Train 74	Average	StDev	CV
Low Idle	136	43.2	146	36.2	44.0	81.2	55.0	0.68	38.2	1154	152	295	111	163	319	417	1.31
High Idle	111	2.05	86.5	69.3	6.77	55.2	48.7	0.88	21.9	419	151	206	83.9	126	168	138	0.82
Dyn Brake	---	---	---	--	--	---	---	---	18.0	480	91.3	161	78.9	96.9	154	166	1.07
1	21.2	39.6	23.7	13.8	7.01	21.1	12.3	0.58	7.79	96.8	71.4	53.4	41.0	52.2	53.8	29.8	0.55
2	24.9	14.7	25.2	3.94	5.18	14.8	10.3	0.69	9.50	58.3	15.7	82.5	18.6	28.5	35.5	28.7	0.81
3	9.96	18.2	12.2	1.21	0.50	8.42	7.54	0.90	5.61	0.00	14.6	41.9	16.0	18.0	16.0	14.4	0.90
4	13.7	5.19	16.9	1.26	0.32	7.46	7.45	1.00	5.43	90.2	60.5	47.9	8.13	13.5	37.6	34.3	0.91
5	7.74	0.55	9.16	1.96	0.09	3.90	4.24	1.09	6.95	163	31.4	14.0	9.44	15.6	40.0	60.7	1.52
6	7.55	3.71	21.7	0.37	0.18	6.70	8.90	1.33	6.61	110	8.45	4.79	3.62	25.1	26.4	41.6	1.58
7	19.3	10.9	20.4	6.33	5.36	12.5	7.09	0.57	5.20	43.0	---	0.00	3.65	15.4	13.5	17.5	1.30
8	17.7	18.3	26.5	9.01	5.30	15.3	8.35	0.54	26.1	11.8	32.9	41.7	12.8	17.1	23.7	12.0	0.51

Throttle	Engine Output-Based CO Emission Rates (g/bhp-hr)																	
Notch	10/27	10/27	10/27	11/24	11/24	5 Reps	5 Reps	3 Reps	8/9	8/9	8/10	8/10	10/26	10/26	6 Trains	6 Trains	6 Trains
Position	RY AX1	RY AX2	RY AX3	RY Rep4	RY Rep5	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 73	Train 74	Average	StDev	CV
Low Idle	40.4	12.3	38.2	12.3	14.3	23.5	14.45	0.61	11.1	276	45.7	84.9	30.7	33.3	80.3	99.09	1.23
High Idle	54.7	0.92	39.4	34.2	3.58	26.5	23.45	0.88	11.3	205	66.7	108	41.5	51.6	80.6	68.58	0.85
Dyn Brake	---	---	---	--	--	---	---	---	9.43	279	43.8	87.7	41.3	66.1	87.9	97.30	1.11
1	1.47	2.72	1.48	0.97	0.48	1.43	0.83	0.59	0.47	5.22	3.46	2.42	1.83	2.78	2.70	1.60	0.59
2	1.42	0.87	1.30	0.23	0.29	0.82	0.55	0.67	0.43	2.33	0.58	2.87	0.77	1.25	1.37	1.00	0.73
3	0.51	0.93	0.60	0.06	0.02	0.42	0.38	0.90	0.24	0.00	0.58	1.56	0.74	0.84	0.66	0.54	0.82
4	0.67	0.25	0.82	0.06	0.02	0.36	0.36	1.00	0.23	3.79	2.22	1.94	0.36	0.61	1.53	1.39	0.91
5	0.38	0.03	0.45	0.10	0.00	0.19	0.21	1.09	0.33	7.07	1.10	0.58	0.44	0.73	1.71	2.64	1.55
6	0.38	0.19	1.13	0.02	0.01	0.35	0.47	1.35	0.31	5.25	0.25	0.21	0.18	1.22	1.24	2.00	1.62
7	1.04	0.59	1.12	0.31	0.26	0.66	0.40	0.60	0.21	2.01	---	0.00	0.18	0.70	0.62	0.82	1.32
8	0.99	1.01	1.44	0.49	0.27	0.84	0.46	0.55	1.26	0.54	1.38	1.74	0.57	0.78	1.05	0.49	0.47
Duty Cycle Avg (Raw)	1.2	0.9	1.5	0.4	0.3	0.9	0.49	0.58	1.0	3.5	1.6	1.9	0.7	1.1	1.6	1.02	0.62
Duty Cycle Avg (Adjusted)	1.2	0.9	1.5	0.4	0.3	0.9	0.49	0.58	1.0	3.5	1.6	1.9	0.7	1.1	1.6	1.02	0.62

Throttle	Exhaust CO Concentrations (%)																	
Notch	10/27	10/27	10/27	11/24	11/24	5 Reps	5 Reps	3 Reps	8/9	8/9	8/10	8/10	10/26	10/26	6 Trains	6 Trains	6 Trains
Position	RY AX1	RY AX2	RY AX3	RY Rep4	RY Rep5	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 73	Train 74	Average	StDev	CV
Low Idle	0.014	0.004	0.014	0.004	0.005	0.008	0.005	0.62	0.004	0.107	0.015	0.029	0.011	0.013	0.03	0.04	1.29
High Idle	0.013	0.000	0.009	0.008	0.001	0.006	0.006	0.89	0.003	0.049	0.014	0.023	0.010	0.013	0.02	0.02	0.88
Dyn Brake	---	---	---	--	--	---	---	---	0.002	0.065	0.009	0.018	0.010	0.013	0.02	0.02	1.17
1	0.006	0.012	0.007	0.004	0.002	0.006	0.004	0.59	0.002	0.023	0.016	0.011	0.008	0.013	0.01	0.01	0.59
2	0.011	0.007	0.010	0.002	0.002	0.006	0.004	0.68	0.004	0.019	0.005	0.022	0.006	0.011	0.01	0.01	0.70
3	0.006	0.011	0.007	0.001	0.000	0.005	0.004	0.91	0.003	0.000	0.006	0.017	0.008	0.010	0.01	0.01	0.81
4	0.009	0.004	0.011	0.001	0.000	0.005	0.005	1.00	0.003	0.054	0.033	0.027	0.005	0.009	0.02	0.02	0.91
5	0.006	0.000	0.007	0.001	0.000	0.003	0.003	1.09	0.005	0.113	0.017	0.009	0.007	0.011	0.03	0.04	1.57
6	0.006	0.003	0.019	0.000	0.000	0.006	0.008	1.36	0.005	0.087	0.004	0.003	0.003	0.020	0.02	0.03	1.63
7	0.019	0.010	0.020	0.006	0.005	0.012	0.007	0.60	0.005	0.037	---	0.000	0.003	0.013	0.01	0.02	1.29
8	0.019	0.019	0.027	0.009	0.005	0.016	0.009	0.56	0.028	0.011	0.029	0.035	0.011	0.016	0.02	0.01	0.47

Table E-31. Measured Hydrocarbon Emission Rates for NC-1810 and B60



Throttle	Time-Based HC Emission Rates (g/s)																
Notch	10/27	10/27	10/27	11/24	11/24	5 Reps	5 Reps	5 Reps	8/9	8/9	8/10	8/10	10/26	10/26	6 Trains	6 Trains	6 Trains
Position	RY AX1	RY AX2	RY AX3	RY Rep4	RY Rep5	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 73	Train 74	Average	StDev	CV
Low Idle	0.13	0.15	0.16	0.03	0.00	0.09	0.08	0.80	0.14	0.44	0.00	0.19	0.07	0.17	0.17	0.15	0.88
High Idle	0.17	0.10	0.21	0.01	0.01	0.10	0.09	0.91	0.15	0.15	0.14	0.22	0.15	0.25	0.17	0.05	0.26
Dyn Brake	---	---	---	--	--	---	---	---	0.15	0.09	0.22	0.17	0.10	0.31	0.17	0.08	0.48
1	0.05	0.28	0.23	0.00	0.00	0.11	0.13	1.17	0.19	0.10	0.18	0.25	0.10	0.22	0.18	0.06	0.36
2	0.09	0.26	0.27	0.00	0.00	0.12	0.13	1.06	0.13	0.98	0.23	0.00	0.05	0.20	0.26	0.36	1.36
3	0.04	0.32	0.31	0.00	0.00	0.13	0.16	1.24	0.11	0.74	0.30	0.53	0.05	0.27	0.33	0.26	0.78
4	0.00	0.18	0.30	0.00	0.00	0.10	0.14	1.41	0.19	0.29	0.27	1.12	0.10	0.32	0.38	0.37	0.97
5	0.08	0.01	0.25	0.00	0.00	0.07	0.11	1.58	0.14	2.77	0.00	0.34	0.09	0.41	0.63	1.06	1.70
6	0.20	0.18	0.59	0.04	0.09	0.22	0.22	0.99	0.44	0.49	0.00	0.37	0.09	0.76	0.36	0.28	0.77
7	0.15	0.05	0.37	0.04	0.13	0.15	0.13	0.91	0.20	0.00	---	0.00	0.99	0.49	0.34	0.42	1.24
8	0.05	0.55	1.04	0.06	0.16	0.37	0.42	1.14	0.26	1.44	0.56	1.74	0.13	0.51	0.77	0.66	0.85

Throttle	Fuel-Based HC Emission Rates (g/gal)																
Notch	10/27	10/27	10/27	11/24	11/24	5 Reps	5 Reps	3 Reps	8/9	8/9	8/10	8/10	10/26	10/26	6 Trains	6 Trains	6 Trains
Position	RY AX1	RY AX2	RY AX3	RY Rep4	RY Rep5	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 73	Train 74	Average	StDev	CV
Low Idle	158	189	227	26.8	1.98	121	100	0.83	176	656	0.00	269	90.8	299	248	228	0.92
High Idle	123	77.3	163	4.50	10.2	75.5	69.2	0.92	105	113	123	165	107	215	138	43.7	0.32
Dyn Brake	---	---	---	--	--	---	---	---	101	54.9	180	126	67.9	164	116	50.5	0.44
1	14.2	76.2	69.9	0.58	0.03	32.2	37.8	1.17	59.5	34.5	70.2	107	44.4	79.7	65.8	25.9	0.39
2	17.6	49.1	56.3	0.14	0.29	24.7	26.7	1.08	28.2	252	65.5	0.00	13.2	47.5	67.7	93.1	1.38
3	4.11	33.1	33.7	0.00	0.00	14.2	17.6	1.24	14.1	95.3	40.2	76.0	6.07	30.9	43.8	35.1	0.80
4	0.26	13.7	22.5	0.03	0.09	7.31	10.3	1.41	16.3	25.0	26.9	100	8.47	25.5	33.7	33.1	0.98
5	4.19	0.56	14.3	0.15	0.00	3.84	6.09	1.59	8.45	176	0.00	22.5	5.39	24.2	39.5	67.8	1.72
6	8.94	7.98	25.3	1.69	4.02	9.60	9.28	0.97	20.8	23.0	0.00	19.3	4.13	35.1	17.0	12.9	0.76
7	4.71	1.44	11.5	1.13	3.82	4.51	4.17	0.92	7.48	0.00	---	0.00	30.5	15.9	10.8	12.8	1.19
8	1.13	13.4	25.4	1.57	4.24	9.16	10.4	1.13	6.39	37.6	16.1	50.0	3.48	13.4	21.1	18.5	0.88

Throttle	Engine Output-Based HC Emission Rates (g/bhp-hr)																
Notch	10/27	10/27	10/27	11/24	11/24	5 Reps	5 Reps	3 Reps	8/9	8/9	8/10	8/10	10/26	10/26	6 Trains	6 Trains	6 Trains
Position	RY AX1	RY AX2	RY AX3	RY Rep4	RY Rep5	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 73	Train 74	Average	StDev	CV
Low Idle	46.8	54.0	59.1	9.12	0.64	33.9	27.1	0.80	50.9	157	0.00	77.6	25.2	61.3	62.0	54.03	0.87
High Idle	60.4	34.6	74.1	2.22	5.38	35.3	32.1	0.91	54.3	55.3	54.4	86.9	52.8	88.4	65.4	17.31	0.26
Dyn Brake	---	---	---	--	--	---	---	---	52.7	31.9	86.3	68.8	35.6	112	64.5	30.91	0.48
1	0.99	5.24	4.38	0.04	0.00	2.13	2.50	1.17	3.60	1.86	3.40	4.82	1.98	4.24	3.32	1.19	0.36
2	1.00	2.90	2.91	0.01	0.02	1.37	1.46	1.07	1.29	10.0	2.42	0.00	0.55	2.08	2.73	3.69	1.35
3	0.21	1.69	1.65	0.00	0.00	0.71	0.88	1.24	0.60	3.96	1.58	2.83	0.28	1.44	1.78	1.39	0.78
4	0.01	0.67	1.09	0.00	0.00	0.35	0.50	1.41	0.69	1.05	0.99	4.05	0.38	1.15	1.38	1.34	0.97
5	0.21	0.03	0.70	0.01	0.00	0.19	0.30	1.58	0.40	7.67	0.00	0.93	0.25	1.13	1.73	2.94	1.70
6	0.45	0.40	1.33	0.08	0.20	0.49	0.49	0.99	0.99	1.10	0.00	0.84	0.21	1.71	0.81	0.62	0.77
7	0.25	0.08	0.63	0.06	0.19	0.24	0.23	0.96	0.31	0.00	---	0.00	1.48	0.73	0.50	0.62	1.24
8	0.06	0.74	1.38	0.09	0.22	0.50	0.56	1.13	0.31	1.72	0.67	2.09	0.15	0.61	0.93	0.79	0.85
Duty Cycle Avg (Raw)	0.20	0.46	0.70	0.05	0.07	0.30	0.28	0.95	0.32	1.20	0.35	0.91	0.21	0.55	0.59	0.39	0.66
Duty Cycle Avg (Adjusted)	0.49	1.16	1.76	0.13	0.17	0.74	0.70	0.95	0.81	2.99	0.86	2.28	0.52	1.38	1.47	0.97	0.66

Throttle	Exhaust HC Concentrations (ppm)																
Notch	10/27	10/27	10/27	11/24	11/24	5 Reps	5 Reps	3 Reps	8/9	8/9	8/10	8/10	10/26	10/26	6 Trains	6 Trains	6 Trains
Position	RY AX1	RY AX2	RY AX3	RY Rep4	RY Rep5	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 73	Train 74	Average	StDev	CV
Low Idle	22	25	28	4	0	16	13	0.80	25	79	0	35	12	31	30	27	0.90
High Idle	19	11	23	1	2	11	10	0.91	17	17	15	24	16	28	20	5	0.27
Dyn Brake	---	---	---	--	--	---	---	---	16	10	24	19	11	29	18	7	0.41
1	6	30	25	0	0	12	14	1.17	21	11	20	28	11	26	20	7	0.36
2	10	29	30	0	0	14	15	1.06	14	107	25	0	6	23	29	39	1.35
3	3	25	24	0	0	10	13	1.24	9	56	23	40	4	22	26	20	0.76
4	0	12	20	0	0	6	9	1.41	13	20	19	73	7	22	26	24	0.93
5	4	1	14	0	0	4	6	1.58	8	159	0	18	5	23	36	61	1.72
6	10	9	29	2	4	11	11	1.01	22	24	0	17	4	36	17	13	0.77
7	6	2	15	1	5	6	5	0.96	9	0	---	0	37	18	13	16	1.23
8	2	18	34	2	5	12	14	1.14	9	47	18	55	4	17	25	21	0.83

Table E-32. Measured Particulate Matter Emission Rates for NC-1810 and B60

Throttle	Time-Based PM Emission Rates (g/s)																
Notch	10/27	10/27	10/27	11/24	11/24	5 Reps	5 Reps	5 Reps	8/9	8/9	8/10	8/10	10/26	10/26	6 Trains	6 Trains	6 Trains
Position	RY AX1	RY AX2	RY AX3	RY Rep4	RY Rep5	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 73	Train 74	Average	StDev	CV
Low Idle	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.09	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.00	0.35
High Idle	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.22	0.02	0.02	0.02	0.02	0.01	0.01	0.02	0.01	0.39
Dyn Brake	---	---	---	--	--	---	---	---	0.02	0.02	0.02	0.02	0.01	0.01	0.02	0.01	0.41
1	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.07	0.03	0.03	0.04	0.03	0.02	0.01	0.03	0.01	0.36
2	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.05	0.04	0.05	0.05	0.04	0.02	0.02	0.04	0.01	0.31
3	0.03	0.02	0.02	0.02	0.02	0.02	0.00	0.06	0.07	0.07	0.09	0.07	0.03	0.03	0.06	0.02	0.41
4	0.04	0.04	0.03	0.04	0.04	0.04	0.00	0.07	0.10	0.11	0.12	0.12	0.06	0.04	0.09	0.03	0.37
5	0.06	0.05	0.05	0.05	0.04	0.05	0.01	0.11	0.17	0.17	0.20	0.13	0.06	0.06	0.13	0.06	0.43
6	0.07	0.07	0.07	0.05	0.05	0.06	0.01	0.14	0.25	0.22	0.11	0.23	0.09	0.07	0.16	0.08	0.48
7	0.14	0.13	0.13	0.11	0.11	0.12	0.02	0.13	0.25	0.40	---	0.10	0.18	0.08	0.20	0.13	0.63
8	0.22	0.18	0.18	0.17	0.13	0.18	0.03	0.18	0.42	0.58	0.49	0.49	0.17	0.16	0.39	0.18	0.46

Throttle	Fuel-Based PM Emission Rates (g/gal)																
Notch	10/27	10/27	10/27	11/24	11/24	5 Reps	5 Reps	5 Reps	8/9	8/9	8/10	8/10	10/26	10/26	6 Trains	6 Trains	6 Trains
Position	RY AX1	RY AX2	RY AX3	RY Rep4	RY Rep5	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 73	Train 74	Average	StDev	CV
Low Idle	12.9	11.1	13.8	12.0	10.9	12.1	1.22	0.10	27.0	26.8	27.7	28.8	13.2	14.6	23.0	7.11	0.31
High Idle	5.30	3.75	4.06	5.43	3.42	4.39	0.92	0.21	16.3	18.6	23.6	19.5	9.23	6.71	15.7	6.45	0.41
Dyn Brake	---	---	---	--	--	---	---	---	16.2	16.5	25.0	19.7	7.63	5.16	15.0	7.45	0.50
1	4.76	4.39	5.39	5.12	5.10	4.95	0.39	0.08	12.1	13.4	18.6	15.4	8.81	5.70	12.3	4.62	0.37
2	5.12	4.78	5.32	5.15	4.90	5.06	0.21	0.04	12.1	15.9	17.5	16.2	7.20	6.92	12.6	4.67	0.37
3	3.51	3.06	3.47	3.32	3.08	3.29	0.21	0.06	11.2	12.1	15.8	13.1	4.69	4.20	10.2	4.72	0.46
4	3.97	3.49	3.38	3.69	3.55	3.62	0.23	0.06	11.2	12.3	15.8	14.3	6.01	4.60	10.7	4.50	0.42
5	4.23	3.96	3.94	3.38	3.22	3.75	0.43	0.11	12.9	14.1	20.0	11.5	5.04	4.92	11.4	5.75	0.50
6	4.03	4.05	3.81	3.16	3.04	3.62	0.48	0.13	15.3	13.3	11.0	15.8	5.33	4.52	10.9	4.93	0.45
7	5.75	5.46	5.37	4.30	4.33	5.04	0.68	0.13	12.0	16.8	---	9.36	7.37	3.57	9.82	4.96	0.51
8	6.84	5.71	5.68	5.44	4.53	5.64	0.82	0.15	13.6	20.0	18.4	18.5	6.04	5.48	13.7	6.51	0.48

Throttle	Engine Output-Based PM Emission Rates (g/bhp-hr)																
Notch	10/27	10/27	10/27	11/24	11/24	5 Reps	5 Reps	5 Reps	8/9	8/9	8/10	8/10	10/26	10/26	6 Trains	6 Trains	6 Trains
Position	RY AX1	RY AX2	RY AX3	RY Rep4	RY Rep5	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 73	Train 74	Average	StDev	CV
Low Idle	2.92	2.42	2.74	3.12	2.70	2.78	0.26	0.09	5.96	4.90	6.35	6.32	2.80	2.28	4.77	1.81	0.38
High Idle	1.99	1.28	1.41	2.04	1.38	1.62	0.36	0.22	6.40	6.93	7.95	7.80	3.48	2.10	5.78	2.42	0.42
Dyn Brake	---	---	---	--	--	---	---	---	6.47	7.33	9.17	8.18	3.05	2.68	6.15	2.70	0.44
1	0.25	0.23	0.26	0.27	0.27	0.26	0.02	0.07	0.56	0.55	0.69	0.53	0.30	0.23	0.48	0.17	0.36
2	0.22	0.22	0.21	0.22	0.21	0.22	0.01	0.03	0.42	0.48	0.49	0.43	0.23	0.23	0.38	0.12	0.32
3	0.14	0.12	0.13	0.13	0.12	0.13	0.01	0.07	0.36	0.38	0.48	0.37	0.17	0.15	0.32	0.13	0.41
4	0.15	0.13	0.12	0.14	0.13	0.13	0.01	0.07	0.36	0.39	0.44	0.44	0.20	0.16	0.33	0.12	0.37
5	0.16	0.15	0.15	0.13	0.12	0.14	0.02	0.12	0.46	0.47	0.53	0.36	0.18	0.18	0.36	0.15	0.42
6	0.16	0.16	0.15	0.12	0.12	0.14	0.02	0.14	0.55	0.49	0.25	0.53	0.20	0.17	0.36	0.18	0.48
7	0.24	0.23	0.22	0.16	0.16	0.20	0.04	0.19	0.38	0.60	---	0.16	0.27	0.12	0.31	0.19	0.63
8	0.29	0.24	0.24	0.22	0.18	0.23	0.04	0.18	0.50	0.70	0.59	0.59	0.20	0.19	0.46	0.21	0.46
Duty Cycle Avg (Raw)	0.05	0.05	0.05	0.04	0.04	0.04	0.01	0.14	0.10	0.13	0.12	0.11	0.05	0.04	0.09	0.04	0.43
Duty Cycle Avg (Adjusted)	0.27	0.23	0.23	0.21	0.18	0.22	0.03	0.14	0.51	0.65	0.58	0.54	0.23	0.19	0.45	0.19	0.43

Throttle	Exhaust PM Concentrations (mg/m^3)																
Notch	10/27	10/27	10/27	11/24	11/24	5 Reps	5 Reps	5 Reps	8/9	8/9	8/10	8/10	10/26	10/26	6 Trains	6 Trains	6 Trains
Position	RY AX1	RY AX2	RY AX3	RY Rep4	RY Rep5	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 73	Train 74	Average	StDev	CV
Low Idle	2.45	2.06	2.34	2.56	2.23	2.33	0.20	0.08	5.3	4.4	5.0	5.1	2.4	2.0	4.0	1.4	0.36
High Idle	1.11	0.71	0.79	1.11	0.76	0.90	0.20	0.22	3.6	3.9	4.0	3.9	1.9	1.2	3.1	1.2	0.39
Dyn Brake	---	---	---	--	--	---	---	---	3.6	4.0	4.6	4.0	1.6	1.2	3.2	1.4	0.44
1	2.62	2.41	2.69	2.80	2.75	2.65	0.15	0.06	6.0	5.8	7.3	5.5	3.1	2.5	5.0	1.8	0.36
2	4.12	3.82	3.84	4.16	3.91	3.97	0.16	0.04	8.4	9.3	9.2	7.7	4.4	4.6	7.3	2.2	0.30
3	3.59	3.16	3.40	3.26	3.04	3.29	0.21	0.06	10.0	9.8	12.5	9.5	4.3	4.0	8.4	3.4	0.41
4	4.91	4.27	4.11	4.46	4.32	4.41	0.30	0.07	12.5	13.2	15.4	14.4	6.6	5.4	11.3	4.2	0.37
5	5.86	5.45	5.40	4.55	4.35	5.12	0.64	0.13	17.7	17.5	19.3	12.7	6.3	6.4	13.3	5.8	0.44
6	5.97	5.96	5.93	4.49	4.37	5.34	0.84	0.16	22.6	19.0	9.9	19.2	7.6	6.4	14.1	7.0	0.49
7	10.0	9.23	9.52	6.99	7.11	8.58	1.42	0.17	19.0	26.0	---	7.0	12.4	5.4	14.0	8.6	0.61
8	12.9	10.4	10.3	9.47	7.67	10.1	1.89	0.19	26.5	34.4	29.2	27.9	9.6	9.4	22.8	10.7	0.47

Table E-33. Measured CO_2 Emission Rates for NC-1810 and B60

Throttle	Time-Based CO2 Emission Rates (g/s)																
Notch	10/27	10/27	10/27	11/24	11/24	5 Reps	5 Reps	5 Reps	8/9	8/9	8/10	8/10	10/26	10/26	6 Trains	6 Trains	6 Trains
Position	RY AX1	RY AX2	RY AX3	RY Rep4	RY Rep5	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 73	Train 74	Average	StDev	CV
Low Idle	8.05	7.84	7.03	9.45	9.05	8.28	0.97	0.12	7.97	5.23	7.38	6.80	7.60	5.48	6.74	1.14	0.17
High Idle	13.4	12.5	12.5	13.6	14.8	13.4	0.96	0.07	14.3	12.7	10.8	12.7	13.6	11.1	12.5	1.35	0.11
Dyn Brake	---	---	---	--	--	---	---	---	14.5	15.0	11.8	13.3	14.4	18.6	14.6	2.28	0.16
1	36.7	36.1	33.0	37.3	36.7	36.0	1.70	0.05	32.0	28.2	25.4	23.7	23.5	27.9	26.8	3.24	0.12
2	53.0	52.6	47.4	54.4	53.6	52.2	2.79	0.05	44.5	38.1	35.5	33.1	40.6	42.6	39.1	4.31	0.11
3	96.1	95.8	91.2	94.4	93.9	94.3	1.95	0.02	79.6	77.9	74.0	69.4	87.2	87.5	79.3	7.16	0.09
4	135	133	132	136	135	134	1.57	0.01	117	116	102	112	124	126	116	8.74	0.08
5	183	179	179	182	182	181	1.88	0.01	170	152	129	153	169	170	157	16.2	0.10
6	227	225	233	222	225	226	4.15	0.02	213	210	134	194	223	217	198	33.0	0.17
7	330	318	321	326	329	325	5.07	0.02	276	311	---	146	325	306	273	73.1	0.27
8	423	408	408	408	389	407	12.2	0.03	404	383	350	348	372	384	373	21.6	0.06

Throttle	Fuel-Based CO2 Emission Rates (g/gal)																
Notch	10/27	10/27	10/27	11/24	11/24	5 Reps	5 Reps	5 Reps	8/9	8/9	8/10	8/10	10/26	10/26	6 Trains	6 Trains	6 Trains
Position	RY AX1	RY AX2	RY AX3	RY Rep4	RY Rep5	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 73	Train 74	Average	StDev	CV
Low Idle	9764	9890	9705	10001	10004	9873	136	0.01	9906	7859	9835	9445	9845	9635	9421	784	0.08
High Idle	9824	10024	9839	9963	10057	9941	106	0.01	9975	9347	9761	9649	9877	9745	9726	217	0.02
Dyn Brake	---	---	---	--	--	---	---	---	9984	9287	9820	9744	9909	9821	9761	247	0.03
1	10032	9965	9994	10052	10063	10021	41	0.00	10025	9901	9919	9925	9983	9943	9949	46	0.00
2	10024	10021	10000	10068	10066	10036	30	0.00	10042	9828	10009	9945	10037	10000	9977	81	0.01
3	10056	10025	10034	10072	10073	10052	22	0.00	10057	10016	10027	9962	10045	10027	10022	33	0.00
4	10053	10058	10034	10072	10074	10058	16	0.00	10056	9917	9963	9938	10056	10037	9994	63	0.01
5	10059	10073	10051	10071	10074	10066	10	0.00	10058	9710	10025	10038	10056	10035	9987	136	0.01
6	10057	10064	10025	10073	10071	10058	20	0.00	10051	9888	10061	10055	10066	10013	10022	69	0.01
7	10041	10056	10035	10064	10063	10052	13	0.00	10061	10007	---	10074	10050	10040	10046	26	0.00
8	10046	10037	10017	10059	10063	10045	19	0.00	10029	10033	10013	9978	10052	10039	10024	26	0.00

Throttle	Engine Output-Based CO2 Emission Rates (g/bhp-hr)																
Notch	10/27	10/27	10/27	11/24	11/24	5 Reps	5 Reps	5 Reps	8/9	8/9	8/10	8/10	10/26	10/26	6 Trains	6 Trains	6 Trains
Position	RY AX1	RY AX2	RY AX3	RY Rep4	RY Rep5	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 73	Train 74	Average	StDev	CV
Low Idle	2898	2822	2531	3401	3257	2982	349	0.12	2869	1882	2950	2719	2736	1974	2522	469	0.19
High Idle	4833	4494	4482	4911	5317	4808	344	0.07	5134	4567	4310	5072	4882	4008	4662	447	0.10
Dyn Brake	---	---	---	--	--	---	---	---	5224	5406	4714	5310	5190	6698	5424	669	0.12
1	695	685	626	707	695	682	32	0.05	606	534	481	449	446	529	507	61	0.12
2	569	592	517	576	568	564	28	0.05	458	392	371	345	417	438	403	42	0.10
3	516	511	490	504	501	504	10	0.02	425	416	395	370	465	467	423	38	0.09
4	495	492	485	489	486	489	4	0.01	423	417	366	404	446	453	418	31	0.08
5	500	496	496	494	493	496	2	0.00	471	422	350	415	467	470	432	48	0.11
6	511	509	524	499	507	510	9	0.02	478	473	301	437	501	489	446	74	0.17
7	540	546	550	490	494	524	30	0.06	414	467	---	219	488	459	409	110	0.27
8	565	555	544	545	519	545	17	0.03	484	460	420	418	447	461	448	26	0.06

Throttle	Exhaust CO2 Concentrations (%)																
Notch	10/27	10/27	10/27	11/24	11/24	5 Reps	5 Reps	5 Reps	8/9	8/9	8/10	8/10	10/26	10/26	6 Trains	6 Trains	6 Trains
Position	RY AX1	RY AX2	RY AX3	RY Rep4	RY Rep5	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 73	Train 74	Average	StDev	CV
Low Idle	0.66	0.65	0.59	0.76	0.73	0.68	0.07	0.10	0.69	0.46	0.63	0.59	0.64	0.48	0.58	0.09	0.16
High Idle	0.73	0.68	0.68	0.73	0.79	0.72	0.05	0.06	0.78	0.69	0.59	0.69	0.72	0.62	0.68	0.07	0.10
Dyn Brake	---	---	---	--	--	---	---	---	0.79	0.81	0.64	0.70	0.76	0.84	0.76	0.07	0.10
1	1.96	1.94	1.77	1.95	1.93	1.91	0.08	0.04	1.77	1.52	1.38	1.26	1.26	1.56	1.46	0.20	0.14
2	2.86	2.84	2.56	2.89	2.85	2.80	0.14	0.05	2.48	2.05	1.87	1.68	2.19	2.38	2.11	0.30	0.14
3	3.65	3.68	3.50	3.51	3.53	3.58	0.08	0.02	3.17	2.90	2.81	2.57	3.26	3.43	3.02	0.32	0.11
4	4.41	4.38	4.34	4.32	4.35	4.36	0.04	0.01	3.98	3.78	3.45	3.56	3.92	4.20	3.81	0.28	0.07
5	4.94	4.93	4.89	4.82	4.83	4.88	0.06	0.01	4.91	4.28	3.45	3.92	4.44	4.67	4.28	0.53	0.12
6	5.29	5.26	5.54	5.08	5.13	5.26	0.18	0.03	5.27	4.99	3.22	4.34	5.11	5.01	4.66	0.77	0.17
7	6.22	6.04	6.32	5.81	5.87	6.05	0.22	0.04	5.66	5.51	---	2.69	6.02	5.39	5.06	1.34	0.27
8	6.73	6.48	6.46	6.22	6.04	6.39	0.26	0.04	6.92	6.13	5.63	5.34	5.67	6.15	5.97	0.56	0.09

E.4 Summary of Results for NC-1810 on B40 and B10

RY and OTR measurements were conducted on the prime mover engine of locomotive NC-1810 (City of Greensboro) with different fuel blends using a portable emissions measurement system (PEMS).

The prime mover engine was an EMD 12-710G3B. The engine was originally manufactured in 1988 and was rebuilt by American Motive Power, Inc. (AMP) in 2010. The 140 L engine has a peak engine output of 3000 horsepower (hp) at an engine speed of 900 revolutions per minute (RPM). The prime mover engine operated on four different fuel blends of petrodiesel and soy-based biodiesel, as shown in Table E-34.

Table E-34. Fuel Characteristics and Dates Measured on NC-1810 Prime Mover Engine

Fuel Name	Percent Petrodiesel	Percent Biodiesel	Fuel Supplier	Dates of Measurements	
				Rail Yard	Over-the-Rail
B10	90	10	Monson Oil Co.	Sept. 14, 2012	Aug. 29-31, 2012
B40	60	40	Red Star Oil Co.	Nov. 19, 2012	Nov. 16, 19, 21, 2012

The PEMS utilized for measurements were the Montana and Axion systems manufactured by Clean Air Technologies International, Inc. (CATI). Prior to each set of measurements, the PEMS was calibrated with a California Bureau of Automotive Repair (BAR) certified calibration gas (BAR-97 Low).

This appendix focuses on summary results from measurement of NC-1810 on B10 and B40. The cycle average emission rates for the RY and OTR measurements of the NC-1810 prime mover engine are shown in Table E-35. The cycle average emission rates are based on the line-haul duty cycle used by the U.S. Environmental Protection Agency (EPA) for regulatory purposes. During RY measurements, dynamic braking was not performed; thus, the time apportioned for dynamic braking in the line-haul duty cycle (12.5 percent) was combined with the time apportioned for idling in the line-haul duty cycle (38.0 percent). Therefore, idling accounts for 50.5 percent of the duty cycle used to calculate RY cycle average emission rates.

Table E-35. Cycle Average Emission Rates for the NC-1810 Prime Mover Engine with B10 and B40 Measured in the Rail Yard and Over-the-Rail[a,b]

(a) Rail Yard

Fuel	NO_x (g/bhp-hr)	HC (g/bhp-hr)	CO (g/bhp-hr)	Opacity-based PM (g/bhp-hr)
B10	7.4	0.36	1.3	0.34
B40	8.9	0.15	0.6	0.31

(b) Over-the-Rail

Fuel	NO_x (g/bhp-hr)	HC (g/bhp-hr)	CO (g/bhp-hr)	Opacity-based PM (g/bhp-hr)
B10	6.5	0.88	1.5	0.53
B40	7.8	0.20	1.2	0.36

[a] The cycle average emission rates are based on the U.S. EPA line-haul duty cycle used for regulatory purposes.

[b] NO_x, HC, and opacity-based PM emission rates are adjusted with multipliers of 1.053, 2.5, and 5, respectively, as bias correction.

[c] Dynamic braking not observed during ULSD over-the-rail measurements. Therefore, idling accounts for 50.5 percent of the duty cycle used to calculate rail yard cycle average emission rates.

Comparisons are given in Figure E-14 of the measured NOx emission rates by notch position for each of several fuels. The fuel-based NOx emission rate was typically highest at idle. The rate tends to increase with engine load from notch 1 to notch 3, and then to decrease with load from notch 3 to notch 8. In contrast, the PM emission rate, as shown in Figure E-15, although highest at idle, tends to be approximately constant with increasing engine load. Figure E-16 illustrates the trend in notch fuel-based emission rate for over-the-rail, rather than rail yard, measurements. Although the magnitude of the numbers differ, the qualitative trends with regard to engine load are similar.

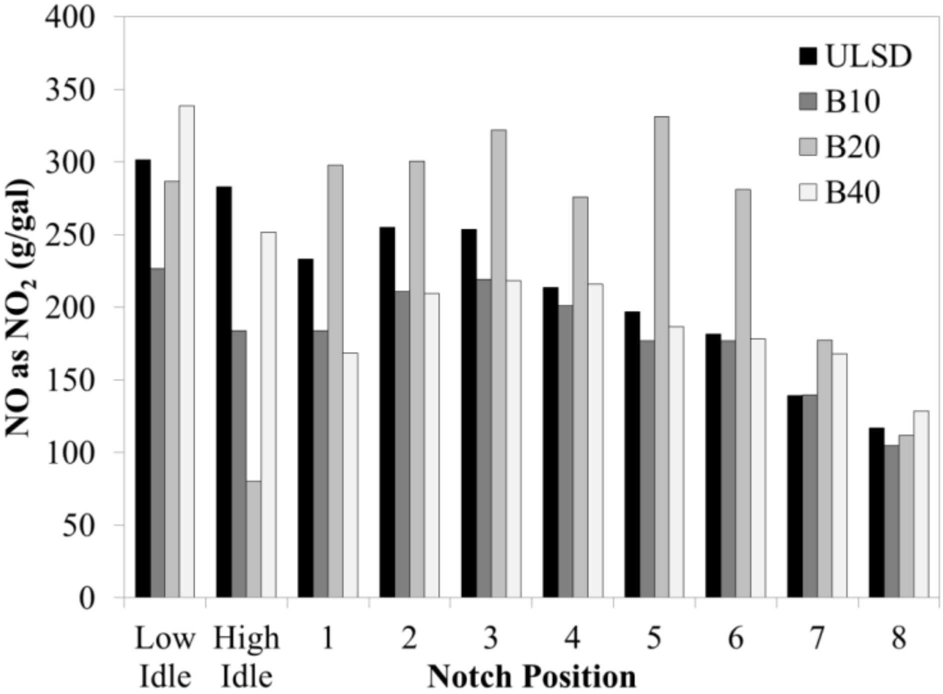


Figure E-14. Fuel-based NO_x emission rates during rail yard measurements of the NC-1810 prime mover engine

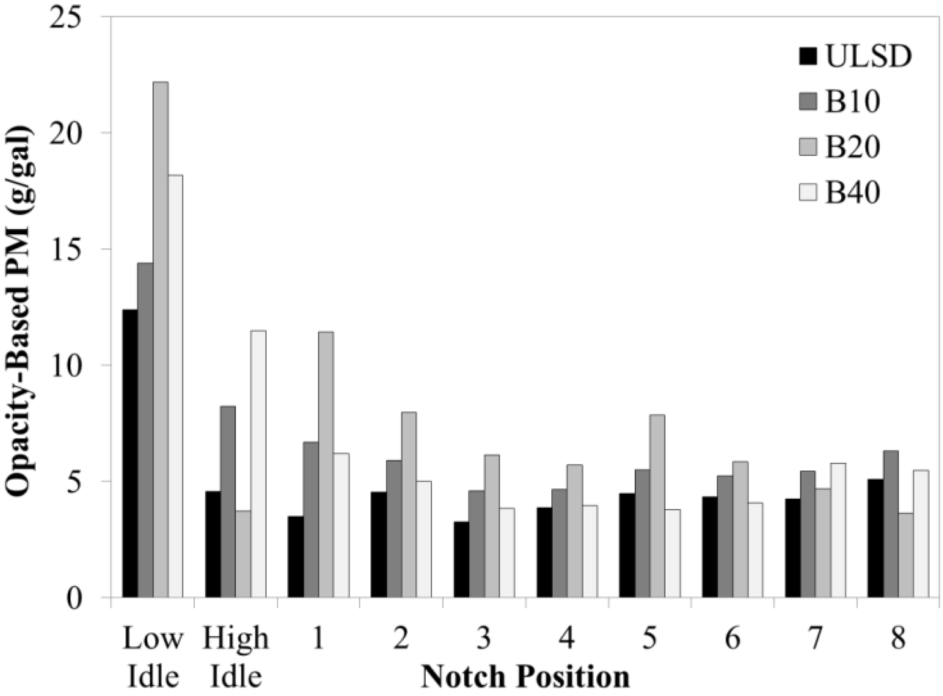


Figure E-15. Fuel-based PM emission rates during rail yard measurements of the NC-1810 prime mover engine

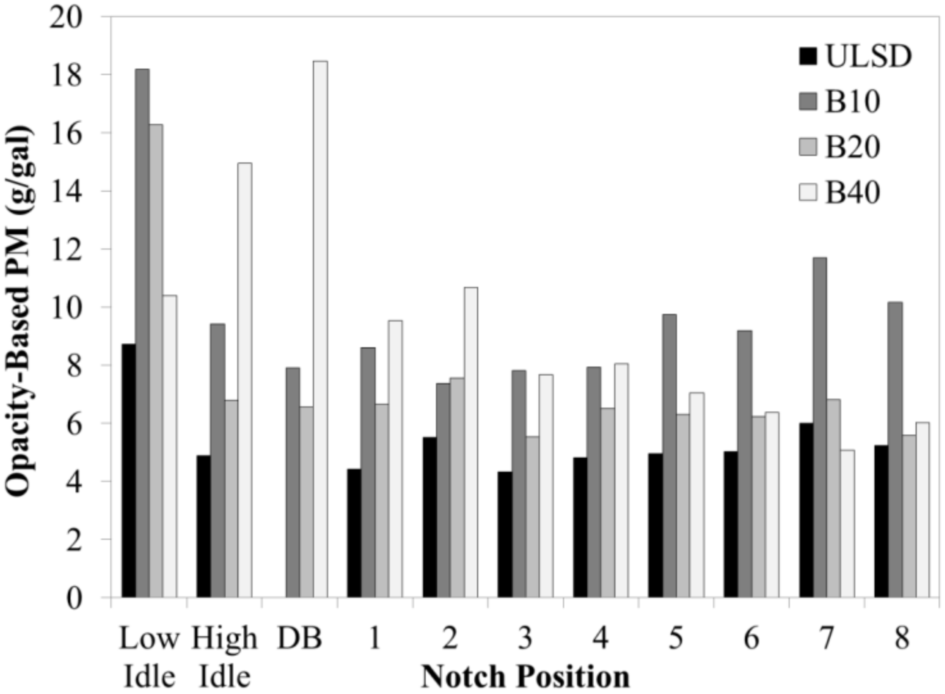


Figure E-16. Fuel-based PM emission rates during over-the-rail measurements of the NC-1810 prime mover engine

E.5 Summary of Results for NC-1810 on B20

Rail yard and over-the-rail measurements were conducted in June 2013 on the prime mover engine of locomotive NC-1810 (City of Greensboro) with B20 using a portable emissions measurement system (PEMS).

The prime mover engine was an EMD 12-710G3B. The engine was originally manufactured in 1988 and was rebuilt by American Motive Power, Inc. (AMP) in 2010. The 140-Liter engine has a peak engine output of 3000 horsepower (hp) at an engine speed of 900 revolutions per minute (rpm). The prime mover engine operated on a blend of 20 percent soy-based biodiesel and 80 percent ULSD.

The PEMS utilized for measurements were the Montana system manufactured by Clean Air Technologies International, Inc. (CATI). The Montana was used for both rail yard and over-the-rail measurements. Prior to each set of measurements, the PEMS was calibrated with a California Bureau of Automotive Repair (BAR) certified calibration gas (BAR-97 Low).

The cycle average emission rates for the rail yard and over-the-rail measurements of the NC-1810 prime mover engine are shown in Tables E-36 and E-37. The cycle average emission rates are based on the line-haul duty cycle used by the U.S. Environmental Protection Agency (EPA) for regulatory purposes. Three replicates of each rail yard measurement were conducted. During rail yard measurements, dynamic braking was not observed; thus, the time apportioned for dynamic braking in the line-haul duty cycle (12.5 percent) was combined with the time apportioned for idling in the line-haul duty cycle (38.0 percent). Therefore, idling accounts for 50.5 percent of the duty cycle used to calculate rail yard cycle average emission rates.

Table E-36. Preliminary Cycle Average Emission Rates for the NC-1893 Prime Mover Engine Using B20 in the Rail Yard[a,b,c]

(a) Montana

Fuel	NO_x (g/bhp-hr)	HC (g/bhp-hr)	CO (g/bhp-hr)	Opacity-based PM (g/bhp-hr)[d]
Replicate 1	7.2	1.84	1.6	0.43
Replicate 2	7.2	1.82	1.8	0.42
Replicate 3	7.2	1.74	1.7	0.40
Average	7.2	1.80	1.7	0.42

[a] The cycle average emission rates are based on the U.S. EPA line-haul duty cycle used for regulatory purposes.

[b] NO_x, HC, and opacity-based PM emission rates from the Montana are adjusted with multipliers of 1.053, 2.5, and 5, respectively, as bias correction.

[c] Dynamic braking not observed during rail yard measurements. Therefore, idling accounts for 50.5 percent of the duty cycle used to calculate rail yard cycle average emission rates.

[d] Opacity-based PM emission rates are based on measurements with the Montana PEMS.

Table E-37. Preliminary Cycle Average Emission Rates for the NC-1893 Prime Mover Engine Measured Using B20 Over-the-Rail[a,b]

Fuel	NO_x (g/bhp-hr)	HC (g/bhp-hr)	CO (g/bhp-hr)	Opacity-based PM (g/bhp-hr)
June 2013	**5.4**	**1.31**	**2.6**	**0.44**
EPA Tier 0+	**8.0**	**1.00**	**5.0**	**0.22**
EPA Tier 1+	7.4	0.55	2.2	0.22

[a] The cycle average emission rates are based on the U.S. EPA line-haul duty cycle used for regulatory purposes.

[b] NO_x, HC, and opacity-based PM emission rates are adjusted with multipliers of 1.053, 2.5, and 5, respectively, as bias correction.

Rail Yard Measurements

The team performed three rail yard emissions measurement replicates on the prime mover engine of NC-1810 during June 20, 2013. Results for the rail yard measurements are presented and discussed in this section. The most recent results are compared to previous measurements of the prime mover engine of NC-1810.

The cycle average emission rates for the rail yard measurements of the NC-1810 prime mover engine are shown in Table E-36. These cycle average emission rates are based on the measured engine activity data (RPM, MAP, and IAT) and measured exhaust concentrations. There was little variability between replicate measured engine activity data (see Figure E-22) and engine fuel use rate, as shown in Figure E-17. This indicates that the prime mover engine was operating consistently during all three replicate measurements.

An increasing trend in fuel use rates was apparent as notch position increased during the rail yard measurements, as shown in Figure E-17. Higher inter-replicate variability was observed at notches 7 and 8. The NO emission rates estimated with the Montana during the three replicates were fairly consistent, as shown in Figure E-18. There was variability in the estimated HC emission rates between the three replicate measurements and the two PEMS systems, as shown in Figure E-19. Inter-replicate variability in the estimated HC emission rates were up to 17 percent for the Montana. There was also variability in the estimated CO emission rates between the three replicate measurements and the two PEMS systems, as shown in Figure E-20. Inter-replicate variability in the estimated CO emission rates were up to 65 percent for the. There was variability in the measured PM concentrations between the three replicate measurements, as shown in Figure E-21. However, the PM concentrations measured were of the same magnitude as previous rail yard measurements.

Figure E-17. Estimated Fuel Use Rates during Rail Yard Measurements of the NC-1810 Prime Mover Engine Using B20

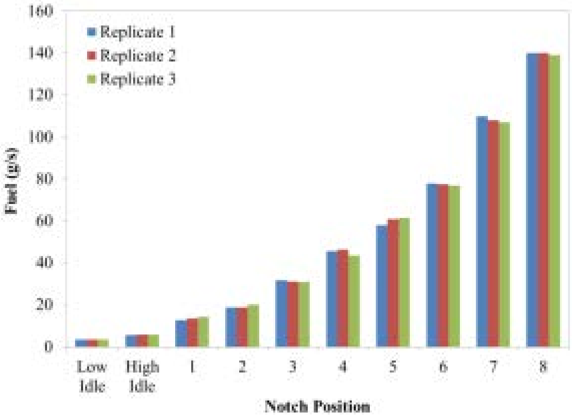


Figure E-18. Estimated NO Emission Rates during Rail Yard Measurements of the NC-1810 Prime Mover Engine Using B20

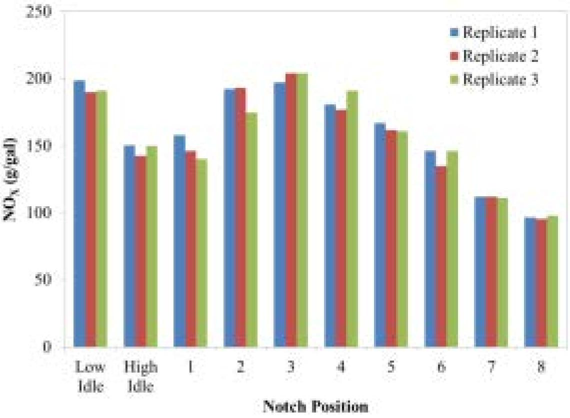


Figure E-19. Estimated HC Emission Rates during Rail Yard Measurements of the NC-1810 Prime Mover Engine Using B20

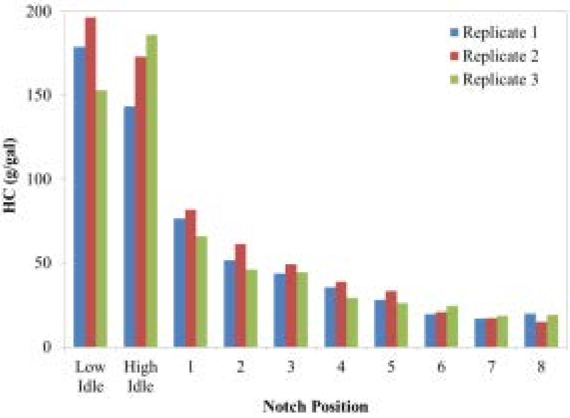


Figure E-20. Estimated CO Emission Rates during Rail Yard Measurements of the NC-1810 Prime Mover Engine Using B20

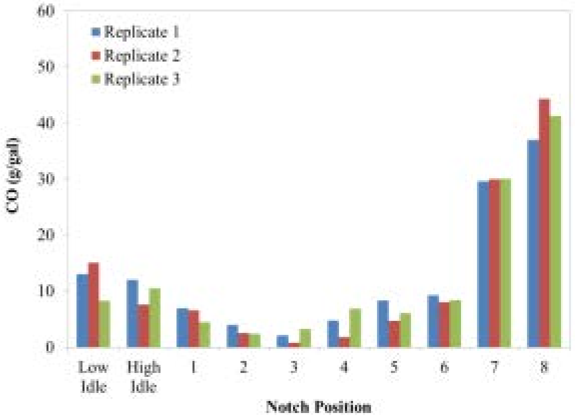
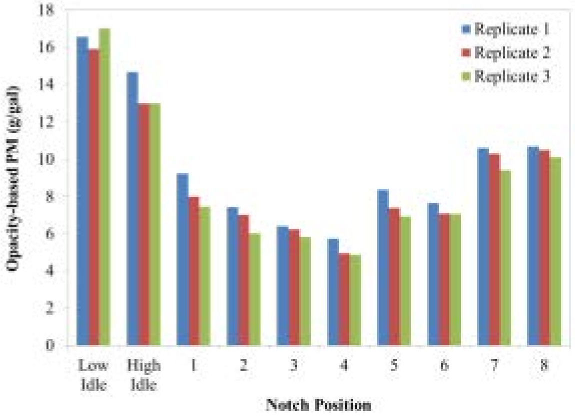


Figure E-21 Measured PM Concentrations during Rail Yard Measurements of the NC-1810 Prime Mover Engine Using B20



The NC-1810's prime mover engine had been measured in the RY with B20 in October 2012 and Table E-38 compares the estimated cycle average emission rates. The CO_2 concentrations measured in the exhaust during October 2012 appeared to be unusually low and the team decided to repeat the RY measurement of the NC-1810 prime mover engine in June 2013.

While the cycle average NO_x emission rates during the June 2013 RY measurements are 6 to 12 percent lower than the cycle average NO_x emission rate during the October 2012 rail yard measurement, the measured NO concentrations during the June 2013 RY measurements were approximately 25 percent higher at each notch position than during the October 2012 rail yard measurement. This difference in cycle average NO_x emission rates can be attributed to the unusually low CO_2 concentrations measured in October 2012.

Table E-38. Cycle Average Emission Rates for Rail Yard Measurement of NC-1810 Prime Mover Engine Using B20

	NO_x (g/bhp-hr)	HC (g/bhp-hr)	CO (g/bhp-hr)	Opacity-based PM (g/bhp-hr)
October 24, 2012	7.7	0.34	0.7	0.28
June 20, 2013 – Montana†	**7.2**	**1.80**	**1.7**	**0.42**
EPA Tier 0+	**8.0**	**1.00**	**5.0**	**0.22**
EPA Tier 1+	7.4	0.55	2.2	0.22

† NO_x, HC, and PM are adjusted with multipliers of 1.05, 2.5, and 5, respectively, as bias correction.

Over-the-Rail Measurements

Three days of over-the-rail measurements on the NC-1810 prime mover engine were conducted on June 17-19, 2013. Results for the over-the-rail measurements are presented and discussed in this section, and are compared to previous measurements of the prime mover engine of NC-1810.

The cycle average emission rates for the over-the-rail measurements of the NC-1810 prime mover engine are shown in Table E-39. These cycle average emission rates are based on the measured engine activity data (RPM, MAP, and IAT) and measured exhaust concentrations. There was little variability between measured engine activity data during all three days of measurements. This indicates that the prime mover engine was operating consistently during over-the-rail measurements. Measured engine activity data during OTR measurements were similar to the measured engine activity data during RY measurements.

The cycle average OTR emission rates are quantitatively similar to the cycle average rail yard emission rates measured in June 2013. The cycle average over-the-rail NO_x emission rate was 21 to 25 percent lower than the cycle average rail yard NO_x emission rates, depending on the PEMS. The cycle average OTR PM emission rate was 5 percent higher than the cycle average PM emission rate estimated from RY measurements. The cycle average OTR HC emission rate was 27 percent lower than the cycle average rail yard HC emission rate estimated. The cycle average OTR CO emission rate was 53 to 86 percent higher than the cycle average CO emission rates estimated from rail yard measurements.

Table E-39. Cycle Average Emission Rates for Over-the-Rail Measurement of NC-1810 Prime Mover Engine Using B20

	NO_x (g/bhp-hr)	HC (g/bhp-hr)	CO (g/bhp-hr)	Opacity-based PM (g/bhp-hr)
October 18-20, 2012	7.2	0.64	1.3	0.33
June 17-19, 2013	**5.4**	**1.31**	**2.6**	**0.44**
EPA Tier 0+	**8.0**	**1.00**	**5.0**	**0.22**
EPA Tier 1+	7.4	0.55	2.2	0.22

† NO_x, HC, and PM are adjusted with multipliers of 1.05, 2.5, and 5, respectively, as bias correction.

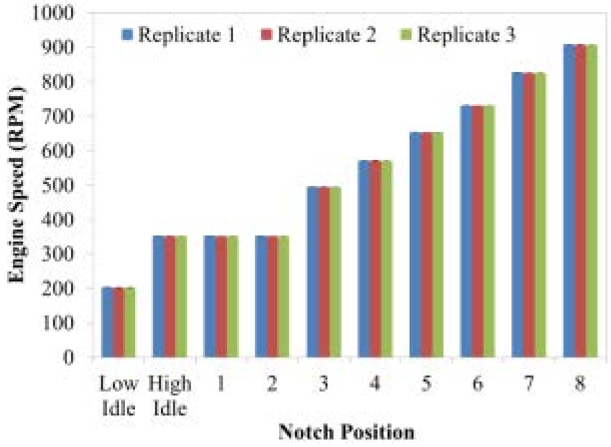
Cycle average OTR NO_x emission rates are lower than during RY measurements. This was observed during the June 2013 measurements. Also, higher cycle average HC, CO, and PM emission rates during over-the-rail measurements compared rail yard measurements have been observed previously.

In this set of measurements, a procedure was demonstrated for rail yard and over-the-rail characterization of emission rates for B20 biodiesel. The rail yard engine activity and emission concentration measurements were consistent across the three rail yard replicates. Comparing these rail yard measurements with three others taken previously, NO_x and PM cycle average emission rates are of the same magnitude. Cycle average HC and CO emission rates were higher during this RY measurement than in a previous RY measurement.

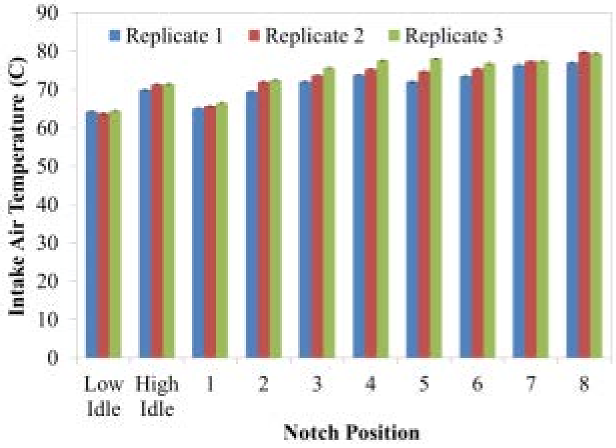
Three days of OTR emissions measurements were conducted on NC-1810's prime mover engine. The cycle average over-the-rail emission rates are quantitatively similar to the cycle average rail yard emission rates measured in June 2013. Cycle average over-the-rail NO_x emission rates are lower than during rail yard measurements, and that cycle average over-the-rail PM emission rates are higher than during rail yard measurements. This was observed during the June 2013 rail yard and over-the-rail measurements of NC-1810 on B20 biodiesel.

Tables E-40 to E-47 provide detailed data regarding measurements of individual railyard replicates and over-the-rail one-way trips.

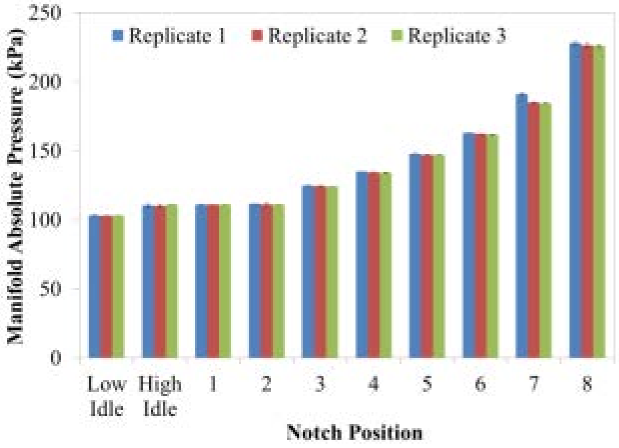
Figure E-22. Measured Engine Activity Data during Rail Yard Measurements of the NC-1810 Prime Mover Engine Using B20



(a) Engine Speed



(b) Intake Air Temperature



(c) Manifold Absolute Pressure

Table E-40. Rail Yard Measurement of NC-1810 on B20: Replicate 1 Engine Activity and Exhaust Concentration Data

Locomotive: [redacted] NC 1810
PEMS: Montana
Measure: Yard
Fuel: [redacted] B20
Date: June 20, 2013 - Replicate 1

Throttle Notch Position	Engine Output [hp]	Barometric Pressure [kPa]	Engine Variables RPM [rpm]	IAT [deg C]	MAP [kPa]	Exhaust Concentrations CO2 [%]	CO [%]	HC [ppm]	NO [ppm]	O2 [%]	PM [mg/m3]
Low Idle	9	101.7	204	64	103	0.84	0.002	31	153	19.09	3.7
High Idle	9	101.7	352	70	111	0.92	0.002	27	126	18.94	3.5
Dyn Brake	---	---	---	---	---	---	---	---	---	---	---
1	190	101.7	352	65	111	2.01	0.002	32	289	17.43	4.9
2	350	101.7	352	69	112	2.97	0.002	31	518	16.05	5.8
3	675	101.7	496	72	125	3.69	0.001	33	658	15.06	6.2
4	1000	101.7	572	74	135	4.57	0.003	33	749	13.92	6.9
5	1300	101.7	654	72	148	4.98	0.006	28	753	13.58	10.9
6	1600	101.7	732	74	163	5.78	0.008	23	761	12.44	11.6
7	2100	101.7	827	76	191	6.86	0.032	24	696	11.49	19.1
8	2700	101.7	909	77	228	7.29	0.042	30	639	11.13	20.5

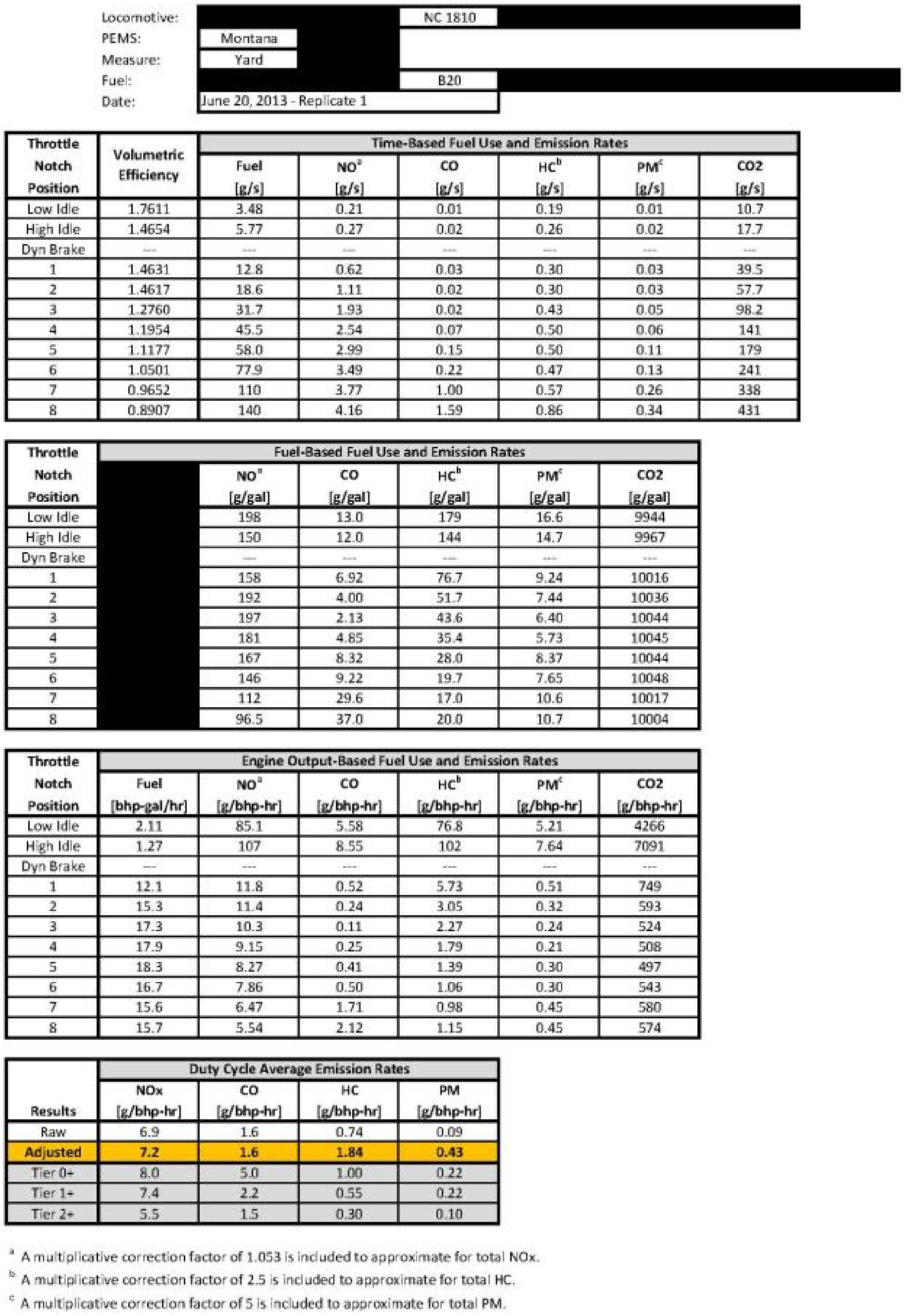
Dynamic Brake is not observed during rail yard measurements.
Engine output was recorded from the locomotive activity data recorder digital display in the locomotive cab for Notches 1 through 8. The HP output at Low and High Idle were assumed to be 9 hp based on dynamometer testing of NC 1859.
Barometric pressure measured by weather probe of the SEMTECH-DS PEMS.
Engine variables and exhaust concentrations were measured by the PEMS.

Fuel Properties	Units	Value
ASTM D240 Gross Heat of Combustion	BTU/lb	18980
ASTM D240 Net Heat of Combustion	BTU/lb	17769
ASTM D2500 Cloud Point	C	---
ASTM D2622 Sulfur Content	ppm	---
ASTM D4052 API	deg	---
ASTM D4052 Density	g/mL	0.8564
ASTM D5291 Carbon Content	wt-%	85
ASTM D5291 Hydrogen Content	wt-%	12.8
ASTM D613 Cetane Number		---

Prime Mover Engine Properties	Units	Value
Cylinders		12
Volume	L	140
Stroke Cycle		2
Compression Ratio		15

Fuel property data derived from diesel and B100 fuel properties from the National Renewable Energy Laboratory Biodiesel Handling and Use Guide: Fourth Edition (2009). Fuel properties will be updated and a reanalysis completed once a fuel sample is sent for analysis.

Table E-41. Rail Yard Measurement of NC-1810 on B20: Replicate 1 Fuel Use and Emission Rates.



Locomotive:	[redacted]	NC 1810	[redacted]
PEMS:	Montana	[redacted]	
Measure:	Yard		
Fuel:	[redacted]	B20	[redacted]
Date:	June 20, 2013 - Replicate 1		

Throttle Notch Position	Volumetric Efficiency	Time-Based Fuel Use and Emission Rates					
		Fuel [g/s]	NO[a] [g/s]	CO [g/s]	HC[b] [g/s]	PM[c] [g/s]	CO2 [g/s]
Low Idle	1.7611	3.48	0.21	0.01	0.19	0.01	10.7
High Idle	1.4654	5.77	0.27	0.02	0.26	0.02	17.7
Dyn Brake	---	---	---	---	---	---	---
1	1.4631	12.8	0.62	0.03	0.30	0.03	39.5
2	1.4617	18.6	1.11	0.02	0.30	0.03	57.7
3	1.2760	31.7	1.93	0.02	0.43	0.05	98.2
4	1.1954	45.5	2.54	0.07	0.50	0.06	141
5	1.1177	58.0	2.99	0.15	0.50	0.11	179
6	1.0501	77.9	3.49	0.22	0.47	0.13	241
7	0.9652	110	3.77	1.00	0.57	0.26	338
8	0.8907	140	4.16	1.59	0.86	0.34	431

Throttle Notch Position	Fuel-Based Fuel Use and Emission Rates					
	[redacted]	NO[a] [g/gal]	CO [g/gal]	HC[b] [g/gal]	PM[c] [g/gal]	CO2 [g/gal]
Low Idle	[redacted]	198	13.0	179	16.6	9944
High Idle	[redacted]	150	12.0	144	14.7	9967
Dyn Brake	[redacted]	---	---	---	---	---
1	[redacted]	158	6.92	76.7	9.24	10016
2	[redacted]	192	4.00	51.7	7.44	10036
3	[redacted]	197	2.13	43.6	6.40	10044
4	[redacted]	181	4.85	35.4	5.73	10045
5	[redacted]	167	8.32	28.0	8.37	10044
6	[redacted]	146	9.22	19.7	7.65	10048
7	[redacted]	112	29.6	17.0	10.6	10017
8	[redacted]	96.5	37.0	20.0	10.7	10004

Throttle Notch Position	Engine Output-Based Fuel Use and Emission Rates					
	Fuel [bhp-gal/hr]	NO[a] [g/bhp-hr]	CO [g/bhp-hr]	HC[b] [g/bhp-hr]	PM[c] [g/bhp-hr]	CO2 [g/bhp-hr]
Low Idle	2.11	85.1	5.58	76.8	5.21	4266
High Idle	1.27	107	8.55	102	7.64	7091
Dyn Brake	---	---	---	---	---	---
1	12.1	11.8	0.52	5.73	0.51	749
2	15.3	11.4	0.24	3.05	0.32	593
3	17.3	10.3	0.11	2.27	0.24	524
4	17.9	9.15	0.25	1.79	0.21	508
5	18.3	8.27	0.41	1.39	0.30	497
6	16.7	7.86	0.50	1.06	0.30	543
7	15.6	6.47	1.71	0.98	0.45	580
8	15.7	5.54	2.12	1.15	0.45	574

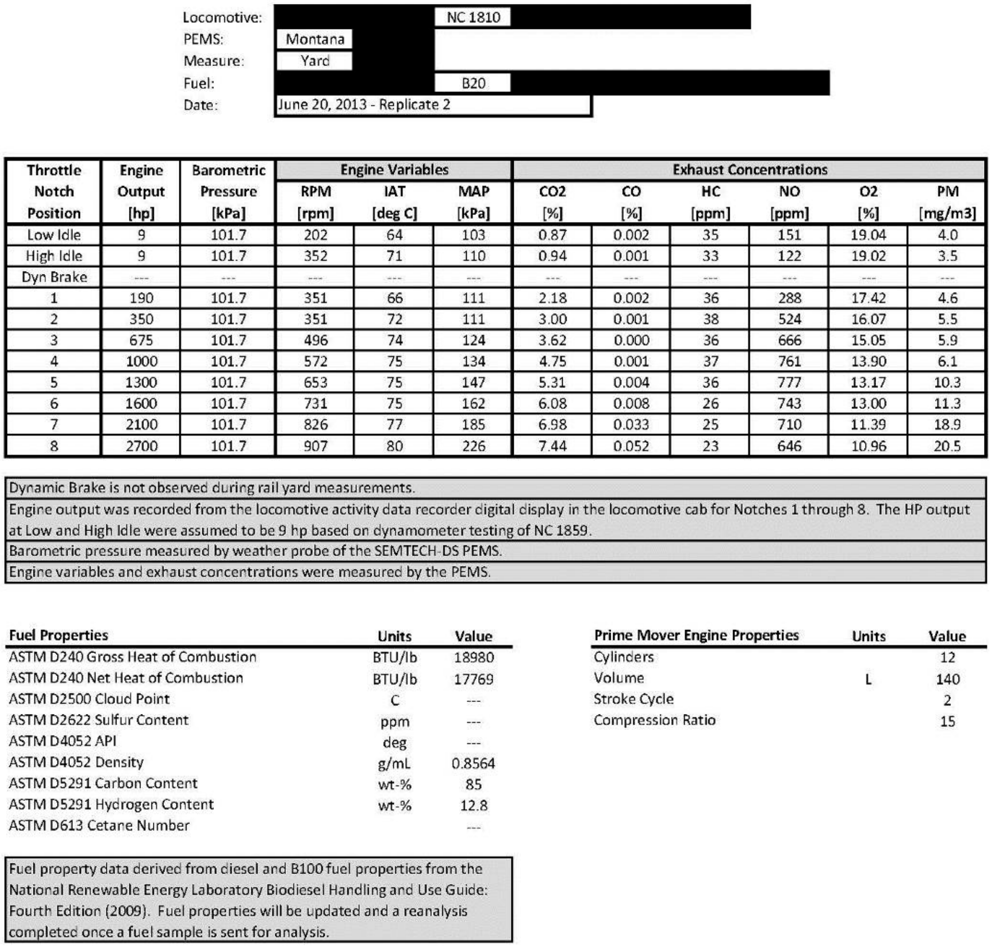
Results	Duty Cycle Average Emission Rates			
	NOx [g/bhp-hr]	CO [g/bhp-hr]	HC [g/bhp-hr]	PM [g/bhp-hr]
Raw	6.9	1.6	0.74	0.09
Adjusted	**7.2**	**1.6**	**1.84**	**0.43**
Tier 0+	8.0	5.0	1.00	0.22
Tier 1+	7.4	2.2	0.55	0.22
Tier 2+	5.5	1.5	0.30	0.10

[a] A multiplicative correction factor of 1.053 is included to approximate for total NOx.

[b] A multiplicative correction factor of 2.5 is included to approximate for total HC.

[c] A multiplicative correction factor of 5 is included to approximate for total PM.

Table E-42. Rail Yard Measurement of NC-1810 on B20: Replicate 2 Engine Activity and Exhaust Concentration Data



Locomotive: NC 1810
PEMS: Montana
Measure: Yard
Fuel: B20
Date: June 20, 2013 - Replicate 2

Throttle Notch Position	Engine Output [hp]	Barometric Pressure [kPa]	Engine Variables RPM [rpm]	IAT [deg C]	MAP [kPa]	Exhaust Concentrations CO2 [%]	CO [%]	HC [ppm]	NO [ppm]	O2 [%]	PM [mg/m3]
Low Idle	9	101.7	202	64	103	0.87	0.002	35	151	19.04	4.0
High Idle	9	101.7	352	71	110	0.94	0.001	33	122	19.02	3.5
Dyn Brake	---	---	---	---	---	---	---	---	---	---	---
1	190	101.7	351	66	111	2.18	0.002	36	288	17.42	4.6
2	350	101.7	351	72	111	3.00	0.001	38	524	16.07	5.5
3	675	101.7	496	74	124	3.62	0.000	36	666	15.05	5.9
4	1000	101.7	572	75	134	4.75	0.001	37	761	13.90	6.1
5	1300	101.7	653	75	147	5.31	0.004	36	777	13.17	10.3
6	1600	101.7	731	75	162	6.08	0.008	26	743	13.00	11.3
7	2100	101.7	826	77	185	6.98	0.033	25	710	11.39	18.9
8	2700	101.7	907	80	226	7.44	0.052	23	646	10.96	20.5

Dynamic Brake is not observed during rail yard measurements.

Engine output was recorded from the locomotive activity data recorder digital display in the locomotive cab for Notches 1 through 8. The HP output at Low and High Idle were assumed to be 9 hp based on dynamometer testing of NC 1859.

Barometric pressure measured by weather probe of the SEMTECH-DS PEMS.

Engine variables and exhaust concentrations were measured by the PEMS.

Fuel Properties	Units	Value
ASTM D240 Gross Heat of Combustion	BTU/lb	18980
ASTM D240 Net Heat of Combustion	BTU/lb	17769
ASTM D2500 Cloud Point	C	---
ASTM D2622 Sulfur Content	ppm	---
ASTM D4052 API	deg	---
ASTM D4052 Density	g/mL	0.8564
ASTM D5291 Carbon Content	wt-%	85
ASTM D5291 Hydrogen Content	wt-%	12.8
ASTM D613 Cetane Number		---

Prime Mover Engine Properties	Units	Value
Cylinders		12
Volume	L	140
Stroke Cycle		2
Compression Ratio		15

Fuel property data derived from diesel and B100 fuel properties from the National Renewable Energy Laboratory Biodiesel Handling and Use Guide: Fourth Edition (2009). Fuel properties will be updated and a reanalysis completed once a fuel sample is sent for analysis.

Table E-43. Rail Yard Measurement of NC-1810 on B20: Replicate 2 Fuel Use and Emission Rates.

Locomotive: [redacted] NC 1810 [redacted]
PEMS: Montana [redacted]
Measure: Yard
Fuel: [redacted] B20 [redacted]
Date: June 20, 2013 - Replicate 2

Throttle Notch Position	Volumetric Efficiency	Time-Based Fuel Use and Emission Rates					
		Fuel [g/s]	NO[a] [g/s]	CO [g/s]	HC[b] [g/s]	PM[c] [g/s]	CO2 [g/s]
Low Idle	1.7656	3.59	0.21	0.02	0.22	0.01	11.0
High Idle	1.4686	5.82	0.26	0.01	0.31	0.02	17.9
Dyn Brake	---	---	---	---	---	---	---
1	1.4654	13.6	0.61	0.03	0.34	0.02	42.0
2	1.4650	18.6	1.10	0.01	0.35	0.03	57.4
3	1.2776	31.1	1.95	0.01	0.47	0.04	96.2
4	1.1967	46.4	2.54	0.03	0.55	0.05	144
5	1.1194	60.9	3.04	0.09	0.63	0.10	189
6	1.0517	77.4	3.23	0.19	0.50	0.12	240
7	0.9751	108	3.73	1.00	0.57	0.25	334
8	0.8929	140	4.13	1.92	0.65	0.33	433

Throttle Notch Position	Fuel-Based Fuel Use and Emission Rates					
	[redacted]	NO[a] [g/gal]	CO [g/gal]	HC[b] [g/gal]	PM[c] [g/gal]	CO2 [g/gal]
Low Idle	[redacted]	190	15.1	197	17.3	9930
High Idle	[redacted]	143	7.56	173	14.1	9956
Dyn Brake	[redacted]	---	---	---	---	---
1	[redacted]	146	6.55	81.8	7.99	10014
2	[redacted]	193	2.54	61.3	7.02	10033
3	[redacted]	204	0.86	49.2	6.23	10043
4	[redacted]	177	1.82	38.7	4.95	10048
5	[redacted]	162	4.76	33.3	7.39	10046
6	[redacted]	135	7.99	21.0	7.08	10049
7	[redacted]	112	30.0	17.3	10.3	10016
8	[redacted]	95.5	44.3	15.0	10.5	9995

Throttle Notch Position	Engine Output-Based Fuel Use and Emission Rates					
	Fuel [bhp-gal/hr]	NO[a] [g/bhp-hr]	CO [g/bhp-hr]	HC[b] [g/bhp-hr]	PM[c] [g/bhp-hr]	CO2 [g/bhp-hr]
Low Idle	2.04	83.9	6.67	87.0	5.60	4393
High Idle	1.26	102	5.43	124	7.42	7150
Dyn Brake	---	---	---	---	---	---
1	11.4	11.6	0.52	6.50	0.47	796
2	15.4	11.3	0.15	3.61	0.30	590
3	17.7	10.4	0.04	2.51	0.23	513
4	17.5	9.13	0.09	1.99	0.19	517
5	17.4	8.41	0.25	1.73	0.28	523
6	16.8	7.26	0.43	1.12	0.28	539
7	15.8	6.40	1.71	0.98	0.43	572
8	15.7	5.51	2.56	0.87	0.44	577

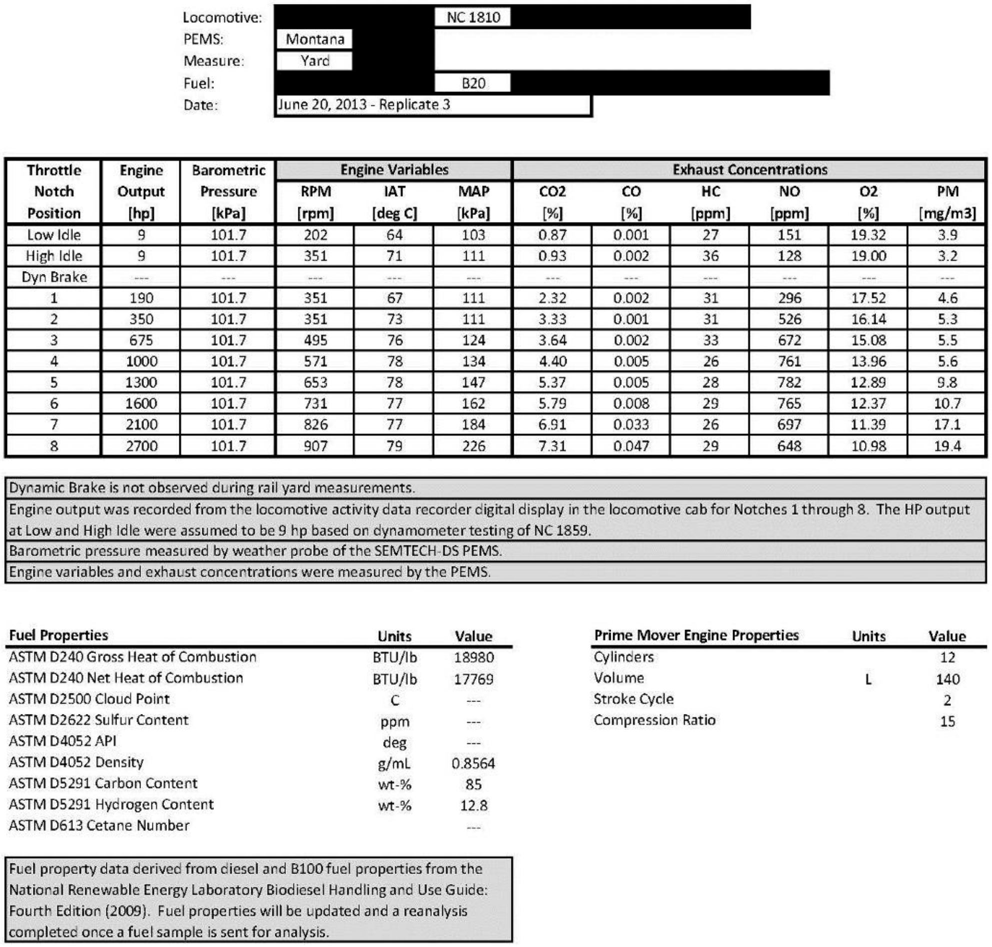
	Duty Cycle Average Emission Rates			
Results	NOx [g/bhp-hr]	CO [g/bhp-hr]	HC [g/bhp-hr]	PM [g/bhp-hr]
Raw	6.8	1.8	0.73	0.08
Adjusted	**7.2**	**1.8**	**1.82**	**0.42**
Tier 0+	8.0	5.0	1.00	0.22
Tier 1+	7.4	2.2	0.55	0.22
Tier 2+	5.5	1.5	0.30	0.10

[a] A multiplicative correction factor of 1.053 is included to approximate for total NOx.

[b] A multiplicative correction factor of 2.5 is included to approximate for total HC.

[c] A multiplicative correction factor of 5 is included to approximate for total PM.

Table E-44. Rail Yard Measurement of NC-1810 on B20: Replicate 3 Engine Activity and Exhaust Concentration Data



Locomotive: NC 1810
PEMS: Montana
Measure: Yard
Fuel: B20
Date: June 20, 2013 - Replicate 3

Throttle Notch Position	Engine Output [hp]	Barometric Pressure [kPa]	Engine Variables RPM [rpm]	IAT [deg C]	MAP [kPa]	Exhaust Concentrations CO2 [%]	CO [%]	HC [ppm]	NO [ppm]	O2 [%]	PM [mg/m3]
Low Idle	9	101.7	202	64	103	0.87	0.001	27	151	19.32	3.9
High Idle	9	101.7	351	71	111	0.93	0.002	36	128	19.00	3.2
Dyn Brake	---	---	---	---	---	---	---	---	---	---	---
1	190	101.7	351	67	111	2.32	0.002	31	296	17.52	4.6
2	350	101.7	351	73	111	3.33	0.001	31	526	16.14	5.3
3	675	101.7	495	76	124	3.64	0.002	33	672	15.08	5.5
4	1000	101.7	571	78	134	4.40	0.005	26	761	13.96	5.6
5	1300	101.7	653	78	147	5.37	0.005	28	782	12.89	9.8
6	1600	101.7	731	77	162	5.79	0.008	29	765	12.37	10.7
7	2100	101.7	826	77	184	6.91	0.033	26	697	11.39	17.1
8	2700	101.7	907	79	226	7.31	0.047	29	648	10.98	19.4

Dynamic Brake is not observed during rail yard measurements.

Engine output was recorded from the locomotive activity data recorder digital display in the locomotive cab for Notches 1 through 8. The HP output at Low and High Idle were assumed to be 9 hp based on dynamometer testing of NC 1859.

Barometric pressure measured by weather probe of the SEMTECH-DS PEMS.

Engine variables and exhaust concentrations were measured by the PEMS.

Fuel Properties	Units	Value
ASTM D240 Gross Heat of Combustion	BTU/lb	18980
ASTM D240 Net Heat of Combustion	BTU/lb	17769
ASTM D2500 Cloud Point	C	---
ASTM D2622 Sulfur Content	ppm	---
ASTM D4052 API	deg	---
ASTM D4052 Density	g/mL	0.8564
ASTM D5291 Carbon Content	wt-%	85
ASTM D5291 Hydrogen Content	wt-%	12.8
ASTM D613 Cetane Number		---

Prime Mover Engine Properties	Units	Value
Cylinders		12
Volume	L	140
Stroke Cycle		2
Compression Ratio		15

Fuel property data derived from diesel and B100 fuel properties from the National Renewable Energy Laboratory Biodiesel Handling and Use Guide: Fourth Edition (2009). Fuel properties will be updated and a reanalysis completed once a fuel sample is sent for analysis.

Table E-45. Rail Yard Measurement of NC-1810 on B20: Replicate 3 Fuel Use and Emission Rates.

Locomotive: [redacted] NC 1810 [redacted]
PEMS: Montana [redacted]
Measure: Yard
Fuel: [redacted] B20 [redacted]
Date: June 20, 2013 - Replicate 3

Throttle Notch Position	Volumetric Efficiency	Time-Based Fuel Use and Emission Rates					
		Fuel [g/s]	NO[a] [g/s]	CO [g/s]	HC[b] [g/s]	PM[c] [g/s]	CO2 [g/s]
Low Idle	1.7657	3.52	0.21	0.01	0.17	0.01	10.8
High Idle	1.4655	5.85	0.27	0.02	0.33	0.02	17.9
Dyn Brake	---	---	---	---	---	---	---
1	1.4655	14.3	0.62	0.02	0.29	0.02	44.1
2	1.4655	20.0	1.07	0.01	0.28	0.03	61.8
3	1.2796	30.8	1.94	0.03	0.42	0.04	95.5
4	1.1984	43.5	2.57	0.09	0.39	0.05	135
5	1.1197	61.5	3.05	0.12	0.49	0.10	191
6	1.0530	76.9	3.47	0.20	0.58	0.12	238
7	0.9761	107	3.67	0.99	0.62	0.23	331
8	0.8936	139	4.18	1.77	0.82	0.32	428

Throttle Notch Position	Fuel-Based Fuel Use and Emission Rates					
	[redacted]	NO[a] [g/gal]	CO [g/gal]	HC[b] [g/gal]	PM[c] [g/gal]	CO2 [g/gal]
Low Idle	[redacted]	191	8.25	153	17.0	9967
High Idle	[redacted]	150	10.5	186	13.0	9944
Dyn Brake	[redacted]	---	---	---	---	---
1	[redacted]	140	4.50	66.0	7.46	10027
2	[redacted]	175	2.39	46.0	6.02	10042
3	[redacted]	204	3.26	44.3	5.82	10042
4	[redacted]	191	6.82	29.2	4.87	10046
5	[redacted]	161	6.10	26.0	6.94	10049
6	[redacted]	146	8.37	24.4	7.06	10046
7	[redacted]	111	30.1	18.7	9.42	10015
8	[redacted]	97.7	41.3	19.1	10.1	9998

Throttle Notch Position	Engine Output-Based Fuel Use and Emission Rates					
	Fuel [bhp-gal/hr]	NO[a] [g/bhp-hr]	CO [g/bhp-hr]	HC[b] [g/bhp-hr]	PM[c] [g/bhp-hr]	CO2 [g/bhp-hr]
Low Idle	2.08	82.9	3.58	66.5	5.41	4328
High Idle	1.25	108	7.58	134	6.86	7168
Dyn Brake	---	---	---	---	---	---
1	10.8	11.7	0.37	5.50	0.46	835
2	14.3	11.1	0.15	2.92	0.28	636
3	17.8	10.4	0.17	2.25	0.22	509
4	18.7	9.24	0.33	1.41	0.17	485
5	17.2	8.45	0.32	1.37	0.27	528
6	16.9	7.80	0.45	1.30	0.28	536
7	16.0	6.30	1.70	1.06	0.39	567
8	15.8	5.57	2.35	1.09	0.42	570

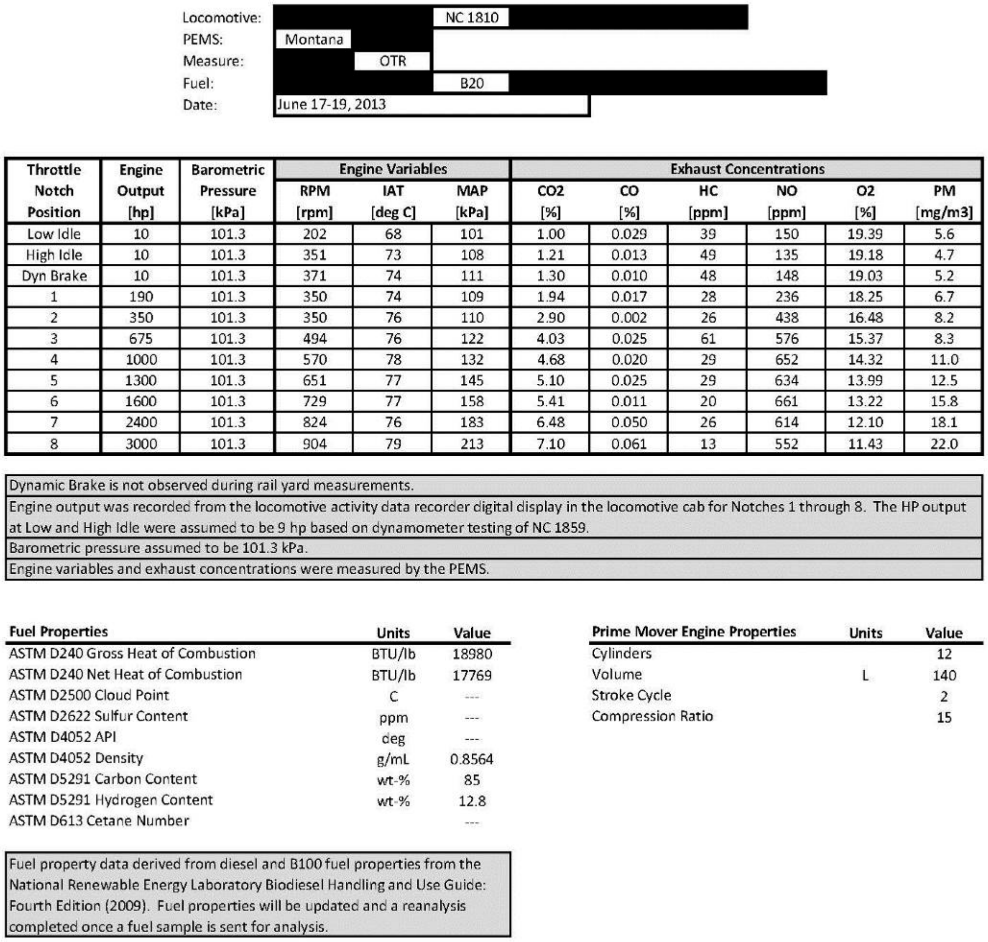
	Duty Cycle Average Emission Rates			
Results	NOx [g/bhp-hr]	CO [g/bhp-hr]	HC [g/bhp-hr]	PM [g/bhp-hr]
Raw	6.9	1.7	0.69	0.08
Adjusted	**7.2**	**1.7**	**1.74**	**0.40**
Tier 0+	8.0	5.0	1.00	0.22
Tier 1+	7.4	2.2	0.55	0.22
Tier 2+	5.5	1.5	0.30	0.10

[a] A multiplicative correction factor of 1.053 is included to approximate for total NOx.

[b] A multiplicative correction factor of 2.5 is included to approximate for total HC.

[c] A multiplicative correction factor of 5 is included to approximate for total PM.

Table E-46. Over-the-Rail Measurement of NC-1810 on B20: Engine Activity and Exhaust Concentration Data



Locomotive: [redacted] NC 1810 [redacted]
PEMS: Montana [redacted]
Measure: [redacted] OTR
Fuel: [redacted] B20 [redacted]
Date: June 17-19, 2013

Throttle Notch Position	Engine Output [hp]	Barometric Pressure [kPa]	Engine Variables			Exhaust Concentrations					
			RPM [rpm]	IAT [deg C]	MAP [kPa]	CO2 [%]	CO [%]	HC [ppm]	NO [ppm]	O2 [%]	PM [mg/m3]
Low Idle	10	101.3	202	68	101	1.00	0.029	39	150	19.39	5.6
High Idle	10	101.3	351	73	108	1.21	0.013	49	135	19.18	4.7
Dyn Brake	10	101.3	371	74	111	1.30	0.010	48	148	19.03	5.2
1	190	101.3	350	74	109	1.94	0.017	28	236	18.25	6.7
2	350	101.3	350	76	110	2.90	0.002	26	438	16.48	8.2
3	675	101.3	494	76	122	4.03	0.025	61	576	15.37	8.3
4	1000	101.3	570	78	132	4.68	0.020	29	652	14.32	11.0
5	1300	101.3	651	77	145	5.10	0.025	29	634	13.99	12.5
6	1600	101.3	729	77	158	5.41	0.011	20	661	13.22	15.8
7	2400	101.3	824	76	183	6.48	0.050	26	614	12.10	18.1
8	3000	101.3	904	79	213	7.10	0.061	13	552	11.43	22.0

Dynamic Brake is not observed during rail yard measurements.

Engine output was recorded from the locomotive activity data recorder digital display in the locomotive cab for Notches 1 through 8. The HP output at Low and High Idle were assumed to be 9 hp based on dynamometer testing of NC 1859.

Barometric pressure assumed to be 101.3 kPa.

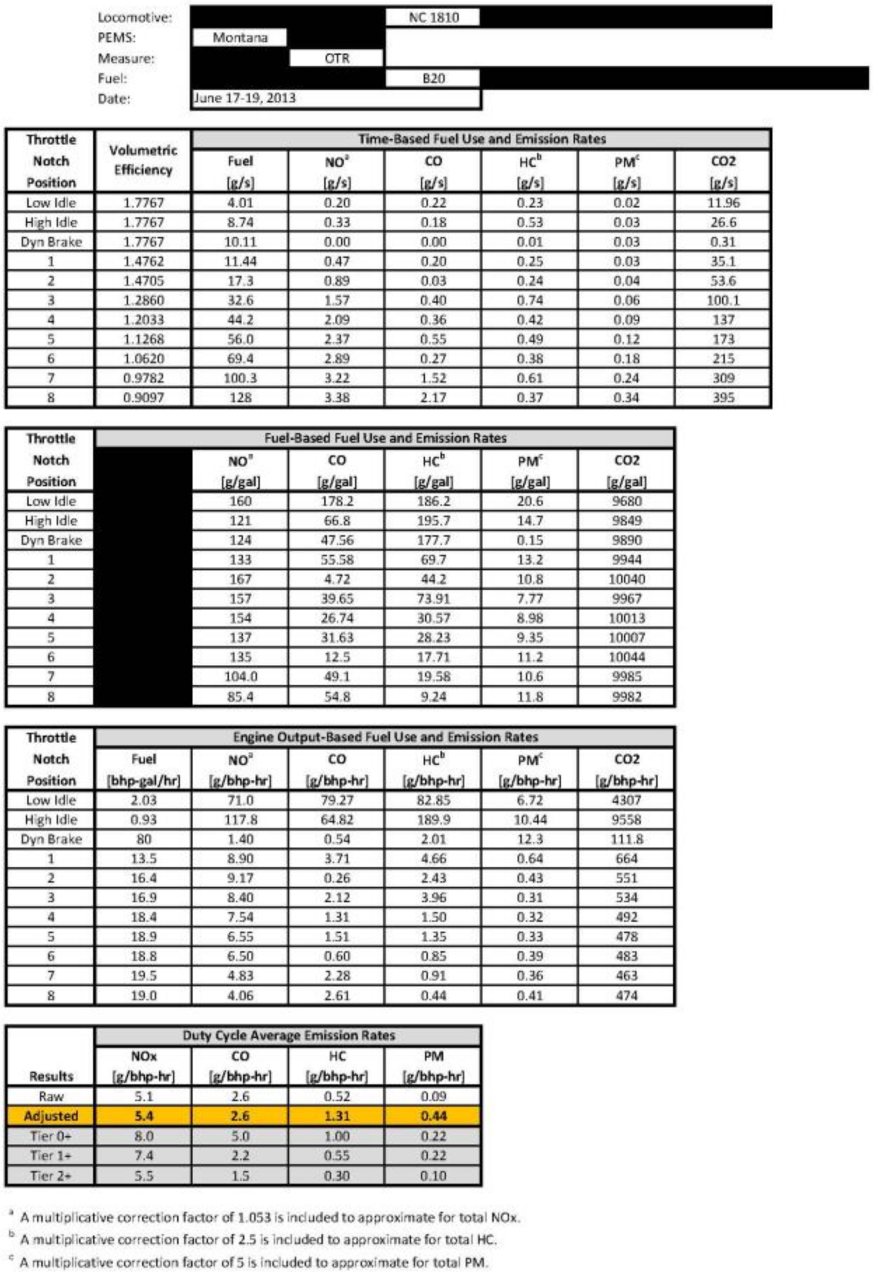
Engine variables and exhaust concentrations were measured by the PEMS.

Fuel Properties	Units	Value
ASTM D240 Gross Heat of Combustion	BTU/lb	18980
ASTM D240 Net Heat of Combustion	BTU/lb	17769
ASTM D2500 Cloud Point	C	---
ASTM D2622 Sulfur Content	ppm	---
ASTM D4052 API	deg	---
ASTM D4052 Density	g/mL	0.8564
ASTM D5291 Carbon Content	wt-%	85
ASTM D5291 Hydrogen Content	wt-%	12.8
ASTM D613 Cetane Number		---

Prime Mover Engine Properties	Units	Value
Cylinders		12
Volume	L	140
Stroke Cycle		2
Compression Ratio		15

Fuel property data derived from diesel and B100 fuel properties from the National Renewable Energy Laboratory Biodiesel Handling and Use Guide: Fourth Edition (2009). Fuel properties will be updated and a reanalysis completed once a fuel sample is sent for analysis.

Table E-47. Over-the-Rail Measurement of NC-1810 on B20: Fuel Use and Emission Rates



Locomotive: [redacted] NC 1810 [redacted]
PEMS: Montana [redacted]
Measure: [redacted] OTR
Fuel: [redacted] B20 [redacted]
Date: June 17-19, 2013

Throttle Notch Position	Volumetric Efficiency	Time-Based Fuel Use and Emission Rates					
		Fuel [g/s]	NO[a] [g/s]	CO [g/s]	HC[b] [g/s]	PM[c] [g/s]	CO2 [g/s]
Low Idle	1.7767	4.01	0.20	0.22	0.23	0.02	11.96
High Idle	1.7767	8.74	0.33	0.18	0.53	0.03	26.6
Dyn Brake	1.7767	10.11	0.00	0.00	0.01	0.03	0.31
1	1.4762	11.44	0.47	0.20	0.25	0.03	35.1
2	1.4705	17.3	0.89	0.03	0.24	0.04	53.6
3	1.2860	32.6	1.57	0.40	0.74	0.06	100.1
4	1.2033	44.2	2.09	0.36	0.42	0.09	137
5	1.1268	56.0	2.37	0.55	0.49	0.12	173
6	1.0620	69.4	2.89	0.27	0.38	0.18	215
7	0.9782	100.3	3.22	1.52	0.61	0.24	309
8	0.9097	128	3.38	2.17	0.37	0.34	395

Throttle Notch Position	Fuel-Based Fuel Use and Emission Rates					
	[redacted]	NO[a] [g/gal]	CO [g/gal]	HC[b] [g/gal]	PM[c] [g/gal]	CO2 [g/gal]
Low Idle		160	178.2	186.2	20.6	9680
High Idle		121	66.8	195.7	14.7	9849
Dyn Brake		124	47.56	177.7	0.15	9890
1		133	55.58	69.7	13.2	9944
2		167	4.72	44.2	10.8	10040
3		157	39.65	73.91	7.77	9967
4		154	26.74	30.57	8.98	10013
5		137	31.63	28.23	9.35	10007
6		135	12.5	17.71	11.2	10044
7		104.0	49.1	19.58	10.6	9985
8		85.4	54.8	9.24	11.8	9982

Throttle Notch Position	Engine Output-Based Fuel Use and Emission Rates					
	Fuel [bhp-gal/hr]	NO[a] [g/bhp-hr]	CO [g/bhp-hr]	HC[b] [g/bhp-hr]	PM[c] [g/bhp-hr]	CO2 [g/bhp-hr]
Low Idle	2.03	71.0	79.27	82.85	6.72	4307
High Idle	0.93	117.8	64.82	189.9	10.44	9558
Dyn Brake	80	1.40	0.54	2.01	12.3	111.8
1	13.5	8.90	3.71	4.66	0.64	664
2	16.4	9.17	0.26	2.43	0.43	551
3	16.9	8.40	2.12	3.96	0.31	534
4	18.4	7.54	1.31	1.50	0.32	492
5	18.9	6.55	1.51	1.35	0.33	478
6	18.8	6.50	0.60	0.85	0.39	483
7	19.5	4.83	2.28	0.91	0.36	463
8	19.0	4.06	2.61	0.44	0.41	474

Results	Duty Cycle Average Emission Rates			
	NOx [g/bhp-hr]	CO [g/bhp-hr]	HC [g/bhp-hr]	PM [g/bhp-hr]
Raw	5.1	2.6	0.52	0.09
Adjusted	**5.4**	**2.6**	**1.31**	**0.44**
Tier 0+	8.0	5.0	1.00	0.22
Tier 1+	7.4	2.2	0.55	0.22
Tier 2+	5.5	1.5	0.30	0.10

[a] A multiplicative correction factor of 1.053 is included to approximate for total NOx.

[b] A multiplicative correction factor of 2.5 is included to approximate for total HC.

[c] A multiplicative correction factor of 5 is included to approximate for total PM.

E.6 Summary of Results for NC-1810 on ULSD

This section discusses the results of the rail yard and over-the-rail measurements of the NC-1810 prime mover engine operated on B100 biodiesel, and includes a comparison to previously reported measurements on ULSD, B10, B20, B40, B60, and B80 biodiesel blends.

Rail Yard Measurements

The team conducted three RY emissions measurement replicates on the prime mover engine of NC-1810 with ULSD on March 28, 2014. In the rail yard, emissions measurements were taken when the engine reached steady state at two idle settings and each of eight notch positions. The Idle and notch average emission rates were weighted by the EPA line-haul cycle to estimate cycle average rates.

The EPA line-haul cycle average emission rates are shown in Table E-48. These cycle average emission rates are based on the measured engine activity data (RPM, MAP, and IAT), inferred engine activity data (MAF, AFR, and VE), and measured exhaust concentrations. There was little variability between replicate measured engine activity data and exhaust NO concentration, given in Figure E-23. This indicates that the prime mover engine was operating consistently during all three replicate measurements.

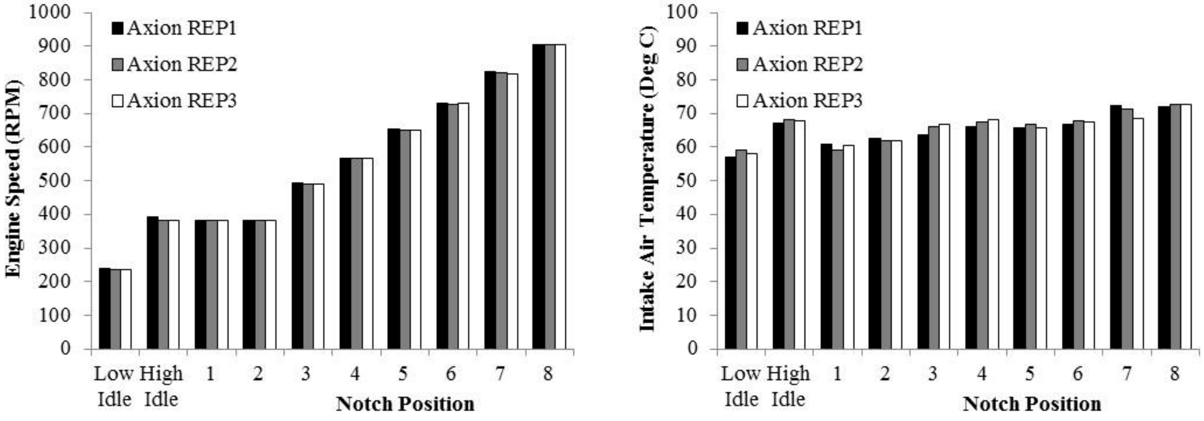
An increasing trend in fuel use rate was apparent with increasing notch position, as shown in Figure E-24. The NO emission rates among the three replicates were consistent, as shown in Figure E-25. The inter-replicate ratios of the standard deviation to the mean (coefficient of variation) for each notch position for the mass per gallon of fuel NO emission rates range from 0.01 to 0.06, which indicates small variability between replicates.

There was variability in the estimated notch-specific HC emission rates between the three replicate measurements, as shown in Figure E-26. The inter-replicate coefficient of variation in the estimated HC emission rates were 17 percent, on average for each notch position. Differences in measured exhaust HC concentrations were the primary reason for the inter-replicate variability. For exhaust HC concentrations across the three replicates, the coefficient of variation varied from 0.02 to 0.45, depending on the notch position.

There was also variability in the estimated notch-specific CO emission rates between the three replicate measurements, as shown in Figure E-27. Approximately 60 percent of the notch-specific CO concentrations measured were below the detection limit. The inter-replicate coefficient of variation in the estimated HC emission rates were 42 percent, on average, for each notch position. However, the large coefficient of variation does not necessarily indicate large inter-replicate variability. On an absolute basis, the exhaust CO concentrations were very low.

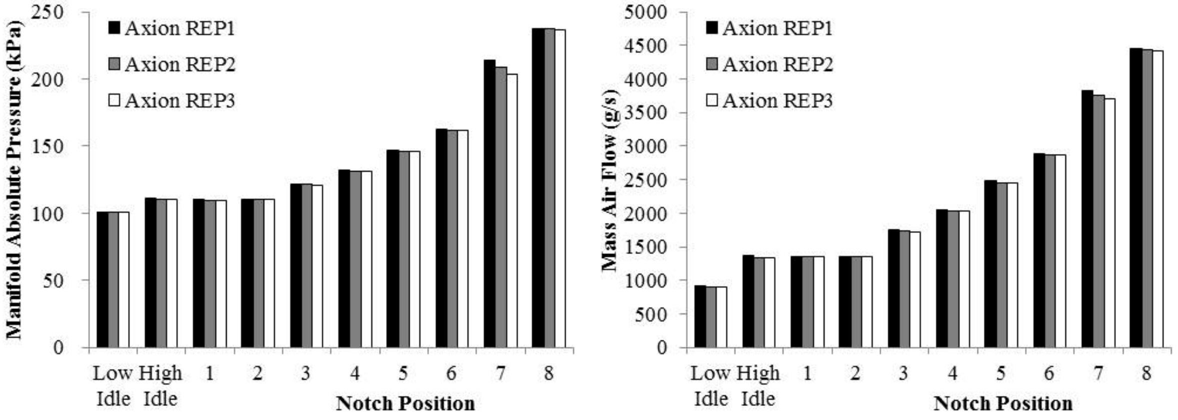
PM emission rates, as shown in Figure E-28, were consistent across the three replicates, with inter-replicate coefficient of variation less than 0.15 for all notch positions.

Figure E-23. Measured Engine Activity Data during Rail Yard Measurements of the NC-1810 Prime Mover Engine Operated on Ultra-Low Sulfur Diesel



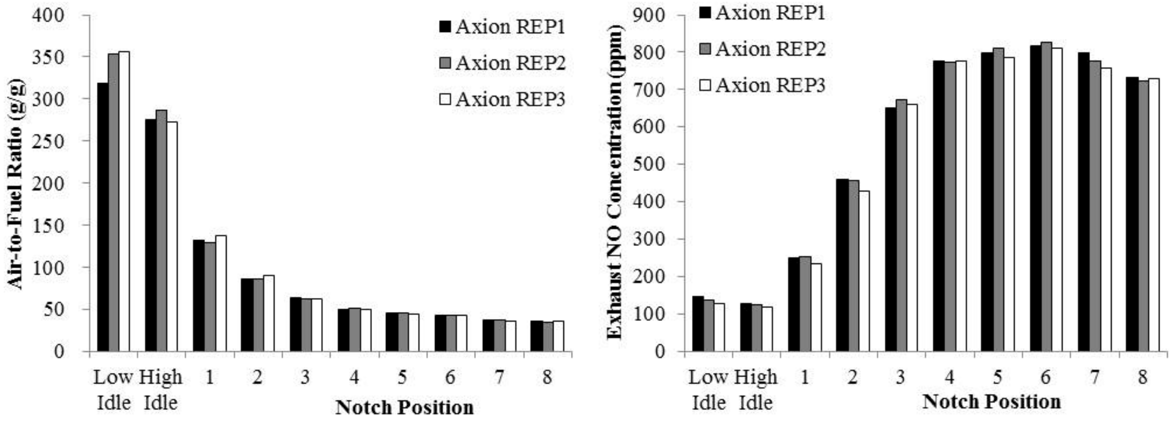
(a) Engine Speed

(b) Intake Air Temperature



(c) Manifold Absolute Pressure

(d) Mass Air Flow



(e) Air-to-Fuel Ratio

(f) Exhaust NO Concentration

Figure E-24. Estimated Fuel Use Rates during Rail Yard Measurements of the NC-1810 Prime Mover Engine Operated on Ultra-Low Sulfur Diesel

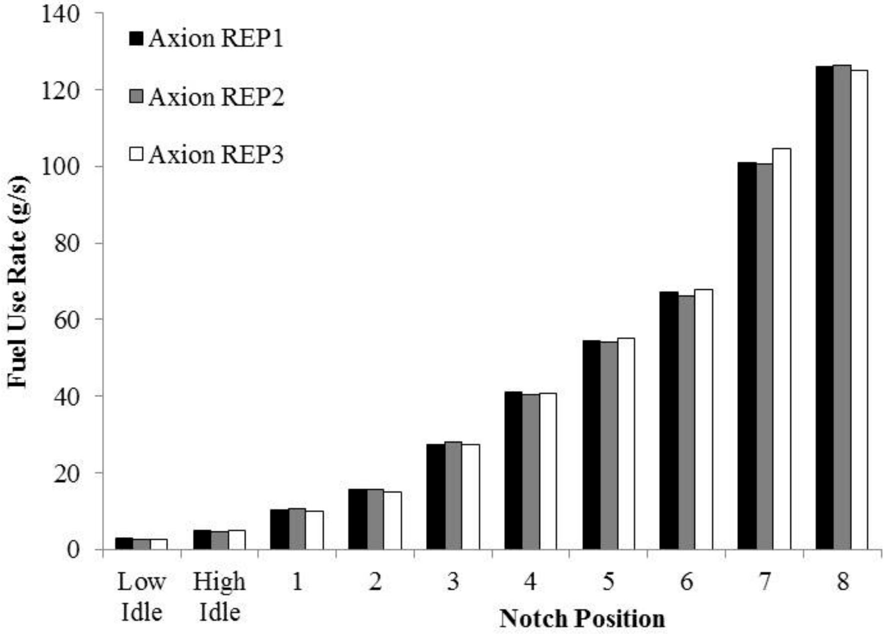


Figure E-25. Estimated NO_x Emission Rates during Rail Yard Measurements of the NC-1810 Prime Mover Engine Operated on Ultra-Low Sulfur Diesel

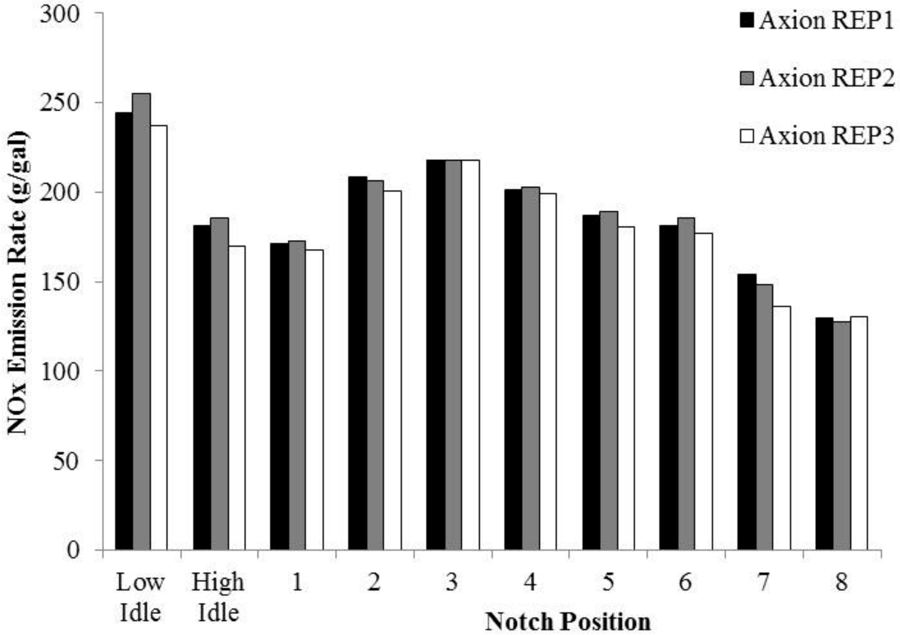


Figure E-26. Estimated HC Emission Rates during Rail Yard Measurements of the NC-1810 Prime Mover Engine Operated on Ultra-Low Sulfur Diesel

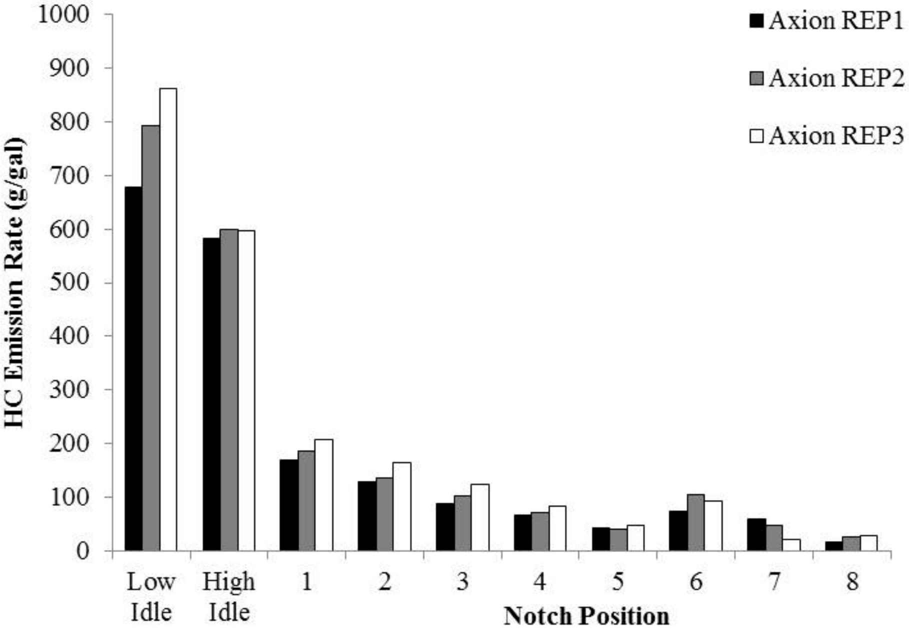


Figure E-27. Estimated CO Emission Rates during Rail Yard Measurements of the NC-1810 Prime Mover Engine Operated on Ultra-Low Sulfur Diesel

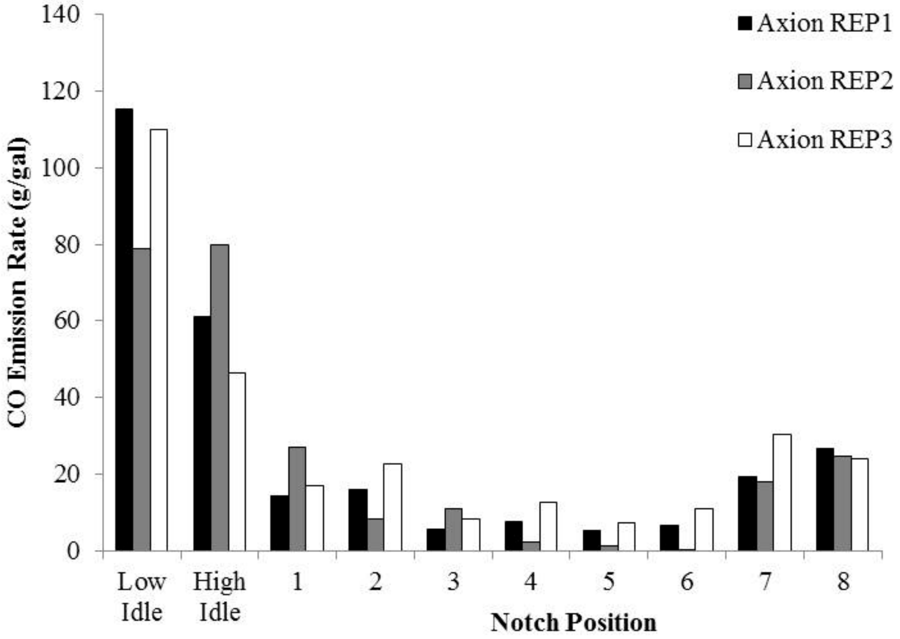


Figure E-28. Measured PM Emission Rate during Rail Yard Measurements of the NC-1810 Prime Mover Engine Operated on Ultra-Low Sulfur Diesel

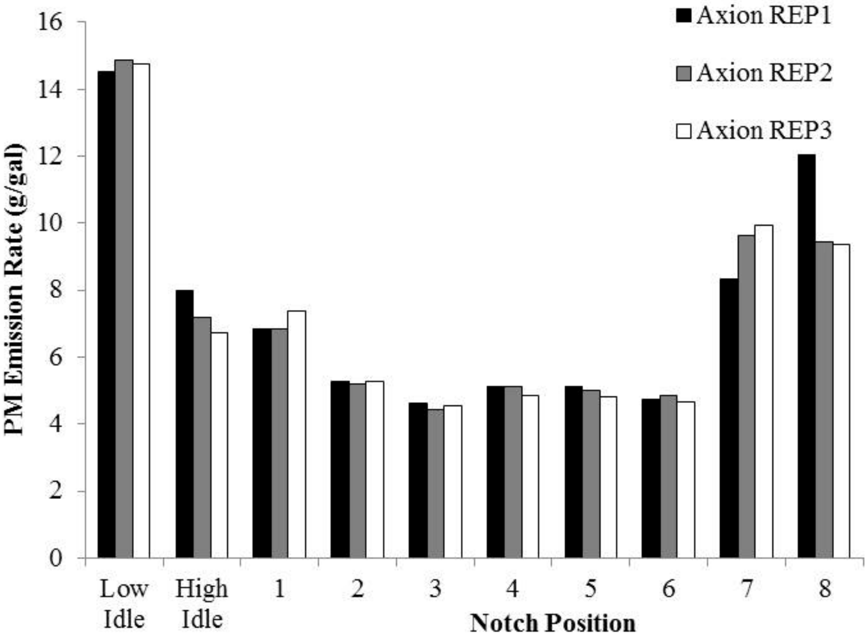


Table E-48 provides the estimated EPA line-haul cycle average emission rates for each of the three replicate rail yard measurements. The cycle average NO_x, HC, CO, and PM cycle average emission rates were consistent among the replicates, with coefficient of variations less than 0.10. Differences in emission rates are attributable to differences in measured exhaust concentrations. Values for engine activity parameters (i.e., RPM, IAT, MAP) were similar across all measurements (Figure E-23) and thus are not the cause of inter-replicate variation in emission rates. The inter-replicate variation in emission rates for a given pollutant was mainly a result of the variations in measured exhaust concentrations.

Table E-48. Estimated EPA Line-Haul Cycle Average Emission Rates for Rail Yard Replicate Measurements of NC-1810 Prime Mover Engine Operated on Ultra-Low Sulfur Diesel

	NO_x **(g/bhp-hr)**	**HC** **(g/bhp-hr)**	**CO** **(g/bhp-hr)**	**Opacity-based PM** **(g/bhp-hr)**
Replicate 1	8.0	3.43	1.3	0.36
Replicate 2	7.9	3.89	1.1	0.31
Replicate 3	7.8	4.10	1.3	0.30
Average of 3 Replicates	**7.9**	**3.81**	**1.2**	**0.32**
Coefficient of Variation	**0.01**	**0.09**	**0.09**	**0.10**

NO_x, HC, and PM are adjusted with multipliers of 1.053, 2.5, and 5, respectively, as bias correction.

Cycle average emission rates are based on EPA Line-Haul duty cycle.

Over-the-Rail Measurements

Three days of over-the-rail measurements on the NC-1810 prime mover engine operating on ULSD were conducted on March 20-22, 2014.

Based on the over-the-rail measurements, notch average emission rates were estimated for Low and High Idle, Dynamic Brake, and Notches 1 to 8. To enable comparisons with other data, the notch average emission rates are weighted based on the EPA line-haul duty cycle. However, we also quantified the actual observed duty cycle for each one-way trip. The EPA line-haul cycle average emission rates for the over-the-rail measurements of the NC-1810 prime mover engine operating on ULSD are shown in Table E-49. These cycle average emission rates are based on the measured engine activity data (RPM, MAP, and IAT) and measured exhaust concentrations. It was desirable to enable comparison on a consistent basis. The estimate was based on measured notch-based emission rates and time fraction spent for each notch from the EPA line-haul duty cycle. For each set of measurements, there was little variability between measured engine activity data during all three days of measurements. This indicates that the prime mover engine was operating consistently during over-the-rail measurements. Measured engine activity data during over-the-rail measurements were similar to the measured engine activity data during rail yard measurements.

For the notch average NO_x emission rates, the coefficient of variation was less than 15 percent for each notch position amongst the six one-way trips. The coefficients of variation for HC and CO are 29 and 27 percent, respectively. For PM, the coefficient of variation was 8 percent for the six one-way trips. Differences in measured exhaust pollutant concentrations were one of the key reasons for the variability.

The EPA line-haul duty cycle average over-the-rail emission rates are quantitatively similar to the EPA line-haul duty cycle average rail yard emission rates. The average cycle averages OTR NO_x, HC, and PM emission rate over six one-way trips were within 11 percent, 6 percent, and 11 percent of the cycle average rail yard emission rates, respectively. The over-the-rail cycle average CO emission rate was 21 percent higher than the rail yard cycle average rates. However, on an absolute basis, they differed only by 0.3 g/bhp-hr.

Differences in cycle average emission rates between rail yard and over-the-rail measurements can be attributed to various factors. RPM and MAP were essentially the same for rail yard and over-the-rail measurements. IAT differed on an absolute basis by less than 6 percent from run-to-run during OTR measurements. At notch 8, the engine output during rail yard measurements was 2,700 horsepower, while engine output was 3,000 horsepower during over-the-rail measurements. With notch 8 accounting for 16 percent of the EPA line-haul duty cycle, higher engine output decreases engine output based emission rates and, therefore, cycle average emission rates. Finally, differences in measured exhaust concentrations between rail yard and over-the-rail measurements lead to differences in fuel use and emission rates.

Throttle notch position data obtained from the locomotive data activity recorder was used to quantify the actual real-world duty cycles for the over-the-rail measurements. The measured duty cycles are compared to the EPA line-haul duty cycle in Table E-50. The prime mover engine operated in notch 8 during the over-the-rail measurements more than double the percentage of time, on average, than EPA estimates a line-haul locomotive operates in notch 8. For the other notch positions, the observed time was on average less than the EPA line-haul duty cycle. Although not shown here, the real-world duty cycles can be used to estimate inter-cycle variability in cycle average for use and emission rates.

Details of results of rail yard and over-the-rail measurements of NC-1810 on ULSD are given in attached supplemental tables.

Table E-51 summarizes the average measured engine speed (RPM), intake air temperature (IAT), manifold absolute pressure (MAP), estimated mass air flow (MAF), and air-to-fuel ratio (AFR) for each throttle notch position and for each replicate of the rail yard (RY) measurement and for each one-way over-the-rail (OTR) trip. Engine speed ranges from 237 to 908 RPM in both RY and OTR measurements, depending on notch position. For the RY measurements, engine RPM was highly repeatable among replicates for a given notch position, with a standard deviation of less than 7 RPM for all notch positions. For the OTR measurements, the RPM was also repeatable among replicates for a given notch position, with coefficient of variation less than 0.05 for all notch positions. For some one-way trips, the sample sizes in these notches are too small to infer a steady-state engine operating speed. The intake air temperature varies with ambient temperature and was generally in the range of 57 to 76 °C during all measurements. MAP was highly repeatable in the RY measurements, ranging from 100 to 237 kPa depending on notch position. The inter-replicate standard deviation of measured MAP was less than 1 kPa for each notch position except for Notch 7. For OTR measurements, there was slightly more inter-run variability in MAP. However, the coefficient of variation for each notch position was 0.03 or less, except for notch 7.

Estimated MAF was highly repeatable for both RY and OTR measurements, with the coefficient of variation typically 0.04 or less for all notch positions. The MAF ranged from 850 to 4,600 g/s, depending on notch position. Estimated AFR was highly repeatable among replicates for a given notch position in the RY measurements, with coefficient of variation less than 0.06 for all notch positions. For OTR measurements, there was slightly more inter-run variability in AFR for each notch position, but the coefficient of variation was less than 0.10 except for high idle and notch 7. Overall, the engine activity during the measurements was consistent for the three

Table E-49. EPA Line-Haul Cycle Average Emission Rates for Over-the-Rail Measurements of NC-1810 Prime Mover Engine Operated on Ultra-Low Sulfur Diesel

	NO_x (g/bhp-hr)	**HC** (g/bhp-hr)	**CO** (g/bhp-hr)	**Opacity-based PM** (g/bhp-hr)
Mar. 20, 2014 – Train 73	7.1	2.55	1.3	0.29
Mar. 20, 2014 – Train 74	7.1	3.80	1.6	0.32
Mar. 21, 2014 – Train 73	7.1	2.70	1.0	0.26
Mar. 21, 2014 – Train 74	6.8	4.73	1.6	0.26
Mar. 22, 2014 – Train 73	7.0	2.77	1.2	0.27
Mar. 22, 2014 – Train 74	7.2	4.84	2.1	0.29
Average	**7.0**	**3.57**	**1.5**	**0.28**
Coefficient of Variation	**0.02**	**0.29**	**0.27**	**0.08**

NO_x, HC, and PM are adjusted with multipliers of 1.053, 2.5, and 5, respectively, as bias correction.

Cycle average emission rates are based on EPA Line-Haul driving cycle.

Table E-50. Observed Real-World Over-the-Rail Duty Cycles from Measurement of NC-1810 Operated on Ultra-Low Sulfur Diesel

Notch	**Percent Time in Each Notch**							
	EPA Line-Haul	**Measured Over-the-Rail**						
		Average	**3/20/2014 Train 73**	**3/20/2013 Train 74**	**3/21/2014 Train 73**	**3/21/2014 Train 74**	**3/22/2014 Train 73**	**3/22/2014 Train 74**
Idle	38.0	26.0	24.3	22.0	27.9	33.8	28.3	19.6
DB	12.5	13.6	17.4	10.0	15.1	15.7	13.6	9.8
1	6.5	5.5	1.8	14.0	3.1	1.8	2.4	9.8
2	6.5	5.0	6.5	7.9	1.6	3.3	2.6	8.5
3	5.2	3.3	2.0	3.4	1.9	4.6	1.4	6.4
4	4.4	3.9	2.5	7.1	2.9	4.8	1.7	4.4
5	3.8	1.9	0.4	3.2	2.2	2.4	0.4	2.6
6	3.9	2.5	1.1	7.1	2.2	2.9	0.7	1.3
7	3.0	0.8	0.0	2.5	0.8	0.7	0.3	0.2
8	16.2	37.6	44.2	22.9	42.4	30.2	48.6	37.4

Train 73 is from Raleigh to Charlotte. Train 74 is from Charlotte to Raleigh.

replicates in the rail yard, and from run to run for the six one-way trips observed between Raleigh and Charlotte.

Table E-52 summarizes the estimated fuel use rates inferred from the engine data of Table E-51. For the RY measurements, fuel use rates range from 2.5 to 126 g/sec depending on notch position, and were highly repeatable among replicates for a given notch position, with a coefficient of variation of 0.07 or less. There was more variability in run-to-run estimates of fuel use for the OTR measurements, in part because the amount of time spent in some notch positions was low. The OTR estimated fuel use ranged from 2.5 to 134 g/sec, depending on notch position. The coefficient of variation for all notches was less than 0.11 for all notch positions.

During RY measurements, the maximum engine output was 2,700 hp, whereas during OTR measurements the maximum engine output was 3,000 hp. Furthermore, as shown later in Table E-57, the average CO_2 concentrations for each notch position are lower for OTR than for RY measurements, which implies a lower fuel-to-air ratio. Because the engine activity and engine air flow are approximately the same in OTR and RY measurements, the combination of higher engine output and lower fuel-to-air ratio lead to higher values of fuel-specific engine output (FSEO) in bhp-hr per gallon of fuel consumed, as shown in Table E-52. The FSEO was highly repeatable for the OTR measurements of each notch position, especially Notch 8 (which represents a significant portion of the observed duty cycle).

The measured NO exhaust concentration and the estimated NO_x emission rates are shown in Table E-53 for each notch position, each RY replicate, and each OTR one-way run. The average measured concentrations range among notch positions from approximately 130 to 830 parts per million (ppm) in the RY measurements, and 130 to 840 ppm in the OTR measurements, depending on notch position. The measurements are highly repeatable among replicates for a given notch position for both the RY and OTR measurements, with coefficients of variation typically less than 0.07 for the former and less than 0.11 for the latter. The estimated mass emission rates range from 0.2 to 5.1 g/sec for the RY measurements and 0.2 to 5.0 g/sec for the OTR measurements, depending on notch position. Because the observed concentrations tend to be lower for the OTR versus RY measurements, the mass emission rates also tend to be slightly lower for the OTR versus RY measurements.

On a fuel basis, the average NO_x emission rates range from 130 to 260 g/gallon for the RY measurements and 110 to 240 g/gallon for the OTR measurements, depending on notch position. For both the RY and OTR measurements, the fuel-based emission rates are highly repeatable among replicates for a given notch position, with coefficient of variation typically less than 0.07. The fuel-based emission rates tend to be lowest at high load.

On an engine output basis, excluding idle and dynamic braking, the notch average NO_x emission rates range from 6.7 g/bhp-hr at Notch 8 to 10.6 g/bhp-hr at notch 1 in the RY measurements, and range from 5.7 g/bhp-hr at Notch 8 to 10.6 g/bhp-hr at notch 1 in the OTR measurements. The notch average NO_x emission rates for idle and dynamic braking were higher than the other notch positions. In general, the emission rates on an engine output basis are lower for the OTR measurements than for the RY measurements. This results from a combination of lower exhaust concentration and higher engine output, especially at notch 8.

Results are given for exhaust concentrations and emission rates in Tables E-54, E-55, E-56, and E-57 for CO, HC, PM, and CO_2, respectively. The CO exhaust concentrations during OTR measurements are higher than during RY measurements. However, on an absolute basis, the cycle average CO emission rates are within 0.3 g/bhp-hr of difference between OTR and RY measurements. On average, the HC exhaust concentrations and average emission rates tend to be slightly lower for OTR than RY. However, on an absolute basis, the cycle average CO emission rates are within 0.3 g/bhp-hr of difference between RY and OTR. For PM, the measured exhaust levels tend to be slightly lower for OTR than RY for a given notch position, and thus the cycle average PM emission rate tends to also be lower. The trends in CO_2 emission rates are similar to those for fuel use on a mass per time and mass per engine output basis. CO_2 emission rates are also shown on a g/gallon basis. Since typically over 99 percent of the carbon in the fuel is emitted as CO_2, the fuel-based CO_2 emission rates are approximately constant.

SUMMARY

Over-the-rail emissions measurements on the prime mover engine of NC-1810 were conducted on ULSD. The cycle average over-the-rail emission rates are of the same magnitude to the cycle average rail yard emission rates. The inter-replicate variation in cycle average emission rates were 10 percent or less for all pollutants during rail yard measurements. The inter-run variation in cycle average NO_x and PM emission rates were ten percent or less for over-the-rail measurements, and 30 to 32 percent for cycle average CO and HC emission rates.

Table E-51. Measured Engine Parameters for NC-1810 and ULSD

Engine Speed (RPM)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/27	3/27	3/27	3 Reps	3 Reps	3 Reps	3/20	3/20	3/21	3/21	3/22	3/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Low Idle	239	237	237	238	1.16	0.00	238	237	238	237	238	237	238	0.54	0.00
High Idle	393	382	382	386	6.42	0.02	381	380	381	380	381	380	381	0.60	0.00
Dyn Brake	--	--	--	--	--	--	402	385	376	370	379	424	389	20.1	0.05
1	383	382	382	382	0.93	0.00	380	379	380	379	380	379	380	0.52	0.00
2	382	381	381	382	0.69	0.00	380	379	380	379	380	379	380	0.52	0.00
3	492	491	490	491	1.00	0.00	490	490	489	488	490	489	489	0.71	0.00
4	566	565	565	566	0.66	0.00	565	565	565	564	565	564	565	0.63	0.00
5	653	651	652	652	0.98	0.00	655	654	654	653	654	654	654	0.43	0.00
6	729	729	729	729	0.25	0.00	730	730	730	730	731	730	730	0.43	0.00
7	823	820	818	821	2.73	0.00	--	826	826	825	826	826	826	0.35	0.00
8	906	906	906	906	0.16	0.00	908	908	908	907	908	907	907	0.60	0.00

Intake Air Temepratura (°C)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/27	3/27	3/27	3 Reps	3 Reps	3 Reps	3/20	3/20	3/21	3/21	3/22	3/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Low Idle	57	59	58	58	0.88	0.02	63	66	63	66	67	70	66	2.60	0.04
High Idle	67	68	68	68	0.58	0.01	67	70	66	69	68	72	69	2.18	0.03
Dyn Brake	--	--	--	--	--	--	65	70	65	69	68	72	68	2.88	0.04
1	61	59	61	60	0.87	0.01	68	68	66	67	67	73	68	2.34	0.03
2	63	62	62	62	0.48	0.01	66	71	64	68	69	73	68	3.20	0.05
3	63	66	67	65	1.68	0.03	65	72	68	69	66	74	69	3.22	0.05
4	66	68	68	67	1.03	0.02	66	69	66	71	70	75	70	3.45	0.05
5	66	67	66	66	0.58	0.01	68	71	69	72	69	78	71	3.53	0.05
6	67	68	68	67	0.59	0.01	68	73	71	71	66	78	71	4.16	0.06
7	72	71	69	71	1.91	0.03	--	74	73	77	66	76	73	4.38	0.06
8	72	73	73	72	0.34	0.00	71	74	71	74	72	76	73	1.90	0.03

Manifold Absolute Pressure (kPa)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/27	3/27	3/27	3 Reps	3 Reps	3 Reps	3/20	3/20	3/21	3/21	3/22	3/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Low Idle	101	101	100	101	0.23	0.00	98	97	99	98	99	97	98	0.65	0.01
High Idle	111	110	110	110	0.78	0.01	107	106	108	107	108	107	107	0.74	0.01
Dyn Brake	--	--	--	--	--	--	109	106	108	106	108	110	108	1.49	0.01
1	110	110	110	110	0.26	0.00	109	107	108	107	109	107	108	1.01	0.01
2	111	110	110	110	0.27	0.00	108	107	108	107	110	108	108	1.12	0.01
3	122	121	121	121	0.39	0.00	119	117	121	119	120	118	119	1.15	0.01
4	132	132	131	132	0.48	0.00	129	127	131	129	134	128	130	2.29	0.02
5	147	146	146	146	0.66	0.00	155	142	144	145	150	144	147	4.89	0.03
6	163	162	162	162	0.62	0.00	160	157	162	158	161	157	159	2.01	0.01
7	214	208	203	208	5.28	0.03	--	196	201	197	184	197	195	6.39	0.03
8	237	237	236	237	0.51	0.00	246	242	254	240	246	236	244	6.12	0.03

Mass Air Flow (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/27	3/27	3/27	3 Reps	3 Reps	3 Reps	3/20	3/20	3/21	3/21	3/22	3/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Low Idle	912	899	900	904	6.82	0.01	871	856	879	861	867	847	863	11.2	0.01
High Idle	1373	1329	1328	1343	25.9	0.02	1294	1279	1318	1289	1305	1278	1294	15.5	0.01
Dyn Brake	--	--	--	--	--	--	1377	1294	1305	1260	1300	1418	1326	59.1	0.04
1	1362	1361	1354	1359	4.21	0.00	1312	1288	1309	1296	1318	1276	1300	15.9	0.01
2	1355	1351	1351	1352	2.48	0.00	1308	1280	1323	1298	1320	1282	1302	18.6	0.01
3	1753	1731	1723	1736	15.6	0.01	1709	1657	1709	1682	1707	1648	1685	27.4	0.02
4	2054	2035	2028	2039	13.6	0.01	2016	1974	2035	1975	2041	1944	1998	38.8	0.02
5	2477	2451	2456	2461	13.7	0.01	2566	2376	2422	2408	2494	2354	2437	79.3	0.03
6	2894	2871	2871	2879	13.3	0.00	2843	2769	2842	2788	2877	2722	2807	57.1	0.02
7	3827	3754	3704	3762	61.7	0.02	--	3565	3658	3556	3489	3566	3567	60.2	0.02
8	4444	4433	4422	4433	10.9	0.00	4583	4481	4694	4458	4566	4381	4527	110	0.02

Air to Fuel Ratio (g/g)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/27	3/27	3/27	3 Reps	3 Reps	3 Reps	3/20	3/20	3/21	3/21	3/22	3/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Low Idle	319	353	356	343	20.6	0.06	292	305	353	323	281	295	308	26.1	0.08
High Idle	275	286	273	278	7.15	0.03	254	204	269	250	253	229	243	23.3	0.10
Dyn Brake	--	--	--	--	--	--	235	241	265	247	239	212	240	17.3	0.07
1	131	130	137	133	4.10	0.03	145	120	133	134	142	116	131	11.5	0.09
2	86.4	86.2	89.7	87.4	1.96	0.02	89.6	80.2	97.1	92.5	93.5	81.1	89.0	6.91	0.08
3	63.8	62.1	63.0	63.0	0.86	0.01	62.2	57.2	67.4	61.8	59.8	57.6	61.0	3.76	0.06
4	50.2	50.5	49.7	50.1	0.41	0.01	52.2	47.4	51.0	51.0	51.9	46.0	49.9	2.58	0.05
5	45.4	45.2	44.7	45.1	0.38	0.01	52.2	42.0	44.5	44.3	47.9	40.5	45.2	4.25	0.09
6	43.0	43.4	42.3	42.9	0.54	0.01	43.9	39.7	40.7	40.0	42.4	36.9	40.6	2.41	0.06
7	37.9	37.3	35.4	36.9	1.32	0.04	--	33.9	37.1	37.9	38.4	36.8	36.8	1.76	0.05
8	35.3	35.1	35.4	35.3	0.16	0.00	35.9	33.6	36.5	33.2	35.5	32.9	34.6	1.56	0.05

Table E-52. Estimated Fuel Use Rates for NC-1810 and ULSD

Time-Based Fuel Use Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/27	3/27	3/27	3 Reps	3 Reps	3 Reps	3/20	3/20	3/21	3/21	3/22	3/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Low Idle	2.86	2.55	2.53	2.64	0.18	0.07	2.98	2.81	2.49	2.66	3.08	2.87	2.82	0.22	0.08
High Idle	4.99	4.64	4.86	4.83	0.18	0.04	5.09	6.28	4.90	5.16	5.16	5.59	5.36	0.50	0.09
Dyn Brake	--	--	--	--	--	--	5.87	5.36	4.92	5.10	5.43	6.69	5.56	0.64	0.11
1	10.4	10.5	9.85	10.2	0.34	0.03	9.07	10.8	9.87	9.65	9.30	11.0	9.94	0.78	0.08
2	15.7	15.7	15.1	15.5	0.36	0.02	14.6	16.0	13.6	14.0	14.1	15.8	14.7	0.98	0.07
3	27.5	27.9	27.4	27.6	0.27	0.01	27.5	29.0	25.3	27.2	28.5	28.6	27.7	1.34	0.05
4	40.9	40.3	40.8	40.7	0.34	0.01	38.6	41.6	39.9	38.7	39.3	42.3	40.1	1.54	0.04
5	54.6	54.2	55.0	54.6	0.38	0.01	49.2	56.6	54.4	54.4	52.1	58.2	54.1	3.21	0.06
6	67.3	66.2	67.8	67.1	0.84	0.01	64.8	69.8	69.9	69.7	67.9	73.8	69.3	2.95	0.04
7	101	101	105	102	2.26	0.02	---	105	98.7	93.8	90.7	96.8	97.0	5.44	0.06
8	126	126	125	126	0.73	0.01	128	134	129	134	129	133	131	3.02	0.02

Engine Output-Based Fuel Use Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/27	3/27	3/27	3 Reps	3 Reps	3 Reps	3/20	3/20	3/21	3/21	3/22	3/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Low Idle	2.83	3.17	3.19	3.06	0.21	0.07	2.71	2.88	3.25	3.03	2.62	2.81	2.88	0.23	0.08
High Idle	1.62	1.74	1.66	1.67	0.06	0.04	1.59	1.29	1.65	1.57	1.57	1.45	1.52	0.13	0.09
Dyn Brake	--	--	--	--	--	--	1.38	1.51	1.64	1.58	1.49	1.21	1.47	0.16	0.11
1	14.8	14.6	15.6	15.0	0.51	0.03	16.9	14.2	15.5	15.9	16.5	14.0	15.5	1.20	0.08
2	18.0	18.0	18.8	18.3	0.43	0.02	19.4	17.7	20.7	20.1	20.0	17.9	19.3	1.25	0.06
3	19.9	19.6	19.9	19.8	0.19	0.01	19.9	18.8	21.5	20.0	19.1	19.1	19.7	1.00	0.05
4	19.7	20.1	19.8	19.9	0.17	0.01	20.9	19.4	20.2	20.9	20.5	19.1	20.2	0.76	0.04
5	20.0	20.1	19.8	20.0	0.14	0.01	22.2	19.3	20.0	20.1	21.0	18.7	20.2	1.23	0.06
6	19.2	19.5	19.1	19.3	0.24	0.01	20.0	18.5	18.5	18.6	19.0	17.5	18.7	0.80	0.04
7	19.2	19.3	18.5	19.0	0.42	0.02	---	20.7	22.1	23.3	24.0	22.5	22.5	1.24	0.06
8	17.3	17.3	17.5	17.3	0.10	0.01	19.0	18.1	18.8	18.0	18.9	18.2	18.5	0.43	0.02

Table E-53. Measured NO$_x$ Emission Rates for NC-1810 and ULSD

Time-Based NO$_x$ Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/27	3/27	3/27	3 Reps	3 Reps	3 Reps	3/20	3/20	3/21	3/21	3/22	3/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Low Idle	0.22	0.20	0.19	0.20	0.02	0.08	0.21	0.19	0.18	0.19	0.22	0.22	0.20	0.02	0.09
High Idle	0.28	0.27	0.26	0.27	0.01	0.05	0.29	0.36	0.27	0.29	0.30	0.32	0.30	0.03	0.10
Dyn Brake	--	--	--	--	--	--	0.31	0.30	0.28	0.29	0.31	0.35	0.31	0.03	0.09
1	0.55	0.56	0.51	0.54	0.03	0.05	0.53	0.58	0.52	0.55	0.55	0.62	0.56	0.04	0.07
2	1.02	1.00	0.94	0.99	0.04	0.04	0.87	1.00	0.82	0.83	0.91	1.02	0.91	0.09	0.09
3	1.86	1.88	1.85	1.86	0.02	0.01	1.73	1.87	1.54	1.74	1.75	1.86	1.75	0.12	0.07
4	2.56	2.54	2.53	2.54	0.02	0.01	2.30	2.43	2.31	2.27	2.41	2.52	2.37	0.09	0.04
5	3.17	3.18	3.08	3.15	0.06	0.02	3.10	2.99	2.90	2.99	2.95	3.11	3.01	0.08	0.03
6	3.78	3.82	3.73	3.78	0.04	0.01	3.52	3.61	3.68	3.53	3.25	3.67	3.54	0.16	0.04
7	4.83	4.63	4.43	4.63	0.20	0.04	---	4.31	4.63	3.10	4.09	4.55	4.14	0.62	0.15
8	5.08	5.00	5.06	5.05	0.04	0.01	4.71	4.81	5.02	4.75	4.81	4.65	4.79	0.13	0.03

Fuel-Based NO$_x$ Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/27	3/27	3/27	3 Reps	3 Reps	3 Reps	3/20	3/20	3/21	3/21	3/22	3/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Low Idle	245	255	237	245	8.89	0.04	230	219	229	230	232	242	230	7.35	0.03
High Idle	181	186	170	179	8.13	0.05	181	182	179	179	186	187	182	3.16	0.02
Dyn Brake	--	--	--	--	--	--	173	180	182	182	185	170	179	5.75	0.03
1	171	172	167	170	2.57	0.02	189	174	169	183	190	183	181	8.34	0.05
2	208	206	201	205	4.00	0.02	191	203	193	191	207	207	199	7.67	0.04
3	218	218	218	218	0.16	0.00	202	208	196	206	197	209	203	5.67	0.03
4	202	203	199	201	1.86	0.01	192	188	187	189	197	192	191	3.74	0.02
5	187	189	180	185	4.48	0.02	203	170	171	177	183	172	179	12.4	0.07
6	181	186	177	181	4.39	0.02	175	167	170	163	154	160	165	7.43	0.05
7	154	148	136	146	9.05	0.06	---	132	151	107	145	151	137	18.9	0.14
8	130	127	130	129	1.60	0.01	119	116	125	114	120	112	118	4.77	0.04

Engine Output-Based NO$_x$ Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/27	3/27	3/27	3 Reps	3 Reps	3 Reps	3/20	3/20	3/21	3/21	3/22	3/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Low Idle	78.1	72.5	67.1	72.6	5.53	0.08	76.7	68.7	63.7	68.4	79.9	77.7	72.5	6.44	0.09
High Idle	101	96.4	92.4	96.7	4.49	0.05	103	128	98.2	103	107	117	109	11.0	0.10
Dyn Brake	--	--	--	--	--	--	113	108	100	104	112	127	111	9.51	0.09
1	10.4	10.6	9.71	10.3	0.49	0.05	10.1	11.0	9.83	10.4	10.4	11.8	10.6	0.72	0.07
2	10.4	10.3	9.65	10.1	0.43	0.04	8.91	10.3	8.40	8.58	9.33	10.5	9.33	0.88	0.09
3	9.90	10.0	9.87	9.94	0.09	0.01	9.20	10.0	8.22	9.30	9.32	9.92	9.33	0.64	0.07
4	9.23	9.15	9.10	9.16	0.06	0.01	8.29	8.76	8.32	8.17	8.66	9.06	8.54	0.34	0.04
5	8.45	8.49	8.22	8.39	0.15	0.02	8.26	7.99	7.73	7.96	7.88	8.29	8.02	0.22	0.03
6	8.50	8.60	8.39	8.50	0.10	0.01	7.93	8.13	8.29	7.95	7.31	8.25	7.98	0.36	0.04
7	7.25	6.95	6.65	6.95	0.30	0.04	---	5.75	6.18	4.14	5.46	6.06	5.52	0.82	0.15
8	6.77	6.67	6.75	6.73	0.06	0.01	5.65	5.77	6.02	5.70	5.77	5.58	5.75	0.15	0.03
Duty Cycle Avg (Raw)	7.6	7.5	7.4	7.5	0.10	0.01	6.8	6.8	6.7	6.4	6.6	6.8	6.7	0.1	0.02
Duty Cycle Avg (Adj)	8.0	7.9	7.8	7.9	0.11	0.01	7.1	7.1	7.1	6.8	7.0	7.2	7.0	0.1	0.02

Exhaust NO$_x$ Concentrations (ppm)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/27	3/27	3/27	3 Reps	3 Reps	3 Reps	3/20	3/20	3/21	3/21	3/22	3/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Low Idle	146	138	127	137	9.33	0.07	151	139	125	137	158	158	145	13.3	0.09
High Idle	127	124	119	124	3.86	0.03	137	173	128	138	141	157	146	16.4	0.11
Dyn Brake	--	--	--	--	--	--	142	144	132	142	148	155	144	7.52	0.05
1	249	254	233	246	11.0	0.04	252	282	246	262	258	304	268	21.6	0.08
2	461	458	428	449	18.3	0.04	413	490	386	401	424	493	435	45.9	0.11
3	652	672	661	662	9.78	0.01	631	707	568	649	641	706	650	52.1	0.08
4	776	773	776	775	1.88	0.00	713	773	716	722	743	815	747	40.0	0.05
5	799	810	786	798	12.0	0.02	747	797	750	779	748	829	775	33.4	0.04
6	818	827	812	819	7.48	0.01	768	827	815	798	714	840	794	46.4	0.06
7	798	777	756	777	20.9	0.03	--	764	788	607	713	782	731	75.5	0.10
8	734	723	729	728	5.53	0.01	660	696	691	690	678	679	682	12.8	0.02

Table E-54. Measured CO Emission Rates for NC-1810 and ULSD

Time-Based CO Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	**3/27**	**3/27**	**3/27**	**3 Reps**	**3 Reps**	**3 Reps**	**3/20**	**3/20**	**3/21**	**3/21**	**3/22**	**3/22**	**6 Trains**	**6 Trains**	**6 Trains**
Position	**Axion REP1**	**Axion REP2**	**Axion REP3**	**Average**	**StDev**	**CV**	**Train 73**	**Train 74**	**Train 73**	**Train 74**	**Train 73**	**Train 73**	**Average**	**StDev**	**CV**
Low Idle	0.10	0.06	0.09	0.08	0.02	0.24	0.07	0.04	0.05	0.07	0.06	0.09	0.06	0.02	0.31
High Idle	0.09	0.12	0.07	0.09	0.02	0.24	0.07	0.08	0.08	0.11	0.08	0.14	0.09	0.03	0.29
Dyn Brake	--	--	--	--	--	--	0.09	0.09	0.07	0.10	0.08	0.22	0.11	0.05	0.49
1	0.05	0.09	0.05	0.06	0.02	0.37	0.16	0.05	0.06	0.12	0.11	0.12	0.10	0.04	0.39
2	0.08	0.04	0.11	0.07	0.03	0.44	0.07	0.10	0.07	0.07	0.09	0.11	0.09	0.02	0.19
3	0.05	0.09	0.07	0.07	0.02	0.33	0.11	0.15	0.06	0.10	0.10	0.18	0.12	0.04	0.35
4	0.10	0.03	0.16	0.09	0.07	0.70	0.09	0.17	0.08	0.22	0.14	0.22	0.15	0.06	0.40
5	0.09	0.02	0.13	0.08	0.05	0.67	0.16	0.20	0.18	0.34	0.19	0.51	0.26	0.14	0.52
6	0.14	0.00	0.23	0.12	0.11	0.91	0.28	0.27	0.23	0.35	0.21	0.66	0.33	0.17	0.50
7	0.61	0.56	0.99	0.72	0.24	0.33	---	1.34	0.54	0.69	0.33	1.22	0.82	0.44	0.53
8	1.04	0.97	0.93	0.98	0.06	0.06	1.06	1.52	0.86	1.54	1.10	1.75	1.30	0.34	0.26

Fuel-Based CO Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	**3/27**	**3/27**	**3/27**	**3 Reps**	**3 Reps**	**3 Reps**	**3/20**	**3/20**	**3/21**	**3/21**	**3/22**	**3/22**	**6 Trains**	**6 Trains**	**6 Trains**
Position	**Axion REP1**	**Axion REP2**	**Axion REP3**	**Average**	**StDev**	**CV**	**Train 73**	**Train 74**	**Train 73**	**Train 74**	**Train 73**	**Train 73**	**Average**	**StDev**	**CV**
Low Idle	115	79.0	110	101	19.6	0.19	76.9	41.5	62.7	79.8	64.4	104	71.5	20.7	0.29
High Idle	61.2	79.9	46.4	62.5	16.8	0.27	45.7	38.8	52.8	67.9	47.1	80.1	55.4	15.6	0.28
Dyn Brake	--	--	--	--	--	--	50.0	56.0	48.7	66.0	45.1	105	61.7	22.3	0.36
1	14.4	27.0	16.8	19.4	6.69	0.34	56.3	15.2	19.8	39.5	38.8	35.0	34.1	14.9	0.44
2	15.9	8.39	22.8	15.7	7.18	0.46	15.4	20.3	17.5	17.1	20.2	22.2	18.8	2.54	0.14
3	5.58	10.9	8.34	8.26	2.64	0.32	12.5	16.6	8.21	11.8	11.8	20.2	13.5	4.22	0.31
4	7.51	2.16	12.6	7.41	5.21	0.70	7.81	13.2	6.52	18.7	11.3	16.8	12.4	4.82	0.39
5	5.46	1.28	7.44	4.73	3.14	0.67	10.8	11.4	10.6	19.9	11.8	28.5	15.5	7.26	0.47
6	6.59	0.24	10.8	5.89	5.34	0.91	13.9	12.5	10.8	16.3	9.74	28.7	15.3	6.97	0.45
7	19.3	17.9	30.4	22.5	6.84	0.30	---	41.1	17.7	23.7	11.8	40.4	26.9	13.3	0.49
8	26.6	24.7	24.0	25.1	1.35	0.05	26.7	36.7	21.6	36.9	27.6	42.2	31.9	7.82	0.24

Engine Output-Based CO Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	**3/27**	**3/27**	**3/27**	**3 Reps**	**3 Reps**	**3 Reps**	**3/20**	**3/20**	**3/21**	**3/21**	**3/22**	**3/22**	**6 Trains**	**6 Trains**	**6 Trains**
Position	**Axion REP1**	**Axion REP2**	**Axion REP3**	**Average**	**StDev**	**CV**	**Train 73**	**Train 74**	**Train 73**	**Train 74**	**Train 73**	**Train 73**	**Average**	**StDev**	**CV**
Low Idle	36.9	22.5	31.1	30.2	7.24	0.24	25.6	13.0	17.5	23.8	22.2	33.3	22.6	6.96	0.31
High Idle	34.2	41.5	25.2	33.6	8.15	0.24	26.0	27.2	28.9	39.1	27.2	50.1	33.1	9.60	0.29
Dyn Brake	--	--	--	--	--	--	32.8	33.5	26.7	37.7	27.4	78.2	39.4	19.5	0.49
1	0.88	1.67	0.98	1.18	0.43	0.37	3.01	0.97	1.15	2.24	2.12	2.27	1.96	0.77	0.39
2	0.80	0.42	1.09	0.77	0.34	0.44	0.72	1.04	0.76	0.77	0.91	1.12	0.89	0.17	0.19
3	0.25	0.50	0.38	0.38	0.12	0.33	0.57	0.80	0.34	0.53	0.56	0.96	0.63	0.22	0.35
4	0.34	0.10	0.57	0.34	0.24	0.70	0.34	0.62	0.29	0.81	0.49	0.79	0.56	0.22	0.40
5	0.25	0.06	0.34	0.21	0.14	0.67	0.44	0.53	0.48	0.90	0.51	1.37	0.70	0.37	0.52
6	0.31	0.01	0.51	0.28	0.25	0.91	0.63	0.61	0.53	0.79	0.46	1.48	0.75	0.38	0.50
7	0.91	0.84	1.48	1.08	0.35	0.33	---	1.79	0.72	0.92	0.44	1.62	1.10	0.58	0.53
8	1.39	1.29	1.24	1.31	0.07	0.06	1.27	1.83	1.04	1.85	1.32	2.09	1.57	0.41	0.26
Duty Cycle Avg (Raw)	1.27	1.07	1.25	1.20	0.11	0.09	1.26	1.60	0.97	1.63	1.18	2.07	1.45	0.40	0.27
Duty Cycle Avg (Adj)	1.27	1.07	1.25	1.20	0.11	0.09	1.26	1.60	0.97	1.63	1.18	2.07	1.45	0.40	0.27

Exhaust CO Concentrations (%)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	**3/27**	**3/27**	**3/27**	**3 Reps**	**3 Reps**	**3 Reps**	**3/20**	**3/20**	**3/21**	**3/21**	**3/22**	**3/22**	**6 Trains**	**6 Trains**	**6 Trains**
Position	**Axion REP1**	**Axion REP2**	**Axion REP3**	**Average**	**StDev**	**CV**	**Train 73**	**Train 74**	**Train 73**	**Train 74**	**Train 73**	**Train 73**	**Average**	**StDev**	**CV**
Low Idle	0.012	0.007	0.010	0.010	0.00	0.23	0.009	0.005	0.006	0.008	0.008	0.012	0.008	0.00	0.32
High Idle	0.007	0.009	0.006	0.007	0.00	0.24	0.006	0.006	0.007	0.009	0.006	0.012	0.008	0.00	0.30
Dyn Brake	--	--	--	--	--	--	0.007	0.008	0.006	0.009	0.006	0.016	0.009	0.00	0.45
1	0.004	0.007	0.004	0.005	0.00	0.37	0.013	0.004	0.005	0.010	0.009	0.010	0.009	0.00	0.39
2	0.006	0.003	0.008	0.006	0.00	0.44	0.006	0.009	0.006	0.006	0.007	0.009	0.007	0.00	0.20
3	0.003	0.006	0.004	0.004	0.00	0.33	0.007	0.010	0.004	0.006	0.007	0.012	0.008	0.00	0.36
4	0.005	0.001	0.008	0.005	0.00	0.71	0.005	0.009	0.004	0.012	0.007	0.012	0.008	0.00	0.41
5	0.004	0.001	0.006	0.004	0.00	0.67	0.007	0.009	0.008	0.015	0.008	0.024	0.012	0.01	0.54
6	0.005	0.000	0.009	0.005	0.00	0.91	0.011	0.011	0.009	0.014	0.008	0.026	0.013	0.01	0.52
7	0.017	0.016	0.029	0.021	0.01	0.34	--	0.041	0.016	0.023	0.010	0.036	0.025	0.01	0.52
8	0.026	0.024	0.023	0.024	0.00	0.06	0.026	0.038	0.021	0.039	0.027	0.044	0.032	0.01	0.28

Table E-55. Measured Hydrocarbon Emission Rates for NC-1810 and ULSD

Time-Based HC Emission Rates (g/s)															
Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/27	3/27	3/27	3 Reps	3 Reps	3 Reps	3/20	3/20	3/21	3/21	3/22	3/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Low Idle	0.60	0.63	0.68	0.63	0.04	0.06	0.37	0.25	0.33	0.67	0.43	0.50	0.43	0.15	0.35
High Idle	0.90	0.86	0.90	0.89	0.02	0.03	0.43	0.61	0.58	1.07	0.59	0.86	0.69	0.23	0.33
Dyn Brake	--	--	--	--	--	--	0.62	0.68	0.52	0.98	0.56	0.89	0.71	0.18	0.26
1	0.54	0.60	0.64	0.59	0.05	0.08	0.48	0.66	0.49	1.32	0.47	0.83	0.71	0.33	0.47
2	0.63	0.66	0.76	0.68	0.07	0.10	0.44	0.73	0.59	0.64	0.43	0.76	0.60	0.14	0.24
3	0.76	0.89	1.06	0.90	0.15	0.16	0.47	1.45	0.69	1.50	0.75	1.07	0.99	0.42	0.43
4	0.83	0.89	1.05	0.92	0.11	0.12	0.54	1.46	0.61	1.23	0.58	1.14	0.93	0.40	0.43
5	0.72	0.67	0.82	0.73	0.07	0.10	0.56	0.97	1.31	1.53	0.61	1.58	1.09	0.45	0.41
6	1.55	2.15	1.94	1.88	0.31	0.16	0.95	1.45	1.22	1.58	1.35	2.50	1.51	0.53	0.35
7	1.87	1.47	0.66	1.34	0.62	0.46	---	2.19	1.50	1.84	1.30	3.36	2.04	0.81	0.40
8	0.67	1.02	1.14	0.94	0.25	0.26	0.76	1.70	0.82	1.47	0.90	1.89	1.26	0.49	0.39

Fuel-Based HC Emission Rates (g/gal)															
Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/27	3/27	3/27	3 Reps	3 Reps	3 Reps	3/20	3/20	3/21	3/21	3/22	3/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Low Idle	677	792	861	777	92.9	0.12	404	286	432	813	445	564	491	181	0.37
High Idle	582	598	598	593	9.60	0.02	274	315	384	666	366	497	417	143	0.34
Dyn Brake	--	--	--	--	--	--	340	410	341	618	332	426	411	109	0.26
1	168	185	208	187	20.2	0.11	171	197	160	442	164	243	230	109	0.47
2	129	136	163	143	18.4	0.13	96.0	146	140	146	98.2	156	130	26.3	0.20
3	89.2	103	124	105	17.6	0.17	55.2	161	87.9	177	85.1	120	114	47.3	0.41
4	65.5	70.9	82.8	73.1	8.82	0.12	45.1	113	49.5	102	47.2	86.6	73.9	30.3	0.41
5	42.3	39.8	47.7	43.3	4.05	0.09	36.4	55.3	77.3	90.7	38.0	87.7	64.2	24.3	0.38
6	74.1	105	92.2	90.4	15.4	0.17	47.3	67.1	56.1	72.8	64.0	109	69.4	21.4	0.31
7	59.7	47.2	20.4	42.4	20.1	0.47	---	67.2	48.9	63.1	46.0	112	67.4	26.4	0.39
8	17.0	26.0	29.4	24.1	6.39	0.26	19.1	41.1	20.6	35.2	22.4	45.7	30.7	11.5	0.37

Engine Output-Based HC Emission Rates (g/bhp-hr)															
Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/27	3/27	3/27	3 Reps	3 Reps	3 Reps	3/20	3/20	3/21	3/21	3/22	3/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Low Idle	216	225	244	228	13.9	0.06	135	89.8	120	242	153	181	154	53.2	0.35
High Idle	325	310	325	320	8.24	0.03	156	221	210	384	211	311	249	82.8	0.33
Dyn Brake	--	--	--	--	--	--	223	246	187	353	202	319	255	66.5	0.26
1	10.2	11.4	12.1	11.2	0.92	0.08	9.12	12.5	9.27	25.1	8.99	15.8	13.5	6.29	0.47
2	6.44	6.80	7.86	7.03	0.74	0.10	4.48	7.46	6.11	6.54	4.43	7.86	6.15	1.45	0.24
3	4.06	4.74	5.63	4.81	0.79	0.16	2.51	7.74	3.69	7.98	4.02	5.71	5.28	2.25	0.43
4	3.00	3.20	3.78	3.32	0.40	0.12	1.95	5.24	2.21	4.42	2.08	4.10	3.33	1.43	0.43
5	1.91	1.79	2.17	1.96	0.20	0.10	1.48	2.59	3.49	4.08	1.64	4.22	2.92	1.20	0.41
6	3.48	4.85	4.37	4.23	0.69	0.16	2.14	3.27	2.74	3.55	3.04	5.62	3.39	1.19	0.35
7	2.81	2.21	1.00	2.00	0.92	0.46	---	2.92	2.00	2.45	1.73	4.48	2.72	1.08	0.40
8	0.89	1.36	1.52	1.26	0.33	0.26	0.91	2.04	0.99	1.76	1.08	2.27	1.51	0.59	0.39
Duty Cycle Avg (Raw)	1.37	1.56	1.64	1.52	0.14	0.09	1.02	1.52	1.08	1.89	1.11	1.94	1.43	0.42	0.29
Duty Cycle Avg (Adj)	3.43	3.89	4.10	3.81	0.34	0.09	2.55	3.80	2.70	4.73	2.77	4.84	3.57	1.04	0.29

Exhaust HC Concentrations (ppm)															
Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/27	3/27	3/27	3 Reps	3 Reps	3 Reps	3/20	3/20	3/21	3/21	3/22	3/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Low Idle	91	96	104	97	6.59	0.07	60	41	53	109	68	83	69	24.2	0.35
High Idle	92	90	95	92	2.24	0.02	47	67	62	116	63	94	75	25.3	0.34
Dyn Brake	--	--	--	--	--	--	63	74	56	109	60	87	75	20.1	0.27
1	55	61	65	61	5.17	0.09	51	72	52	142	50	91	77	36.0	0.47
2	64	68	78	70	7.47	0.11	47	80	63	69	45	84	65	16.1	0.25
3	60	71	85	72	12.3	0.17	39	123	57	125	62	92	83	36.1	0.43
4	57	61	73	63	8.21	0.13	38	104	43	88	40	83	66	29.1	0.44
5	41	38	47	42	4.35	0.10	30	58	76	90	35	95	64	27.6	0.43
6	76	105	95	92	15.0	0.16	47	75	61	80	67	129	76	28.3	0.37
7	70	56	26	50	22.6	0.45	--	88	57	81	51	130	81	31.3	0.38
8	22	33	37	31	7.98	0.26	24	56	26	48	28	62	41	16.7	0.41

Table E-56. Measured Particulate Matter Emission Rates for NC-1810 and ULSD

Time-Based PM Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/27	3/27	3/27	3 Reps	3 Reps	3 Reps	3/20	3/20	3/21	3/21	3/22	3/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Low Idle	0.01	0.01	0.01	0.01	0.00	0.06	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.10
High Idle	0.01	0.01	0.01	0.01	0.00	0.11	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.04
Dyn Brake	--	--	--	--	--	--	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.05
1	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.04
2	0.02	0.02	0.02	0.02	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.06
3	0.03	0.03	0.03	0.03	0.00	0.01	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.00	0.08
4	0.05	0.05	0.04	0.05	0.00	0.03	0.06	0.06	0.06	0.05	0.06	0.07	0.06	0.01	0.09
5	0.06	0.06	0.06	0.06	0.00	0.03	0.05	0.08	0.07	0.07	0.06	0.09	0.07	0.01	0.19
6	0.07	0.07	0.07	0.07	0.00	0.00	0.07	0.09	0.08	0.08	0.08	0.11	0.09	0.01	0.15
7	0.19	0.22	0.24	0.22	0.02	0.11	---	0.25	0.25	0.18	0.17	0.16	0.20	0.04	0.22
8	0.33	0.26	0.26	0.28	0.04	0.15	0.26	0.29	0.21	0.23	0.24	0.26	0.25	0.03	0.11

Fuel-Based PM Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/27	3/27	3/27	3 Reps	3 Reps	3 Reps	3/20	3/20	3/21	3/21	3/22	3/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Low Idle	14.5	14.9	14.8	14.7	0.18	0.01	14.5	15.0	16.4	14.8	13.4	11.3	14.2	1.71	0.12
High Idle	7.99	7.19	6.71	7.30	0.65	0.09	7.69	6.41	7.82	7.09	7.16	6.49	7.11	0.59	0.08
Dyn Brake	--	--	--	--	--	--	7.64	7.58	8.60	7.82	7.86	6.59	7.68	0.65	0.08
1	6.83	6.85	7.39	7.02	0.32	0.04	8.42	6.71	7.11	7.09	7.92	6.50	7.29	0.74	0.10
2	5.26	5.20	5.29	5.25	0.04	0.01	6.31	5.67	6.24	5.71	6.66	5.70	6.05	0.41	0.07
3	4.61	4.42	4.55	4.53	0.10	0.02	5.49	5.82	6.13	4.88	5.57	5.47	5.56	0.42	0.08
4	5.12	5.13	4.85	5.04	0.16	0.03	6.52	6.62	6.69	6.22	6.94	7.41	6.73	0.41	0.06
5	5.10	4.99	4.80	4.97	0.15	0.03	5.30	6.66	5.73	6.23	5.49	7.45	6.14	0.81	0.13
6	4.72	4.84	4.68	4.75	0.08	0.02	4.99	6.03	5.31	5.47	5.49	6.82	5.68	0.65	0.11
7	8.33	9.64	9.91	9.30	0.85	0.09	---	10.5	11.0	8.59	8.07	7.15	9.05	1.62	0.18
8	12.0	9.42	9.34	10.3	1.53	0.15	9.34	9.82	7.55	7.79	8.36	8.82	8.61	0.88	0.10

Engine Output-Based PM Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/27	3/27	3/27	3 Reps	3 Reps	3 Reps	3/20	3/20	3/21	3/21	3/22	3/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Low Idle	3.00	2.74	2.71	2.82	0.16	0.06	3.13	3.06	2.95	2.87	3.00	2.36	2.89	0.28	0.10
High Idle	3.97	3.32	3.24	3.51	0.40	0.11	3.89	4.00	3.80	3.64	3.67	3.61	3.77	0.16	0.04
Dyn Brake	--	--	--	--	--	--	3.51	3.18	3.31	3.12	3.34	3.45	3.32	0.15	0.05
1	0.26	0.26	0.26	0.26	0.00	0.01	0.28	0.26	0.25	0.25	0.27	0.26	0.26	0.01	0.04
2	0.18	0.18	0.18	0.18	0.00	0.02	0.21	0.20	0.19	0.18	0.21	0.20	0.20	0.01	0.06
3	0.15	0.14	0.14	0.14	0.00	0.01	0.17	0.19	0.18	0.15	0.18	0.18	0.18	0.01	0.08
4	0.17	0.17	0.16	0.17	0.00	0.03	0.20	0.22	0.22	0.20	0.22	0.25	0.22	0.02	0.09
5	0.16	0.15	0.15	0.15	0.00	0.03	0.15	0.21	0.17	0.19	0.16	0.24	0.19	0.04	0.19
6	0.16	0.16	0.16	0.16	0.00	0.00	0.16	0.21	0.18	0.19	0.18	0.25	0.19	0.03	0.15
7	0.29	0.33	0.36	0.33	0.03	0.11	---	0.34	0.33	0.25	0.22	0.21	0.27	0.06	0.22
8	0.45	0.35	0.34	0.38	0.06	0.15	0.32	0.35	0.26	0.28	0.28	0.31	0.30	0.03	0.11
Duty Cycle Avg (Raw)	0.07	0.06	0.06	0.06	0.01	0.10	0.06	0.06	0.05	0.05	0.05	0.06	0.06	0.00	0.08
Duty Cycle Avg (Adj)	0.36	0.31	0.30	0.32	0.03	0.10	0.29	0.32	0.26	0.26	0.27	0.29	0.28	0.02	0.08

Exhaust PM Concentrations (mg/m^3)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/27	3/27	3/27	3 Reps	3 Reps	3 Reps	3/20	3/20	3/21	3/21	3/22	3/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Low Idle	2.2	2.1	2.1	2.1	0.10	0.05	2.5	2.5	2.3	2.3	2.4	1.9	2.3	0.20	0.09
High Idle	1.9	1.6	1.6	1.7	0.16	0.10	1.9	2.0	1.8	1.8	1.8	1.8	1.9	0.09	0.05
Dyn Brake	--	--	--	--	--	--	1.7	1.6	1.7	1.6	1.7	1.6	1.6	0.04	0.02
1	2.4	2.5	2.5	2.5	0.04	0.02	2.7	2.7	2.5	2.5	2.6	2.6	2.6	0.10	0.04
2	3.2	3.2	3.1	3.1	0.05	0.02	3.7	3.7	3.4	3.3	3.7	3.7	3.6	0.20	0.06
3	3.8	3.7	3.8	3.8	0.03	0.01	4.7	5.4	4.9	4.2	4.9	5.0	4.9	0.40	0.08
4	5.7	5.6	5.4	5.6	0.12	0.02	7.0	7.8	7.4	6.8	7.5	9.0	7.6	0.80	0.11
5	5.8	5.7	5.5	5.7	0.12	0.02	5.2	8.3	6.7	7.3	6.0	9.5	7.1	1.58	0.22
6	6.0	6.0	6.0	6.0	0.02	0.00	6.1	8.3	7.1	7.5	7.1	10.0	7.7	1.34	0.17
7	12.1	14.1	15.4	13.9	1.67	0.12	--	17.0	16.0	13.7	11.1	10.3	13.6	2.92	0.21
8	18.7	14.7	14.4	15.9	2.42	0.15	14.3	16.2	11.4	13.0	13.0	14.6	13.7	1.66	0.12

Table E-57. Measured CO$_2$ Emission Rates for NC-1810 and ULSD

Time-Based CO$_2$ Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/27	3/27	3/27	3 Reps	3 Reps	3 Reps	3/20	3/20	3/21	3/21	3/22	3/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Low Idle	8.4	7.5	7.4	7.8	0.57	0.07	8.98	8.58	7.51	7.82	9.29	8.53	8.45	0.68	0.08
High Idle	14.9	13.8	14.5	14.4	0.57	0.04	15.5	19.1	14.8	15.3	15.7	16.7	16.2	1.57	0.10
Dyn Brake	--	--	--	--	--	--	17.8	16.2	14.9	15.2	16.5	20.0	16.8	1.89	0.11
1	32.0	32.3	30.4	31.6	1.07	0.03	27.8	33.2	30.5	29.2	28.6	33.7	30.5	2.45	0.08
2	48.6	48.6	46.5	47.9	1.20	0.03	45.3	49.3	42.2	43.4	43.8	48.8	45.5	2.98	0.07
3	85.4	86.5	84.9	85.6	0.85	0.01	85.5	89.5	78.7	84.2	88.7	88.5	85.8	4.05	0.05
4	127	125	127	127	1.00	0.01	120	129	124	120	122	131	125	4.63	0.04
5	170	169	171	170	1.06	0.01	153	176	169	169	162	180	168	9.70	0.06
6	209	206	211	209	2.54	0.01	202	217	218	216	211	228	215	8.74	0.04
7	314	313	325	317	7.06	0.02	---	325	307	291	283	299	301	16.4	0.05
8	392	393	389	391	2.31	0.01	397	414	401	417	400	413	407	8.68	0.02

Fuel-Based CO$_2$ Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/27	3/27	3/27	3 Reps	3 Reps	3 Reps	3/20	3/20	3/21	3/21	3/22	3/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Low Idle	9477	9464	9373	9438	56.9	0.01	9705	9833	9710	9450	9700	9565	9661	134	0.01
High Idle	9621	9581	9634	9612	27.6	0.00	9834	9820	9756	9559	9775	9643	9731	108	0.01
Dyn Brake	--	--	--	--	--	--	9787	9735	9789	9591	9799	9648	9725	86.4	0.01
1	9948	9918	9920	9929	16.9	0.00	9881	9929	9945	9741	9912	9870	9880	73.7	0.01
2	9970	9978	9938	9962	21.0	0.00	9991	9952	9961	9958	9982	9944	9965	18.2	0.00
3	10011	9994	9985	9997	13.1	0.00	10021	9949	10007	9947	10003	9969	9983	31.9	0.00
4	10022	10027	10004	10018	12.4	0.00	10034	9984	10034	9982	10028	9995	10009	25.0	0.00
5	10040	10048	10033	10040	7.29	0.00	10035	10022	10010	9987	10032	9976	10010	24.4	0.00
6	10018	10010	10001	10010	8.88	0.00	10023	10013	10023	10004	10020	9962	10008	23.4	0.00
7	10007	10017	10014	10013	5.12	0.00	---	9968	10016	9998	10027	9942	9991	35.1	0.00
8	10022	10019	10019	10020	1.80	0.00	10021	9991	10028	9995	10017	9980	10005	19.1	0.00

Engine Output-Based CO$_2$ Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/27	3/27	3/27	3 Reps	3 Reps	3 Reps	3/20	3/20	3/21	3/21	3/22	3/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Low Idle	3028	2694	2651	2791	206	0.07	3234	3089	2702	2815	3345	3072	3043	244	0.08
High Idle	5372	4971	5235	5193	204	0.04	5594	6894	5339	5509	5639	6026	5834	567	0.10
Dyn Brake	--	--	--	--	--	--	6421	5831	5381	5473	5950	7211	6045	682	0.11
1	607	613	575	598	20.2	0.03	528	629	578	553	542	639	578	46.4	0.08
2	500	499	478	492	12.4	0.03	466	507	434	446	450	502	468	30.6	0.07
3	456	461	453	457	4.54	0.01	456	477	420	449	473	472	458	21.6	0.05
4	459	452	456	456	3.60	0.01	433	465	448	432	441	473	449	16.7	0.04
5	454	451	457	454	2.82	0.01	409	470	451	450	433	481	449	25.9	0.06
6	471	463	474	469	5.72	0.01	454	488	490	487	475	514	485	19.7	0.04
7	470	469	488	476	10.6	0.02	---	434	409	388	377	398	401	21.8	0.05
8	523	524	518	522	3.08	0.01	476	497	481	500	480	496	488	10.4	0.02

Exhaust CO$_2$ Concentrations (%)

Throttle	Rail Yard Test						Over-The-Rail Test								
Notch	3/27	3/27	3/27	3 Reps	3 Reps	3 Reps	3/20	3/20	3/21	3/21	3/22	3/22	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 73	Train 73	Average	StDev	CV
Low Idle	0.62	0.56	0.55	0.58	0.04	0.06	0.70	0.69	0.58	0.62	0.73	0.69	0.67	0.05	0.08
High Idle	0.74	0.71	0.75	0.73	0.02	0.03	0.82	1.03	0.77	0.81	0.82	0.89	0.86	0.09	0.11
Dyn Brake	--	--	--	--	--	--	0.88	0.86	0.78	0.82	0.87	0.96	0.86	0.06	0.07
1	1.60	1.61	1.52	1.58	0.05	0.03	1.45	1.78	1.59	1.53	1.48	1.81	1.61	0.15	0.09
2	2.43	2.44	2.33	2.40	0.06	0.02	2.37	2.65	2.19	2.30	2.25	2.61	2.40	0.19	0.08
3	3.30	3.40	3.34	3.34	0.05	0.01	3.44	3.72	3.19	3.45	3.58	3.70	3.51	0.20	0.06
4	4.25	4.20	4.29	4.25	0.04	0.01	4.11	4.52	4.24	4.21	4.16	4.68	4.32	0.23	0.05
5	4.72	4.74	4.81	4.76	0.05	0.01	4.07	5.17	4.82	4.84	4.52	5.29	4.78	0.44	0.09
6	4.99	4.90	5.05	4.98	0.07	0.01	4.84	5.46	5.30	5.39	5.11	5.76	5.31	0.31	0.06
7	5.71	5.78	6.11	5.87	0.22	0.04	--	6.35	5.75	6.27	5.42	5.66	5.89	0.40	0.07
8	6.23	6.25	6.16	6.22	0.05	0.01	6.13	6.60	6.08	6.66	6.21	6.64	6.39	0.27	0.04

Appendix F.
Results of Rail Yard and Over the Rail Measurements for NC-1859

F.1 Summary of Results for NC-1859 on B40

RY and OTR measurements were conducted in August and September 2013 on the prime mover engine of locomotive NC-1859 (City of High Point) operating on ULSD using a PEMS. During October 2013, RY and OTR measurements were conducted on the prime mover engine of locomotive NC-1859, which was operating on a 40 percent soy-based biodiesel and 60 percent ULSD blend (B40). The prime mover engine was an EMD 12-710G3B that was originally manufactured in 1988 and rebuilt by AMTRAK in 2012. The 140-Liter engine has a peak engine output of 3000 hp at an engine speed of 900 RPM.

The PEMS utilized for measurements was the Axion system manufactured by Clean Air Technologies International, Inc. (CATI). Prior to each set of measurements, each PEMS was calibrated with a California Bureau of Automotive Repair (BAR) certified calibration gas (BAR-97 Low).

The cycle average emission rates for the RY and OTR measurements of the NC-1859 prime mover engine with the Axion are shown in Table F-1. The cycle average emission rates are based on the line-haul duty cycle used by the U.S. Environmental Protection Agency (EPA) for regulatory purposes. Three replicates of each rail yard measurement were conducted. During rail yard measurements, dynamic braking was not observed; thus, the time apportioned for dynamic braking in the line-haul duty cycle (12.5 percent) was combined with the time apportioned for idling in the line-haul duty cycle (38.0 percent). Therefore, idling accounts for 50.5 percent of the duty cycle used to calculate rail yard cycle average emission rates. OTR measurements were made during six one-way trips between Raleigh and Charlotte, NC. During over-the-rail measurements, dynamic braking was observed.

Rail Yard Measurements

On September 1, 2013, three rail yard emissions measurement replicates were conducted on the prime mover engine of NC-1859 on ULSD biodiesel, while three rail yard emissions measurement replicates on the prime mover engine of NC-1859 on B40 biodiesel were conducted on October 20, 2013.

The cycle average emission rates for the rail yard measurements of the NC-1859 prime mover engine are shown in Table F-1. These cycle average emission rates are based on the measured engine activity data (RPM, MAP, and IAT), inferred engine activity data (MAF, AFR, and VE), and measured exhaust concentrations. For the rail yard measurements of the NC-1859 prime mover engine operated on B40 biodiesel, there was little variability between replicate measured engine activity data, given in Figure F-1. This indicates that the prime mover engine was operating consistently during all three replicate measurements.

Table F-1. Cycle Average Emission Rates for the NC-1859 Prime Mover Engine Operated on B40 Biodiesel in the Rail Yard and Over-the-Rail[a,b,c]

Measurement	NO_x (g/bhp-hr)	HC (g/bhp-hr)	CO (g/bhp-hr)	Opacity-based PM (g/bhp-hr)
Rail Yard	10.1	1.01	0.8	0.22
Over-the-Rail	7.8	1.62	0.5	0.20
EPA Tier 0+	**8.0**	**1.00**	**5.0**	**0.22**
EPA Tier 1+	7.4	0.55	2.2	0.22

[a] The cycle average emission rates are based on the U.S. EPA line-haul duty cycle used for regulatory purposes.

[b] NO_x, HC, and opacity-based PM emission rates from the Axion are adjusted with multipliers of 1.053, 2.5, and 5, respectively, as bias correction.

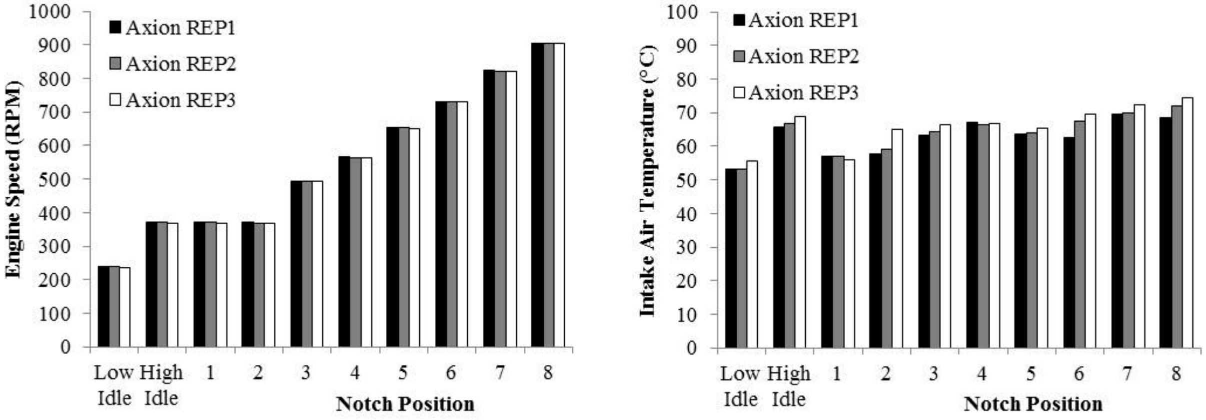
[c] Dynamic braking not observed during rail yard measurements. Therefore, idling accounts for 50.5 percent of the duty cycle used to calculate rail yard cycle average emission rates.

When the rail yard measurements of the NC-1859 prime mover engine operated on B40 biodiesel, an increasing trend in fuel use rates was apparent as notch position increased during the rail yard measurement (see Figure F-2). Higher inter-replicate variability was observed at notches 7 and 8. The NO emission rates estimated with the Axion during the three replicates were consistent, as shown in Figure F-3.

The inter-replicate ratios of the coefficient of variation (CV) for each notch position for the mass per gallon of fuel NO emission rates range from 0.03 to 0.06, which indicates small variability between replicates. There was variability in the estimated HC emission rates between the three replicate measurements, as shown in Figure F-4. The inter-replicate coefficient of variation in the estimated engine output-based HC emission rates were, on average for each notch position, 50 percent. Differences in measured exhaust HC concentrations led to the inter-replicate variability.

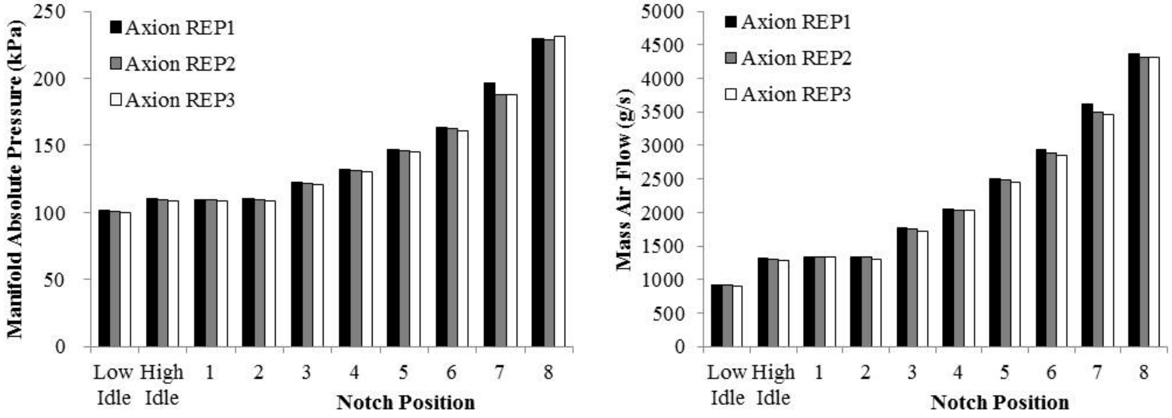
Across the three replicates, the CV varied from 0.18 to 1.18, depending on the notch position. There was also variability in the estimated CO emission rates between the three replicate measurements, as shown in Figure F-5. On average for each notch position, the inter-replicate CV in the estimated CO emission rates were 38 percent. For CO exhaust concentrations, the CV varied from 0.14 to 0.78, depending on the notch position. Therefore, the differences in measured exhaust concentrations primarily contributed to the variability in mass emission rates when comparing replicates. However, on an absolute basis, the exhaust CO concentrations were very low. PM emission rates, as shown in Figure F-6, were consistent across the three replicates, with inter-replicate coefficient of variation less than 0.07 for all notch positions except for high idle. The NO, CO, HC, and PM concentrations measured were of the same magnitude as previous rail yard measurements on NC-1859 prime mover engine operating on ULSD.

Figure F-1. Measured Engine Activity Data during Rail Yard Measurements of the NC-1859 Prime Mover Engine Operated on B40 Biodiesel



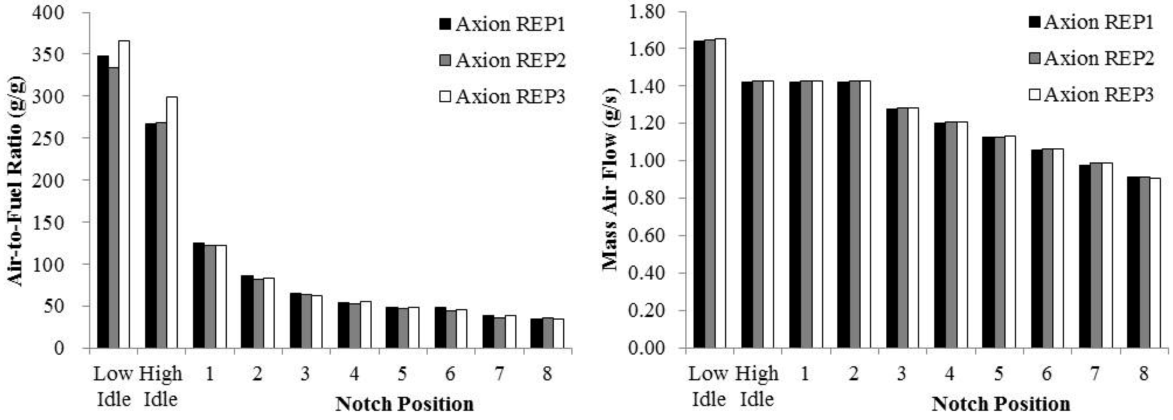
(a) Engine Speed

(b) Intake Air Temperature



(c) Manifold Absolute Pressure

(d) Mass Air Flow



(e) Air-to-Fuel Ratio

(f) Volumetric Efficiency

Figure F-2. Estimated Fuel Use Rates during Rail Yard Measurements of the NC-1859 Prime Mover Engine Operated on B40 Biodiesel

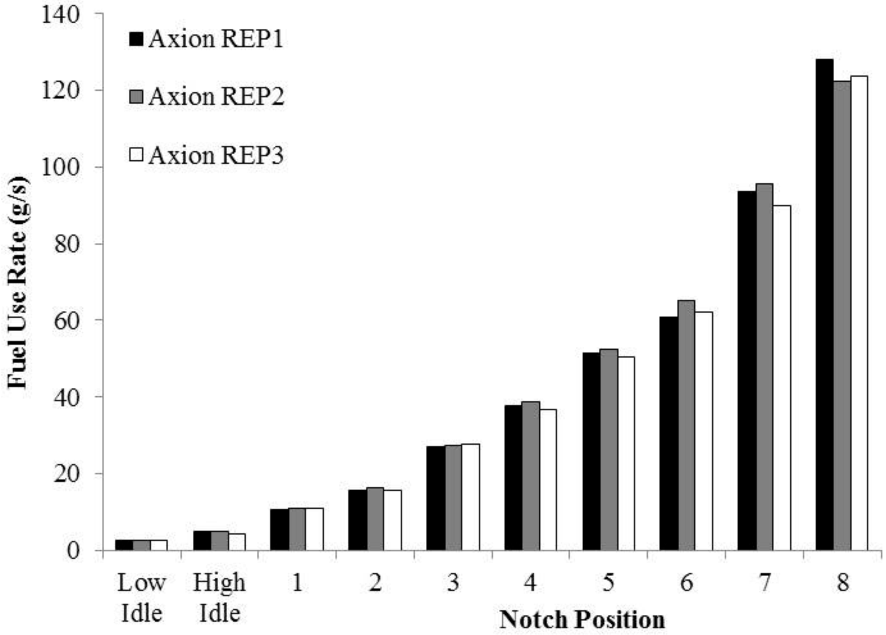


Figure F-3. Estimated NO_x Emission Rates during Rail Yard Measurements of the NC-1859 Prime Mover Engine Operated on B40 Biodiesel

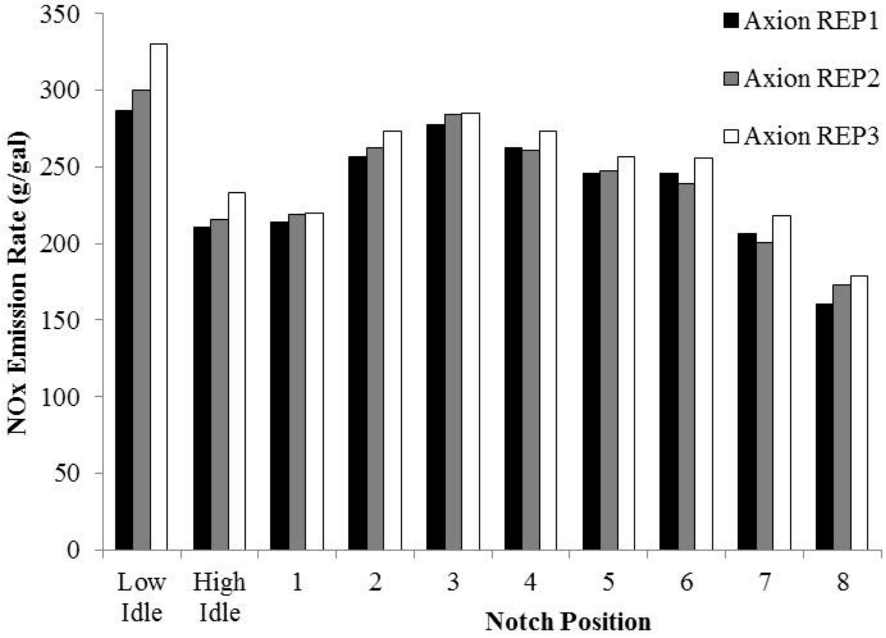


Figure F-4. Estimated HC Emission Rates during Rail Yard Measurements of the NC-1859 Prime Mover Engine Operated on B40 Biodiesel

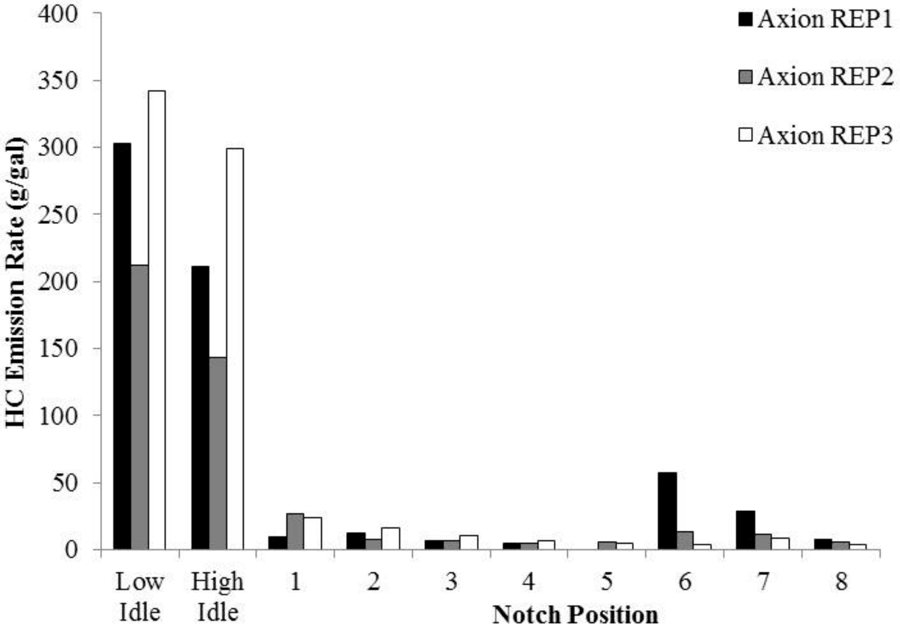


Figure F-5. Estimated CO Emission Rates during Rail Yard Measurements of the NC-1859 Prime Mover Engine Operated on B40 Biodiesel

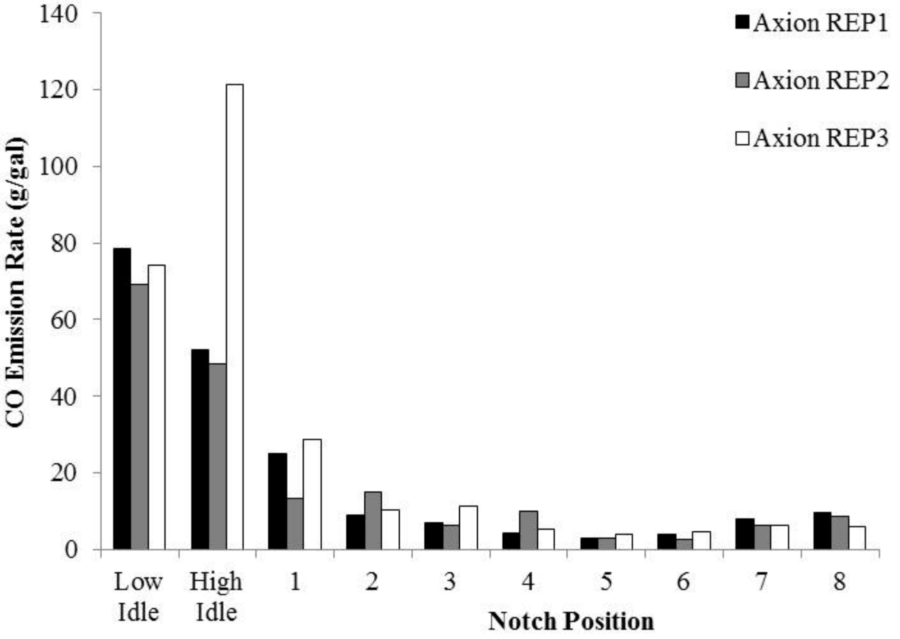
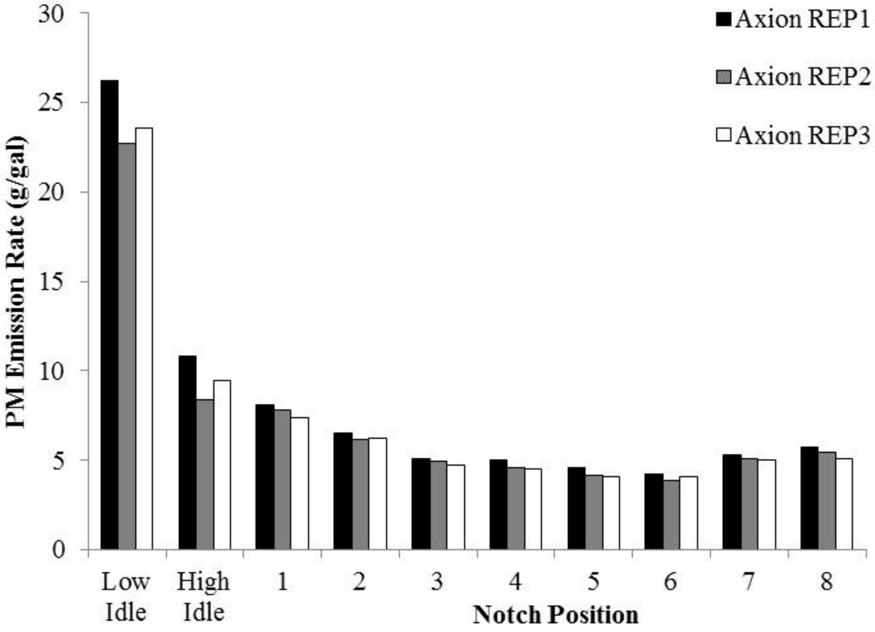


Figure F-6. Measured PM Concentrations during Rail Yard Measurements of the NC-1859 Prime Mover Engine Operated on B40 Biodiesel



Estimated cycle average emission rates for the three replicate rail yard measurements on the NC-1859 prime mover engine operated on B40 biodiesel are given in Table F-2. There was little variability in the NO_x and PM cycle average emission rates among the replicates. Amongst the three replicates, the average coefficient of variation for each notch position averages for CO and HC are 15 and 18 percent, respectively, for measurements on B40 biodiesel. Differences in emission rates are attributable to differences in measured exhaust concentrations. Values for engine activity parameters (RPM, IAT, MAP) were similar across all measurements, as given in Figure F-1.

Over-the-Rail (OTR) Measurements

Three days of OTR measurements on the NC-1859 prime mover engine operating on ULSD were conducted on August 30, 31, and September 2, 2013. Three days of OTR measurements on the NC-1859 prime mover engine operating on B40 biodiesel were conducted on October 18, 19, and 21, 2013. Cycle average emission rates for the OTR measurements are shown in Table F-3. These cycle average emission rates are based on the measured engine activity data (RPM, MAP, and IAT) and measured exhaust concentrations. For each set of measurements, there was little variability between measured engine activity data during all three days of measurements, which indicates that the prime mover engine was operating consistently during the OTR measurements. Measured engine activity data during OTR measurements were similar to the measured engine activity data during RY measurements.

Table F-2. Cycle Average Emission Rates for Rail Yard Replicate Measurements of NC-1859 Prime Mover Engine Operated on B40 Biodiesel

	NO_x (g/bhp-hr)	HC (g/bhp-hr)	CO (g/bhp-hr)	Opacity-based PM (g/bhp-hr)
Replicate 1	9.7	1.29	1.0	0.24
Replicate 2	10.1	0.82	0.9	0.22
Replicate 3	10.4	0.92	0.4	0.21
Average of 3 Replicates	**10.1**	**1.01**	**0.8**	**0.22**
Coefficient of Variation	*0.03*	*0.25*	*0.39*	*0.07*

† NO_x, HC, and PM are adjusted with multipliers of 1.05, 2.5, and 5, respectively, as bias correction.

†† Cycle average emission rates are based on EPA Line-Haul driving cycle.

Table F-3. Cycle Average Emission Rates for Over-the-Rail Measurements of NC-1859 Prime Mover Engine Operated on B40 Biodiesel

	NO_x (g/bhp-hr)	HC (g/bhp-hr)	CO (g/bhp-hr)	Opacity-based PM (g/bhp-hr)
Oct. 18, 2013 – Train 73	7.4	2.25	0.5	0.17
Oct. 18, 2013 – Train 74	8.1	2.25	0.7	0.19
Oct. 19, 2013 – Train 73	7.9	0.96	0.4	0.22
Oct. 19, 2013 – Train 74	7.5	1.60	0.5	0.21
Oct. 21, 2013 – Train 75	8.1	1.32	0.5	0.20
Oct. 21, 2013 – Train 76	7.6	1.34	0.4	0.21
Average	**7.8**	**1.62**	**0.5**	**0.20**
Coefficient of Variation	*0.04*	*0.32*	*0.21*	*0.09*

† NO_x, HC, and PM are adjusted with multipliers of 1.05, 2.5, and 5, respectively, as bias correction.

†† Cycle average emission rates are based on EPA Line-Haul driving cycle.

There was little variability in the NO_x and PM cycle average emission rates among the replicates; less than 3 percent and less than 7 percent coefficient of variation for each notch position amongst the six one way trips with regard to cycle average NO_x and PM emission rates, respectively. Among the six one-way trips, the average coefficient of variation for each notch position average for CO and HC was 21 and 32 percent, respectively, for measurements on B40 biodiesel. Differences in measured exhaust pollutant concentrations were one of the key reasons for the variability. The average coefficient of variation for each notch position, averaged over all notch positions, for the exhaust concentrations across the six one way trips were 36 percent and 38 percent for CO and HC, respectively, for B40 biodiesel.

For the NC-1859 prime mover engine operating on B40 biodiesel, the cycle average over-the-rail emission rates are quantitatively similar to the cycle average RY emission rates. The average cycle average OTR NO_x emission rate over six one-way trips was 16 percent lower than the cycle average rail yard NO_x emission rates. The average cycle average over-the-rail CO emission rate was 6.5 percent higher than the cycle average CO emission rates estimated from rail yard measurements. The average cycle average OTR HC emission rate was 83 percent higher than the cycle average rail yard HC emission rate. The average cycle average over-the-rail PM emission rate very close to the cycle average PM emission rate estimated from rail yard measurements.

Differences in cycle average emission rates between RY and OTR measurements can be attributed to various factors. RPM and MAP was essentially the same for RY and OTR measurements. IAT differed on an absolute basis by less than 6 percent from run-to-run during over-the-rail measurements. At notch 8, the engine output during rail yard measurements was 2700 horsepower, while engine output was 3000 horsepower during over-the-rail measurements. With notch 8 accounting for 16 percent of the EPA line-haul duty cycle used to estimate cycle average emission rates, higher engine output decreases engine output based emission rates and, therefore, cycle average emission rates. Finally, differences in measured exhaust concentrations between rail yard and over-the-rail measurements lead to differences in fuel use and emission rates.

Throttle notch position data was obtained from the locomotive data activity recorder to measure the duty cycles for the over-the-rail measurements. The measured duty cycles are compared to the EPA line-haul duty cycle in Table F-4. The prime mover engine operated in notch 8 during the over-the-rail tests more than double the percentage of time, on average, the EPA estimates a line-haul locomotive is operating in notch 8. The average percentage of time the prime mover engine operated in idle through notch 7 during the over-the-rail tests was lower than the percentage of time the EPA estimates a line-haul locomotive is operating in those throttle notch settings, with the exception of Dynamic Braking, where the amount of time spent during the six one-way trips was similar to the percentage of time allocated in the line-haul duty cycle.

Details of results of the field measurements and of the fuel use and emission rates for rail yard and over-the-rail measurements of NC-1859 using B40 are given in attached supplemental tables.

Table F-5 summarizes the average measured engine speed (RPM), intake air temperature (IAT), manifold absolute pressure (MAP), estimated mass air flow (MAF), and air-to-fuel ratio (AFR) for each throttle notch position and for each replicate of the rail yard (RY) test and for each one-way over-the-rail (OTR) trip. Engine speed ranges from 240 to 900 RPM in both RY and OTR measurements. For the RY measurements, engine RPM was highly repeatable, with a standard deviation of less than 2 RPM for all notch positions. For the OTR measurements, the RPM was also repeatable, with a standard deviation of less than 1 RPM, except for high idle. The intake air temperature varies with ambient temperature and was generally in the range of 53 to 75 degrees C during all measurements. MAP was highly repeatable in the RY tests, ranging from 98 to 233 kPa among notch positions with an inter-test standard deviation of less than 5 kPa for each notch position. For OTR measurements, there was slightly more inter-run variability.

Table F-4. Over-the-Rail Duty Cycles during Measurement of NC-1859 Operated on B40 Biodiesel

Notch	Percent Time in Each Notch							
	EPA Line-Haul	Measured Over-the-Rail						
		Average	10/18/2013 Train 73	10/18/2013 Train 74	10/19/2013 Train 73	10/19/2013 Train 74	10/21/2013 Train 75	10/21/2013 Train 76
Idle	38.0	45.4	40.2	48.1	47.3	48.6	44.3	44.2
DB	12.5	15.2	16.5	14.3	13.2	16.9	13.3	17.0
1	6.5	3.1	3.8	1.7	2.4	1.5	4.3	5.3
2	6.5	2.5	1.8	2.4	2.0	2.1	3.9	2.8
3	5.2	2.6	1.7	3.3	3.1	1.4	3.8	2.3
4	4.4	2.4	1.5	2.6	3.5	0.9	3.7	2.4
5	3.8	2.4	1.8	1.9	4.2	1.2	1.8	3.3
6	3.9	3.5	2.4	2.4	6.5	1.4	2.8	5.4
7	3.0	2.4	1.0	0.8	9.7	0.8	0.7	1.3
8	16.2	35.7	45.8	36.8	21.3	42.2	34.8	33.1

However, the ratio of the standard deviation to the mean of the run average MAP values for each notch position was typically 0.05 or less.

Estimated MAF was highly repeatable for both RY and OTR measurements, ranging from 870 to 4,400 g/s, with the ratio of the standard deviation to the mean of 0.03 or less for all notches. Estimated AFR was highly repeatable in the RY tests, with standard deviations less than 2 for all notches except for the idles and Notch 1. For OTR measurements, there was slightly more inter-run variability. But the ratio of the standard deviation to the mean was typically less than 0.14. Estimated VE was highly repeatable in both the RY and OTR measurements, ranging from 0.9 to 1.7. For all notches, the standard deviation was less than 0.03. Overall, the engine activity during the measurements was consistent from test to test for the three replicates in the rail yard, and from run to run for the six one-way trips observed between Raleigh and Charlotte.

Table F-6 summarizes the estimated fuel use rates inferred from the engine data of Table F-5. For the RY tests, fuel use rates from 2.5 to 127 g/sec depending on notch position, and was highly repeatable, with a coefficient of variation (CV, which was standard deviation divided by the mean) of 0.05 or less. There was more variability in run-to-run estimates of fuel use for the OTR measurements, in part because the amount of time spent in some notch positions was low. The OTR estimated fuel use ranged from 2.2 to 124 g/sec, depending on notch position. The CV for all notches was less than 0.14.

During RY measurements, the maximum engine output was 2,700 hp, whereas during OTR measurements the maximum engine output was 3,000 hp. Furthermore, as shown later in Table F-11, the average CO_2 concentrations for each notch position are lower for OTR than for RY measurements, which implies a lower fuel-to-air ratio. Because the engine activity and, therefore, engine air flow, are approximately the same for OTR versus RY measurements, the combination of higher engine output and lower fuel-to-air ratio lead to higher values of fuel-specific engine output (FSEO) in bhp-hr per gallon of fuel consumed, as shown in Table F-6. The FSEO was highly repeatable for the OTR measurements of all notches, especially Notch 8, which represents significant portion of the observed duty cycle.

The measured NO exhaust concentration and the estimated NO_x emission rates are shown in Table F-7 for each notch position, each RY test replicate, and each OTR one-way run. The average measured concentrations range among notch positions from approximately 150 to 1020 ppm in the RY tests, and 110 to 900 ppm in the OTR measurements. The measurements are highly repeatable for the RY and OTR measurements, with CVs typically less than 0.05 for the former and less than 0.2 for the latter. The estimated mass emission rates range from 0.2 to 6.8 g/sec for the RY measurements and 0.2 to 6.0 g/sec for the OTR measurements. Because the observed concentrations tend to be higher for the OTR versus RY measurements, the mass emission rates also tend to be slightly higher for the OTR versus RY measurements.

On a fuel basis, the average NO_x emission rates range from 160 to 330 g/gallon among notch positions for the RY measurements and 150 to 300 g/gallon for the OTR measurements. For the RY measurements, the fuel-based emission rates are highly repeatable, with CVs less than 0.1. The OTR measurements have slightly more run-to-run variability but are nonetheless consistent, with CVs less than 0.1. The fuel-based emission rates tend to be lowest at high load.

On an engine output basis, the notch average NO_x emission rates range from 8.7 g/bhp-hr at Notch 8 to 14.0 g/bhp-hr at Notch 1 in the RY measurements, with very high values at idle during which engine output was very low. For the OTR measurements, the notch average emission rates range from 6.8 g/bhp-hr at Notch 8 to 10.7 g/bhp-hr at notch 1, with much higher values during idle and dynamic braking. In general, the emission rates on an engine output basis are higher for the OTR measurements than for the RY measurements. This results from a combination of lower exhaust concentration and higher engine output, especially at Notch 8.

Results are given for exhaust concentrations and emission rates in Tables F-8, F-9, F-10, and F-11 for CO, HC, PM, and CO_2, respectively. The CO exhaust concentrations during OTR measurements tend to be higher than during RY measurements. Thus, the cycle average CO emission rates also tend to be higher for OTR than RY measurements. On average, the HC exhaust concentrations and average emission rates tend to be higher for OTR than RY. However, both the CO and HC emission rates are low on an absolute basis, and some of the measured average concentrations for a given notch position and replicate or run are below the gas analyzer detection limit. For PM, the measured exhaust levels tend to be lower for OTR than RY for a given notch position, and thus the cycle average PM emission rate tends to also be lower. The trends in CO_2 emission rates are similar to those for fuel use on a mass per time and mass per engine output basis. CO_2 emission rates are also shown on a g/gallon basis. Since typically over 99 percent of the carbon in the fuel was emitted as CO_2, the fuel-based CO_2 emission rates are approximately constant.

Differences in emission rates are attributable to differences in measured exhaust concentrations. Values for engine activity parameters (RPM, IAT, MAP) were similar across all rail yard and over-the-rail measurements.

Table F-5. Measured Engine Parameters for NC-1859 and B40

Engine Speed (RPM)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	10/20	10/20	10/20	3 Reps	3 Reps	3 Reps	10/18	10/18	10/19	10/19	10/21	10/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	239	239	238	239	0.58	0.00	237	237	238	237	238	237	237	0.52	0.00
High Idle	372	370	370	371	1.15	0.00	370	369	370	369	370	369	370	0.55	0.00
Dyn Brake	---	---	---	--	--	--	396	375	378	365	386	368	378	11.5	0.03
1	371	370	370	370	0.58	0.00	370	370	370	369	370	370	370	0.41	0.00
2	371	370	370	370	0.58	0.00	369	370	369	369	369	368	369	0.63	0.00
3	493	492	492	492	0.58	0.00	492	490	491	490	492	491	491	0.89	0.00
4	566	564	564	565	1.15	0.00	564	564	564	563	564	564	564	0.41	0.00
5	653	653	652	653	0.58	0.00	652	650	652	652	651	651	651	0.82	0.00
6	731	730	730	730	0.58	0.00	728	728	729	729	729	729	729	0.52	0.00
7	823	821	821	822	1.15	0.00	820	818	820	819	820	819	819	0.82	0.00
8	905	904	903	904	1.00	0.00	902	902	903	902	903	902	902	0.52	0.00

Intake Air Temepratura (°C)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	10/20	10/20	10/20	3 Reps	3 Reps	3 Reps	10/18	10/18	10/19	10/19	10/21	10/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	53	53	56	54	1.73	0.03	66	66	61	66	64	64	65	1.97	0.03
High Idle	66	67	69	67	1.53	0.02	70	71	67	69	69	68	69	1.41	0.02
Dyn Brake	---	---	---	--	--	--	69	70	67	68	67	67	68	1.26	0.02
1	57	57	56	57	0.58	0.01	74	69	67	67	68	68	69	2.64	0.04
2	58	59	65	61	3.79	0.06	66	71	68	67	66	64	67	2.37	0.04
3	63	64	66	64	1.53	0.02	67	70	66	72	67	66	68	2.45	0.04
4	67	67	67	67	0.00	0.00	72	69	67	71	66	67	69	2.42	0.04
5	64	64	65	64	0.58	0.01	71	70	69	73	67	69	70	2.04	0.03
6	63	67	70	67	3.51	0.05	73	72	70	72	69	69	71	1.72	0.02
7	70	70	72	71	1.15	0.02	74	72	71	77	71	70	73	2.59	0.04
8	69	72	75	72	3.00	0.04	74	75	72	74	71	71	73	1.72	0.02

Manifold Absolute Pressure (kPa)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	10/20	10/20	10/20	3 Reps	3 Reps	3 Reps	10/18	10/18	10/19	10/19	10/21	10/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	101	101	100	101	0.58	0.01	99	99	99	99	98	98	99	0.52	0.01
High Idle	110	110	108	109	1.15	0.01	108	107	108	107	107	107	107	0.52	0.00
Dyn Brake	---	---	---	--	--	--	111	108	109	107	109	107	109	1.52	0.01
1	110	109	108	109	1.00	0.01	111	108	109	108	107	107	108	1.51	0.01
2	110	110	109	110	0.58	0.01	109	110	109	108	108	107	109	1.05	0.01
3	122	122	121	122	0.58	0.00	120	121	120	122	120	118	120	1.33	0.01
4	132	132	130	131	1.15	0.01	130	131	131	131	130	128	130	1.17	0.01
5	147	146	145	146	1.00	0.01	146	145	145	146	145	143	145	1.10	0.01
6	163	162	161	162	1.00	0.01	160	158	161	161	158	159	160	1.38	0.01
7	196	188	188	191	4.62	0.02	185	180	191	203	181	181	187	8.91	0.05
8	229	228	231	229	1.53	0.01	233	226	232	225	217	218	225	6.74	0.03

Mass Air Flow (g/s)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	10/20	10/20	10/20	3 Reps	3 Reps	3 Reps	10/18	10/18	10/19	10/19	10/21	10/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	924	924	905	917	10.6	0.01	869	869	884	869	869	867	871	6.56	0.01
High Idle	1310	1301	1275	1296	18.3	0.01	1272	1256	1283	1263	1266	1267	1268	8.93	0.01
Dyn Brake	---	---	---	--	--	--	1369	1284	1312	1257	1332	1268	1304	42.4	0.03
1	1343	1331	1326	1333	9.18	0.01	1284	1275	1292	1280	1270	1270	1278	8.88	0.01
2	1339	1333	1300	1324	21.3	0.02	1293	1286	1286	1280	1284	1280	1285	5.03	0.00
3	1760	1752	1731	1748	15.2	0.01	1714	1705	1717	1706	1714	1694	1709	8.40	0.00
4	2045	2040	2015	2033	15.7	0.01	1986	2016	2028	2001	2021	1991	2007	16.8	0.01
5	2488	2475	2452	2472	18.4	0.01	2422	2411	2423	2408	2435	2395	2416	14.0	0.01
6	2934	2882	2844	2887	45.1	0.02	2800	2781	2841	2824	2808	2822	2813	21.0	0.01
7	3607	3488	3467	3521	75.2	0.02	3402	3345	3517	3617	3375	3382	3440	105	0.03
8	4361	4305	4307	4325	31.6	0.01	4345	4233	4359	4231	4156	4167	4249	86.2	0.02

Air to Fuel Ratio (g/g)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	10/20	10/20	10/20	3 Reps	3 Reps	3 Reps	10/18	10/18	10/19	10/19	10/21	10/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	347	345	364	352	10.3	0.03	343	376	377	384	345	388	369	19.5	0.05
High Idle	307	313	299	307	7.20	0.02	266	274	268	292	271	289	277	11.2	0.04
Dyn Brake	---	---	---	--	--	--	235	257	274	288	264	292	268	21.1	0.08
1	123	116	122	120	3.44	0.03	160	145	149	186	136	148	154	17.3	0.11
2	82.2	79.7	83.2	81.7	1.76	0.02	121	117	98.8	134	91.9	118	114	15.5	0.14
3	62.0	59.8	62.1	61.3	1.28	0.02	60.9	69.6	67.5	71.9	70.0	67.3	67.9	3.81	0.06
4	52.0	51.2	54.9	52.7	1.97	0.04	56.1	56.3	52.9	55.5	57.8	60.4	56.5	2.49	0.04
5	45.8	46.3	48.4	46.8	1.42	0.03	50.6	50.8	45.5	45.1	51.6	51.6	49.2	3.04	0.06
6	44.7	43.4	45.8	44.7	1.19	0.03	44.2	43.6	43.1	43.2	48.4	45.3	44.6	2.01	0.05
7	37.1	35.1	38.6	36.9	1.74	0.05	37.4	39.1	36.4	39.3	40.9	42.1	39.2	2.13	0.05
8	34.4	34.2	35.0	34.5	0.41	0.01	36.8	35.4	35.0	35.9	36.9	37.3	36.2	0.90	0.02

Table F-6. Estimated Fuel Use Rates for NC-1859 and B40

Time-Based Fuel Use Rates (g/s)

Throttle Notch Position	Rail Yard Measurements						Over-The-Rail Measurements								
	10/20	10/20	10/20	3 Reps	3 Reps	3 Reps	10/18	10/18	10/19	10/19	10/21	10/21	6 Trains	6 Trains	6 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	2.66	2.67	2.49	2.61	0.10	0.04	2.53	2.31	2.34	2.26	2.52	2.24	2.37	0.13	0.05
High Idle	4.27	4.15	4.26	4.23	0.07	0.02	4.78	4.58	4.78	4.32	4.68	4.38	4.59	0.20	0.04
Dyn Brake	--	--	--	--	--	--	5.83	4.99	4.79	4.36	5.05	4.35	4.89	0.55	0.11
1	11.0	11.4	10.9	11.1	0.31	0.03	8.02	8.80	8.66	6.90	9.33	8.59	8.38	0.84	0.10
2	16.3	16.7	15.6	16.2	0.55	0.03	10.7	11.0	13.0	9.54	14.0	10.8	11.5	1.65	0.14
3	28.4	29.3	27.9	28.5	0.72	0.03	28.1	24.5	25.4	23.7	24.5	25.2	25.2	1.54	0.06
4	39.3	39.9	36.7	38.6	1.70	0.04	35.4	35.8	38.3	36.0	35.0	33.0	35.6	1.73	0.05
5	54.4	53.5	50.6	52.8	1.96	0.04	47.9	47.5	53.2	53.4	47.2	46.4	49.3	3.17	0.06
6	65.6	66.4	62.1	64.7	2.29	0.04	63.4	63.8	65.9	65.4	58.1	62.3	63.2	2.83	0.04
7	97.2	99.4	89.9	95.5	4.96	0.05	90.9	85.6	96.7	92.0	82.5	80.3	88.0	6.25	0.07
8	127	126	123	125	1.93	0.02	118	120	124	118	113	112	117	4.64	0.04

Engine Output-Based Fuel Use Rates (g/bhp-hr)

Throttle Notch Position	Rail Yard Measurements						Over-The-Rail Measurements								
	10/20	10/20	10/20	3 Reps	3 Reps	3 Reps	10/18	10/18	10/19	10/19	10/21	10/21	6 Trains	6 Trains	6 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	3.07	3.06	3.29	3.14	0.13	0.04	3.23	3.54	3.49	3.61	3.25	3.66	3.46	0.18	0.05
High Idle	1.92	1.97	1.92	1.93	0.03	0.02	1.71	1.79	1.71	1.89	1.75	1.87	1.79	0.08	0.04
Dyn Brake	--	--	--	--	--	--	1.40	1.64	1.71	1.88	1.62	1.88	1.69	0.18	0.11
1	14.2	13.6	14.3	14.0	0.39	0.03	19.4	17.7	17.9	22.5	16.7	18.1	18.7	2.06	0.11
2	17.6	17.1	18.3	17.7	0.60	0.03	26.9	26.1	22.0	30.0	20.5	26.4	25.3	3.47	0.14
3	19.4	18.8	19.8	19.4	0.48	0.02	19.6	22.5	21.7	23.2	22.5	21.9	21.9	1.26	0.06
4	20.8	20.5	22.3	21.2	0.95	0.04	23.1	22.8	21.3	22.7	23.4	24.8	23.0	1.12	0.05
5	19.6	19.9	21.0	20.1	0.76	0.04	22.2	22.4	20.0	19.9	22.5	22.9	21.6	1.34	0.06
6	19.9	19.7	21.1	20.2	0.73	0.04	20.6	20.5	19.8	20.0	22.5	21.0	20.8	0.97	0.05
7	20.2	19.7	21.8	20.6	1.10	0.05	24.3	25.8	22.8	24.0	26.8	27.5	25.2	1.79	0.07
8	17.4	17.5	17.9	17.6	0.27	0.02	20.8	20.5	19.7	20.8	21.8	21.9	20.9	0.82	0.04

Table F-7. Estimated NO_x Emission Rates for NC-1859 and B40

Time-Based NO_x Emission Rates (g/s)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	10/20	10/20	10/20	3 Reps	3 Reps	3 Reps	10/18	10/18	10/19	10/19	10/21	10/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	0.23	0.26	0.25	0.25	0.01	0.05	0.20	0.20	0.17	0.17	0.23	0.19	0.19	0.02	0.12
High Idle	0.29	0.30	0.31	0.30	0.01	0.02	0.30	0.29	0.29	0.26	0.32	0.30	0.29	0.02	0.07
Dyn Brake	---	---	---	--	--	--	0.34	0.31	0.29	0.26	0.34	0.30	0.31	0.03	0.10
1	0.72	0.76	0.73	0.74	0.02	0.03	0.57	0.58	0.54	0.43	0.65	0.61	0.56	0.08	0.13
2	1.27	1.33	1.31	1.30	0.03	0.02	0.70	0.80	0.85	0.63	1.02	0.73	0.79	0.14	0.17
3	2.30	2.42	2.44	2.39	0.07	0.03	2.01	1.76	1.72	1.65	1.89	1.78	1.80	0.13	0.07
4	3.02	3.10	3.08	3.07	0.04	0.01	2.51	2.54	2.53	2.32	2.57	2.31	2.46	0.12	0.05
5	3.85	3.90	3.98	3.91	0.07	0.02	3.21	3.17	3.37	3.36	3.51	3.12	3.29	0.15	0.04
6	4.31	4.76	4.88	4.65	0.30	0.06	3.98	4.10	3.97	3.85	3.93	3.99	3.97	0.08	0.02
7	5.78	5.76	6.03	5.86	0.15	0.03	5.02	4.83	5.19	5.40	4.72	4.55	4.95	0.31	0.06
8	6.22	6.48	6.75	6.49	0.26	0.04	5.79	6.00	5.72	5.37	5.70	5.43	5.67	0.23	0.04

Fuel-Based NO_x Emission Rates (g/gal)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	10/20	10/20	10/20	3 Reps	3 Reps	3 Reps	10/18	10/18	10/19	10/19	10/21	10/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	287	314	330	310	22.0	0.07	257	278	234	248	300	282	266	24.5	0.09
High Idle	225	236	233	231	5.59	0.02	204	210	198	196	226	224	210	12.9	0.06
Dyn Brake	---	---	---	--	--	--	192	203	194	196	220	227	206	14.6	0.07
1	214	215	221	216	3.63	0.02	232	215	203	203	226	232	219	13.5	0.06
2	254	260	273	262	9.36	0.04	214	237	213	215	238	220	223	11.5	0.05
3	264	269	285	273	11.2	0.04	233	235	221	227	251	230	233	10.3	0.04
4	250	254	274	259	12.8	0.05	231	231	215	210	239	228	226	11.2	0.05
5	231	237	256	242	13.3	0.06	219	218	206	205	242	219	218	13.3	0.06
6	214	234	256	235	21.1	0.09	204	209	196	192	220	209	205	10.3	0.05
7	194	189	218	200	15.8	0.08	180	184	175	191	186	185	184	5.60	0.03
8	160	168	179	169	9.42	0.06	160	163	150	148	165	158	157	6.86	0.04

Engine Output-Based NO_x Emission Rates (g/bhp-hr)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	10/20	10/20	10/20	3 Reps	3 Reps	3 Reps	10/18	10/18	10/19	10/19	10/21	10/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	84.3	92.6	90.7	89.2	4.36	0.05	71.8	70.8	60.5	62.1	83.5	69.6	69.7	8.24	0.12
High Idle	106	108	110	108	1.94	0.02	108	106	104	93.7	117	108	106	7.44	0.07
Dyn Brake	---	---	---	--	--	--	124	112	103	94.6	123	109	111	11.2	0.10
1	13.6	14.3	13.9	14.0	0.35	0.03	10.8	11.0	10.2	8.13	12.3	11.6	10.7	1.43	0.13
2	13.1	13.7	13.4	13.4	0.32	0.02	7.19	8.21	8.74	6.48	10.5	7.54	8.11	1.40	0.17
3	12.3	12.9	13.0	12.7	0.40	0.03	10.7	9.41	9.19	8.82	10.1	9.48	9.61	0.68	0.07
4	10.9	11.2	11.1	11.0	0.16	0.01	9.03	9.15	9.10	8.35	9.26	8.31	8.87	0.42	0.05
5	10.7	10.8	11.0	10.8	0.19	0.02	8.90	8.78	9.33	9.31	9.72	8.64	9.11	0.41	0.04
6	9.70	10.7	11.0	10.5	0.68	0.06	8.95	9.23	8.92	8.66	8.84	8.98	8.93	0.19	0.02
7	8.67	8.64	9.04	8.78	0.22	0.03	7.88	6.44	6.92	7.20	6.29	6.07	6.80	0.67	0.10
8	8.30	8.64	9.00	8.65	0.35	0.04	6.95	7.20	6.87	6.44	6.84	6.52	6.80	0.28	0.04
Duty Cycle Avg (Raw)	9.2	9.6	9.9	9.6	0.33	0.03	7.0	7.7	7.5	7.1	7.7	7.2	7.4	0.32	0.04
Duty Cycle Avg (Adj)	9.7	10.1	10.4	10.1	0.35	0.03	7.4	8.1	7.9	7.5	8.1	7.6	7.8	0.33	0.04

Exhaust NO_x Concentrations (ppm)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	10/20	10/20	10/20	3 Reps	3 Reps	3 Reps	10/18	10/18	10/19	10/19	10/21	10/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	151	166	163	160	7.94	0.05	138	135	114	119	159	133	133	15.9	0.12
High Idle	134	136	140	137	3.06	0.02	141	140	135	123	152	142	139	9.54	0.07
Dyn Brake	---	---	---	--	--	--	150	145	130	125	152	142	141	10.9	0.08
1	318	336	328	327	9.02	0.03	266	272	251	200	304	286	263	35.8	0.14
2	564	591	589	581	15.0	0.03	325	371	399	294	474	342	368	63.6	0.17
3	780	821	825	809	24.9	0.03	707	623	602	586	655	630	634	43.0	0.07
4	888	908	890	895	11.0	0.01	757	760	754	706	756	688	737	31.4	0.04
5	935	941	958	945	11.9	0.01	800	791	835	842	840	774	814	29.1	0.04
6	883	973	1002	953	62.1	0.07	860	886	843	816	819	840	844	26.3	0.03
7	961	988	1012	987	25.5	0.03	887	873	897	892	836	798	864	39.0	0.05
8	872	924	947	914	38.4	0.04	822	869	811	777	820	780	813	33.6	0.04

Table F-8. Measured CO Emission Rates for NC-1859 and B40

Time-Based CO Emission Rates (g/s)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	10/20	10/20	10/20	3 Reps	3 Reps	3 Reps	10/18	10/18	10/19	10/19	10/21	10/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	0.12	0.08	0.05	0.08	0.03	0.38	0.06	0.07	0.04	0.03	0.06	0.04	0.05	0.01	0.26
High Idle	0.13	0.17	0.16	0.15	0.02	0.14	0.10	0.09	0.04	0.07	0.07	0.06	0.07	0.02	0.29
Dyn Brake	---	---	---	--	--	--	0.12	0.10	0.06	0.07	0.08	0.06	0.08	0.02	0.27
1	0.13	0.12	0.09	0.11	0.02	0.18	0.09	0.10	0.04	0.06	0.10	0.04	0.07	0.03	0.41
2	0.10	0.13	0.05	0.10	0.04	0.42	0.05	0.09	0.02	0.05	0.06	0.05	0.05	0.02	0.38
3	0.10	0.14	0.10	0.11	0.02	0.17	0.05	0.15	0.07	0.07	0.08	0.05	0.08	0.04	0.48
4	0.08	0.20	0.06	0.11	0.07	0.67	0.10	0.10	0.06	0.11	0.10	0.06	0.09	0.02	0.27
5	0.10	0.10	0.07	0.09	0.01	0.15	0.07	0.14	0.07	0.21	0.07	0.09	0.11	0.06	0.51
6	0.34	0.11	0.08	0.18	0.14	0.78	0.19	0.05	0.14	0.11	0.11	0.08	0.11	0.05	0.41
7	0.38	0.51	0.17	0.35	0.17	0.48	0.23	0.19	0.13	0.39	0.23	0.20	0.23	0.08	0.37
8	0.54	0.61	0.21	0.45	0.21	0.48	0.33	0.48	0.29	0.32	0.28	0.24	0.32	0.08	0.26

Fuel-Based CO Emission Rates (g/gal)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	10/20	10/20	10/20	3 Reps	3 Reps	3 Reps	10/18	10/18	10/19	10/19	10/21	10/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	143	98.3	70.3	104	36.5	0.35	75.3	95.1	59.3	48.2	76.4	61.2	69.3	16.5	0.24
High Idle	97.1	130	125	118	17.9	0.15	66.8	60.7	25.4	55.3	51.5	45.6	50.9	14.5	0.28
Dyn Brake	---	---	---	--	--	--	66.5	64.8	43.2	54.5	50.2	46.2	54.3	9.65	0.18
1	38.8	33.3	27.2	33.1	5.82	0.18	35.3	36.5	14.1	29.3	34.4	14.1	27.3	10.5	0.39
2	20.9	25.4	10.7	19.0	7.54	0.40	15.2	25.9	6.17	16.9	14.5	14.9	15.6	6.29	0.40
3	11.7	15.1	12.0	13.0	1.89	0.15	5.71	19.6	8.48	8.96	11.1	6.33	10.0	5.07	0.51
4	6.52	16.1	5.34	9.33	5.93	0.64	8.81	8.80	4.95	10.3	9.16	5.76	7.96	2.11	0.26
5	5.71	5.83	4.64	5.39	0.66	0.12	4.74	9.55	4.28	12.7	5.00	6.54	7.13	3.33	0.47
6	16.8	5.55	4.44	8.94	6.86	0.77	9.62	2.73	6.72	5.43	6.22	4.31	5.84	2.34	0.40
7	12.8	16.6	6.24	11.9	5.24	0.44	8.21	7.31	4.51	13.6	9.02	8.04	8.45	2.98	0.35
8	13.8	15.7	5.45	11.7	5.46	0.47	8.99	13.0	7.48	8.82	8.13	7.04	8.92	2.15	0.24

Engine Output-Based CO Emission Rates (g/bhp-hr)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	10/20	10/20	10/20	3 Reps	3 Reps	3 Reps	10/18	10/18	10/19	10/19	10/21	10/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	42.0	29.0	19.3	30.1	11.36	0.38	21.0	24.2	15.3	12.1	21.3	15.1	18.2	4.67	0.26
High Idle	45.8	59.7	59.0	54.9	7.87	0.14	35.3	30.7	13.4	26.4	26.6	22.1	25.7	7.52	0.29
Dyn Brake	---	---	---	--	--	--	42.9	35.7	22.9	26.3	28.0	22.2	29.7	8.09	0.27
1	2.48	2.22	1.72	2.14	0.38	0.18	1.65	1.87	0.71	1.17	1.87	0.70	1.33	0.54	0.41
2	1.07	1.34	0.53	0.98	0.41	0.42	0.51	0.90	0.25	0.51	0.64	0.51	0.55	0.21	0.38
3	0.55	0.73	0.55	0.61	0.10	0.17	0.26	0.79	0.35	0.35	0.44	0.26	0.41	0.20	0.48
4	0.28	0.71	0.22	0.40	0.27	0.67	0.34	0.35	0.21	0.41	0.35	0.21	0.31	0.08	0.27
5	0.26	0.27	0.20	0.24	0.04	0.15	0.19	0.38	0.19	0.58	0.20	0.26	0.30	0.15	0.51
6	0.76	0.25	0.19	0.40	0.31	0.78	0.42	0.12	0.31	0.25	0.25	0.19	0.25	0.10	0.41
7	0.57	0.76	0.26	0.53	0.25	0.48	0.36	0.26	0.18	0.51	0.30	0.26	0.31	0.12	0.37
8	0.72	0.81	0.27	0.60	0.29	0.48	0.39	0.57	0.34	0.38	0.34	0.29	0.39	0.10	0.26
Duty Cycle Avg (Raw)	1.0	0.9	0.4	0.8	0.30	0.39	0.5	0.7	0.4	0.5	0.5	0.4	0.5	0.11	0.21
Duty Cycle Avg (Adj)	1.0	0.9	0.4	0.8	0.30	0.39	0.5	0.7	0.4	0.5	0.5	0.4	0.5	0.11	0.21

Exhaust CO Concentrations (%)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	10/20	10/20	10/20	3 Reps	3 Reps	3 Reps	10/18	10/18	10/19	10/19	10/21	10/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	0.013	0.009	0.006	0.009	0.00	0.38	0.007	0.008	0.005	0.004	0.007	0.005	0.006	0.00	0.26
High Idle	0.010	0.013	0.013	0.012	0.00	0.14	0.008	0.007	0.003	0.006	0.006	0.005	0.006	0.00	0.30
Dyn Brake	---	---	---	--	--	--	0.009	0.008	0.005	0.006	0.006	0.005	0.007	0.00	0.25
1	0.010	0.009	0.007	0.009	0.00	0.18	0.007	0.008	0.003	0.005	0.008	0.003	0.006	0.00	0.41
2	0.008	0.010	0.004	0.007	0.00	0.42	0.004	0.007	0.002	0.004	0.005	0.004	0.004	0.00	0.38
3	0.006	0.008	0.006	0.007	0.00	0.17	0.003	0.009	0.004	0.004	0.005	0.003	0.005	0.00	0.48
4	0.004	0.010	0.003	0.006	0.00	0.67	0.005	0.005	0.003	0.006	0.005	0.003	0.005	0.00	0.27
5	0.004	0.004	0.003	0.004	0.00	0.16	0.003	0.006	0.003	0.009	0.003	0.004	0.005	0.00	0.52
6	0.012	0.004	0.003	0.006	0.00	0.78	0.007	0.002	0.005	0.004	0.004	0.003	0.004	0.00	0.41
7	0.011	0.015	0.005	0.010	0.01	0.49	0.007	0.006	0.004	0.011	0.007	0.006	0.007	0.00	0.34
8	0.013	0.015	0.005	0.011	0.01	0.48	0.008	0.012	0.007	0.008	0.007	0.006	0.008	0.00	0.26

Table F-9. Measured Hydrocarbon Emission Rates for NC-1859 and B40

Time-Based HC Emission Rates (g/s)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	10/20	10/20	10/20	3 Reps	3 Reps	3 Reps	10/18	10/18	10/19	10/19	10/21	10/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	0.25	0.19	0.26	0.23	0.04	0.18	0.40	0.25	0.13	0.16	0.23	0.18	0.22	0.10	0.43
High Idle	0.33	0.23	0.39	0.31	0.08	0.26	0.61	0.38	0.14	0.29	0.32	0.25	0.33	0.16	0.47
Dyn Brake	---	---	---	--	--	--	0.61	0.41	0.21	0.30	0.34	0.27	0.36	0.14	0.40
1	0.03	0.09	0.08	0.07	0.03	0.48	0.44	0.49	0.17	0.30	0.38	0.15	0.32	0.14	0.43
2	0.06	0.04	0.08	0.06	0.02	0.32	0.38	0.28	0.22	0.33	0.25	0.26	0.29	0.06	0.21
3	0.05	0.05	0.09	0.07	0.02	0.35	0.28	0.59	0.37	0.39	0.28	0.23	0.36	0.13	0.37
4	0.05	0.05	0.08	0.06	0.02	0.33	0.68	0.43	0.25	0.47	0.30	0.39	0.42	0.15	0.36
5	0.00	0.09	0.07	0.06	0.05	0.88	0.39	0.77	0.47	0.78	0.22	0.38	0.50	0.23	0.45
6	1.39	0.30	0.09	0.59	0.70	1.18	0.51	0.72	0.38	0.48	0.40	0.46	0.49	0.12	0.25
7	0.85	0.34	0.24	0.48	0.33	0.70	0.60	0.59	0.28	0.89	0.70	0.94	0.67	0.24	0.36
8	0.29	0.22	0.16	0.22	0.06	0.29	0.84	1.10	0.25	0.61	0.31	0.49	0.60	0.33	0.54

Fuel-Based HC Emission Rates (g/gal)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	10/20	10/20	10/20	3 Reps	3 Reps	3 Reps	10/18	10/18	10/19	10/19	10/21	10/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	312	226	342	293	59.9	0.20	520	347	182	232	293	263	306	119	0.39
High Idle	254	177	296	242	60.4	0.25	417	273	97.5	219	224	189	237	106	0.45
Dyn Brake	---	---	---	--	--	--	341	268	146	223	218	199	232	66.1	0.28
1	8.95	25.6	23.9	19.5	9.15	0.47	178	182	64.8	144	132	57.6	126	54.2	0.43
2	12.0	7.81	16.4	12.1	4.31	0.36	117	82.2	54.5	114	57.8	77.2	83.7	26.7	0.32
3	6.01	5.81	10.7	7.52	2.79	0.37	32.1	78.6	47.2	53.3	37.5	29.2	46.3	18.3	0.39
4	3.75	3.72	6.83	4.77	1.79	0.37	62.2	39.2	21.5	42.2	28.1	38.3	38.6	13.9	0.36
5	0.00	5.60	4.75	3.45	3.02	0.87	26.7	52.5	28.5	47.6	15.4	26.4	32.8	14.2	0.43
6	68.9	14.9	4.54	29.5	34.6	1.17	26.4	36.7	18.6	24.0	22.7	24.3	25.4	6.10	0.24
7	28.6	11.0	8.62	16.1	10.9	0.68	21.6	22.4	9.5	31.4	27.7	38.0	25.1	9.76	0.39
8	7.33	5.64	4.19	5.72	1.57	0.27	23.3	30.0	6.56	16.9	8.92	14.4	16.7	8.83	0.53

Engine Output-Based HC Emission Rates (g/bhp-hr)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	10/20	10/20	10/20	3 Reps	3 Reps	3 Reps	10/18	10/18	10/19	10/19	10/21	10/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	91.7	66.9	93.9	84.2	15.0	0.18	145	88.4	47.1	57.9	81.6	65.1	80.9	35.0	0.43
High Idle	120	81.2	139	113	29.6	0.26	220	138	51.5	105	116	91.5	120	56.8	0.47
Dyn Brake	---	---	---	--	--	--	219	147	77.3	108	122	95.5	128	50.6	0.40
1	0.57	1.70	1.51	1.26	0.61	0.48	8.31	9.33	3.26	5.77	7.17	2.88	6.12	2.65	0.43
2	0.62	0.41	0.81	0.61	0.20	0.32	3.93	2.85	2.24	3.43	2.55	2.64	2.94	0.63	0.21
3	0.28	0.28	0.49	0.35	0.12	0.35	1.48	3.15	1.96	2.07	1.50	1.20	1.90	0.70	0.37
4	0.16	0.16	0.28	0.20	0.07	0.33	2.44	1.55	0.91	1.68	1.09	1.39	1.51	0.54	0.36
5	0.00	0.25	0.20	0.15	0.13	0.88	1.09	2.12	1.29	2.16	0.62	1.04	1.38	0.62	0.45
6	3.12	0.68	0.19	1.33	1.57	1.18	1.16	1.62	0.85	1.08	0.91	1.04	1.11	0.27	0.25
7	1.28	0.50	0.36	0.71	0.50	0.70	0.95	0.79	0.38	1.18	0.94	1.25	0.91	0.31	0.34
8	0.38	0.29	0.21	0.29	0.08	0.29	1.01	1.32	0.30	0.74	0.37	0.59	0.72	0.39	0.54
Duty Cycle Avg (Raw)	0.52	0.33	0.37	0.40	0.10	0.25	0.90	0.90	0.39	0.64	0.53	0.54	0.65	0.21	0.32
Duty Cycle Avg (Adj)	1.29	0.82	0.92	1.01	0.25	0.25	2.25	2.25	0.96	1.60	1.32	1.34	1.62	0.53	0.32

Exhaust HC Concentrations (ppm)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	10/20	10/20	10/20	3 Reps	3 Reps	3 Reps	10/18	10/18	10/19	10/19	10/21	10/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	37	27	38	34	6.08	0.18	63	38	20	25	35	28	35	15.3	0.44
High Idle	34	23	40	32	8.62	0.27	65	41	15	31	34	27	36	16.8	0.47
Dyn Brake	---	---	---	--	--	--	60	43	22	32	34	28	37	13.4	0.37
1	3	9	8	7	3.21	0.48	46	52	18	32	40	16	34	14.8	0.43
2	6	4	8	6	2.00	0.33	40	29	23	35	26	27	30	6.32	0.21
3	4	4	7	5	1.73	0.35	22	47	29	31	22	18	28	10.4	0.37
4	3	3	5	4	1.15	0.31	46	29	17	32	20	26	28	10.3	0.36
5	0	5	4	3	2.65	0.88	22	43	26	44	12	21	28	12.9	0.46
6	64	14	4	27	32.1	1.18	25	35	18	23	19	22	24	6.12	0.26
7	32	13	9	18	12.3	0.68	24	24	11	33	28	37	26	9.02	0.34
8	9	7	5	7	2.00	0.29	27	36	8	20	10	16	20	10.6	0.54

Table F-10. Measured Particulate Matter Emission Rates for NC-1859 and B40

Time-Based PM Emission Rates (g/s)															
Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	10/20	10/20	10/20	3 Reps	3 Reps	3 Reps	10/18	10/18	10/19	10/19	10/21	10/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	0.02	0.01	0.01	0.01	0.00	0.08	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.00	0.06
High Idle	0.01	0.01	0.01	0.01	0.00	0.16	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.10
Dyn Brake	---	---	---	--	--	--	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.08
1	0.02	0.02	0.02	0.02	0.00	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.11
2	0.02	0.02	0.02	0.02	0.00	0.02	0.02	0.02	0.03	0.02	0.03	0.02	0.02	0.00	0.15
3	0.03	0.03	0.03	0.03	0.00	0.00	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.00	0.04
4	0.04	0.04	0.04	0.04	0.00	0.05	0.04	0.04	0.05	0.05	0.04	0.04	0.05	0.00	0.08
5	0.05	0.05	0.05	0.05	0.00	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.06	0.01	0.09
6	0.06	0.06	0.06	0.06	0.00	0.01	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.00	0.06
7	0.11	0.11	0.10	0.11	0.00	0.03	0.12	0.09	0.11	0.10	0.10	0.08	0.10	0.01	0.14
8	0.17	0.15	0.14	0.15	0.01	0.08	0.12	0.13	0.16	0.16	0.14	0.16	0.15	0.02	0.10

Fuel-Based PM Emission Rates (g/gal)															
Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	10/20	10/20	10/20	3 Reps	3 Reps	3 Reps	10/18	10/18	10/19	10/19	10/21	10/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	26.1	23.4	23.8	24.4	1.45	0.06	26.2	26.2	30.9	30.8	27.9	31.3	28.9	2.40	0.08
High Idle	12.4	9.88	9.51	10.6	1.57	0.15	9.69	9.56	10.8	10.7	12.0	12.7	10.9	1.24	0.11
Dyn Brake	---	---	---	--	--	--	9.01	9.88	10.5	11.1	11.7	12.9	10.8	1.36	0.13
1	7.89	7.52	7.44	7.62	0.24	0.03	12.0	8.48	9.52	10.5	8.74	10.3	9.93	1.31	0.13
2	6.20	5.90	6.21	6.10	0.17	0.03	8.61	8.79	9.48	9.33	8.57	8.86	8.94	0.38	0.04
3	4.65	4.50	4.75	4.64	0.13	0.03	5.30	5.69	5.54	6.24	6.18	5.39	5.72	0.40	0.07
4	4.73	4.40	4.54	4.56	0.16	0.04	5.42	5.10	5.55	6.27	5.63	5.68	5.61	0.39	0.07
5	4.22	3.98	4.13	4.11	0.12	0.03	4.77	4.52	4.72	5.23	5.13	5.12	4.92	0.28	0.06
6	3.74	3.79	4.03	3.85	0.16	0.04	4.47	4.36	4.52	4.73	4.52	4.59	4.53	0.12	0.03
7	5.00	4.75	5.07	4.94	0.17	0.03	5.99	4.66	5.23	4.96	5.46	4.58	5.15	0.53	0.10
8	5.78	5.24	5.06	5.36	0.38	0.07	4.63	4.85	5.70	5.89	5.66	6.13	5.48	0.60	0.11

Engine Output-Based PM Emission Rates (g/bhp-hr)															
Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	10/20	10/20	10/20	3 Reps	3 Reps	3 Reps	10/18	10/18	10/19	10/19	10/21	10/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	5.68	5.13	4.84	5.22	0.43	0.08	5.42	4.95	5.93	5.70	5.74	5.72	5.58	0.35	0.06
High Idle	4.32	3.36	3.32	3.67	0.57	0.16	3.79	3.58	4.22	3.78	4.57	4.55	4.08	0.43	0.10
Dyn Brake	---	---	---	--	--	--	4.29	4.03	4.13	3.95	4.81	4.58	4.30	0.34	0.08
1	0.37	0.37	0.35	0.36	0.01	0.04	0.41	0.32	0.35	0.31	0.35	0.38	0.36	0.04	0.11
2	0.24	0.23	0.23	0.23	0.00	0.02	0.21	0.23	0.29	0.21	0.28	0.22	0.24	0.03	0.15
3	0.16	0.16	0.16	0.16	0.00	0.00	0.18	0.17	0.17	0.18	0.18	0.16	0.17	0.01	0.04
4	0.15	0.14	0.14	0.14	0.01	0.05	0.16	0.15	0.17	0.18	0.16	0.15	0.16	0.01	0.08
5	0.14	0.13	0.13	0.14	0.01	0.05	0.14	0.14	0.16	0.18	0.15	0.15	0.15	0.01	0.09
6	0.13	0.13	0.13	0.13	0.00	0.01	0.14	0.14	0.15	0.16	0.13	0.15	0.15	0.01	0.06
7	0.17	0.16	0.16	0.16	0.01	0.03	0.28	0.12	0.15	0.14	0.14	0.11	0.16	0.06	0.39
8	0.22	0.20	0.19	0.20	0.02	0.08	0.15	0.16	0.19	0.19	0.17	0.19	0.18	0.02	0.10
Duty Cycle Avg (Raw)	0.05	0.04	0.04	0.04	0.00	0.07	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.00	0.09
Duty Cycle Avg (Adj)	0.24	0.22	0.21	0.22	0.01	0.07	0.17	0.19	0.22	0.21	0.20	0.21	0.20	0.02	0.09

Exhaust PM Concentrations (mg/m^3)															
Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	10/20	10/20	10/20	3 Reps	3 Reps	3 Reps	10/18	10/18	10/19	10/19	10/21	10/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	4.1	3.7	3.5	3.8	0.31	0.08	4.2	3.8	4.5	4.4	4.4	4.4	4.3	0.26	0.06
High Idle	2.2	1.7	1.7	1.9	0.29	0.15	2.0	1.9	2.2	2.0	2.4	2.4	2.2	0.22	0.10
Dyn Brake	---	---	---	--	--	--	2.1	2.1	2.1	2.1	2.4	2.4	2.2	0.15	0.07
1	3.5	3.5	3.3	3.4	0.12	0.03	4.1	3.2	3.5	3.1	3.5	3.8	3.5	0.37	0.11
2	4.1	4.0	4.0	4.0	0.06	0.01	3.9	4.1	5.3	3.8	5.1	4.1	4.4	0.65	0.15
3	4.1	4.1	4.1	4.1	0.00	0.00	4.8	4.5	4.5	4.8	4.8	4.4	4.6	0.19	0.04
4	5.0	4.7	4.4	4.7	0.30	0.06	5.3	5.0	5.8	6.3	5.3	5.1	5.5	0.49	0.09
5	5.1	4.7	4.6	4.8	0.26	0.06	5.2	4.9	5.7	6.4	5.3	5.4	5.5	0.52	0.09
6	4.6	4.7	4.7	4.7	0.06	0.01	5.6	5.5	5.8	6.0	5.0	5.5	5.6	0.34	0.06
7	7.4	7.4	7.0	7.3	0.23	0.03	8.8	6.6	8.0	6.9	7.3	5.9	7.3	1.03	0.14
8	9.4	8.6	8.0	8.7	0.70	0.08	7.1	7.7	9.2	9.2	8.4	9.0	8.4	0.87	0.10

Table F-11. Measured CO_2 Emission Rates for NC-1859 and B40

Time-Based CO_2 Emission Rates (g/s)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	10/20	10/20	10/20	3 Reps	3 Reps	3 Reps	10/18	10/18	10/19	10/19	10/21	10/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	7.89	8.03	7.44	7.79	0.30	0.04	7.48	6.88	7.10	6.85	7.56	6.74	7.10	0.35	0.05
High Idle	12.8	12.4	12.7	12.6	0.18	0.01	14.2	13.8	14.6	13.1	14.1	13.3	13.9	0.60	0.04
Dyn Brake	---	---	---	--	--	--	17.5	15.0	14.6	13.2	15.3	13.2	14.8	1.59	0.11
1	33.7	35.1	33.4	34.1	0.94	0.03	24.4	26.7	26.6	21.0	28.4	26.4	25.6	2.58	0.10
2	50.2	51.4	48.2	49.9	1.64	0.03	32.6	33.6	40.1	29.2	42.9	33.3	35.3	5.14	0.15
3	87.6	90.3	86.0	88.0	2.20	0.02	86.8	75.1	78.2	73.1	75.4	77.6	77.7	4.81	0.06
4	121	123	113	119	5.17	0.04	109	110	118	111	108	102	110	5.37	0.05
5	168	165	156	163	6.06	0.04	148	146	164	164	146	143	152	9.71	0.06
6	201	205	192	199	6.80	0.03	195	197	203	202	179	192	195	8.7	0.04
7	299	306	278	294	15.0	0.05	280	264	299	283	254	247	271	19.4	0.07
8	391	388	380	386	5.63	0.01	364	369	384	364	348	345	362	14.3	0.04

Fuel-Based CO_2 Emission Rates (g/gal)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	10/20	10/20	10/20	3 Reps	3 Reps	3 Reps	10/18	10/18	10/19	10/19	10/21	10/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	9659	9781	9754	9731	64.3	0.01	9636	9712	9869	9856	9774	9816	9777	89.9	0.01
High Idle	9766	9761	9696	9741	39.3	0.00	9713	9811	9974	9853	9856	9887	9849	86.1	0.01
Dyn Brake	---	---	---	--	--	--	9761	9808	9917	9852	9861	9880	9846	55.0	0.01
1	10008	10006	10017	10010	5.75	0.00	9909	9905	10012	9940	9939	10017	9954	49.4	0.00
2	10034	10029	10047	10037	9.26	0.00	9979	9983	10031	9978	10016	10003	9998	22.2	0.00
3	10052	10047	10049	10049	2.64	0.00	10046	9995	10032	10027	10034	10046	10030	18.7	0.00
4	10062	10047	10062	10057	8.71	0.00	10022	10036	10053	10032	10043	10042	10038	10.5	0.00
5	10065	10062	10064	10064	1.85	0.00	10050	10027	10050	10025	10057	10048	10043	13.4	0.00
6	10005	10056	10064	10042	32.0	0.00	10043	10047	10052	10051	10051	10053	10049	3.68	0.00
7	10037	10041	10059	10046	11.9	0.00	10048	10049	10061	10034	10043	10038	10046	9.70	0.00
8	10048	10046	10063	10052	9.32	0.00	10046	10035	10058	10050	10056	10054	10050	8.47	0.00

Engine Output-Based CO_2 Emission Rates (g/bhp-hr)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	10/20	10/20	10/20	3 Reps	3 Reps	3 Reps	10/18	10/18	10/19	10/19	10/21	10/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	2840	2889	2680	2803	110	0.04	2693	2477	2556	2465	2721	2426	2556	124	0.05
High Idle	4603	4478	4568	4550	64.7	0.01	5130	4961	5267	4703	5090	4783	4989	215	0.04
Dyn Brake	---	---	---	--	--	--	6286	5404	5252	4745	5497	4744	5321	572	0.11
1	638	666	633	645	17.8	0.03	462	507	504	399	539	500	485	48.9	0.10
2	516	529	496	514	16.9	0.03	336	346	412	300	442	342	363	52.8	0.15
3	467	482	459	469	11.7	0.02	463	401	417	390	402	414	414	25.7	0.06
4	437	443	408	429	18.6	0.04	392	397	425	399	388	366	395	19.3	0.05
5	465	458	433	452	16.8	0.04	409	404	454	455	404	396	420	26.9	0.06
6	453	461	431	448	15.3	0.03	440	443	458	454	403	432	438	19.6	0.04
7	449	459	416	442	22.5	0.05	374	352	398	378	339	330	362	25.9	0.07
8	521	517	507	515	7.51	0.01	437	442	461	437	418	414	435	17.1	0.04

Exhaust CO_2 Concentrations (%)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	10/20	10/20	10/20	3 Reps	3 Reps	3 Reps	10/18	10/18	10/19	10/19	10/21	10/21	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	0.56	0.57	0.53	0.55	0.02	0.04	0.57	0.52	0.53	0.52	0.57	0.51	0.54	0.03	0.05
High Idle	0.64	0.62	0.64	0.63	0.01	0.02	0.74	0.72	0.75	0.68	0.73	0.69	0.72	0.03	0.04
Dyn Brake	---	---	---	--	--	--	0.84	0.77	0.73	0.69	0.75	0.68	0.74	0.06	0.08
1	1.64	1.72	1.64	1.67	0.05	0.03	1.25	1.38	1.36	1.08	1.47	1.36	1.32	0.14	0.10
2	2.45	2.51	2.39	2.45	0.06	0.02	1.67	1.72	2.07	1.50	2.20	1.71	1.81	0.27	0.15
3	3.27	3.38	3.20	3.28	0.09	0.03	3.36	2.92	3.01	2.85	2.88	3.03	3.01	0.19	0.06
4	3.93	3.96	3.60	3.83	0.20	0.05	3.62	3.63	3.88	3.72	3.49	3.33	3.61	0.19	0.05
5	4.49	4.39	4.14	4.34	0.18	0.04	4.05	4.01	4.48	4.53	3.84	3.91	4.14	0.30	0.07
6	4.54	4.61	4.33	4.49	0.15	0.03	4.65	4.68	4.76	4.71	4.11	4.45	4.56	0.24	0.05
7	5.48	5.78	5.13	5.46	0.33	0.06	5.45	5.25	5.68	5.15	4.96	4.77	5.21	0.33	0.06
8	6.03	6.09	5.87	6.00	0.11	0.02	5.69	5.88	5.99	5.80	5.51	5.45	5.72	0.21	0.04

F.2 Summary of Results for NC-1859 on B20

RY and OTR measurements were conducted in December 2013 on the prime mover engine of locomotive NC-1859 operating on a 20 percent soy-based biodiesel and 80 percent ULSD blend (B20).

The prime mover engine was an EMD 12-710G3B. The engine was originally manufactured in 1988 and was rebuilt by Amtrak in 2012. The 140-Liter (L) engine has a peak engine output of 3000 horsepower (hp) at an engine speed of 900 revolutions per minute (rpm).

The PEMS utilized for measurements was the Axion system manufactured by Clean Air Technologies International, Inc. (CATI). Prior to each set of measurements, each PEMS was calibrated with a California Bureau of Automotive Repair (BAR) certified calibration gas (BAR-97 Low).

The cycle average emission rates for the rail yard and over-the-rail measurements of the NC-1859 prime mover engine with the Axion are shown in Table F-12. The cycle average emission rates are based on the line-haul duty cycle used by the U.S. Environmental Protection Agency (EPA) for regulatory purposes. Three replicates of each rail yard measurement were conducted. During rail yard measurements, dynamic braking was not observed; thus, the time apportioned for dynamic braking in the line-haul duty cycle (12.5 percent) was combined with the time apportioned for idling in the line-haul duty cycle (38.0 percent). Therefore, idling accounts for 50.5 percent of the duty cycle used to calculate rail yard cycle average emission rates. Over-the-rail measurements were made during six one-way trips between Raleigh and Charlotte, NC. During over-the-rail measurements, dynamic braking was observed.

Table F-12. Cycle Average Emission Rates for the NC-1859 Prime Mover Engine Operated on B20 Biodiesel in the Rail Yard and Over-the-Rail[a,b,c] (Measurements were made from December 5 to 18, 2013)

Measurement	**NO_x (g/bhp-hr)**	**HC (g/bhp-hr)**	**CO (g/bhp-hr)**	**Opacity-based PM (g/bhp-hr)**
Rail Yard	8.5	2.04	0.5	0.13
Over-the-Rail	7.6	1.72	0.4	0.16
EPA Tier 0+	**8.0**	**1.00**	**5.0**	**0.22**
EPA Tier 1+	7.4	0.55	2.2	0.22

[a] The cycle average emission rates are based on the U.S. EPA line-haul duty cycle used for regulatory purposes.

[b] NO_x, HC, and opacity-based PM emission rates from the Axion are adjusted with multipliers of 1.053, 2.5, and 5, respectively, as bias correction.

[c] Dynamic braking not observed during rail yard measurements. Therefore, idling accounts for 50.5 percent of the duty cycle used to calculate rail yard cycle average emission rates.

Rail Yard (RY) Measurements

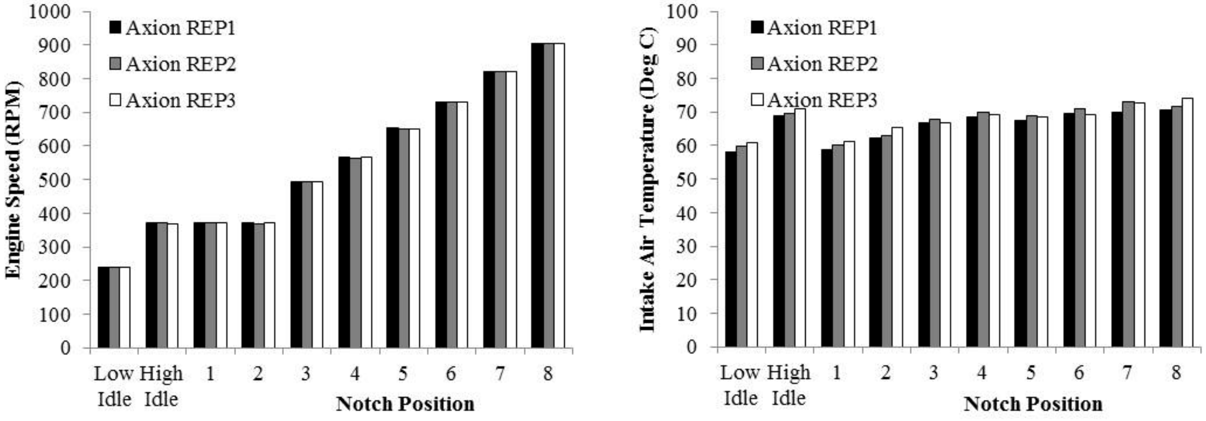
Three RY emissions measurement replicates on the prime mover engine of NC-1859 on B20 biodiesel were conducted on December 15, 2013. The cycle average emission rates for the RY measurements of the NC-1859 prime mover engine are shown in Table F-12. These cycle average emission rates are based on the measured engine activity data (RPM, MAP, and IAT), inferred engine activity data (MAF, AFR, and VE), and measured exhaust concentrations. For the RY measurements of the NC-1859 prime mover engine operated on B20 biodiesel, there was little variability between replicate measured engine activity data, given in Figure F-7. This indicates that the prime mover engine was operating consistently during all three replicate measurements.

For the RY measurements of the NC-1859 prime mover engine operated on B20 biodiesel, an increasing trend in fuel use rates was apparent as notch position increased during the rail yard measurements, as shown in Figure F-8. Higher inter-replicate variability was observed at Notch 8. The NO emission rates estimated with the Axion during the three replicates were consistent, as shown in Figure F-9. The inter-replicate ratios of the standard deviation to the mean (coefficient of variation) for each notch position for the mass per gallon of fuel NO emission rates range from 0.02 to 0.06, which indicates small variability between replicates. There was variability in the estimated HC emission rates between the three replicate measurements, as shown in Figure F-10. Inter-replicate coefficient of variation in the estimated HC emission rates were, on average for each notch position, 41 percent. Differences in measured exhaust HC concentrations were the primary reason for the inter-replicate variability.

Across the three replicates, the coefficient of variation varied from 0.14 to 0.65, depending on the notch position. There was also variability in the estimated CO emission rates between the three replicate measurements, as shown in Figure F-11. Inter-replicate coefficient of variation in the estimated CO emission rates were, on average for each notch position, 47 percent. For CO exhaust concentrations, the coefficient of variation varied from 0.21 to 0.89, depending on the notch position. Therefore, differences in measured exhaust concentrations primarily contributed to the variability in mass emission rates when comparing replicates. However, on an absolute basis, the exhaust CO concentrations were very low. PM emission rates, as shown in Figure F-12, were consistent across the three replicates, with inter-replicate coefficient of variation less than 0.10 for all notch positions except for Notch 8. Both the NO, CO, HC, and PM concentrations measured were of the same magnitude as previous rail yard measurements on NC-1859 prime mover engine operating on ULSD and on B40 biodiesel.

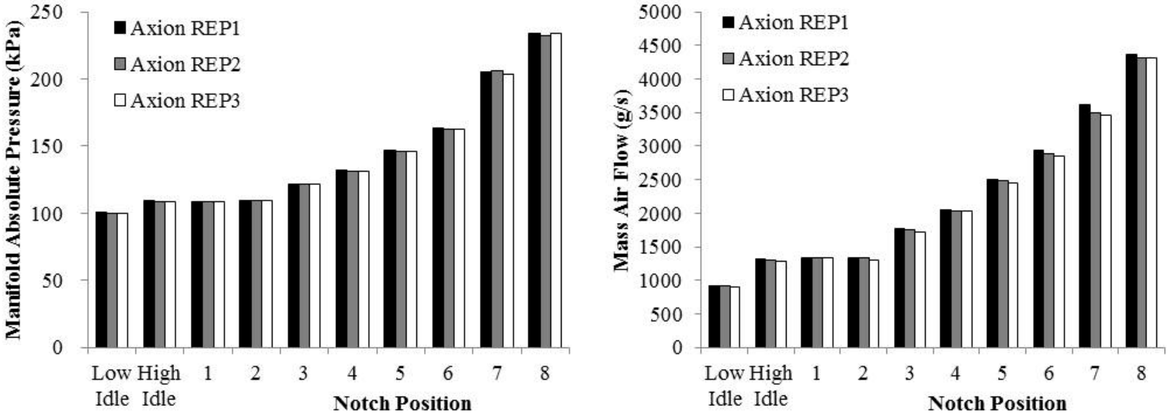
Estimated cycle average emission rates for the three replicate rail yard measurements on the NC-1859 prime mover engine operated on B20 biodiesel are given in Table F-3. For each set of the measurements, there was little variability in the NO_x and PM cycle average emission rates among the replicates. For measurements on B20 biodiesel, amongst the three replicates, the average coefficient of variation for each notch position averages for CO and HC are 16 and 40 percent, respectively. Differences in emission rates are attributable to differences in measured exhaust concentrations. Values for engine activity parameters (RPM, IAT, and MAP) were similar across all measurements, as given in Figure F-2.

Figure F-7. Measured Engine Activity Data during Rail Yard Measurements of the NC-1859 Prime Mover Engine Operated on B20 Biodiesel



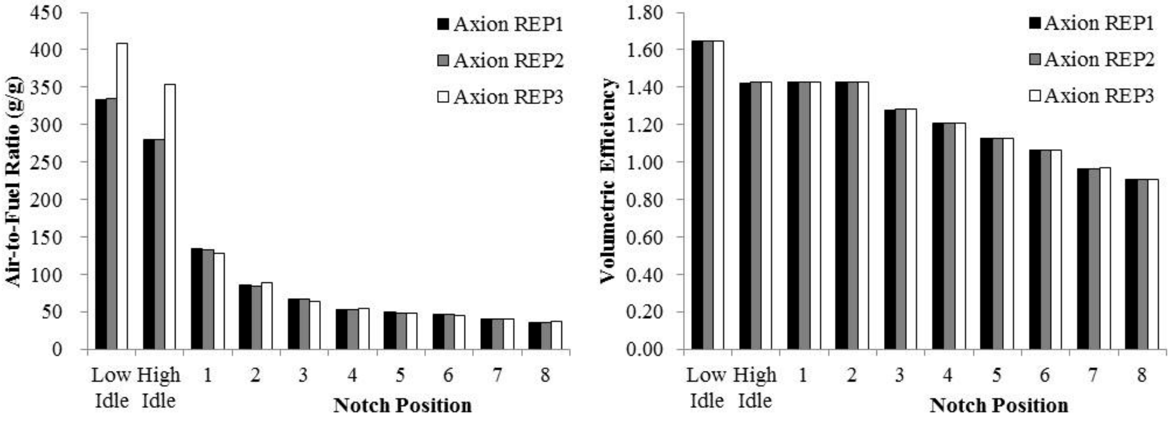
(a) Engine Speed

(b) Intake Air Temperature



(c) Manifold Absolute Pressure

(d) Mass Air Flow



(e) Air-to-Fuel Ratio

(f) Volumetric Efficiency

Figure F-8. Estimated Fuel Use Rates during Rail Yard Measurements of the NC-1859 Prime Mover Engine Operated on B20 Biodiesel

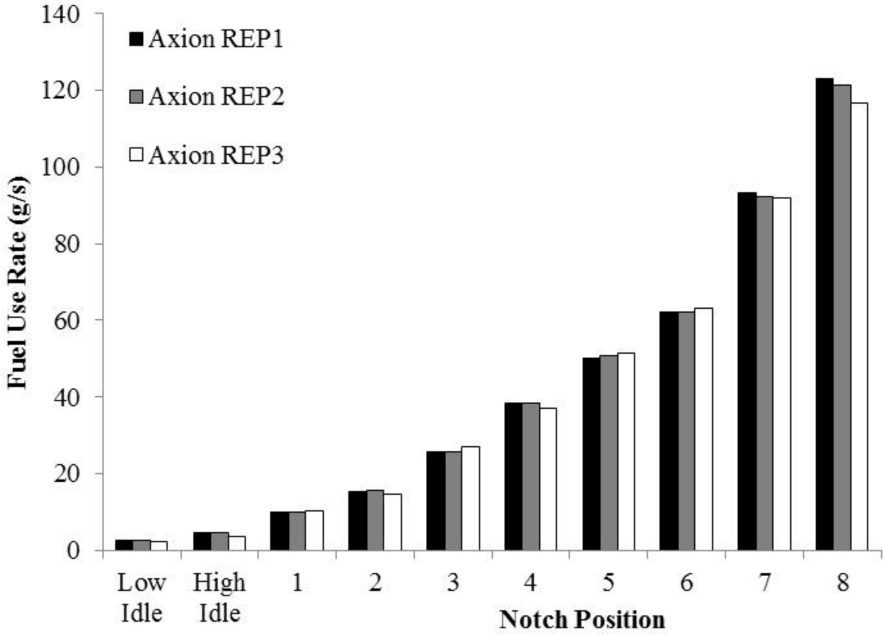


Figure F-9. Estimated NO_x Emission Rates during Rail Yard Measurements of the NC-1859 Prime Mover Engine Operated on B20 Biodiesel

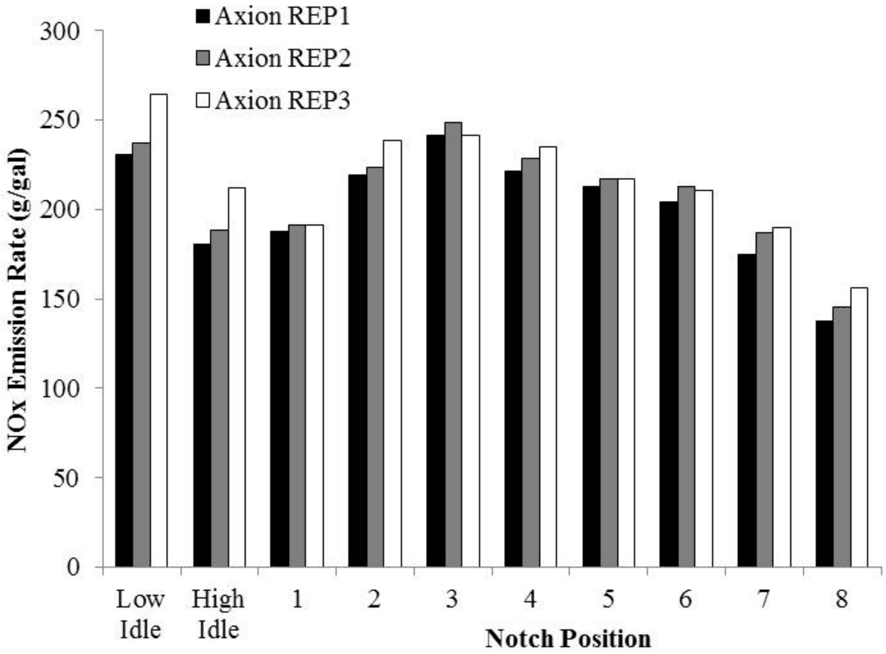


Figure F-10. Estimated HC Emission Rates during Rail Yard Measurements of the NC-1859 Prime Mover Engine Operated on B20 Biodiesel

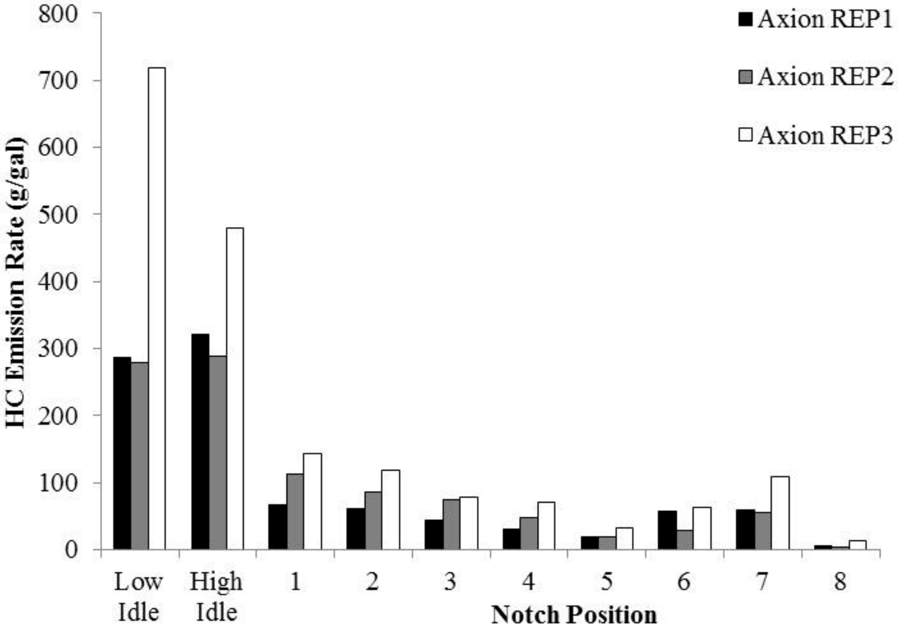


Figure F-11. Estimated CO Emission Rates during Rail Yard Measurements of the NC-1859 Prime Mover Engine Operated on B20 Biodiesel

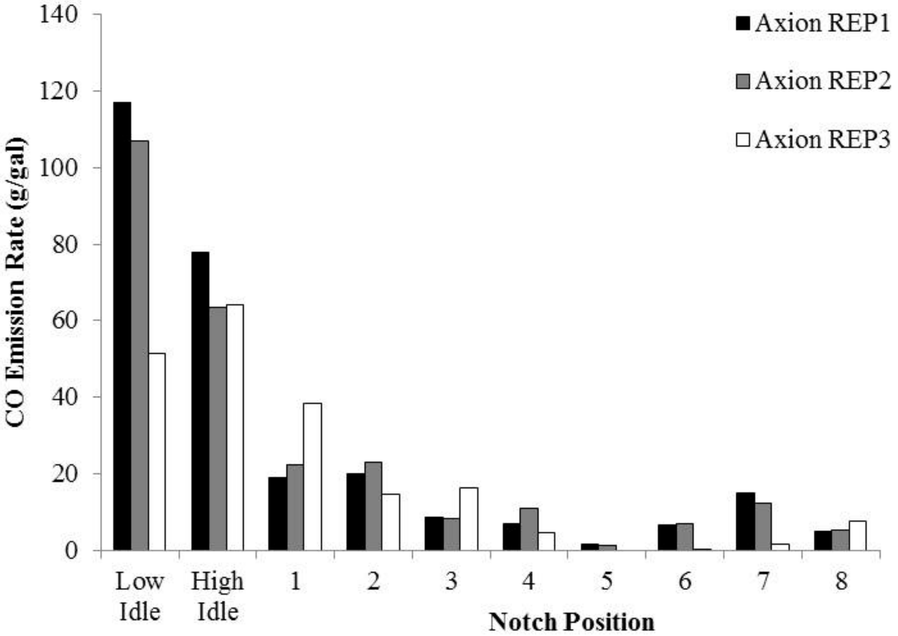


Figure F-12. Measured PM Concentrations during Rail Yard Measurements of the NC-1859 Prime Mover Engine Operated on B20 Biodiesel

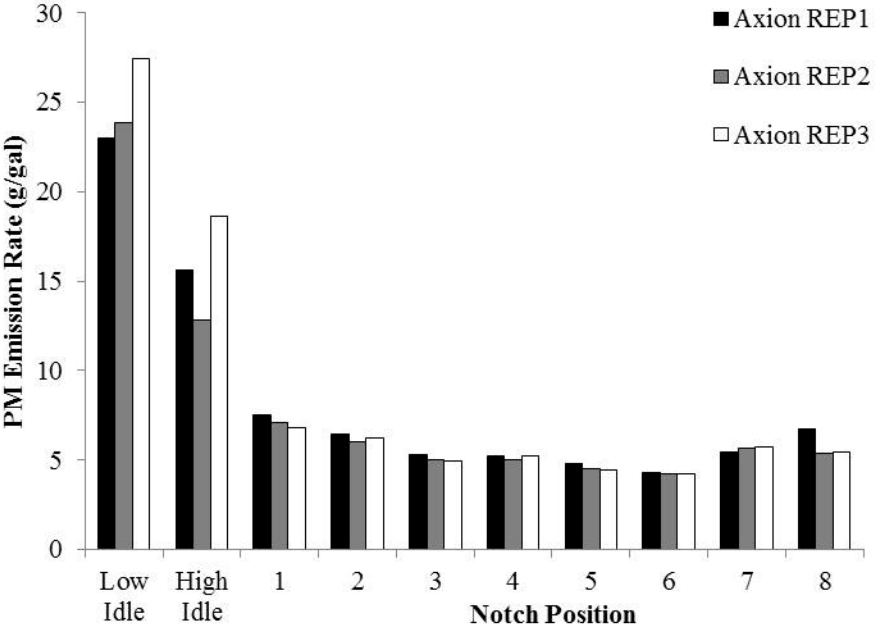


Table F-13. Cycle Average Emission Rates for Rail Yard Replicate Measurements of NC-1859 Prime Mover Engine Operated on B20 Biodiesel

	NO_x **(g/bhp-hr)**	**HC** **(g/bhp-hr)**	**CO** **(g/bhp-hr)**	**Opacity-based PM** **(g/bhp-hr)**
Replicate 1	8.2	1.55	0.6	0.15
Replicate 2	8.5	1.57	0.5	0.13
Replicate 3	8.7	2.99	0.4	0.12
Average of 3 Replicates	**8.5**	**2.04**	**0.5**	**0.13**
Coefficient of Variation	*0.03*	*0.40*	*0.16*	*0.10*

† NO_x, HC, and PM are adjusted with multipliers of 1.05, 2.5, and 5, respectively, as bias correction.

†† Cycle average emission rates are based on EPA Line-Haul driving cycle.

Over-the-Rail (OTR) Measurements

Five days of OTR measurements on the NC-1859 prime mover engine operating on ULSD were conducted on December 12 to 18, 2013. However, there were no PM data measured for three out of these five days. On December 12 and 13, the PM exhaust line was later found to be disconnected to the sampling hose. On December 17, the PM photometer was unable to work due to a loose wire connection to the instrument. At the end of the day, a new PM photometer was replaced to the PEMS, and valid PM data was collected on December 18.

The cycle average emission rates for the over-the-rail measurements of the NC-1859 prime mover engine operating on B20 biodiesel are shown in Table F-14. These cycle average emission rates are based on the measured engine activity data (RPM, MAP, and IAT) and measured exhaust concentrations. For each set of measurements, there was little variability between measured engine activity data during all three days of measurements. This indicates that the prime mover engine was operating consistently during over-the-rail measurements. Measured engine activity data during over-the-rail measurements were similar to the measured engine activity data during rail yard measurements.

Table F-14. Cycle Average Emission Rates for Over-the-Rail Measurements of NC-1859 Prime Mover Engine Operated on B20 Biodiesel

	NO_x (g/bhp-hr)	**HC (g/bhp-hr)**	**CO (g/bhp-hr)**	**Opacity-based PM (g/bhp-hr)**
Dec. 12, 2013 – Train 73	7.7	0.82	0.4	n/a
Dec. 12, 2013 – Train 74	7.8	1.57	0.5	n/a
Dec. 13, 2013 – Train 73	8.0	0.26	0.2	n/a
Dec. 13, 2013 – Train 74	7.3	1.21	0.2	n/a
Dec. 16, 2013 – Train 73	7.4	0.50	0.4	0.12
Dec. 16, 2013 – Train 74	7.4	2.65	0.7	0.12
Dec. 17, 2013 – Train 73	6.8	1.30	0.4	n/a
Dec. 17, 2013 – Train 74	8.0	4.30	1.0	n/a
Dec. 18, 2013 – Train 73	8.1	1.97	0.4	0.19
Dec. 18, 2013 – Train 74	7.4	2.67	0.4	0.21
Average	**7.6**	**1.72**	**0.4**	**0.16**
Coefficient of Variation	*0.05*	*0.71*	*0.54*	*0.29*

† NO_x, HC, and PM are adjusted with multipliers of 1.05, 2.5, and 5, respectively, as bias correction.

†† Cycle average emission rates are based on EPA Line-Haul driving cycle.

For each set of the measurements, there was little variability in the NO_x cycle average emission rates among the trips. There was less than 15 percent coefficient of variation for each notch position amongst the ten one way trips operated on B20 with regard to cycle average NO_x emission rates, except for at high idle. The coefficient of variation in cycle average NO_x emission rates were also typically less than 15 percent. Amongst the ten one-way trips, the average coefficient of variation for each notch position, averaged over all notch positions, for CO and HC are 71 and 54 percent, respectively, for measurements on B40 biodiesel. For PM cycle average emission rates among the trips, the average coefficient of variation for each notch position, averaged over all notch positions, was 26 percent for the available four one-way trips for B20 biodiesel measurements. Differences in emission rates are primarily attributable to differences in measured exhaust concentrations. Differences in PM emission rates are partially attributable to different PM photometers used. Differences in measured exhaust pollutant concentrations were one of the key reasons for the variability.

For the NC-1859 prime mover engine operating on B20 biodiesel, the cycle average OTR emission rates are quantitatively similar to the cycle average RY emission rates. The average cycle averages OTR CO and HC emission rates over ten one-way trips were very close to the cycle average rail yard emission rates, within 9 percent of differences. The average cycle average OTR PM emission rate, on an absolute basis, was very close to the cycle average PM emission rate estimated from rail yard measurements. The cycle average NO_x emission rate for OTR measurements was 1.0 g/bhp-hr, or 13 percent higher, than the cycle average NO_x emission rate for RY measurements.

Differences in cycle average emission rates between RY and OTR measurements can be attributed to various factors. RPM and MAP was essentially the same for rail yard and over-the-rail measurements. IAT differed on an absolute basis by less than 6 percent from run-to-run during over-the-rail measurements. At Notch 8, the engine output during RY measurements was 2700 horsepower, while engine output was 3000 horsepower during OTR measurements. With notch 8 accounting for 16 percent of the EPA line-haul duty cycle used to estimate cycle average emission rates, higher engine output decreases engine output based emission rates and, therefore, cycle average emission rates. Finally, differences in measured exhaust concentrations between rail yard and over-the-rail measurements lead to differences in fuel use and emission rates.

PM emission rates on December 18, 2013 were collected using a replaced PM photometer which was different than the one used on December 16, 2013. Therefore, the differences in PM emission rates between the two days were likely to be attributable to different photometers. The ratio of cycle average PM emission rate on December 16 versus December 18 was 0.58. The ratio of notch-based PM emission rates in bhp-hr on December 16 versus December 18 were 0.38 to 0.75, depending on the notches. However, on an absolute basis, the cycle average PM emission rates were close between the two days.

Throttle notch position data was obtained from the locomotive data activity recorder to measure the duty cycles for the over-the-rail measurements. The measured duty cycles are compared to the EPA line-haul duty cycle in Table F-15. The prime mover engine operated in notch 8 during the over-the-rail tests more than double the percentage of time, on average, the EPA estimates a line-haul locomotive is operating in notch 8. The average percentage of time the prime mover engine operated in idle through notch 7 during the over-the-rail tests was lower than the

Table F-15. Over-the-Rail Duty Cycles during Measurement of NC-1859 Operated on B20 Biodiesel

Notch	Percent Time in Each Notch											
	EPA Line-Haul	Measured Over-the-Rail										
		Average	12/12 T73	12/12 T74	12/13 T73	12/13 T74	12/16 T73	12/16 T74	12/17 T73	12/17 T74	12/18 T73	12/18 T74
Idle	38.0	42.1	28.9	35.2	44.1	46.9	45.7	47.1	42.5	32.6	44.7	53.8
DB	12.5	13.3	12.2	10.0	12.7	14.0	15.4	19.1	12.6	10.0	15.0	11.7
1	6.5	4.2	6.8	11.5	3.1	1.6	1.5	3.0	1.2	10.1	1.6	2.1
2	6.5	5.0	8.5	7.3	2.9	4.2	3.7	3.8	4.5	7.7	4.0	3.7
3	5.2	4.1	6.5	3.9	2.9	5.0	3.6	3.3	2.5	4.0	4.6	4.7
4	4.4	4.3	5.5	6.3	3.7	3.4	6.0	3.2	1.1	6.6	3.5	3.8
5	3.8	2.9	1.5	4.1	4.2	2.2	2.3	4.0	0.9	4.3	3.0	2.7
6	3.9	3.5	1.7	8.4	1.8	1.5	1.7	6.3	0.8	8.7	1.7	2.3
7	3.0	1.0	0.3	1.3	2.4	0.3	0.7	2.4	0.1	1.6	0.2	0.7
8	16.2	32.8	40.4	22.1	35.0	35.0	34.9	27.0	46.5	24.5	36.6	26.3

percentage of time the EPA estimates a line-haul locomotive is operating in those throttle notch settings, with the exception of dynamic braking, where the amount of time spent during the six one-way trips was similar to the percentage of time allocated in the line-haul duty cycle.

Details of results of the field measurements and of the fuel use and emission rates for rail yard and over-the-rail measurements of NC-1859 using B20 biodiesel are given in following supplemental tables.

Table F-16 summarizes the average measured engine speed (RPM), intake air temperature (IAT), manifold absolute pressure (MAP), estimated mass air flow (MAF), and air-to-fuel ratio (AFR) for each throttle notch position and for each replicate of the RY test and for each one-way OTR trip. Engine speed ranges from 237 to 903 RPM in both RY and OTR measurements. For the RY measurements, engine RPM was highly repeatable, with a standard deviation of less than 2 RPM for all notch positions. For the OTR measurements, the RPM was also repeatable, with a standard deviation of 6 RPM or less except for high idle and dynamic breaking. For some one-way trips, the sample sizes in these notches are too small to infer a steady-state engine operating speed. The intake air temperature varies with ambient temperature and was generally in the range of 60 to 78 degrees C during all measurements. MAP was highly repeatable in the RY tests, ranging from 99 to 234 kPa among notch positions with an inter-test standard deviation of less than 2 kPa for each notch position. For OTR measurements, there was slightly more inter-run variability. However, the ratio of the standard deviation to the mean of the run average MAP values for each notch position was typically 0.04 or less.

Estimated MAF was highly repeatable for both RY and OTR measurements, ranging from 870 to 4,500 g/s, with the ratio of the standard deviation to the mean of 0.06 or less for all notches. Estimated AFR was highly repeatable in the RY tests, with standard deviations less than 4 for all notches except for low and high idle. For OTR measurements, there was slightly more inter-run variability. But the ratio of the standard deviation to the mean was typically less than 0.2. Estimated VE was highly repeatable in both the RY and OTR measurements, ranging from 0.9 to 1.7. For all notches, the standard deviation was less than 0.02. Overall, the engine activity during the measurements was consistent from test to test for the three replicates in the rail yard, and from run to run for the six one-way trips observed between Raleigh and Charlotte.

Table F-17 summarizes the estimated fuel use rates inferred from the engine data of Table F-16. For the RY tests, fuel use rates from 2.5 to 120 g/sec depending on notch position, and was highly repeatable, with a coefficient of variation (CV, which was standard deviation divided by the mean) of typically 0.04 or less at high engine load. The CV was slightly higher at low engine load, but the absolute variability in fuel use rates at low load was small. There was more variability in run-to-run estimates of fuel use for the OTR measurements, in part because the amount of time spent in some notch positions was low. The OTR estimated fuel use ranged from 2 to 120 g/sec, depending on notch position. The CV for all notches was less than 0.3.

During RY measurements, the maximum engine output was 2,700 hp, whereas during OTR measurements the maximum engine output was 3,000 hp. Furthermore, as shown later in Table F-22, the average CO_2 concentrations for each notch position are lower for OTR than for RY measurements, which implies a lower fuel-to-air ratio. Because the engine activity and, therefore, engine air flow, are approximately the same for OTR versus RY measurements, the combination of higher engine output and lower fuel-to-air ratio lead to higher values of fuel-specific engine output (FSEO) in bhp-hr per gallon of fuel consumed, as shown in Table F-17. The FSEO was highly repeatable for the OTR measurements of all notches, especially Notch 8, which represents significant portion of the observed duty cycle.

The measured NO exhaust concentration and the estimated NO_x emission rates are shown in Table F-18 for each notch position, each RY test replicate, and each OTR one-way run. The average measured concentrations range among notch positions from approximately 120 to 850 ppm in the RY tests, and 120 to 840 ppm in the OTR measurements. The measurements are highly repeatable for the RY and OTR measurements, with CVs typically less than 0.05 for the former and less than 0.25 for the latter. The estimated mass emission rates range from 0.2 to 5.4 g/sec for the RY measurements and 0.1 to 5.2 g/sec for the OTR measurements. Because the observed concentrations tend to be higher for the OTR versus RY measurements, the mass emission rates also tend to be slightly higher for the OTR versus RY measurements.

On a fuel basis, the average NO_x emission rates range from 140 to 270 g/gallon among notch positions for the RY measurements and 120 to 330 g/gallon for the OTR measurements. For the RY measurements, the fuel-based emission rates are highly repeatable, with CV typically less than 0.08. The OTR measurements have slightly more run-to-run variability but are nonetheless consistent, with CVs less than 0.16. The fuel-based emission rates tend to be lowest at high load.

On an engine output basis, the notch average NO_x emission rates range from 7.0 g/bhp-hr at Notch 8 to 11.5 g/bhp-hr at Notch 1 in the RY measurements, with very high values at idle during which engine output was very low. For the OTR measurements, the notch average emission rates range from 6.6 g/bhp-hr at Notch 8 to 10.7 g/bhp-hr at Notch 1, with much higher values during idle and dynamic braking.

Results are given for exhaust concentrations and emission rates in Tables F-19, F-20, F-21, and F-22 for CO, HC, PM, and CO_2, respectively. The CO exhaust concentrations during OTR measurements tend to be higher than during RY measurements. Thus, the cycle average CO emission rates also tend to be higher for OTR than RY measurements. On average, the HC exhaust concentrations and average emission rates tend to be higher for OTR than RY. However, both the CO and HC emission rates are low on an absolute basis, and some of the measured average concentrations for a given notch position and replicate or run are below the gas analyzer detection limit. For PM, the measured exhaust levels tend to be lower for OTR than RY for a given notch position, and thus the cycle average PM emission rate tends to also be lower. The trends in CO_2 emission rates are similar to those for fuel use on a mass per time and mass per engine output basis. CO_2 emission rates are also shown on a g/gallon basis. Since typically over 99 percent of the carbon in the fuel is emitted as CO_2, the fuel-based CO_2 emission rates are approximately constant.

Differences in emission rates are attributable to differences in measured exhaust concentrations. Values for engine activity parameters (RPM, IAT, MAP) were similar across all rail yard and over-the-rail measurements.

Table F-16. Measured Engine Parameters for NC-1859 and B20

Engine Speed (RPM)

Throttle	Rail Yard Test						Over-The-Rail Test																	
Notch	12/15	12/15	12/15	3 Reps	3 Reps	3 Reps	12/5	12/5	12/6	12/6	12/7	12/12	12/12	12/13	12/13	12/16	12/16	12/17	12/17	12/18	12/18	15 Trains	15 Trains	15 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	239	238	238	238	0.58	0.00	238	238	237	237	238	238	238	238	238	238	237	238	238	238	238	238	0.35	0.00
High Idle	372	371	370	371	1.00	0.00	375	409	380	384	381	411	428	397	380	371	370	371	370	371	371	385	18.3	0.05
Dyn Brake	---	---	---	--	--	--	375	402	379	369	373	403	375	381	372	370	392	391	377	371	359	379	12.5	0.03
1	371	370	370	370	0.58	0.00	375	370	372	370	370	370	371	371	376	372	370	372	370	371	370	371	1.75	0.00
2	371	370	370	370	0.58	0.00	370	370	370	372	369	371	371	371	374	375	371	370	370	372	372	371	1.69	0.00
3	494	492	492	493	1.15	0.00	495	492	491	491	491	494	495	498	490	496	492	493	492	493	491	493	2.32	0.00
4	566	565	565	565	0.58	0.00	562	563	568	563	564	564	565	566	564	565	565	564	565	564	563	564	1.27	0.00
5	653	652	651	652	1.00	0.00	650	651	651	653	652	654	654	653	651	653	651	652	653	653	653	652	1.28	0.00
6	730	729	729	729	0.58	0.00	---	727	729	726	729	728	729	728	729	725	729	729	730	729	730	728	1.39	0.00
7	822	820	820	821	1.15	0.00	---	816	823	820	820	821	819	822	--	820	820	---	821	820	817	820	1.94	0.00
8	905	903	903	904	1.15	0.00	902	902	902	901	903	903	902	903	903	903	902	903	903	903	902	903	0.59	0.00

Intake Air Temeprature (°C)

Throttle	Rail Yard Test						Over-The-Rail Test																	
Notch	12/15	12/15	12/15	3 Reps	3 Reps	3 Reps	12/5	12/5	12/6	12/6	12/7	12/12	12/12	12/13	12/13	12/16	12/16	12/17	12/17	12/18	12/18	15 Trains	15 Trains	15 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	58	60	61	60	1.53	0.03	65	67	69	67	64	62	60	58	63	61	64	63	65	61	65	64	2.91	0.05
High Idle	69	70	71	70	1.00	0.01	71	72	75	72	68	66	66	65	68	65	67	65	70	66	65	68	3.03	0.04
Dyn Brake	---	---	---	--	--	--	70	70	74	71	66	64	65	64	66	64	66	64	70	64	65	67	3.23	0.05
1	59	60	61	60	1.00	0.02	68	71	73	72	66	67	64	65	67	62	67	62	68	66	63	67	3.49	0.05
2	62	63	65	63	1.53	0.02	73	72	73	70	66	67	65	66	68	65	67	65	70	65	64	68	3.10	0.05
3	67	68	67	67	0.58	0.01	68	73	74	70	69	67	63	63	68	64	66	64	69	65	66	67	3.32	0.05
4	69	70	69	69	0.58	0.01	72	73	76	72	68	69	67	65	69	67	69	65	70	65	67	69	3.16	0.05
5	68	69	68	68	0.58	0.01	73	74	76	74	69	65	68	65	68	65	69	66	71	68	68	69	3.43	0.05
6	70	71	69	70	1.00	0.01	---	75	76	73	70	68	70	69	69	67	71	68	73	66	69	70	3.05	0.04
7	70	73	73	72	1.73	0.02	---	78	73	75	74	65	69	67	--	70	73	---	73	66	70	71	3.83	0.05
8	71	72	74	72	1.53	0.02	75	75	77	76	72	70	71	69	72	69	71	69	73	69	70	72	2.73	0.04

Manifold Absolute Pressure (kPa)

Throttle	Rail Yard Test						Over-The-Rail Test																	
Notch	12/15	12/15	12/15	3 Reps	3 Reps	3 Reps	12/5	12/5	12/6	12/6	12/7	12/12	12/12	12/13	12/13	12/16	12/16	12/17	12/17	12/18	12/18	15 Trains	15 Trains	15 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	100	100	100	100	0.00	0.00	99	98	100	99	101	101	101	100	100	100	99	99	98	103	102	100	1.35	0.01
High Idle	109	109	109	109	0.00	0.00	108	113	109	110	111	116	118	114	110	109	107	108	107	112	112	111	3.28	0.03
Dyn Brake	---	---	---	--	--	--	108	110	109	108	110	114	110	111	109	110	110	111	107	112	111	110	1.67	0.02
1	109	109	109	109	0.00	0.00	110	108	109	108	110	111	110	110	110	110	107	109	107	113	112	110	1.66	0.02
2	109	109	109	109	0.00	0.00	109	108	109	108	110	111	110	111	111	110	108	109	108	113	113	110	1.72	0.02
3	122	122	122	122	0.00	0.00	121	121	120	120	124	125	123	125	123	124	119	122	120	126	125	123	2.26	0.02
4	132	132	132	132	0.00	0.00	129	130	131	130	134	136	133	135	133	134	130	132	129	137	135	133	2.59	0.02
5	147	146	146	146	0.58	0.00	147	144	145	145	149	152	149	152	147	149	144	148	143	152	152	148	3.20	0.02
6	163	163	162	163	0.58	0.00	---	161	157	158	163	169	166	166	162	166	160	163	160	169	166	163	3.74	0.02
7	205	206	204	205	1.00	0.00	---	193	183	184	192	196	196	204	--	210	192	---	187	189	191	193	7.82	0.04
8	234	232	234	233	1.15	0.00	226	226	224	223	244	240	240	245	233	240	225	231	229	242	228	233	8.01	0.03

Mass Air Flow (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test																	
Notch	12/15	12/15	12/15	3 Reps	3 Reps	3 Reps	12/5	12/5	12/6	12/6	12/7	12/12	12/12	12/13	12/13	12/16	12/16	12/17	12/17	12/18	12/18	15 Trains	15 Trains	15 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	902	894	892	896	5.62	0.01	874	864	866	867	889	893	900	899	885	892	876	879	867	913	895	884	14.87	0.02
High Idle	1290	1283	1277	1283	6.25	0.00	1283	1407	1288	1318	1337	1467	1537	1415	1326	1302	1276	1293	1262	1327	1331	1345	78.16	0.06
Dyn Brake	---	---	---	--	--	--	1285	1369	1288	1264	1314	1433	1323	1351	1300	1313	1367	1377	1279	1335	1290	1326	45.92	0.03
1	1326	1319	1315	1320	5.30	0.00	1304	1266	1277	1268	1306	1312	1318	1312	1315	1326	1283	1317	1270	1336	1336	1303	24.13	0.02
2	1314	1307	1300	1307	7.10	0.01	1265	1269	1270	1279	1306	1313	1316	1322	1320	1322	1298	1300	1272	1343	1347	1303	26.70	0.02
3	1742	1732	1737	1737	5.09	0.00	1730	1691	1683	1696	1747	1774	1776	1814	1732	1785	1735	1755	1704	1794	1773	1746	40.32	0.02
4	2033	2024	2030	2029	4.36	0.00	1971	1977	1986	1981	2058	2071	2058	2088	2047	2066	2046	2052	1988	2112	2073	2038	45.30	0.02
5	2459	2436	2441	2445	12.10	0.00	2415	2377	2372	2391	2473	2546	2487	2539	2455	2507	2458	2484	2386	2524	2524	2462	61.14	0.02
6	2871	2860	2863	2865	5.80	0.00	---	2791	2744	2772	2871	2963	2916	2917	2860	2922	2885	2885	2806	2984	2920	2874	71.90	0.03
7	3729	3704	3676	3703	26.19	0.01	---	3469	3393	3385	3507	3663	3603	3751	--	3791	3604	---	3444	3540	3518	3556	131.18	0.04
8	4407	4359	4362	4376	26.97	0.01	4233	4241	4171	4174	4530	4501	4485	4573	4372	4511	4386	4383	4304	4540	4324	4382	137.49	0.03

Air to Fuel Ratio (g/g)

Throttle	Rail Yard Test						Over-The-Rail Test																	
Notch	12/15	12/15	12/15	3 Reps	3 Reps	3 Reps	12/5	12/5	12/6	12/6	12/7	12/12	12/12	12/13	12/13	12/16	12/16	12/17	12/17	12/18	12/18	15 Trains	15 Trains	15 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	335	336	410	360	43.0	0.12	294	369	323	374	374	431	476	317	573	355	381	284	316	327	354	370	75.7	0.20
High Idle	280	281	356	306	43.7	0.14	195	142	214	215	235	162	144	204	312	291	399	244	241	246	258	233	66.7	0.29
Dyn Brake	---	---	---	--	--	--	233	224	235	262	285	281	325	303	402	291	253	230	255	252	271	274	45.7	0.17
1	135	133	129	132	3.18	0.02	122	119	139	141	142	137	150	158	197	152	134	122	121	122	131	139	20.2	0.15
2	85.9	84.2	89.7	86.6	2.85	0.03	76.8	81.2	104	114	109	92.4	102	104	134	94.3	98.6	84.3	79.8	88.4	102	97.6	15.0	0.15
3	67.7	67.4	64.5	66.5	1.75	0.03	59.8	57.1	62.5	69.9	73.3	68.2	70.3	75.2	94.7	68.7	64.4	65.2	59.4	63.4	71.3	68.2	9.05	0.13
4	52.8	52.7	54.7	53.4	1.10	0.02	53.8	49.8	51.4	52.9	57.9	58.5	56.4	65.5	70.1	57.5	50.9	56.7	49.8	55.3	58.7	56.4	5.66	0.10
5	49.0	48.1	47.5	48.2	0.76	0.02	46.6	43.9	44.9	45.5	51.6	51.8	49.2	53.8	63.8	51.3	48.4	49.4	43.9	46.4	49.3	49.3	5.03	0.10
6	46.3	45.9	45.4	45.9	0.46	0.01	---	41.1	41.1	43.4	47.2	48.5	47.2	51.7	56.9	48.2	42.9	47.7	41.8	47.2	44.9	46.4	4.4	0.09
7	39.9	40.3	40.0	40.1	0.18	0.00	---	35.5	34.9	35.2	38.7	38.3	39.6	38.7	--	42.4	37.5	---	35.8	42.8	39.2	38.2	2.62	0.07
8	35.8	36.0	37.4	36.4	0.88	0.02	36.4	36.0	34.9	35.1	38.7	40.8	38.5	43.4	42.6	40.7	36.3	40.1	34.9	38.9	37.7	38.3	2.78	0.07

Table F-17. Estimated Fuel Use Rates for NC-1859 and B20

Time-Based Fuel Use Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test																	
Notch	12/15	12/15	12/15	3 Reps	3 Reps	3 Reps	12/5	12/5	12/6	12/6	12/7	12/12	12/12	12/13	12/13	12/16	12/16	12/17	12/17	12/18	12/18	15 Trains	15 Trains	15 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	2.69	2.66	2.18	2.51	0.29	0.12	2.98	2.34	2.68	2.31	2.38	2.07	1.89	2.83	1.54	2.51	2.29	3.10	2.74	2.79	2.53	2.47	0.42	0.17
High Idle	4.61	4.57	3.59	4.25	0.58	0.14	6.60	9.91	6.03	6.13	5.68	9.06	10.7	6.93	4.25	4.47	3.19	5.30	5.23	5.39	5.15	6.27	2.11	0.34
Dyn Brake	--	--	--	--	--	--	5.51	6.11	5.49	4.82	4.62	5.10	4.07	4.46	3.23	4.51	5.37	5.98	5.01	5.29	4.75	4.96	0.74	0.15
1	9.84	9.93	10.2	10.0	0.21	0.02	10.7	10.7	9.21	8.97	9.22	9.60	8.77	8.30	6.68	8.71	9.50	10.8	10.5	10.9	10.2	9.52	1.17	0.12
2	15.3	15.5	14.5	15.1	0.55	0.04	16.5	15.6	12.2	11.2	12.0	14.2	13.0	12.7	9.9	14.0	13.0	15.4	15.9	15.2	13.2	13.6	1.89	0.14
3	25.7	25.7	26.9	26.1	0.70	0.03	29.0	29.6	26.9	24.3	23.8	26.0	25.3	24.1	18.3	26.0	26.5	26.9	28.7	28.3	24.9	25.9	2.79	0.11
4	38.5	38.4	37.1	38.0	0.76	0.02	36.7	39.7	38.6	37.4	35.5	35.4	36.5	31.9	29.2	36.0	39.4	36.2	39.9	38.2	35.3	36.4	2.90	0.08
5	50.2	50.6	51.4	50.7	0.62	0.01	51.8	54.2	52.9	52.5	48.0	49.1	50.6	47.2	38.5	48.9	49.8	50.3	54.4	54.4	51.1	50.2	3.97	0.08
6	62.0	62.3	63.1	62.5	0.54	0.01	---	68.0	66.8	63.8	60.9	61.1	61.8	56.4	50.2	60.6	65.7	60.5	67.1	63.2	65.0	62.2	4.71	0.08
7	93.4	92.0	91.9	92.4	0.80	0.01	--	97.6	97.1	96.2	90.7	95.6	91.0	96.8	--	89.4	93.7	---	96.3	82.7	89.8	93.1	4.47	0.05
8	123	121	117	120	3.32	0.03	116	118	120	119	117	110	117	105	103	111	118	109	123	117	115	114	5.67	0.05

Engine Output-Based Fuel Use Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test																	
Notch	12/15	12/15	12/15	3 Reps	3 Reps	3 Reps	12/5	12/5	12/6	12/6	12/7	12/12	12/12	12/13	12/13	12/16	12/16	12/17	12/17	12/18	12/18	15 Trains	15 Trains	15 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	3.02	3.05	3.73	3.27	0.41	0.12	2.73	3.47	3.03	3.51	3.42	3.92	4.30	2.87	5.26	3.24	3.55	2.62	2.96	2.91	3.21	3.40	0.68	0.20
High Idle	1.76	1.78	2.26	1.94	0.29	0.15	1.23	0.82	1.35	1.33	1.43	0.90	0.76	1.17	1.91	1.82	2.54	1.53	1.55	1.51	1.58	1.43	0.46	0.32
Dyn Brake	--	--	--	--	--	--	1.47	1.33	1.48	1.69	1.76	1.59	1.99	1.82	2.51	1.80	1.51	1.36	1.62	1.54	1.71	1.68	0.29	0.17
1	15.7	15.5	15.1	15.4	0.32	0.02	14.5	14.5	16.8	17.2	16.8	16.1	17.6	18.6	23.1	17.7	16.3	14.3	14.7	14.1	15.2	16.5	2.33	0.14
2	18.6	18.3	19.6	18.8	0.70	0.04	17.3	18.2	23.3	25.3	23.8	20.0	21.9	22.4	28.8	20.3	21.8	18.5	17.8	18.7	21.6	21.3	3.17	0.15
3	21.3	21.3	20.4	21.0	0.55	0.03	18.9	18.5	20.4	22.6	23.0	21.1	21.7	22.7	30.0	21.1	20.7	20.4	19.1	19.4	22.1	21.4	2.76	0.13
4	21.1	21.2	21.9	21.4	0.43	0.02	22.2	20.4	21.0	21.7	22.9	22.9	22.3	25.5	27.8	22.6	20.6	22.5	20.3	21.3	23.0	22.5	1.98	0.09
5	21.0	20.9	20.5	20.8	0.25	0.01	20.4	19.5	20.0	20.1	22.0	21.9	21.3	22.8	28.0	21.6	21.2	21.0	19.4	19.4	20.7	21.3	2.11	0.10
6	21.0	20.9	20.6	20.8	0.18	0.01	---	19.1	19.5	20.4	21.4	21.3	21.0	23.0	25.9	21.4	19.8	21.5	19.4	20.6	20.0	21.0	1.76	0.08
7	20.9	21.2	21.2	21.1	0.18	0.01	---	18.3	18.4	18.6	19.7	20.4	21.4	20.1	--	24.6	23.4	---	22.8	26.5	24.4	21.6	2.75	0.13
8	17.8	18.1	18.8	18.2	0.51	0.03	18.9	18.6	18.3	18.5	18.7	19.9	18.8	20.8	21.4	22.0	20.7	22.3	19.7	20.9	21.2	20.1	1.36	0.07

Table F-18. Measured NO_x Emission Rates for NC-1859 and B20

Time-Based NO_x Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test																	
Notch	12/15	12/15	12/15	3 Reps	3 Reps	3 Reps	12/5	12/5	12/6	12/6	12/7	12/12	12/12	12/13	12/13	12/16	12/16	12/17	12/17	12/18	12/18	15 Trains	15 Trains	15 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	0.19	0.20	0.18	0.19	0.01	0.05	0.20	0.15	0.18	0.15	0.19	0.18	0.15	0.23	0.16	0.21	0.16	0.22	0.19	0.21	0.17	0.18	0.03	0.15
High Idle	0.26	0.27	0.24	0.25	0.02	0.06	0.35	0.52	0.31	0.31	0.36	0.60	0.72	0.52	0.33	0.31	0.30	0.30	0.30	0.33	0.31	0.39	0.13	0.34
Dyn Brake	---	---	---	--	--	--	0.29	0.30	0.28	0.24	0.29	0.32	0.26	0.33	0.25	0.30	0.29	0.33	0.28	0.32	0.28	0.29	0.03	0.09
1	0.57	0.59	0.61	0.59	0.02	0.03	0.53	0.54	0.50	0.48	0.53	0.62	0.56	0.61	0.50	0.57	0.58	0.61	0.61	0.65	0.58	0.56	0.05	0.09
2	1.04	1.07	1.07	1.06	0.02	0.02	0.95	0.89	0.66	0.62	0.70	1.04	0.94	0.98	0.76	1.03	0.80	0.97	1.07	1.01	0.74	0.88	0.15	0.17
3	1.92	1.98	2.01	1.97	0.05	0.02	1.62	1.78	1.57	1.38	1.50	1.89	1.84	1.81	1.48	1.89	1.74	1.75	1.97	1.95	1.57	1.72	0.18	0.11
4	2.63	2.71	2.69	2.68	0.04	0.02	2.08	2.26	2.15	2.08	2.20	2.47	2.62	2.48	2.33	2.61	2.53	2.18	2.66	2.50	2.13	2.35	0.21	0.09
5	3.30	3.39	3.44	3.38	0.07	0.02	2.60	2.82	2.72	2.72	2.86	3.30	3.38	3.47	2.83	3.27	2.94	3.03	3.34	3.50	3.18	3.06	0.30	0.10
6	3.90	4.10	4.11	4.04	0.11	0.03	---	3.38	3.31	3.05	3.48	3.97	4.08	4.15	3.59	4.07	3.89	3.75	4.06	3.90	3.82	3.75	0.34	0.09
7	5.05	5.31	5.39	5.25	0.18	0.03	---	4.14	4.02	4.00	4.62	5.21	5.14	5.55	--	5.37	5.03	---	5.06	4.79	4.96	4.82	0.52	0.11
8	5.23	5.44	5.63	5.43	0.20	0.04	4.37	4.40	4.48	4.40	5.12	5.49	5.73	5.72	5.55	5.65	5.17	5.13	5.54	5.67	5.30	5.18	0.52	0.10

Fuel-Based NO_x Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test																	
Notch	12/15	12/15	12/15	3 Reps	3 Reps	3 Reps	12/5	12/5	12/6	12/6	12/7	12/12	12/12	12/13	12/13	12/16	12/16	12/17	12/17	12/18	12/18	15 Trains	15 Trains	15 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	232	238	265	245	17.7	0.07	220	210	213	209	257	277	265	265	326	271	221	231	226	240	220	243	32.9	0.14
High Idle	181	189	213	194	16.9	0.09	172	171	168	166	204	214	218	241	249	223	307	184	185	196	192	206	38.1	0.19
Dyn Brake	---	---	---	--	--	--	171	159	163	163	204	203	207	237	253	217	172	181	182	193	192	193	27.7	0.14
1	189	191	192	191	1.78	0.01	160	165	177	173	186	210	206	236	242	210	197	184	189	193	184	194	23.7	0.12
2	219	224	239	227	10.3	0.05	187	184	174	177	191	237	236	251	249	237	199	203	217	215	182	209	27.0	0.13
3	241	249	242	244	4.43	0.02	181	195	189	184	204	235	237	242	263	236	213	211	222	224	204	216	23.6	0.11
4	221	229	235	228	6.92	0.03	184	184	180	180	200	226	232	252	258	235	208	195	215	212	196	211	25.7	0.12
5	213	217	217	216	2.11	0.01	163	169	166	168	193	218	216	238	238	217	191	195	199	208	201	199	24.6	0.12
6	204	213	211	209	4.69	0.02	---	161	161	155	185	210	214	238	231	217	192	201	196	200	190	197	25.3	0.13
7	175	187	190	184	7.82	0.04	---	137	134	135	165	177	183	186	--	194	174	---	170	188	179	168	21.4	0.13
8	137	145	156	146	9.38	0.06	122	121	121	120	142	161	159	176	175	165	142	152	145	157	150	147	19.3	0.13

Engine Output-Based NO_x Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test																	
Notch	12/15	12/15	12/15	3 Reps	3 Reps	3 Reps	12/5	12/5	12/6	12/6	12/7	12/12	12/12	12/13	12/13	12/16	12/16	12/17	12/17	12/18	12/18	15 Trains	15 Trains	15 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	69.5	70.4	64.1	68.0	3.39	0.05	72.7	54.7	63.4	53.8	68.0	63.7	55.7	83.6	55.9	75.5	56.2	79.4	68.9	74.5	61.9	65.9	9.71	0.15
High Idle	92.5	95.9	85.0	91.1	5.60	0.06	126	188	113	113	129	216	258	186	118	111	109	108	108	118	110	141	47.5	0.34
Dyn Brake	---	---	---	--	--	--	105	108	99.4	87.2	105	115	93.8	117	91.0	109	103	121	101	114	102	105	9.61	0.09
1	10.9	11.1	11.5	11.2	0.32	0.03	9.97	10.3	9.52	9.08	10.0	11.8	10.6	11.5	9.47	10.7	11.0	11.6	11.6	12.3	11.0	10.7	0.97	0.09
2	10.7	11.0	11.0	10.9	0.21	0.02	9.80	9.15	6.77	6.33	7.24	10.7	9.71	10.1	7.78	10.6	8.25	9.94	11.0	10.4	7.62	9.02	1.55	0.17
3	10.2	10.5	10.7	10.5	0.25	0.02	8.65	9.49	8.38	7.37	8.02	10.1	9.84	9.63	7.90	10.1	9.29	9.36	10.5	10.4	8.37	9.16	0.98	0.11
4	9.46	9.76	9.70	9.64	0.16	0.02	7.48	8.14	7.73	7.48	7.92	8.90	9.43	8.94	8.37	9.41	9.10	7.84	9.56	9.01	7.69	8.47	0.76	0.09
5	9.15	9.39	9.52	9.35	0.19	0.02	7.21	7.82	7.52	7.53	7.91	8.98	9.18	9.43	7.68	9.06	8.14	8.38	9.24	9.69	8.80	8.44	0.80	0.10
6	8.78	9.21	9.24	9.08	0.26	0.03	---	7.61	7.46	6.87	7.84	8.94	9.18	9.33	8.07	9.16	8.75	8.45	9.13	8.77	8.61	8.44	0.76	0.09
7	7.57	7.96	8.09	7.87	0.27	0.03	---	6.77	6.58	6.55	7.57	7.82	7.70	8.32	--	8.19	6.70	---	6.75	6.39	6.61	7.16	0.70	0.10
8	6.97	7.25	7.50	7.24	0.27	0.04	5.83	5.86	5.97	5.87	6.83	7.32	7.64	7.62	7.40	6.78	6.21	6.16	6.65	6.80	6.37	6.62	0.65	0.10
Duty Cycle Avg (Raw)	7.8	8.1	8.2	8.1	0.22	0.03	6.0	6.8	6.1	5.9	6.7	7.3	7.5	7.6	6.9	7.0	7.0	6.5	7.6	7.6	7.0	6.9	0.6	0.09
Duty Cycle Avg (Adj)	8.2	8.5	8.7	8.5	0.23	0.03	6.3	7.1	6.4	6.2	7.0	7.7	7.8	8.0	7.3	7.4	7.4	6.8	8.0	8.1	7.4	7.3	0.6	0.09

Exhaust NO_x Concentrations (ppm)

Throttle	Rail Yard Test						Over-The-Rail Test																	
Notch	12/15	12/15	12/15	3 Reps	3 Reps	3 Reps	12/5	12/5	12/6	12/6	12/7	12/12	12/12	12/13	12/13	12/16	12/16	12/17	12/17	12/18	12/18	15 Trains	15 Trains	15 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	130	133	121	128	6.24	0.05	141	106	123	105	128	120	104	148	106	142	109	153	135	138	117	125	16.9	0.14
High Idle	121	126	112	120	7.09	0.06	167	225	148	145	162	248	283	221	149	143	142	142	145	150	140	174	46.3	0.27
Dyn Brake	---	---	---	--	--	--	138	132	130	117	134	135	119	146	117	139	128	148	134	144	133	133	9.72	0.07
1	262	270	281	271	9.54	0.04	248	262	239	231	245	288	257	278	228	258	277	285	297	299	266	264	23.0	0.09
2	480	499	496	492	10.2	0.02	463	430	318	292	327	480	434	449	344	467	383	460	516	460	341	411	70.1	0.17
3	664	689	702	685	19.3	0.03	583	649	574	500	526	649	632	604	513	645	627	617	714	669	549	603	61.5	0.10
4	788	816	803	802	14.0	0.02	645	703	664	647	653	730	771	721	678	763	778	663	826	733	644	708	57.8	0.08
5	810	846	861	839	26.2	0.03	672	730	709	703	697	793	823	823	684	789	754	757	866	854	783	762	62.5	0.08
6	816	858	863	846	25.8	0.03	---	745	739	680	731	817	849	843	735	840	853	799	892	811	815	796	60.5	0.08
7	813	864	879	852	34.6	0.04	---	744	746	740	787	870	862	914	--	869	881	---	910	826	870	835	64.7	0.08
8	747	790	814	784	33.9	0.04	656	658	673	658	696	754	788	773	751	770	762	735	811	787	770	736	53.4	0.07

Table F-19. Measured CO Emission Rates for NC-1859 and B20

Time-Based CO Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test																	
Notch	12/15	12/15	12/15	3 Reps	3 Reps	3 Reps	12/5	12/5	12/6	12/6	12/7	12/12	12/12	12/13	12/13	12/16	12/16	12/17	12/17	12/18	12/18	15 Trains	15 Trains	15 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	0.09	0.09	0.03	0.07	0.03	0.46	0.05	0.04	0.27	0.20	0.19	0.06	0.05	0.03	0.03	0.06	0.09	0.05	0.12	0.05	0.04	0.09	0.07	0.83
High Idle	0.11	0.09	0.07	0.09	0.02	0.21	0.08	0.28	0.32	0.57	0.16	0.09	0.09	0.04	0.03	0.07	0.10	0.07	0.13	0.06	0.05	0.14	0.14	1.00
Dyn Brake	---	---	---	--	--	--	0.08	0.25	0.34	0.47	0.21	0.08	0.10	0.06	0.05	0.08	0.10	0.08	0.13	0.06	0.05	0.14	0.12	0.87
1	0.06	0.06	0.12	0.08	0.04	0.43	0.12	0.13	0.40	0.27	0.23	0.04	0.09	0.05	0.03	0.08	0.08	0.07	0.12	0.04	0.06	0.12	0.10	0.84
2	0.10	0.11	0.06	0.09	0.03	0.28	0.08	0.11	0.16	0.55	0.15	0.06	0.08	0.03	0.03	0.04	0.08	0.06	0.14	0.04	0.05	0.11	0.13	1.17
3	0.07	0.07	0.13	0.09	0.04	0.43	0.10	0.11	0.45	0.52	0.14	0.06	0.09	0.03	0.02	0.05	0.10	0.08	0.21	0.05	0.07	0.14	0.15	1.07
4	0.08	0.13	0.06	0.09	0.04	0.44	0.07	0.16	0.19	0.34	0.20	0.07	0.10	0.02	0.02	0.08	0.13	0.04	0.19	0.06	0.08	0.12	0.09	0.75
5	0.02	0.02	0.00	0.02	0.01	0.87	0.09	0.24	0.46	0.70	0.12	0.04	0.16	0.02	0.01	0.07	0.18	0.07	0.40	0.09	0.09	0.18	0.19	1.05
6	0.11	0.14	0.00	0.08	0.07	0.88	---	0.36	0.54	0.59	0.15	0.07	0.10	0.04	0.03	0.11	0.13	0.03	0.24	0.06	0.14	0.18	0.19	1.01
7	0.43	0.36	0.04	0.27	0.21	0.77	---	0.35	0.29	0.79	0.51	0.04	0.06	0.02	--	0.11	0.23	---	0.45	0.13	0.13	0.26	0.23	0.89
8	0.20	0.20	0.28	0.23	0.05	0.20	0.53	0.49	0.68	0.97	0.33	0.15	0.25	0.06	0.07	0.17	0.35	0.20	0.47	0.21	0.24	0.35	0.25	0.72

Fuel-Based CO Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test																	
Notch	12/15	12/15	12/15	3 Reps	3 Reps	3 Reps	12/5	12/5	12/6	12/6	12/7	12/12	12/12	12/13	12/13	12/16	12/16	12/17	12/17	12/18	12/18	15 Trains	15 Trains	15 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	113	103	50.7	89.1	33.7	0.38	57.0	54.0	328	273	262	94.7	85.7	29.5	62.1	77.1	129	52.3	145	60.3	54.4	118	94.0	0.80
High Idle	77.6	60.7	66.0	68.1	8.68	0.13	39.3	92.5	173	300	90.8	32.6	28.1	20.9	26.3	54.2	100	45.0	81.2	37.8	31.7	76.9	73.9	0.96
Dyn Brake	---	---	---	--	--	--	46.0	134	202	315	151	49.4	77.7	40.4	49.1	54.2	62.2	42.5	86.2	38.8	33.4	92.1	78.7	0.85
1	20.8	20.5	39.5	26.9	10.9	0.40	37.4	39.2	140	97.8	79.9	15.0	33.2	20.7	14.4	28.3	28.8	22.4	36.8	11.2	20.0	41.7	36.3	0.87
2	21.1	23.3	13.9	19.5	4.92	0.25	16.0	23.3	41.5	159	40.6	14.4	19.0	8.61	8.31	8.80	21.1	12.8	29.2	8.11	12.3	28.2	37.9	1.34
3	8.40	8.36	15.9	10.9	4.35	0.40	11.4	12.6	53.6	70.1	18.8	7.83	12.1	3.70	3.34	6.34	11.8	9.88	23.4	5.79	8.60	17.3	19.1	1.11
4	6.49	11.34	5.08	7.63	3.28	0.43	5.98	12.8	16.3	29.2	18.2	6.19	8.69	1.58	2.05	7.13	10.8	3.40	15.1	5.02	7.03	10.0	7.37	0.74
5	1.52	1.48	0.00	1.00	0.87	0.87	5.66	14.2	28.1	42.9	8.33	2.78	10.2	1.50	1.05	4.77	11.7	4.46	23.9	5.64	5.94	11.4	11.7	1.02
6	5.78	7.17	0.00	4.31	3.80	0.88	---	17.1	26.1	30.2	7.89	3.81	5.23	2.32	1.63	5.98	6.49	1.45	11.4	2.85	6.75	9.23	9.06	0.98
7	14.9	12.5	1.25	9.56	7.30	0.76	---	11.7	9.59	26.6	18.2	1.29	2.20	0.74	--	3.88	7.98	---	15.1	5.25	4.75	8.95	7.83	0.87
8	5.32	5.32	7.76	6.13	1.41	0.23	14.6	13.4	18.4	26.5	9.26	4.46	6.94	1.87	2.08	4.96	9.72	5.98	12.4	5.78	6.74	9.55	6.65	0.70

Engine Output-Based CO Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test																	
Notch	12/15	12/15	12/15	3 Reps	3 Reps	3 Reps	12/5	12/5	12/6	12/6	12/7	12/12	12/12	12/13	12/13	12/16	12/16	12/17	12/17	12/18	12/18	15 Trains	15 Trains	15 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	34.0	30.6	12.3	25.6	11.7	0.46	18.9	14.0	97.9	70.3	69.3	21.8	18.0	9.30	10.6	21.5	32.8	18.0	44.2	18.7	15.3	32.0	26.6	0.83
High Idle	39.8	30.8	26.3	32.3	6.86	0.21	28.8	102	116	204	57.4	32.8	33.3	16.1	12.4	26.9	35.5	26.5	47.2	22.7	18.2	52.0	51.8	1.00
Dyn Brake	---	---	---	--	--	--	28.2	91.0	123	169	77.3	28.0	35.2	20.0	17.7	27.2	37.1	28.2	48.0	22.8	17.7	51.4	44.7	0.87
1	1.20	1.19	2.36	1.58	0.68	0.43	2.33	2.45	7.54	5.13	4.31	0.84	1.71	1.01	0.56	1.44	1.60	1.42	2.26	0.72	1.19	2.30	1.94	0.84
2	1.03	1.15	0.64	0.94	0.27	0.28	0.84	1.16	1.61	5.69	1.54	0.65	0.78	0.35	0.26	0.39	0.87	0.62	1.48	0.39	0.52	1.14	1.33	1.17
3	0.36	0.35	0.71	0.47	0.20	0.43	0.54	0.61	2.38	2.80	0.74	0.34	0.50	0.15	0.10	0.27	0.51	0.44	1.10	0.27	0.35	0.74	0.79	1.07
4	0.28	0.48	0.21	0.32	0.14	0.44	0.24	0.57	0.70	1.21	0.72	0.24	0.35	0.06	0.07	0.29	0.47	0.14	0.67	0.21	0.28	0.41	0.31	0.75
5	0.07	0.06	0.00	0.04	0.04	0.87	0.25	0.66	1.27	1.93	0.34	0.11	0.43	0.06	0.03	0.20	0.50	0.19	1.11	0.26	0.26	0.51	0.53	1.05
6	0.25	0.31	0.00	0.19	0.16	0.88	---	0.81	1.21	1.34	0.33	0.16	0.22	0.09	0.06	0.25	0.30	0.06	0.53	0.13	0.31	0.41	0.42	1.01
7	0.65	0.53	0.05	0.41	0.31	0.77	---	0.58	0.47	1.29	0.83	0.06	0.09	0.03	--	0.16	0.31	---	0.60	0.18	0.18	0.40	0.38	0.95
8	0.27	0.27	0.37	0.30	0.06	0.20	0.70	0.65	0.91	1.30	0.45	0.20	0.33	0.08	0.09	0.20	0.42	0.24	0.57	0.25	0.29	0.45	0.33	0.75
Duty Cycle Avg (Raw)	0.56	0.55	0.41	0.51	0.08	0.16	0.69	0.92	1.78	2.14	1.01	0.36	0.49	0.18	0.17	0.36	0.66	0.36	0.97	0.37	0.40	0.72	0.57	0.79
Duty Cycle Avg (Adj)	0.56	0.55	0.41	0.51	0.08	0.16	0.69	0.92	1.78	2.14	1.01	0.36	0.49	0.18	0.17	0.36	0.66	0.36	0.97	0.37	0.40	0.72	0.57	0.79

Exhaust CO Concentrations (%)

Throttle	Rail Yard Test						Over-The-Rail Test																	
Notch	12/15	12/15	12/15	3 Reps	3 Reps	3 Reps	12/5	12/5	12/6	12/6	12/7	12/12	12/12	12/13	12/13	12/16	12/16	12/17	12/17	12/18	12/18	15 Trains	15 Trains	15 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	0.011	0.010	0.004	0.008	0.00	0.45	0.006	0.005	0.033	0.024	0.023	0.007	0.006	0.003	0.004	0.007	0.011	0.006	0.015	0.006	0.005	0.011	0.01	0.84
High Idle	0.009	0.007	0.006	0.007	0.00	0.21	0.007	0.021	0.026	0.045	0.012	0.007	0.006	0.003	0.003	0.006	0.008	0.006	0.011	0.005	0.004	0.011	0.01	1.01
Dyn Brake	---	---	---	--	--	--	0.006	0.019	0.028	0.039	0.017	0.006	0.008	0.004	0.004	0.006	0.008	0.006	0.011	0.005	0.004	0.011	0.01	0.90
1	0.005	0.005	0.010	0.007	0.00	0.43	0.010	0.011	0.033	0.023	0.018	0.004	0.007	0.004	0.002	0.006	0.007	0.006	0.010	0.003	0.005	0.010	0.01	0.85
2	0.008	0.009	0.005	0.007	0.00	0.28	0.007	0.009	0.013	0.045	0.012	0.005	0.006	0.003	0.002	0.003	0.007	0.005	0.012	0.003	0.004	0.009	0.01	1.17
3	0.004	0.004	0.008	0.005	0.00	0.43	0.006	0.007	0.028	0.033	0.008	0.004	0.006	0.002	0.001	0.003	0.006	0.005	0.013	0.003	0.004	0.009	0.01	1.09
4	0.004	0.007	0.003	0.005	0.00	0.45	0.004	0.008	0.010	0.018	0.010	0.003	0.005	0.001	0.001	0.004	0.007	0.002	0.010	0.003	0.004	0.006	0.00	0.77
5	0.001	0.001	0.000	0.001	0.00	0.87	0.004	0.011	0.021	0.031	0.005	0.002	0.007	0.001	0.001	0.003	0.008	0.003	0.018	0.004	0.004	0.008	0.01	1.07
6	0.004	0.005	0.000	0.003	0.00	0.88	---	0.014	0.021	0.023	0.005	0.003	0.004	0.001	0.001	0.004	0.005	0.001	0.009	0.002	0.005	0.007	0.01	1.03
7	0.012	0.010	0.001	0.008	0.01	0.76	---	0.011	0.009	0.025	0.015	0.001	0.002	0.001	--	0.003	0.007	---	0.014	0.004	0.004	0.008	0.01	0.92
8	0.005	0.005	0.007	0.006	0.00	0.20	0.014	0.013	0.018	0.025	0.008	0.004	0.006	0.001	0.002	0.004	0.009	0.005	0.012	0.005	0.006	0.009	0.01	0.75

Table F-20. Measured Hydrocarbon Emission Rates for NC-1859 and B20

Time-Based HC Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test																	
Notch	12/15	12/15	12/15	3 Reps	3 Reps	3 Reps	12/5	12/5	12/6	12/6	12/7	12/12	12/12	12/13	12/13	12/16	12/16	12/17	12/17	12/18	12/18	15 Trains	15 Trains	15 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	0.24	0.23	0.48	0.32	0.14	0.46	0.10	1.57	1.13	1.14	0.60	0.21	0.28	0.03	0.19	0.11	0.36	0.21	0.58	0.27	0.31	0.47	0.45	0.96
High Idle	0.45	0.40	0.53	0.46	0.07	0.14	0.26	1.09	1.19	1.15	0.68	0.16	0.36	0.05	0.21	0.11	0.47	0.29	0.82	0.40	0.46	0.51	0.38	0.75
Dyn Brake	---	---	---	--	--	--	0.35	1.07	1.19	1.27	0.82	0.18	0.39	0.10	0.27	0.14	0.56	0.30	0.84	0.34	0.42	0.55	0.39	0.71
1	0.20	0.35	0.45	0.33	0.12	0.37	0.31	0.92	0.97	1.08	0.80	0.08	0.29	0.10	0.22	0.15	0.32	0.15	0.63	0.85	0.34	0.48	0.35	0.74
2	0.29	0.41	0.54	0.41	0.12	0.30	0.21	0.77	0.82	1.65	0.85	0.13	0.29	0.04	0.19	0.09	0.45	0.19	0.72	0.31	0.48	0.48	0.43	0.89
3	0.35	0.59	0.65	0.53	0.16	0.30	0.13	0.84	1.32	1.22	0.78	0.16	0.49	0.07	0.24	0.08	0.60	0.39	0.83	0.27	0.69	0.54	0.40	0.74
4	0.36	0.56	0.82	0.58	0.23	0.40	0.42	1.41	3.51	1.21	0.83	0.18	0.38	0.07	0.25	0.09	0.78	0.50	1.11	0.47	0.57	0.79	0.86	1.09
5	0.27	0.28	0.53	0.36	0.15	0.40	0.05	1.68	1.71	1.25	1.24	0.09	0.56	0.02	0.29	0.15	0.88	0.28	1.57	1.38	0.63	0.79	0.64	0.81
6	1.08	0.55	1.25	0.96	0.36	0.38	---	1.37	1.49	2.73	1.19	0.20	0.38	0.19	0.48	0.15	0.99	0.65	1.61	0.77	0.83	0.93	0.71	0.77
7	1.71	1.55	3.10	2.12	0.85	0.40	---	0.96	0.54	1.08	2.39	0.08	0.38	0.04	--	0.33	1.19	---	1.70	0.85	1.19	0.89	0.69	0.77
8	0.19	0.15	0.46	0.27	0.17	0.63	0.48	1.16	2.73	2.32	1.10	0.17	0.31	0.03	0.38	0.10	0.96	0.43	1.70	0.45	1.31	0.91	0.82	0.90

Fuel-Based HC Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test																	
Notch	12/15	12/15	12/15	3 Reps	3 Reps	3 Reps	12/5	12/5	12/6	12/6	12/7	12/12	12/12	12/13	12/13	12/16	12/16	12/17	12/17	12/18	12/18	15 Trains	15 Trains	15 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	285	278	720	427	253	0.59	113	2166	1365	1588	814	322	488	38.8	406	144	512	221	683	316	401	639	610	0.95
High Idle	318	286	481	362	105	0.29	127	356	638	607	385	58.7	110	21.7	161	83.2	480	178	510	238	292	283	203	0.72
Dyn Brake	---	---	---	--	--	--	207	565	700	852	574	114	312	74.3	271	97.0	340	163	542	209	289	354	238	0.67
1	67.1	113	142	108	38.0	0.35	93.2	278	341	388	280	26.2	106	37.6	106	54.3	111	45.8	195	252	107	161	118	0.73
2	60.8	85.6	120	88.7	29.6	0.33	41.3	160	217	475	230	29.9	71.5	9.17	62.4	20.3	111	39.2	146	66.4	118	120	120	1.00
3	43.5	73.8	77.9	65.1	18.8	0.29	14.6	92.2	158	163	106	19.9	63.3	8.84	42.1	9.73	73.7	47.0	93.9	31.1	89.2	67.6	50.0	0.74
4	29.9	47.3	71.4	49.5	20.9	0.42	37.4	115	294	105	75.2	16.6	34.1	7.09	27.3	8.21	64.0	44.4	90.3	39.8	52.7	67.4	71.0	1.05
5	17.5	18.2	33.5	23.1	9.03	0.39	3.23	101	105	77.2	84.0	6.24	35.9	1.53	24.7	9.76	57.4	18.3	93.7	82.3	39.9	49.3	38.3	0.78
6	56.6	28.6	64.0	49.7	18.7	0.38	---	65.3	72.2	138	63.2	10.4	20.0	11.1	30.7	8.04	48.8	34.6	77.9	39.4	41.5	47.2	35.0	0.74
7	59.3	54.7	109	74.4	30.3	0.41	---	31.9	18.2	36.5	85.4	2.60	13.6	1.29	--	11.9	41.2	---	57.3	33.3	42.9	31.3	24.2	0.77
8	4.90	4.08	12.8	7.25	4.80	0.66	13.5	31.9	73.9	63.2	30.5	4.90	8.60	1.00	12.0	2.85	26.5	12.9	44.5	12.4	37.1	25.1	22.1	0.88

Engine Output-Based HC Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test																	
Notch	12/15	12/15	12/15	3 Reps	3 Reps	3 Reps	12/5	12/5	12/6	12/6	12/7	12/12	12/12	12/13	12/13	12/16	12/16	12/17	12/17	12/18	12/18	15 Trains	15 Trains	15 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	85.4	82.3	174	114	52.1	0.46	37.3	564	407	409	215	74.2	102	12.2	69.7	40.1	130	76.0	208	98.2	113	170	163	0.96
High Idle	163	145	192	167	23.6	0.14	93.1	392	428	413	243	59.1	131	16.7	76.4	41.4	170	105	297	143	167	185	138	0.75
Dyn Brake	---	---	---	--	--	--	127	384	427	456	294	64.8	141	36.8	97.3	48.7	203	108	302	123	152	198	140	0.71
1	3.86	6.58	8.53	6.32	2.35	0.37	5.81	17.4	18.4	20.4	15.1	1.47	5.43	1.83	4.16	2.77	6.15	2.90	12.0	16.1	6.40	9.08	6.71	0.74
2	2.96	4.22	5.51	4.23	1.28	0.30	2.16	7.92	8.44	17.0	8.72	1.35	2.94	0.37	1.95	0.90	4.59	1.92	7.38	3.20	4.96	4.92	4.38	0.89
3	1.85	3.12	3.45	2.81	0.85	0.30	0.70	4.49	7.02	6.53	4.16	0.85	2.63	0.35	1.27	0.42	3.22	2.09	4.44	1.45	3.65	2.88	2.15	0.74
4	1.28	2.02	2.95	2.08	0.84	0.40	1.52	5.06	12.6	4.35	2.97	0.65	1.38	0.25	0.88	0.33	2.80	1.78	4.01	1.69	2.07	2.83	3.08	1.09
5	0.75	0.79	1.47	1.00	0.41	0.40	0.14	4.67	4.74	3.47	3.45	0.26	1.52	0.06	0.80	0.41	2.44	0.79	4.36	3.83	1.75	2.18	1.76	0.81
6	2.44	1.24	2.80	2.16	0.82	0.38	---	3.08	3.35	6.14	2.67	0.44	0.86	0.43	1.07	0.34	2.23	1.45	3.63	1.73	1.87	2.09	1.60	0.77
7	2.56	2.33	4.65	3.18	1.28	0.40	---	1.57	0.89	1.77	3.92	0.11	0.57	0.06	--	0.50	1.59	---	2.27	1.13	1.58	1.33	1.07	0.80
8	0.25	0.20	0.61	0.36	0.22	0.63	0.64	1.55	3.64	3.09	1.47	0.22	0.41	0.04	0.51	0.12	1.16	0.52	2.04	0.54	1.58	1.17	1.08	0.92
Duty Cycle Avg (Raw)	0.62	0.63	1.19	0.81	0.33	0.40	0.44	2.51	2.91	2.77	1.54	0.33	0.63	0.11	0.48	0.20	1.06	0.52	1.72	0.79	1.07	1.14	0.94	0.83
Duty Cycle Avg (Adj)	1.55	1.57	2.99	2.04	0.82	0.40	1.09	6.26	7.27	6.93	3.85	0.82	1.57	0.26	1.21	0.50	2.65	1.30	4.30	1.97	2.67	2.84	2.36	0.83

Exhaust HC Concentrations (ppm)

Throttle	Rail Yard Test						Over-The-Rail Test																	
Notch	12/15	12/15	12/15	3 Reps	3 Reps	3 Reps	12/5	12/5	12/6	12/6	12/7	12/12	12/12	12/13	12/13	12/16	12/16	12/17	12/17	12/18	12/18	15 Trains	15 Trains	15 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	36	35	74	48	22.2	0.46	16	246	178	179	92	32	43	5	30	17	57	33	92	41	48	74	71.7	0.97
High Idle	48	43	57	49	7.09	0.14	28	106	126	119	69	15	32	4	22	12	50	31	90	41	48	53	40.0	0.75
Dyn Brake	---	---	---	--	--	--	38	106	126	137	85	17	40	10	28	14	57	30	90	35	45	57	41.4	0.72
1	21	36	47	35	13.1	0.38	33	100	104	117	83	8	30	10	23	15	35	16	69	88	35	51	38.1	0.75
2	30	43	56	43	13.0	0.30	23	84	89	176	89	14	30	4	19	9	48	20	78	32	50	51	45.7	0.90
3	27	46	51	41	12.7	0.31	11	69	108	100	61	12	38	5	19	6	49	31	68	21	54	43	33.1	0.76
4	24	38	55	39	15.5	0.40	30	99	244	85	55	12	25	5	16	6	54	34	78	31	39	54	59.9	1.11
5	15	16	30	20	8.39	0.41	3	98	101	73	68	5	31	1	16	8	51	16	92	76	35	45	36.9	0.82
6	51	26	59	45	17.2	0.38	---	68	75	137	56	9	18	9	22	7	49	31	80	36	40	45	35.9	0.79
7	62	57	114	78	31.6	0.41	---	39	23	45	92	3	14	1	--	12	47	---	69	33	47	35	27.0	0.76
8	6	5	15	9	5.51	0.64	16	39	92	78	34	5	10	1	12	3	32	14	56	14	43	30	27.8	0.93

Table F-21. Measured Particulate Matter Emission Rates for NC-1859 and B20

Time-Based PM Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test																	
Notch	12/15	12/15	12/15	3 Reps	3 Reps	3 Reps	12/5	12/5	12/6	12/6	12/7	12/12	12/12	12/13	12/13	12/16	12/16	12/17	12/17	12/18	12/18	15 Trains	15 Trains	15 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	0.01	0.01	0.01	0.01	0.00	0.04	0.01	0.01	0.02	0.02	0.02	--	--	--	--	0.01	0.00	---	---	0.01	0.01	0.01	0.00	0.34
High Idle	0.01	0.01	0.01	0.01	0.00	0.09	0.01	0.01	0.01	0.01	0.01	--	--	--	--	0.01	0.00	---	---	0.02	0.01	0.01	0.00	0.32
Dyn Brake	---	---	---	--	--	--	0.01	0.01	0.01	0.01	0.02	--	--	--	--	0.01	0.00	---	---	0.01	0.01	0.01	0.00	0.37
1	0.01	0.01	0.01	0.01	0.00	0.03	0.01	0.01	0.02	0.01	0.02	--	--	--	--	0.01	0.01	---	---	0.02	0.02	0.01	0.00	0.32
2	0.01	0.01	0.01	0.01	0.00	0.04	0.02	0.02	0.02	0.02	0.02	--	--	--	--	0.01	0.01	---	---	0.02	0.02	0.02	0.01	0.30
3	0.01	0.01	0.01	0.01	0.00	0.03	0.03	0.02	0.03	0.02	0.03	--	--	--	--	0.01	0.01	---	---	0.03	0.03	0.02	0.01	0.28
4	0.02	0.02	0.02	0.02	0.00	0.02	0.04	0.03	0.04	0.03	0.04	--	--	--	--	0.02	0.02	---	---	0.04	0.04	0.03	0.01	0.24
5	0.03	0.03	0.03	0.03	0.00	0.03	0.06	0.04	0.06	0.04	0.05	--	--	--	--	0.02	0.02	---	---	0.05	0.04	0.04	0.01	0.34
6	0.03	0.03	0.03	0.03	0.00	0.01	---	0.07	0.08	0.05	0.05	--	--	--	--	0.02	0.03	---	---	0.04	0.05	0.05	0.02	0.39
7	0.06	0.06	0.06	0.06	0.00	0.02	---	0.12	0.27	0.10	0.13	--	--	--	--	0.08	0.06	---	---	0.07	0.12	0.12	0.07	0.57
8	0.13	0.10	0.10	0.11	0.02	0.15	0.20	0.17	0.21	0.17	0.19	--	--	--	--	0.12	0.11	---	---	0.14	0.16	0.16	0.04	0.22

Fuel-Based PM Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test																	
Notch	12/15	12/15	12/15	3 Reps	3 Reps	3 Reps	12/5	12/5	12/6	12/6	12/7	12/12	12/12	12/13	12/13	12/16	12/16	12/17	12/17	12/18	12/18	15 Trains	15 Trains	15 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	9.97	10.5	11.9	10.8	1.00	0.09	22.2	22.2	27.8	28.8	32.5	--	--	--	--	11.8	9.48	---	---	22.6	22.2	22.2	7.51	0.34
High Idle	6.24	5.23	7.43	6.30	1.10	0.17	8.40	5.71	10.8	8.83	11.2	--	--	--	--	6.10	6.93	---	---	13.0	12.2	9.24	2.68	0.29
Dyn Brake	---	---	---	--	--	--	8.63	6.68	11.3	10.3	16.0	--	--	--	--	5.42	3.63	---	---	11.4	12.1	9.49	3.82	0.40
1	2.77	2.64	2.54	2.65	0.12	0.04	6.15	5.20	8.77	6.58	7.67	--	--	--	--	3.72	2.97	---	---	7.71	7.24	6.22	1.93	0.31
2	2.52	2.35	2.46	2.44	0.08	0.03	5.80	4.98	8.45	6.89	7.59	--	--	--	--	3.49	2.59	---	---	6.98	6.95	5.97	1.94	0.33
3	2.23	2.12	2.06	2.14	0.09	0.04	3.86	3.52	5.16	4.34	5.03	--	--	--	--	2.47	1.81	---	---	4.46	4.91	3.95	1.17	0.30
4	2.38	2.29	2.39	2.35	0.06	0.02	4.29	3.83	4.61	3.34	4.49	--	--	--	--	2.62	2.31	---	---	4.76	5.17	3.94	0.99	0.25
5	2.47	2.31	2.27	2.35	0.10	0.04	5.53	3.55	4.75	3.73	4.25	--	--	--	--	2.06	1.65	---	---	3.82	3.64	3.66	1.21	0.33
6	2.04	2.02	2.04	2.03	0.01	0.00	---	4.28	5.22	3.68	3.48	--	--	--	--	1.59	1.77	---	---	3.11	3.48	3.33	1.20	0.36
7	2.75	2.84	2.91	2.84	0.08	0.03	---	5.42	12.5	4.74	6.55	--	--	--	--	3.77	2.89	---	---	3.71	5.83	5.68	3.01	0.53
8	4.65	3.76	3.78	4.06	0.50	0.12	7.56	6.37	7.91	6.28	7.12	--	--	--	--	4.69	4.04	---	---	5.25	6.26	6.17	1.30	0.21

Engine Output-Based PM Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test																	
Notch	12/15	12/15	12/15	3 Reps	3 Reps	3 Reps	12/5	12/5	12/6	12/6	12/7	12/12	12/12	12/13	12/13	12/16	12/16	12/17	12/17	12/18	12/18	15 Trains	15 Trains	15 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	2.18	2.28	2.11	2.19	0.09	0.04	5.38	4.23	6.06	5.42	6.28	--	--	--	--	2.41	1.76	---	---	5.13	4.55	4.58	1.56	0.34
High Idle	2.34	1.94	2.16	2.15	0.20	0.09	4.50	4.60	5.29	4.40	5.17	--	--	--	--	2.22	1.80	---	---	5.68	5.12	4.31	1.37	0.32
Dyn Brake	---	---	---	--	--	--	3.87	3.31	5.05	4.02	6.02	--	--	--	--	1.99	1.58	---	---	4.90	4.66	3.93	1.45	0.37
1	0.12	0.11	0.11	0.11	0.00	0.03	0.28	0.24	0.35	0.25	0.30	--	--	--	--	0.14	0.12	---	---	0.36	0.32	0.26	0.08	0.32
2	0.09	0.08	0.08	0.09	0.00	0.04	0.22	0.18	0.24	0.18	0.21	--	--	--	--	0.11	0.08	---	---	0.25	0.21	0.19	0.06	0.30
3	0.07	0.07	0.07	0.07	0.00	0.03	0.13	0.13	0.17	0.13	0.14	--	--	--	--	0.08	0.06	---	---	0.15	0.15	0.13	0.04	0.28
4	0.07	0.07	0.07	0.07	0.00	0.02	0.13	0.12	0.14	0.10	0.13	--	--	--	--	0.08	0.07	---	---	0.15	0.15	0.12	0.03	0.24
5	0.08	0.07	0.07	0.07	0.00	0.03	0.18	0.12	0.16	0.12	0.13	--	--	--	--	0.06	0.05	---	---	0.13	0.12	0.12	0.04	0.34
6	0.06	0.06	0.07	0.06	0.00	0.01	---	0.15	0.18	0.12	0.11	--	--	--	--	0.05	0.06	---	---	0.10	0.11	0.11	0.04	0.39
7	0.09	0.09	0.09	0.09	0.00	0.02	---	0.20	0.45	0.17	0.22	--	--	--	--	0.17	0.08	---	---	0.09	0.16	0.19	0.11	0.59
8	0.17	0.14	0.13	0.15	0.02	0.15	0.26	0.23	0.28	0.22	0.25	--	--	--	--	0.14	0.13	---	---	0.17	0.19	0.21	0.06	0.26
Duty Cycle Avg (Raw)	0.03	0.03	0.02	0.03	0.00	0.10	0.05	0.04	0.05	0.04	0.05	--	--	--	--	0.02	0.02	---	---	0.04	0.04	0.04	0.01	0.26
Duty Cycle Avg (Adj)	0.15	0.13	0.12	0.13	0.01	0.10	0.24	0.22	0.27	0.21	0.24	--	--	--	--	0.12	0.12	---	---	0.19	0.21	0.20	0.05	0.26

Exhaust PM Concentrations (mg/m^3)

Throttle	Rail Yard Test						Over-The-Rail Test																	
Notch	12/15	12/15	12/15	3 Reps	3 Reps	3 Reps	12/5	12/5	12/6	12/6	12/7	12/12	12/12	12/13	12/13	12/16	12/16	12/17	12/17	12/18	12/18	15 Trains	15 Trains	15 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	1.6	1.7	1.6	1.6	0.07	0.04	4.1	3.2	4.6	4.2	4.7	--	--	--	--	1.8	1.4	---	---	3.8	3.4	3.5	1.19	0.34
High Idle	1.2	1.0	1.1	1.1	0.10	0.09	2.4	2.2	2.7	2.2	2.6	--	--	--	--	1.1	0.9	---	---	2.9	2.6	2.2	0.69	0.32
Dyn Brake	---	---	---	--	--	--	2.0	1.6	2.6	2.1	3.0	--	--	--	--	1.0	0.8	---	---	2.5	2.4	2.0	0.75	0.37
1	1.1	1.1	1.1	1.1	0.02	0.02	2.8	2.4	3.4	2.5	2.9	--	--	--	--	1.3	1.2	---	---	3.5	3.0	2.6	0.82	0.32
2	1.6	1.5	1.5	1.5	0.06	0.04	4.2	3.4	4.5	3.3	3.8	--	--	--	--	2.0	1.4	---	---	4.3	3.8	3.4	1.04	0.31
3	1.8	1.7	1.7	1.7	0.04	0.02	3.6	3.4	4.5	3.4	3.7	--	--	--	--	2.0	1.5	---	---	3.9	3.8	3.3	0.96	0.29
4	2.5	2.4	2.4	2.4	0.05	0.02	4.4	4.2	4.9	3.5	4.2	--	--	--	--	2.5	2.5	---	---	4.8	4.9	4.0	0.96	0.24
5	2.7	2.6	2.6	2.6	0.06	0.02	6.6	4.4	5.8	4.5	4.4	--	--	--	--	2.2	1.9	---	---	4.5	4.1	4.3	1.51	0.35
6	2.4	2.4	2.4	2.4	0.03	0.01	---	5.7	6.9	4.7	4.0	--	--	--	--	1.8	2.3	---	---	3.6	4.3	4.2	1.69	0.41
7	3.7	3.8	3.9	3.8	0.10	0.03	---	8.5	20.1	7.5	9.0	--	--	--	--	4.9	4.2	---	---	4.7	8.2	8.4	5.09	0.61
8	7.3	5.9	5.7	6.3	0.87	0.14	11.8	10.0	12.7	10.0	10.1	--	--	--	--	6.3	6.3	---	---	7.6	9.3	9.3	2.24	0.24

Table F-22. Measured CO_2 Emission Rates for NC-1859 and B20

Time-Based CO_2 Emission Rates (g/s)

Throttle	Rail Yard Test						Over-The-Rail Test																	
Notch	12/15	12/15	12/15	3 Reps	3 Reps	3 Reps	12/5	12/5	12/6	12/6	12/7	12/12	12/12	12/13	12/13	12/16	12/16	12/17	12/17	12/18	12/18	15 Trains	15 Trains	15 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	8.09	8.02	6.42	7.51	0.94	0.13	9.11	6.26	7.23	6.20	6.73	6.22	5.62	8.76	4.64	7.65	6.76	9.43	7.98	8.45	7.60	7.24	1.36	0.19
High Idle	13.9	13.8	10.7	12.8	1.81	0.14	20.2	29.7	17.5	17.5	17.0	27.9	32.8	21.5	13.1	13.7	9.49	16.2	15.6	16.4	15.7	19.0	6.51	0.34
Dyn Brake	---	---	---	--	--	--	16.8	17.9	15.8	13.5	13.5	15.6	12.3	13.7	9.82	13.8	16.2	18.3	14.9	16.2	14.4	14.9	2.21	0.15
1	30.4	30.6	31.4	30.8	0.52	0.02	32.8	32.5	27.4	26.8	27.8	29.7	27.0	25.7	20.6	26.9	29.2	33.5	32.1	33.5	31.4	29.1	3.59	0.12
2	47.3	47.9	44.6	46.6	1.73	0.04	51.0	48.0	37.3	33.1	36.4	44.0	40.0	39.4	30.5	43.5	40.2	47.7	48.9	47.0	40.6	41.8	6.03	0.14
3	79.7	79.5	83.1	80.8	2.05	0.03	89.8	91.4	82.3	73.9	73.4	80.7	78.1	75.0	56.7	80.7	82.0	83.4	88.4	87.8	76.8	80.0	8.62	0.11
4	119	119	115	118	2.45	0.02	114	123	118	115	110	110	113	99.1	90.6	112	122	112	123	118	109	113	8.70	0.08
5	156	157	160	158	1.86	0.01	161	167	163	162	148	153	157	147	120	152	154	156	168	168	159	156	12.0	0.08
6	192	193	195	194	1.71	0.01	---	210	206	196	188	190	192	175	156	188	204	188	207	196	202	193	14.3	0.07
7	289	285	284	286	2.52	0.01	---	302	301	297	280	297	283	301	--	278	290	---	298	256	278	289	13.9	0.05
8	383	377	362	374	10.5	0.03	361	365	369	367	363	343	362	328	319	345	365	339	382	363	356	355	17.0	0.05

Fuel-Based CO_2 Emission Rates (g/gal)

Throttle	Rail Yard Test						Over-The-Rail Test																	
Notch	12/15	12/15	12/15	3 Reps	3 Reps	3 Reps	12/5	12/5	12/6	12/6	12/7	12/12	12/12	12/13	12/13	12/16	12/16	12/17	12/17	12/18	12/18	15 Trains	15 Trains	15 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	9721	9741	9553	9672	104	0.01	9915	8660	8720	8670	9163	9728	9640	10004	9727	9865	9558	9857	9427	9785	9743	9497	469	0.05
High Idle	9757	9803	9675	9745	64.9	0.01	9934	9710	9411	9230	9695	9987	9962	10028	9934	9938	9623	9894	9633	9869	9845	9780	229	0.02
Dyn Brake	---	---	---	--	--	--	9875	9516	9326	9056	9485	9927	9761	9965	9831	9930	9768	9907	9606	9885	9845	9712	263	0.03
1	10000	9973	9925	9966	38.3	0.00	9958	9842	9645	9682	9777	10035	9957	10019	9986	9996	9961	10011	9897	9902	9977	9910	122	0.01
2	10004	9985	9979	9989	12.9	0.00	10024	9940	9876	9532	9869	10033	10001	10055	10023	10048	9973	10030	9939	10021	9982	9956	131	0.01
3	10034	10016	10001	10017	16.5	0.00	10047	9998	9893	9864	9980	10050	10016	10063	10043	10058	10010	10030	9980	10046	10006	10006	58.4	0.01
4	10046	10027	10022	10032	12.3	0.00	10042	9984	9868	9964	10000	10054	10040	10067	10054	10058	10018	10042	9995	10042	10031	10017	51.0	0.01
5	10061	10061	10054	10059	4.18	0.00	10063	9990	9966	9959	10010	10066	10036	10071	10057	10061	10021	10056	9979	10015	10040	10026	38.2	0.00
6	10030	10045	10035	10037	7.68	0.00	---	10007	9989	9942	10023	10062	10054	10064	10053	10060	10034	10051	10008	10046	10038	10031	34.4	0.00
7	10014	10021	10005	10014	7.94	0.00	---	10036	10048	10010	9993	10071	10062	10072	--	10061	10036	---	10015	10046	10040	10041	24.7	0.00
8	10063	10063	10054	10060	5.16	0.00	10043	10034	10000	9994	10041	10064	10058	10071	10064	10065	10043	10057	10027	10058	10041	10044	22.9	0.00

Engine Output-Based CO_2 Emission Rates (g/bhp-hr)

Throttle	Rail Yard Test						Over-The-Rail Test																	
Notch	12/15	12/15	12/15	3 Reps	3 Reps	3 Reps	12/5	12/5	12/6	12/6	12/7	12/12	12/12	12/13	12/13	12/16	12/16	12/17	12/17	12/18	12/18	15 Trains	15 Trains	15 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	2912	2886	2311	2703	340	0.13	3281	2254	2602	2231	2423	2240	2025	3152	1669	2753	2434	3393	2873	3040	2737	2607	489	0.19
High Idle	5001	4977	3859	4612	653	0.14	7285	10698	6310	6289	6127	10054	11817	7723	4698	4941	3415	5829	5600	5915	5635	6822	2343	0.34
Dyn Brake	---	---	---	--	--	--	6053	6459	5692	4850	4868	5629	4422	4937	3535	4982	5833	6585	5353	5814	5201	5348	795	0.15
1	576	580	594	583	9.79	0.02	621	615	520	508	527	564	511	487	390	510	553	634	608	634	595	552	68.1	0.12
2	486	493	459	479	17.8	0.04	524	493	383	340	375	453	412	405	314	447	413	491	503	483	418	430	62.0	0.14
3	425	424	443	431	10.9	0.03	479	487	439	394	392	430	417	400	302	430	437	445	471	468	410	427	46.0	0.11
4	430	428	414	424	8.82	0.02	409	441	424	415	395	396	407	357	326	402	439	404	444	426	394	405	31.3	0.08
5	432	436	442	436	5.16	0.01	446	463	450	447	411	415	426	399	325	421	426	432	464	466	439	429	35.2	0.08
6	432	435	440	436	3.84	0.01	---	473	464	441	424	427	431	394	351	424	458	423	467	441	454	434	32.1	0.07
7	433	427	426	429	3.79	0.01	---	495	493	487	458	446	424	452	--	370	387	---	397	342	371	427	52.7	0.12
8	510	502	483	498	14.0	0.03	481	487	493	489	484	457	483	437	425	414	438	407	459	435	427	454	29.9	0.07

Exhaust CO_2 Concentrations (%)

Throttle	Rail Yard Test						Over-The-Rail Test																	
Notch	12/15	12/15	12/15	3 Reps	3 Reps	3 Reps	12/5	12/5	12/6	12/6	12/7	12/12	12/12	12/13	12/13	12/16	12/16	12/17	12/17	12/18	12/18	15 Trains	15 Trains	15 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 75	Train 76	Train 75	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	0.60	0.60	0.48	0.56	0.07	0.12	0.70	0.48	0.56	0.48	0.50	0.46	0.42	0.61	0.35	0.57	0.52	0.72	0.62	0.62	0.57	0.55	0.10	0.19
High Idle	0.72	0.72	0.56	0.67	0.09	0.14	1.06	1.41	0.91	0.89	0.85	1.27	1.42	1.01	0.65	0.70	0.49	0.84	0.83	0.83	0.79	0.93	0.27	0.29
Dyn Brake	---	---	---	--	--	--	0.88	0.87	0.82	0.71	0.68	0.73	0.62	0.68	0.50	0.70	0.80	0.89	0.78	0.81	0.75	0.75	0.11	0.14
1	1.53	1.55	1.60	1.56	0.04	0.02	1.71	1.72	1.44	1.42	1.42	1.51	1.37	1.30	1.04	1.35	1.54	1.71	1.71	1.69	1.59	1.50	0.20	0.13
2	2.41	2.45	2.28	2.38	0.09	0.04	2.73	2.55	1.98	1.73	1.86	2.24	2.03	1.98	1.53	2.18	2.11	2.50	2.60	2.36	2.06	2.16	0.34	0.16
3	3.04	3.05	3.20	3.10	0.09	0.03	3.56	3.67	3.31	2.94	2.83	3.05	2.95	2.76	2.16	3.03	3.25	3.23	3.53	3.31	2.96	3.10	0.38	0.12
4	3.94	3.94	3.77	3.88	0.10	0.03	3.88	4.20	4.01	3.95	3.59	3.57	3.67	3.17	2.91	3.59	4.13	3.76	4.22	3.82	3.63	3.74	0.36	0.10
5	4.21	4.32	4.40	4.31	0.10	0.02	4.57	4.76	4.67	4.60	3.99	4.03	4.20	3.83	3.18	4.03	4.35	4.30	4.79	4.52	4.30	4.28	0.42	0.10
6	4.42	4.46	4.52	4.47	0.05	0.01	---	5.09	5.06	4.80	4.35	4.30	4.39	3.92	3.52	4.28	4.92	4.40	5.02	4.49	4.73	4.52	0.45	0.10
7	5.12	5.10	5.10	5.11	0.01	0.00	---	5.99	6.15	6.05	5.25	5.46	5.23	5.46	--	4.95	5.60	---	5.89	4.87	5.38	5.52	0.42	0.08
8	6.02	6.02	5.77	5.94	0.14	0.02	5.96	6.01	6.11	6.03	5.43	5.18	5.48	4.87	4.75	5.17	5.92	5.35	6.16	5.54	5.69	5.58	0.45	0.08

F.3 Summary of Results for NC-1859 on B10

Rail yard and over-the-rail measurements were conducted in January and February 2014 on the prime mover engine of locomotive NC-1859 operating on 10 percent soy-based biodiesel and 90 percent ULSD blend (B10). The dates of the measurements of the NC-1859 prime mover engine in the rail yard and over the rail are given in Table F-23. Each rail yard measurements involved three replicates of a measurements cycle. Each over the rail measurements involved typically three days comprised of six one way trips between Raleigh and Charlotte, NC.

Table F-23. Fuel Characteristics and Dates Measured on NC-1859 Prime Mover Engine

Fuel Name	Percent Petrodiesel	Percent Biodiesel	Dates of Measurements	
			Rail Yard	Over-The-Rail
ULSD	100	0	Sept. 1, 2013	Aug. 30-31, Sept.2, 2013
B10	90	10	Feb. 1, 2014	Jan. 23, 26-27, 2013
B20	80	20	Dec. 15, 2013	Dec. 5-7, 12-13, 16-18, 2013
B40	60	40	Oct. 20, 2013	Oct. 18-19, 21, 2013

The prime mover engine was an EMD 12-710G3B. The engine was originally manufactured in 1988 and was rebuilt by AMTRAK in 2012. The 140-liter (L) engine has a peak engine output of 3000 horsepower (hp) at an engine speed of 900 revolutions per minute (rpm).

The fuel use and emission rates are inferred from measurements made with a Portable Emissions Measurement System (PEMS). The PEMS utilized for measurements was the Axion system manufactured by Clean Air Technologies International, Inc. (CATI). Prior to each set of measurements, each PEMS was calibrated with a California Bureau of Automotive Repair (BAR) certified calibration gas (BAR-97 Low).

The cycle average emission rates for the rail yard and over-the-rail measurements are shown in Table F-24. The cycle average emission rates are based on the line-haul duty cycle used by the U.S. Environmental Protection Agency (EPA) for regulatory purposes. The EPA line haul duty cycle specifies the percentage of operating time spent in idle, each of eight throttle notch positions, and dynamic braking. Three replicates of each rail yard measurement were conducted. Dynamic braking takes place during over-the-rail operation, but cannot be simulated in the rail yard. During dynamic braking, the traction motors act as generators, and the resulting electrical current was dissipated in a resistor grid. Thus, the time apportioned for dynamic braking in the line-haul duty cycle (12.5 percent) was combined with the time apportioned for idling in the line-haul duty cycle (38.0 percent). Therefore, idling accounts for 50.5 percent of the duty cycle used to calculate RY cycle average emission rates. OTR measurements were made during six one-way trips between Raleigh and Charlotte, NC. During over-the-rail measurements, dynamic braking was observed. The results shown in Table F-24 are based on the average of the three rail yard replicates for the rail yard measurements, and the average of typically six one way runs, except as noted, for the over the rail measurements.

Table F-24. Preliminary EPA Line-Haul Cycle Average Emission Rates for the NC-1859 Prime Mover Engine Operated on Multiple Fuels in the Rail Yard and Over-the-Rail[a,b]

(a) Rail Yard Measurements[c]

Measurement	NO_x (g/bhp-hr)	HC (g/bhp-hr)	CO (g/bhp-hr)	Opacity-based PM (g/bhp-hr)
ULSD	7.0	4.49	1.9	0.39
B10	9.2	0.79	0.4	0.22
B20	8.5	2.04	0.5	0.13
B40	10.1	1.01	0.8	0.22

(b) Over-the-Rail Measurements

Measurement	NO_x (g/bhp-hr)	HC (g/bhp-hr)	CO (g/bhp-hr)	Opacity-based PM (g/bhp-hr)
ULSD	6.0	3.64	0.8	0.42
B10	8.2	3.10	0.5	0.21
B20	7.6	1.72	0.4	0.16
B40[d]	7.8	1.62	0.5	0.20

[a] *The cycle average emission rates are based on the U.S. EPA line-haul duty cycle used for regulatory purposes.*

[b] *NO_x, HC, and opacity-based PM emission rates from the Axion are adjusted with multipliers of 1.053, 2.5, and 5, respectively, as bias correction.*

[c] *Dynamic braking not observed during rail yard measurements. Therefore, idling accounts for 50.5 percent of the duty cycle used to calculate rail yard cycle average emission rates.*

[d] *The cycle average emission rates are based on sixteen one way runs.*

Rail Yard (RY) Measurements

Three rail yard emissions measurement replicates on the prime mover engine of NC-1859 on B10 biodiesel were conducted on February 1, 2014. In the RY, emissions measurements were taken when the engine reached steady state at two idle settings and each of eight notch positions. The idle and notch average emission rates were weighted by the EPA line-haul duty cycle to estimate cycle average rates.

The EPA line-haul cycle average emission rates are shown in Table F-24. These cycle average emission rates are based on the measured engine activity data (RPM, MAP, and IAT), inferred engine activity data (MAF, AFR, and VE), and measured exhaust concentrations. There was little variability between replicate measured engine activity data and exhaust NO concentration, given in Figure F-13. This indicates that the prime mover engine was operating consistently during all three replicate measurements.

An increasing trend in fuel use rate was apparent with increasing notch position, as shown in Figure F-14. The NO emission rates among the three replicates were consistent, as shown in

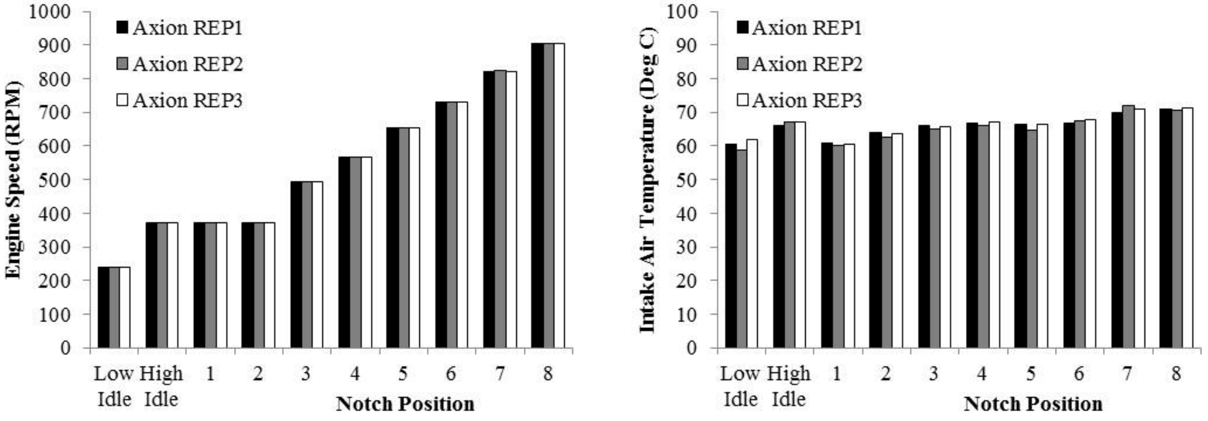
Figure F-15. The inter-replicate ratios of the standard deviation to the mean (coefficient of variation) for each notch position for the mass per gallon of fuel NO emission rates range from 0.03 to 0.06, which indicates small variability between replicates.

Approximately 70 percent of the notch-specific HC concentrations measured were below the detection limit. These concentrations are not significantly different from zero. However, because of imprecision in the measurements at or below the detection limit, there was large variability in estimated average concentrations. The inter-replicate coefficient of variation (CV) in the estimated HC emission rates were 38 percent, on average for each notch position. Variability in measured concentrations result in variability in the estimated notch-specific HC emission rates between the three replicated measurements, as shown in Figure F-16. The inter-replicate CV on the estimated HC emission rates were 44 percent, on average, for each notch position.

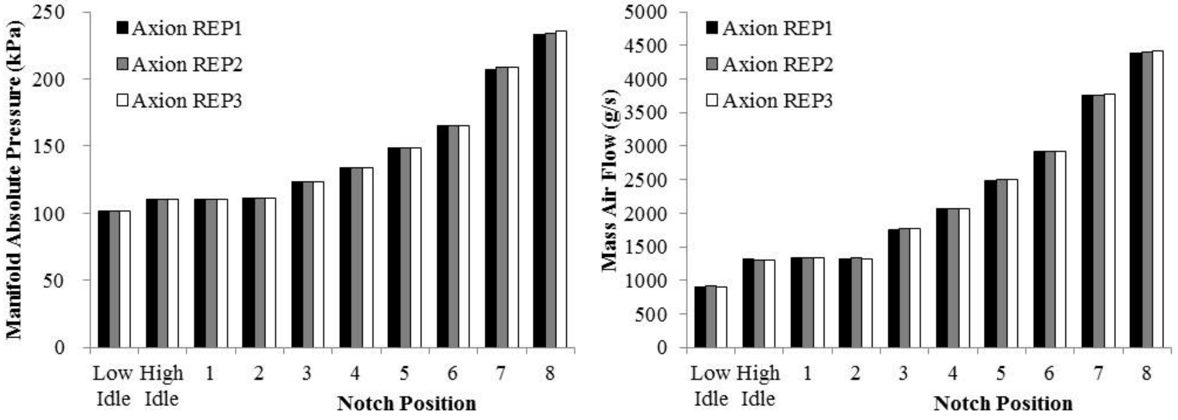
There was also variability in the estimated notch-specific CO concentration and emission rates between the three replicate measurements, as shown in Figure F-17. Approximately 93 percent of the notch-specific CO concentrations measured were below the detection limit. The inter-replicate coefficient of variation in the estimated CO emission rates was 36 percent, on average, for each notch position. However, on an absolute basis, the exhaust CO concentrations were typically less than 0.010 volume percent.

PM emission rates, as shown in Figure F-18, were consistent across the three replicates, with inter-replicate coefficient of variation less than 0.11 for all notch positions except for Notch 8. All of the NO, CO, HC, and PM concentrations measured were of the same magnitude as previous rail yard measurements from the same engine as it operated on ULSD, B20, and B40 biodiesel.

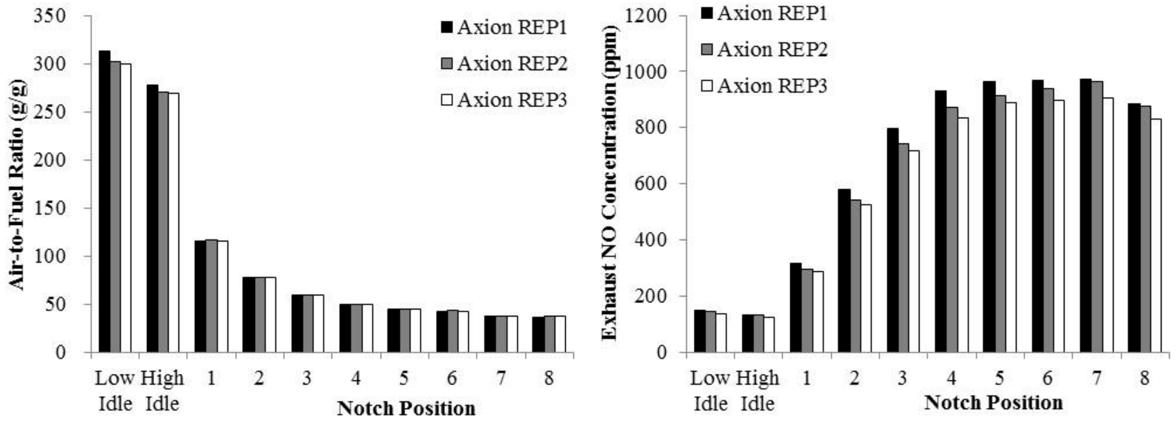
Figure F-13. Measured Engine Activity Data during Rail Yard Measurements of the NC-1859 Prime Mover Engine Operated on B10 Biodiesel



(a) Engine Speed (b) Intake Air Temperature



(c) Manifold Absolute Pressure (d) Mass Air Flow



(e) Air-to-Fuel Ratio (f) Exhaust NO Concentration

Figure F-14. Estimated Fuel Use Rates during Rail Yard Measurements of the NC-1859 Prime Mover Engine Operated on B10 Biodiesel

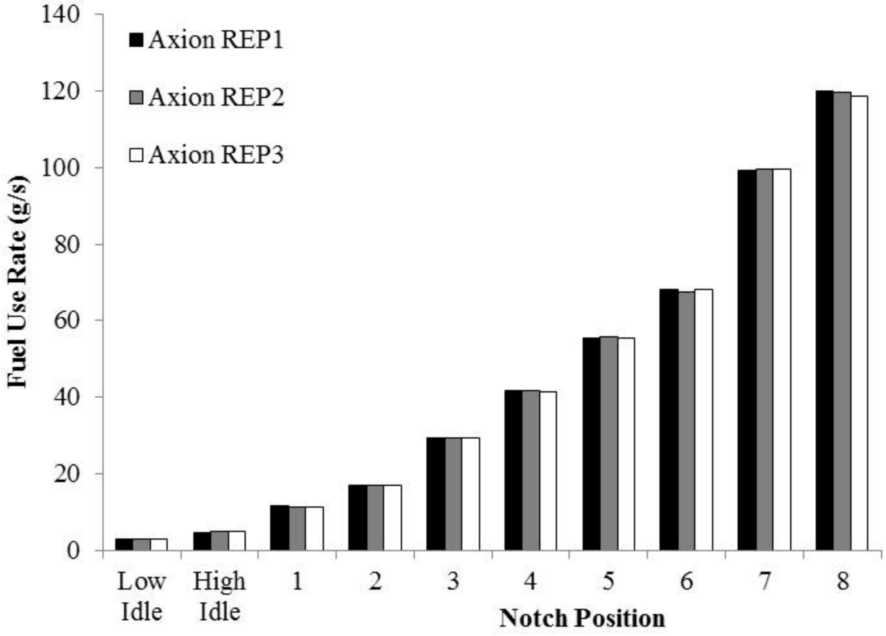


Figure F-15. Estimated NO_x Emission Rates during Rail Yard Measurements of the NC-1859 Prime Mover Engine Operated on B10 Biodiesel

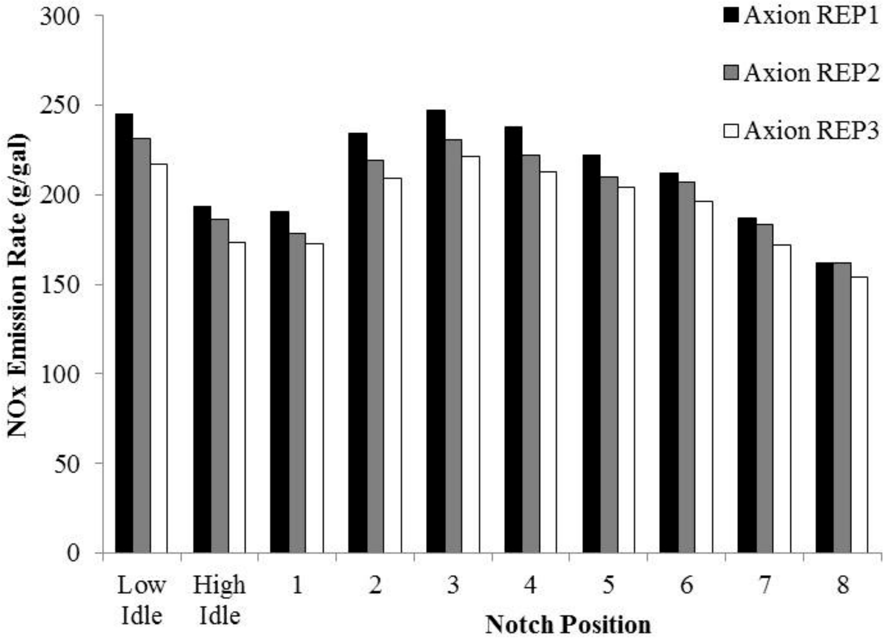


Figure F-16. Estimated HC Emission Rates during Rail Yard Measurements of the NC-1859 Prime Mover Engine Operated on B10 Biodiesel

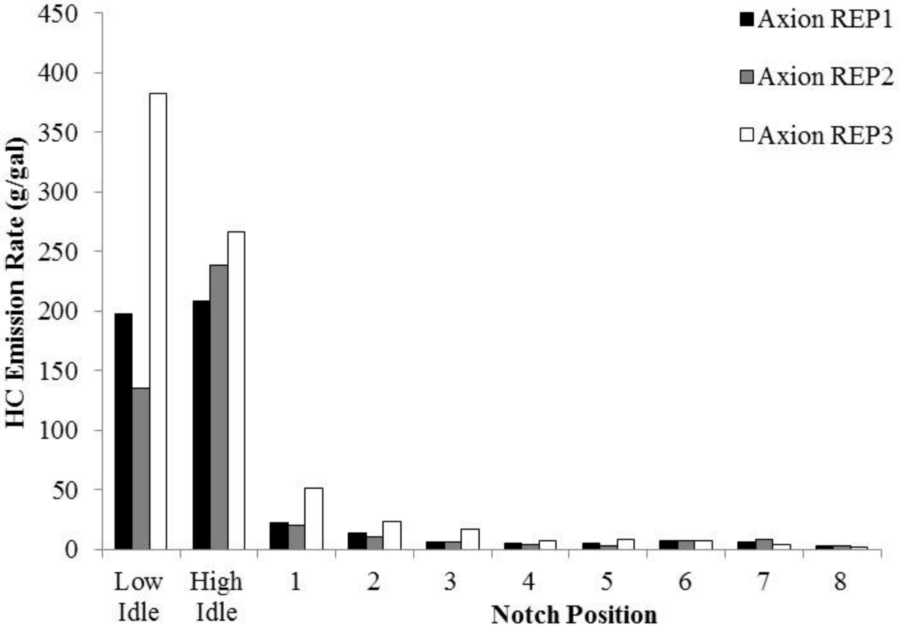


Figure F-17. Estimated CO Emission Rates during Rail Yard Measurements of the NC-1859 Prime Mover Engine Operated on B10 Biodiesel

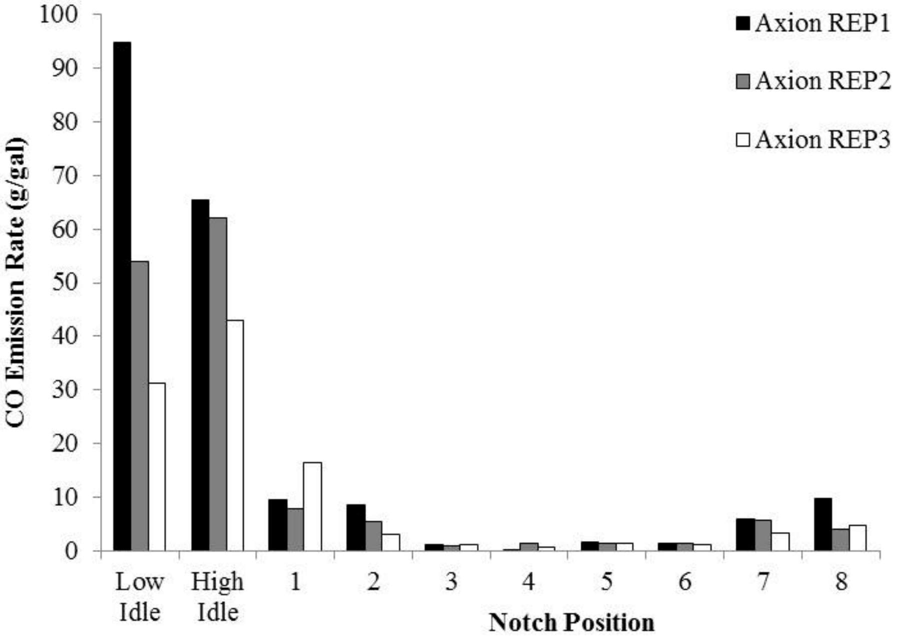
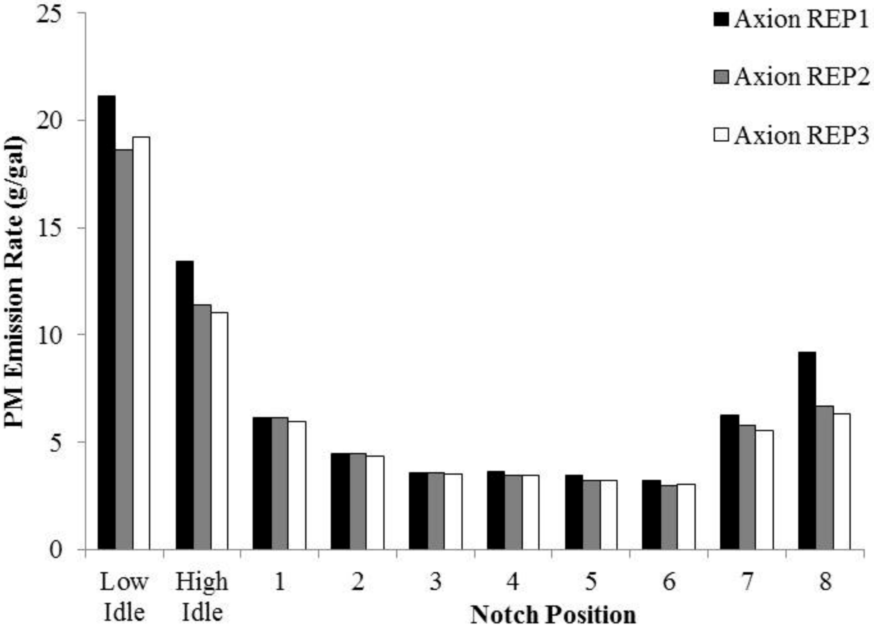


Figure F-18. Measured PM Emission Rate during Rail Yard Measurements of the NC-1859 Prime Mover Engine Operated on B10 Biodiesel



Estimated EPA line-haul cycle average emission rates for each of the three replicate rail yard measurements are given in Table F-25. The cycle average NO_x emission rates were consistent among the replicates, with coefficient of variation of 0.04. The inter-replicate coefficient of variation for HC and CO emission rates are 42 and 45 percent, respectively. Because a substantial number of the HC concentration measurements were near or below the detection limit, the HC measurements are imprecise and, thus, subject to variability. The inter-replicate coefficient of variation for cycle average PM emission rates were 15 percent. Differences in emission rates are attributable to differences in measured exhaust concentrations. Values for engine activity parameters (i.e., RPM, IAT, MAP) were similar across all measurements, given in Figure F-13, and thus are not the cause of inter-replicate variation in emission rates. The inter-replicate variation in emission rates for a given pollutant was mainly a result of the variation in measured exhaust concentration.

Based on the over-the-rail measurements, notch average emission rates were estimated for Low and high idle, dynamic brake, and notches 1 to 8. To enable comparisons with other data, the notch average emission rates are weighted based on the EPA line-haul duty cycle. However, we also quantified the actual observed duty cycle for each one-way trip. The EPA line-haul cycle average emission rates for B10 biodiesel are shown in Table F-26. These cycle average emission rates are based on measured engine activity data (RPM, MAP, and IAT) and measured exhaust concentrations. The cycle average estimate was based on measured notch-based emission rates and time fraction for each notch for the EPA line-haul duty cycle. For each set of measurements, there was little variability between measured engine activity data during both days of measurements. This indicates that the prime mover engine was operating consistently during over-the-rail measurements. Measured engine activity data during over-the-rail measurements were similar to the measured engine activity data during rail yard measurements.

Table F-25. Estimated EPA Line-Haul Cycle Average Emission Rates for Rail Yard Replicate Measurements of NC-1859 Prime Mover Engine Operated on B10 Biodiesel

	NO_x (g/bhp-hr)	HC (g/bhp-hr)	CO (g/bhp-hr)	Opacity-based PM (g/bhp-hr)
Replicate 1	9.5	0.68	0.6	0.26
Replicate 2	9.3	0.52	0.3	0.21
Replicate 3	8.8	1.16	0.2	0.20
Average of 3 Replicates	**9.2**	**0.79**	**0.4**	**0.22**
Coefficient of Variation	*0.04*	*0.42*	*0.45*	*0.15*

NO_x, HC, and PM are adjusted with multipliers of 1.053, 2.5, and 5, respectively, as bias correction.
Cycle average emission rates are based on EPA Line-Haul duty cycle.

Table F-26. EPA Line-Haul Cycle Average Emission Rates for Over-the-Rail Measurements of NC-1859 Prime Mover Engine Operated on B10 Biodiesel

	NO_x (g/bhp-hr)	HC (g/bhp-hr)	CO (g/bhp-hr)	Opacity-based PM (g/bhp-hr)
Jan. 23, 2014 – Train 73	7.3	1.30	0.2	0.19
Jan. 23, 2014 – Train 74	7.1	3.46	0.4	0.25
Jan. 26, 2014 – Train 73	8.8	2.82	0.3	0.17
Jan. 26, 2014 – Train 74	9.0	3.50	0.6	0.18
Jan. 27, 2014 – Train 75	8.4	3.19	0.6	0.23
Jan. 27, 2014 – Train 76	8.6	4.35	0.8	0.25
Average	**8.2**	**3.10**	**0.5**	**0.21**
Coefficient of Variation	0.10	0.33	0.46	0.17

NO_x, HC, and PM are adjusted with multipliers of 1.05, 2.5, and 5, respectively, as bias correction.

Cycle average emission rates are based on EPA Line-Haul duty cycle.

Over-the-Rail Measurements

Three days of over-the-rail measurements on the NC-1859 prime mover engine operating on ULSD were conducted on January 23, 26, and 27, 2014.

For notch average NO_x emission rates, the coefficient of variation was less than 15 percent for each notch position, except for Dynamic Braking amongst the six one-way trips. The coefficients of variation for HC and CO are 46 and 33 percent, respectively. Approximately 20 and 70 percent of the notch-specific HC and CO concentrations, respectively, were below the detection limit, which leads to imprecision that contributes to large inter-run variability. For PM, the coefficient of variation was 17 percent for the six one-way trips. Differences in measured exhaust pollutant concentrations were the key reason for the variability.

The EPA line-haul duty cycle average OTR emission rates are quantitatively similar to the EPA line-haul duty cycle average rail yard emission rates. The cycle average OTR NO_x and PM emission rates over the six one-way trips were within 5 percent of the cycle average rail yard emission rates. The OTR cycle average HC emission rates were an order of magnitude higher than the rail yard cycle average HC emission rate. Therefore, the comparison between rail yard and over-the-rail are not informative.

Differences in cycle average emission rates between RY and OTR measurements can be attributed to various factors. RPM and MAP were essentially the same for RY and OTR measurements. IAT differed on an absolute basis by less than 6 percent from run-to-run during OTR measurements. At notch 8, the engine output during rail yard measurements was 2,700 horsepower, while engine output was 3,000 horsepower during over-the-rail measurements. With notch 8 accounting for 16 percent of the EPA line-haul duty cycle, higher engine output decreases engine output based emission rates and, therefore, cycle average emission rates. Finally, differences in measured exhaust concentrations between RY and OTR measurements lead to differences in fuel use and emission rates.

Throttle notch position data obtained from the locomotive data activity recorder were used to quantify the actual real-world duty cycles for the over-the-rail measurements. The measured duty cycles are compared to the EPA line-haul duty cycle in Table F-27. The prime mover engine operated in notch 8 during the over-the-rail measurements more than double the percentage of time, on average, than EPA estimates a line-haul locomotive operates in notch 8. For the other notch positions, the observed time was, on average, less than the EPA line-haul duty cycle. Although not shown here, the real-world duty cycles can be used to estimate inter-cycle variability in cycle average fuel use and emission rates.

Table F-28 summarizes the average measured engine speed (RPM), intake air temperature (IAT), manifold absolute pressure (MAP), estimated mass air flow (MAF), and air-to-fuel ratio (AFR) for each throttle notch position and for each replicate of the rail yard (RY) measurements and for each one-way over-the-rail (OTR) trip. Engine speed ranges from 240 to 900 RPM in both RY and OTR measurements, depending on notch position. For the RY measurements, engine RPM was highly repeatable among replicates for a given notch position, with a standard deviation of less than 1 RPM for all notch positions. For the OTR measurements, the RPM was also repeatable among replicates for a given notch position, with a standard deviation of 3 RPM or less except in dynamic braking. For some one-way trips, the sample sizes in these notches are too small to infer a steady-state engine operating speed. The intake air temperature varies with ambient temperature and was generally in the range of 57 to 75 degrees C.

Table F-27. Observed Real-World Over-the-Rail Duty Cycles from Measurement of NC-1859 Operated on B10 Biodiesel

Notch	Percent Time in Each Notch							
	EPA Line-Haul	Measured Over-the-Rail						
		Average	1/23/2014 Train 73	1/23/2014 Train 74	1/26/2014 Train 73	1/26/2014 Train 74	1/27/2014 Train 73	1/27/2014 Train 74
Idle	38.0	27.6	32.2	27.5	15.7	22.3	38.8	29.3
DB	12.5	12.2	15.1	12.6	9.0	6.1	14.2	16.4
1	6.5	4.4	3.6	4.7	5.7	8.4	1.7	2.0
2	6.5	5.4	2.9	6.7	10.8	6.9	2.8	2.3
3	5.2	3.9	3.2	3.6	6.8	3.7	2.9	3.2
4	4.4	4.5	3.4	6.4	4.4	6.8	2.6	3.5
5	3.8	2.4	2.7	2.1	1.3	2.9	2.8	2.2
6	3.9	4.0	4.0	5.4	0.9	7.3	4.3	2.0
7	3.0	1.3	1.7	1.3	0.2	2.3	1.7	0.5
8	16.2	34.4	31.1	29.8	45.2	33.3	28.2	38.6

Train 73 and 75 are from Raleigh to Charlotte. Train 74 and 76 is from Charlotte to Raleigh.

MAP was highly repeatable in the RY measurements, ranging from 99 to 246 kPa depending on notch position. The RY inter-replicate standard deviation of measured MAP was less than 2 kPa for each notch position. For OTR measurements, there was slightly more inter-run variability in MAP. However, the coefficient of variation for each notch position was typically 0.06 or less.

Estimated MAF was highly repeatable for both RY and OTR measurements, with the coefficient of variation of 0.06 or less for all notch position. The MAF ranged from 880 to 4,600 g/s, depending on notch position. Estimated AFR was highly repeatable among replicates for a given notch position in the RY measurements, with coefficient of variation less than 0.02 for all notches except for low and high idle. For OTR measurements, there was slightly more inter-run variability in AFR for each notch position, but the coefficient of variation was less than 0.1 except for idle and dynamic braking. Overall, the engine activity during the measurements was consistent for the three replicates in the rail yard, and from run to run for the six one-way trips observed between Raleigh and Charlotte.

Table F-29 summarizes the estimated fuel use rates inferred from the engine data of Table F-28. For the RY measurements, fuel use rates range from 3 to 120 g/sec depending on notch position, and were highly repeatable among replicates for a given notch position, with a coefficient of variation of 0.02 or less. There was more variability in run-to-run estimates of fuel use for the OTR measurements, in part because the amount of time spent in some notch positions was low. The OTR estimated fuel use ranged from 1.8 to 119 g/sec, depending on notch position. The CV for all notches was less than 0.1 for all notch positions except idle and dynamic braking.

During RY measurements, the maximum engine output was 2,700 hp, and during OTR measurements, the maximum engine output was 3,000 hp. Furthermore, as shown later in Table F-34, the average CO_2 concentrations for each notch position are lower for OTR than for RY measurements, which implies a lower fuel-to-air ratio. Because the engine activity and engine air flow are approximately the same for OTR versus RY measurements, the combination of higher engine output and lower fuel-to-air ratio have lead to higher values of fuel-specific engine output (FSEO) in bhp-hr per gallon of fuel consumed (as shown in Table F-29). The FSEO was highly repeatable for the OTR measurements of each notch position, especially Notch 8, which represents significant portion of the observed duty cycle.

The measured NO exhaust concentration and the estimated NO_x emission rates are shown in Table F-30 for each notch position, each RY replicate, and each OTR one-way run. The average measured concentrations range among notch positions from approximately 140 to 950 parts per million (ppm) in the RY measurements, and 150 to 940 ppm in the OTR measurements, depending on notch position. The measurements are highly repeatable among replicates at a given notch position for both the RY and OTR measurements, with coefficients of variation typically less than 0.06 for the former and less than 0.2 for the latter. The estimated mass emission rates range from 0.2 to 5.9 g/sec for the RY measurements and 0.1 to 5.8 g/sec for the OTR measurements, depending on notch position. Because the observed concentrations tend to be higher for the OTR versus RY measurements, the mass emission rates also tend to be slightly higher for the OTR versus RY measurements.

On a fuel basis, the average NO_x emission rates range from 140 to 230 g/gallon for the RY measurements and 170 to 260 g/gallon for the OTR measurements, depending on notch position. For the RY measurements, the fuel-based emission rates are highly repeatable among replicates at a given notch position, with coefficient of variation typically less than 0.06. The OTR measurements have slightly more run-to-run variability but are nonetheless consistent, with coefficient of variation less than 0.17, except for idle. The fuel-based emission rates tend to be lowest at high load.

On an engine output basis, excluding idle and dynamic braking, the notch average NO_x emission rates range from 8.7 g/bhp-hr at notch 8 to 12.2 g/bhp-hr at notch 1 in the RY measurements, and range from 7.8 g/bhp-hr at notch 8 to 12.2 g/bhp-hr at notch 1 in the OTR measurements. The notch average NO_x emission rates for idle and dynamic braking were much higher than the other notch positions. In general, the emission rates on an engine output basis are higher for the OTR measurements than for the RY measurements. This results from a combination of lower exhaust concentration and higher engine output, especially at notch 8.

Results are given for exhaust concentrations and emission rates in Tables F-31, F-32, F-33, and F-34 for CO, HC, PM, and CO_2, respectively. The CO exhaust concentrations during OTR measurements tend to be higher than during RY measurements. Thus, the cycle average CO emission rates also tend to be higher for OTR than RY measurements. On average, the HC exhaust concentrations and average emission rates tend to be higher for OTR than RY. However, both the CO and HC emission rates are low on an absolute basis, and some of the measured average concentrations for a given notch position and replicate or run are below the gas analyzer detection limit. For PM, the measured exhaust levels tend to be lower for OTR than RY for a given notch position, and thus the cycle average PM emission rate tends to also be lower. The trends in CO_2 emission rates are similar to those for fuel use on a mass per time and mass per engine output basis. CO_2 emission rates are also shown on a g/gallon basis. Since typically over 99 percent of the carbon in the fuel was emitted as CO_2, the fuel-based CO_2 emission rates are approximately constant.

The cycle average OTR emission rates are in the same magnitude to the cycle average rail yard emission rates. Observed differences are mostly attributable to exhaust concentrations, rather than engine activity, and may result in part from differences associated with transient operation for over the rail operation versus steady-state operation in the rail yard. Cycle average PM emission rates were the same for RY and OTR measurements.

Table F-28. Measured Engine Parameters for NC-1859 and B10

Engine Speed (RPM)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	2/1	2/1	2/1	3 Reps	3 Reps	3 Reps	1/23	1/23	1/26	1/26	1/27	1/27	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	239	238	238	238	0.58	0.00	239	238	238	238	238	238	238	0.41	0.00
High Idle	371	371	370	371	0.58	0.00	372	371	371	370	370	370	371	0.82	0.00
Dyn Brake	---	---	---	--	--	--	371	375	413	381	379	370	382	16.0	0.04
1	371	370	370	370	0.58	0.00	371	370	371	370	369	371	370	0.82	0.00
2	371	370	370	370	0.58	0.00	371	370	371	372	371	372	371	0.75	0.00
3	493	493	493	493	0.00	0.00	496	495	494	491	491	492	493	2.14	0.00
4	566	565	565	565	0.58	0.00	565	565	564	565	564	566	565	0.75	0.00
5	653	653	653	653	0.00	0.00	654	650	657	654	652	649	653	2.94	0.00
6	730	731	731	731	0.58	0.00	731	730	731	728	728	729	730	1.38	0.00
7	822	823	822	822	0.58	0.00	819	819	822	817	820	823	820	2.19	0.00
8	904	904	905	904	0.58	0.00	904	903	903	902	901	902	903	1.05	0.00

Intake Air Temeprature (°C)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	2/1	2/1	2/1	3 Reps	3 Reps	3 Reps	1/23	1/23	1/26	1/26	1/27	1/27	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	60	59	62	60	1.53	0.03	57	59	59	64	62	63	61	2.73	0.05
High Idle	66	67	67	67	0.58	0.01	58	64	63	69	67	67	65	3.93	0.06
Dyn Brake	---	---	---	--	--	--	58	63	62	68	67	66	64	3.74	0.06
1	61	60	61	61	0.58	0.01	59	62	65	69	65	64	64	3.35	0.05
2	64	63	64	64	0.58	0.01	59	64	65	68	65	64	64	2.93	0.05
3	66	65	66	66	0.58	0.01	60	63	68	68	66	67	65	3.20	0.05
4	67	66	67	67	0.58	0.01	62	66	68	70	72	66	67	3.50	0.05
5	67	65	66	66	1.00	0.02	63	68	71	69	70	67	68	2.83	0.04
6	67	67	68	67	0.58	0.01	64	68	72	74	70	69	70	3.45	0.05
7	70	72	71	71	1.00	0.01	64	73	77	75	70	73	72	4.56	0.06
8	71	71	71	71	0.00	0.00	64	70	70	74	72	71	70	3.37	0.05

Manifold Absolute Pressure (kPa)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	2/1	2/1	2/1	3 Reps	3 Reps	3 Reps	1/23	1/23	1/26	1/26	1/27	1/27	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	102	102	102	102	0.00	0.00	102	102	100	100	99	100	101	1.22	0.01
High Idle	111	111	111	111	0.00	0.00	112	111	110	109	107	108	110	1.87	0.02
Dyn Brake	---	---	---	--	--	--	111	112	114	109	108	109	111	2.26	0.02
1	111	111	111	111	0.00	0.00	112	111	110	109	107	110	110	1.72	0.02
2	111	111	111	111	0.00	0.00	113	112	111	110	108	110	111	1.75	0.02
3	123	124	124	124	0.58	0.00	127	125	125	121	120	122	123	2.73	0.02
4	134	134	134	134	0.00	0.00	137	135	137	132	130	131	134	3.08	0.02
5	148	149	149	149	0.58	0.00	155	150	163	146	146	147	151	6.74	0.04
6	165	165	165	165	0.00	0.00	174	169	170	163	160	163	167	5.32	0.03
7	207	209	209	208	1.15	0.01	199	207	213	197	183	187	198	11.43	0.06
8	233	234	235	234	1.00	0.00	240	243	246	237	218	226	235	10.81	0.05

Mass Air Flow (g/s)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	2/1	2/1	2/1	3 Reps	3 Reps	3 Reps	1/23	1/23	1/26	1/26	1/27	1/27	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	911	911	903	908	4.71	0.01	920	911	897	884	882	886	897	15.7	0.02
High Idle	1317	1313	1311	1314	3.24	0.00	1361	1325	1320	1285	1273	1283	1308	33.6	0.03
Dyn Brake	---	---	---	--	--	--	1349	1349	1472	1316	1305	1296	1348	64.6	0.05
1	1337	1338	1334	1337	2.03	0.00	1355	1330	1312	1285	1278	1316	1313	28.5	0.02
2	1325	1326	1322	1325	2.00	0.00	1364	1332	1321	1303	1293	1318	1322	24.9	0.02
3	1756	1772	1767	1765	8.38	0.00	1841	1799	1770	1718	1717	1737	1764	49.4	0.03
4	2069	2072	2066	2069	3.05	0.00	2134	2084	2093	2024	1986	2039	2060	53.4	0.03
5	2479	2507	2500	2495	14.3	0.01	2603	2490	2652	2442	2429	2455	2512	93.0	0.04
6	2923	2926	2918	2923	4.36	0.00	3075	2969	2951	2832	2825	2876	2921	96.1	0.03
7	3756	3765	3773	3765	8.28	0.00	3700	3714	3762	3550	3414	3450	3598	148	0.04
8	4389	4404	4421	4405	16.0	0.00	4582	4541	4583	4401	4152	4283	4423	178	0.04

Air to Fuel Ratio (g/g)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	2/1	2/1	2/1	3 Reps	3 Reps	3 Reps	1/23	1/23	1/26	1/26	1/27	1/27	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	315	302	299	305	8.57	0.03	274	334	508	292	302	290	333	88.0	0.26
High Idle	277	271	269	272	4.00	0.01	241	241	240	215	245	239	237	10.7	0.05
Dyn Brake	---	---	---	--	--	--	103	261	224	239	240	236	217	57.2	0.26
1	115	116	116	116	0.59	0.01	125	141	125	118	121	130	127	8.21	0.06
2	77.7	77.7	77.2	77.5	0.29	0.00	90.3	94.0	83	82	95.8	90.7	89.4	5.47	0.06
3	59.9	60.0	59.7	59.9	0.15	0.00	66.9	66.6	61.4	59.1	63.8	64.4	63.7	3.01	0.05
4	49.6	49.6	49.7	49.6	0.06	0.00	54.6	54.0	53.9	51.4	51.0	52.9	53.0	1.47	0.03
5	44.9	45.0	44.9	45.0	0.07	0.00	52.3	48.5	49.6	46.1	47.7	47.1	48.6	2.19	0.05
6	42.8	43.1	42.9	43.0	0.16	0.00	50.3	45.8	45.1	42.3	42.9	45.5	45.3	2.83	0.06
7	37.9	37.9	37.8	37.9	0.05	0.00	40.9	41.1	39.4	38.6	38.2	38.1	39.4	1.34	0.03
8	36.6	36.8	37.2	36.9	0.30	0.01	44.7	39.5	40.3	37.0	36.0	38.0	39.3	3.09	0.08

Table F-29. Estimated Fuel Use Rates for NC-1859 and B10

Time-Based Fuel Use Rates (g/s)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	2/1	2/1	2/1	3 Reps	3 Reps	3 Reps	1/23	1/23	1/26	1/26	1/27	1/27	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	2.89	3.02	3.02	2.98	0.07	0.02	3.36	2.73	1.76	3.03	2.92	3.05	2.81	0.55	0.20
High Idle	4.76	4.85	4.87	4.83	0.06	0.01	5.64	5.51	5.50	5.96	5.19	5.37	5.53	0.26	0.05
Dyn Brake	--	--	--	--	--	--	13.1	5.16	6.58	5.50	5.43	5.50	6.87	3.08	0.45
1	11.6	11.5	11.5	11.5	0.06	0.01	10.8	9.42	10.5	10.9	10.6	10.1	10.4	0.55	0.05
2	17.0	17.1	17.1	17.1	0.04	0.00	15.1	14.2	15.9	15.8	13.5	14.5	14.8	0.94	0.06
3	29.3	29.5	29.6	29.5	0.14	0.00	27.5	27.0	28.8	29.1	26.9	27.0	27.7	0.98	0.04
4	41.7	41.8	41.6	41.7	0.10	0.00	39.1	38.6	38.8	39.4	38.9	38.6	38.9	0.30	0.01
5	55.2	55.7	55.6	55.5	0.23	0.00	49.8	51.3	53.5	52.9	50.9	52.2	51.8	1.36	0.03
6	68.2	67.8	68.0	68.0	0.22	0.00	61.2	64.8	65.4	67.0	65.9	63.3	64.6	2.08	0.03
7	99.1	99.4	99.8	99.4	0.34	0.00	90.5	90.3	95.6	92.0	89.3	90.6	91.4	2.22	0.02
8	120	120	119	119	0.54	0.00	102	115	114	119	115	113	113	5.55	0.05

Engine Output-Based Fuel Use Rates (g/bhp-hr)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	2/1	2/1	2/1	3 Reps	3 Reps	3 Reps	1/23	1/23	1/26	1/26	1/27	1/27	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	2.80	2.69	2.68	2.72	0.07	0.02	2.41	2.97	4.59	2.67	2.77	2.65	3.01	0.79	0.26
High Idle	1.70	1.67	1.66	1.68	0.02	0.01	1.44	1.47	1.47	1.36	1.56	1.51	1.47	0.07	0.05
Dyn Brake	--	--	--	--	--	--	0.62	1.57	1.23	1.47	1.49	1.47	1.31	0.36	0.27
1	13.3	13.4	13.4	13.3	0.07	0.01	14.2	16.3	14.7	14.2	14.6	15.2	14.9	0.83	0.06
2	16.6	16.6	16.6	16.6	0.04	0.00	18.8	20.0	17.9	18.0	21.0	19.5	19.2	1.23	0.06
3	18.7	18.5	18.5	18.6	0.09	0.00	19.9	20.3	19.0	18.8	20.3	20.3	19.7	0.68	0.03
4	19.4	19.4	19.5	19.4	0.05	0.00	20.7	21.0	20.9	20.6	20.8	21.0	20.8	0.16	0.01
5	19.1	18.9	18.9	19.0	0.08	0.00	21.2	20.5	19.7	19.9	20.7	20.2	20.4	0.54	0.03
6	19.0	19.1	19.1	19.1	0.06	0.00	21.2	20.0	19.8	19.3	19.7	20.5	20.1	0.66	0.03
7	19.6	19.6	19.5	19.6	0.07	0.00	24.2	24.2	22.9	23.8	24.5	24.1	23.9	0.57	0.02
8	18.3	18.3	18.4	18.3	0.08	0.00	23.7	21.1	21.4	20.5	21.1	21.6	21.6	1.12	0.05

Table F-30. Measured NO_x Emission Rates for NC-1859 and B10

Time-Based NO_x Emission Rates (g/s)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	2/1	2/1	2/1	3 Reps	3 Reps	3 Reps	1/23	1/23	1/26	1/26	1/27	1/27	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	0.22	0.22	0.20	0.21	0.01	0.04	0.25	0.15	0.22	0.22	0.23	0.24	0.22	0.03	0.15
High Idle	0.28	0.28	0.26	0.28	0.01	0.05	0.33	0.28	0.33	0.38	0.33	0.34	0.33	0.03	0.09
Dyn Brake	---	---	---	--	--	--	0.51	0.25	0.37	0.33	0.33	0.34	0.36	0.09	0.24
1	0.68	0.64	0.61	0.65	0.04	0.06	0.63	0.53	0.66	0.73	0.67	0.64	0.65	0.06	0.10
2	1.24	1.16	1.11	1.17	0.06	0.06	0.83	0.85	1.16	1.16	0.90	1.02	0.99	0.15	0.15
3	2.25	2.11	2.03	2.13	0.11	0.05	1.77	1.64	2.18	2.22	2.04	2.06	1.99	0.23	0.12
4	3.07	2.87	2.74	2.89	0.17	0.06	2.39	2.29	2.76	2.85	2.89	2.86	2.67	0.26	0.10
5	3.79	3.62	3.52	3.64	0.14	0.04	2.98	2.93	3.79	3.63	3.57	3.74	3.44	0.38	0.11
6	4.48	4.35	4.13	4.32	0.18	0.04	3.92	3.67	4.38	4.55	4.46	4.41	4.23	0.35	0.08
7	5.74	5.65	5.31	5.57	0.22	0.04	4.91	4.78	5.78	5.70	5.16	5.56	5.31	0.42	0.08
8	6.01	6.00	5.66	5.89	0.20	0.03	5.51	5.01	6.06	6.32	5.77	5.85	5.75	0.46	0.08

Fuel-Based NO_x Emission Rates (g/gal)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	2/1	2/1	2/1	3 Reps	3 Reps	3 Reps	1/23	1/23	1/26	1/26	1/27	1/27	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	246	231	216	231	15.0	0.06	239	182	396	239	254	250	260	71.4	0.27
High Idle	193	186	173	184	10.2	0.06	191	167	195	204	202	203	194	14.1	0.07
Dyn Brake	---	---	---	--	--	--	126	156	182	196	199	199	176	29.7	0.17
1	191	179	172	181	9.21	0.05	189	183	204	216	205	205	200	12.2	0.06
2	234	219	209	221	12.7	0.06	177	194	235	236	216	226	214	24.1	0.11
3	247	230	221	233	13.3	0.06	208	196	244	247	244	247	231	22.7	0.10
4	238	222	212	224	12.8	0.06	197	191	230	234	240	239	222	21.7	0.10
5	222	210	204	212	8.88	0.04	193	185	229	221	226	232	214	20.2	0.09
6	212	207	196	205	8.04	0.04	207	183	216	219	219	225	211	15.2	0.07
7	187	183	172	181	7.88	0.04	175	171	195	200	187	198	188	12.3	0.07
8	162	162	154	159	4.72	0.03	174	140	172	172	162	168	165	12.6	0.08

Engine Output-Based NO_x Emission Rates (g/bhp-hr)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	2/1	2/1	2/1	3 Reps	3 Reps	3 Reps	1/23	1/23	1/26	1/26	1/27	1/27	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	79.2	77.6	72.7	76.5	3.40	0.04	89.4	55.4	77.8	80.8	82.8	85.2	78.6	12.0	0.15
High Idle	103	101	94.0	99.1	4.53	0.05	120	103	120	136	117	122	120	10.6	0.09
Dyn Brake	---	---	---	--	--	--	183	90.0	133	120	120	122	128	30.6	0.24
1	13.0	12.1	11.6	12.2	0.68	0.06	12.0	10.1	12.6	13.8	12.7	12.2	12.2	1.20	0.10
2	12.7	11.9	11.4	12.0	0.67	0.06	8.50	8.76	11.9	11.9	9.28	10.5	10.1	1.52	0.15
3	12.0	11.2	10.8	11.3	0.60	0.05	9.47	8.76	11.6	11.9	10.9	11.0	10.6	1.23	0.12
4	11.1	10.3	9.85	10.4	0.61	0.06	8.60	8.24	9.95	10.3	10.4	10.3	9.63	0.95	0.10
5	10.5	10.0	9.74	10.1	0.39	0.04	8.24	8.12	10.5	10.0	9.88	10.4	9.53	1.06	0.11
6	10.1	9.79	9.30	9.72	0.40	0.04	8.83	8.26	9.85	10.2	10.0	9.92	9.52	0.79	0.08
7	8.61	8.47	7.97	8.35	0.34	0.04	7.46	6.38	7.70	7.60	6.88	7.41	7.24	0.51	0.07
8	8.01	8.00	7.54	7.85	0.27	0.03	6.62	6.01	7.27	7.59	6.93	7.02	6.90	0.55	0.08
Duty Cycle Avg (Raw)	9.0	8.8	8.4	8.7	0.34	0.04	6.9	6.7	8.4	8.6	8.0	8.1	7.8	0.77	0.10
Duty Cycle Avg (Adj)	9.5	9.3	8.8	9.2	0.36	0.04	7.3	7.1	8.8	9.0	8.4	8.6	8.2	0.81	0.10

Exhaust NO_x Concentrations (ppm)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	2/1	2/1	2/1	3 Reps	3 Reps	3 Reps	1/23	1/23	1/26	1/26	1/27	1/27	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	148	146	138	144	5.29	0.04	166	104	144	156	160	164	149	23.4	0.16
High Idle	132	131	123	129	4.93	0.04	152	133	155	181	157	162	157	15.5	0.10
Dyn Brake	---	---	---	--	--	--	252	114	155	156	156	161	166	45.7	0.28
1	317	296	286	300	15.8	0.05	291	247	315	350	323	303	305	34.7	0.11
2	578	543	523	548	27.8	0.05	376	398	546	551	433	478	464	74.2	0.16
3	797	744	719	753	39.8	0.05	606	570	769	809	737	739	705	95.0	0.13
4	931	872	834	879	48.9	0.06	706	690	837	884	906	876	817	94.6	0.12
5	962	914	890	922	36.7	0.04	733	738	913	932	915	948	863	99.7	0.12
6	966	940	898	935	34.3	0.04	831	773	937	1003	985	956	914	91.7	0.10
7	974	964	906	948	36.7	0.04	869	810	986	1011	949	999	937	80.8	0.09
8	885	878	831	865	29.4	0.03	832	705	854	928	887	873	847	76.5	0.09

Table F-31. Measured CO Emission Rates for NC-1859 and B10

Time-Based CO Emission Rates (g/s)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	2/1	2/1	2/1	3 Reps	3 Reps	3 Reps	1/23	1/23	1/26	1/26	1/27	1/27	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	0.09	0.05	0.03	0.05	0.03	0.56	0.03	0.04	0.07	0.08	0.06	0.13	0.07	0.03	0.47
High Idle	0.10	0.10	0.06	0.09	0.02	0.25	0.05	0.07	0.06	0.12	0.11	0.13	0.09	0.03	0.37
Dyn Brake	---	---	---	--	--	--	0.05	0.09	0.08	0.11	0.15	0.13	0.10	0.04	0.36
1	0.04	0.02	0.06	0.04	0.02	0.46	0.03	0.06	0.02	0.10	0.13	0.13	0.08	0.05	0.63
2	0.05	0.02	0.01	0.03	0.02	0.66	0.03	0.06	0.02	0.08	0.10	0.17	0.08	0.06	0.71
3	0.02	0.02	0.02	0.02	0.00	0.00	0.03	0.10	0.05	0.10	0.11	0.16	0.09	0.05	0.50
4	0.00	0.02	0.02	0.01	0.01	0.87	0.02	0.08	0.04	0.13	0.15	0.19	0.10	0.07	0.66
5	0.02	0.02	0.02	0.02	0.00	0.00	0.05	0.14	0.02	0.18	0.18	0.23	0.13	0.08	0.61
6	0.03	0.03	0.03	0.03	0.00	0.00	0.05	0.19	0.03	0.18	0.16	0.19	0.13	0.07	0.55
7	0.17	0.17	0.10	0.15	0.04	0.27	0.07	0.20	0.00	0.23	0.25	0.03	0.13	0.11	0.85
8	0.35	0.16	0.16	0.22	0.11	0.51	0.11	0.21	0.08	0.28	0.34	0.35	0.23	0.11	0.50

Fuel-Based CO Emission Rates (g/gal)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	2/1	2/1	2/1	3 Reps	3 Reps	3 Reps	1/23	1/23	1/26	1/26	1/27	1/27	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	96.0	54.8	27.1	59.3	34.6	0.58	33.3	50.5	127	88.6	64.3	132	82.7	40.7	0.49
High Idle	67.7	65.8	40.7	58.1	15.1	0.26	29.1	43.6	36.4	65.2	67.1	79.7	53.5	20.0	0.37
Dyn Brake	---	---	---	--	--	--	11.5	55.5	40.7	65.4	88.5	78.6	56.7	27.8	0.49
1	10.4	6.99	17.4	11.6	5.31	0.46	7.49	21.4	7.50	28.5	40.4	43.1	24.7	15.5	0.63
2	9.37	4.66	2.31	5.45	3.60	0.66	5.43	14.1	4.98	17.4	23.1	38.3	17.2	12.5	0.72
3	1.79	1.79	1.78	1.79	0.01	0.00	3.97	11.9	5.50	10.6	13.4	19.3	10.8	5.57	0.52
4	0.00	1.47	1.47	0.98	0.85	0.87	1.62	6.41	3.17	10.7	12.2	15.8	8.32	5.51	0.66
5	1.33	1.33	1.33	1.33	0.00	0.00	3.05	8.68	1.45	11.0	11.4	14.1	8.29	5.01	0.60
6	1.27	1.27	1.26	1.27	0.01	0.00	2.88	9.57	1.33	8.84	7.69	9.52	6.64	3.61	0.54
7	5.55	5.50	3.29	4.78	1.29	0.27	2.33	7.32	0.00	8.01	9.09	1.15	4.65	3.94	0.85
8	9.52	4.26	4.28	6.02	3.03	0.50	3.62	5.76	2.33	7.49	9.49	10.0	6.45	3.11	0.48

Engine Output-Based CO Emission Rates (g/bhp-hr)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	2/1	2/1	2/1	3 Reps	3 Reps	3 Reps	1/23	1/23	1/26	1/26	1/27	1/27	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	30.9	18.4	9.14	19.5	10.9	0.56	12.5	15.4	25.0	29.9	20.9	45.1	24.8	11.8	0.47
High Idle	35.9	35.6	22.1	31.2	7.90	0.25	18.3	26.7	22.3	43.4	38.8	47.7	32.9	12.1	0.37
Dyn Brake	---	---	---	--	--	--	16.8	31.9	29.9	40.1	53.6	48.2	36.7	13.4	0.36
1	0.71	0.47	1.18	0.79	0.36	0.46	0.48	1.18	0.46	1.82	2.51	2.55	1.50	0.94	0.63
2	0.51	0.25	0.13	0.30	0.19	0.66	0.26	0.64	0.25	0.87	0.99	1.77	0.80	0.57	0.71
3	0.09	0.09	0.09	0.09	0.00	0.00	0.18	0.53	0.26	0.51	0.60	0.86	0.49	0.24	0.50
4	0.00	0.07	0.07	0.05	0.04	0.87	0.07	0.28	0.14	0.47	0.53	0.68	0.36	0.24	0.66
5	0.06	0.06	0.06	0.06	0.00	0.00	0.13	0.38	0.07	0.50	0.50	0.63	0.37	0.22	0.61
6	0.06	0.06	0.06	0.06	0.00	0.00	0.12	0.43	0.06	0.41	0.35	0.42	0.30	0.16	0.55
7	0.26	0.25	0.15	0.22	0.06	0.27	0.10	0.27	0.00	0.30	0.34	0.04	0.18	0.15	0.83
8	0.47	0.21	0.21	0.30	0.15	0.51	0.14	0.25	0.10	0.33	0.41	0.42	0.27	0.14	0.50
Duty Cycle Avg (Raw)	0.6	0.3	0.2	0.4	0.16	0.45	0.2	0.4	0.3	0.6	0.6	0.8	0.5	0.23	0.46
Duty Cycle Avg (Adj)	0.6	0.3	0.2	0.4	0.16	0.45	0.2	0.4	0.3	0.6	0.6	0.8	0.5	0.23	0.46

Exhaust CO Concentrations (%)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	2/1	2/1	2/1	3 Reps	3 Reps	3 Reps	1/23	1/23	1/26	1/26	1/27	1/27	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	0.010	0.006	0.003	0.006	0.00	0.55	0.004	0.005	0.008	0.010	0.007	0.015	0.008	0.00	0.49
High Idle	0.008	0.008	0.005	0.007	0.00	0.25	0.004	0.006	0.005	0.010	0.009	0.011	0.008	0.00	0.38
Dyn Brake	---	---	---	--	--	--	0.004	0.007	0.006	0.009	0.012	0.011	0.008	0.00	0.37
1	0.003	0.002	0.005	0.003	0.00	0.46	0.002	0.005	0.002	0.008	0.011	0.011	0.007	0.00	0.64
2	0.004	0.002	0.001	0.002	0.00	0.65	0.002	0.005	0.002	0.007	0.008	0.014	0.006	0.00	0.71
3	0.001	0.001	0.001	0.001	0.00	0.00	0.002	0.006	0.003	0.006	0.007	0.010	0.006	0.00	0.51
4	0.000	0.001	0.001	0.001	0.00	0.87	0.001	0.004	0.002	0.007	0.008	0.010	0.005	0.00	0.67
5	0.001	0.001	0.001	0.001	0.00	0.00	0.002	0.006	0.001	0.008	0.008	0.010	0.006	0.00	0.62
6	0.001	0.001	0.001	0.001	0.00	0.00	0.002	0.007	0.001	0.007	0.006	0.007	0.005	0.00	0.55
7	0.005	0.005	0.003	0.004	0.00	0.27	0.002	0.006	0.000	0.007	0.008	0.001	0.004	0.00	0.85
8	0.009	0.004	0.004	0.006	0.00	0.51	0.003	0.005	0.002	0.007	0.009	0.009	0.006	0.00	0.51

Table F-32. Measured Hydrocarbon Emission Rates for NC-1859 and B10

Time-Based HC Emission Rates (g/s)															
Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	2/1	2/1	2/1	3 Reps	3 Reps	3 Reps	1/23	1/23	1/26	1/26	1/27	1/27	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	0.18	0.12	0.36	0.22	0.12	0.55	0.14	0.64	0.53	0.50	0.44	0.67	0.49	0.19	0.39
High Idle	0.31	0.36	0.41	0.36	0.05	0.14	0.24	0.54	0.52	0.71	0.64	0.73	0.57	0.18	0.32
Dyn Brake	---	---	---	--	--	--	0.26	0.69	0.66	0.75	0.88	0.82	0.68	0.22	0.32
1	0.08	0.08	0.18	0.11	0.06	0.54	0.29	0.37	0.24	0.63	0.73	0.82	0.51	0.24	0.47
2	0.08	0.06	0.12	0.09	0.03	0.40	0.26	0.33	0.37	0.56	0.48	0.92	0.49	0.24	0.49
3	0.05	0.06	0.16	0.09	0.06	0.67	0.26	0.56	0.45	0.61	0.74	0.98	0.60	0.24	0.41
4	0.07	0.04	0.10	0.07	0.03	0.40	0.30	0.74	0.34	0.86	0.91	1.04	0.70	0.31	0.44
5	0.09	0.05	0.14	0.09	0.04	0.47	0.38	0.94	0.52	1.31	0.93	1.21	0.88	0.37	0.42
6	0.16	0.14	0.16	0.16	0.01	0.07	0.54	1.43	0.37	1.27	0.90	1.04	0.93	0.41	0.44
7	0.18	0.26	0.13	0.19	0.07	0.34	0.40	1.47	0.05	1.38	1.11	1.75	1.03	0.66	0.65
8	0.12	0.09	0.06	0.09	0.03	0.33	0.65	1.20	1.42	1.27	1.04	1.61	1.20	0.33	0.28

Fuel-Based HC Emission Rates (g/gal)															
Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	2/1	2/1	2/1	3 Reps	3 Reps	3 Reps	1/23	1/23	1/26	1/26	1/27	1/27	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	199	133	382	238	129	0.54	134	760	963	531	487	705	597	284	0.48
High Idle	208	240	269	239	30.4	0.13	140	318	307	386	401	440	332	107	0.32
Dyn Brake	---	---	---	--	--	--	64.2	432	323	441	521	483	377	167	0.44
1	21.3	21.5	50.8	31.2	17.0	0.54	86.3	128	74.9	186	223	262	160	75.7	0.47
2	14.4	10.7	23.1	16.1	6.34	0.39	56.3	75.7	74.6	114	115	204	107	53.1	0.50
3	5.51	6.87	17.8	10.0	6.71	0.67	30.5	67.3	50.7	67.8	88.3	117	70.3	30.0	0.43
4	5.67	3.39	7.92	5.66	2.27	0.40	24.8	61.5	28.0	70.4	75.2	87.3	57.9	25.8	0.45
5	5.11	3.06	8.15	5.44	2.56	0.47	24.6	58.9	31.2	80.1	59.3	74.8	54.8	22.6	0.41
6	7.79	6.85	7.76	7.47	0.54	0.07	28.8	71.4	18.4	61.1	44.3	53.3	46.2	19.9	0.43
7	5.96	8.45	4.21	6.21	2.13	0.34	14.3	52.5	1.76	48.3	40.1	62.5	36.6	23.6	0.65
8	3.25	2.46	1.64	2.45	0.80	0.33	20.4	33.6	40.2	34.5	29.1	46.0	34.0	8.86	0.26

Engine Output-Based HC Emission Rates (g/bhp-hr)															
Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	2/1	2/1	2/1	3 Reps	3 Reps	3 Reps	1/23	1/23	1/26	1/26	1/27	1/27	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	64.2	44.8	129	79.2	43.9	0.55	50.2	232	189	179	159	240	175	68.5	0.39
High Idle	110	130	146	129	17.8	0.14	87.9	195	188	256	232	263	204	64.5	0.32
Dyn Brake	---	---	---	--	--	--	93.6	249	237	270	315	296	243	78.9	0.32
1	1.45	1.45	3.4	2.11	1.14	0.54	5.49	7.09	4.61	11.9	13.8	15.5	9.73	4.60	0.47
2	0.78	0.58	1.26	0.87	0.35	0.40	2.71	3.42	3.77	5.75	4.95	9.44	5.01	2.43	0.49
3	0.27	0.33	0.87	0.49	0.33	0.67	1.39	3.00	2.41	3.25	3.93	5.21	3.20	1.31	0.41
4	0.26	0.16	0.37	0.26	0.10	0.40	1.08	2.65	1.21	3.09	3.27	3.75	2.51	1.11	0.44
5	0.24	0.15	0.39	0.26	0.12	0.47	1.05	2.59	1.43	3.63	2.59	3.35	2.44	1.03	0.42
6	0.37	0.32	0.37	0.35	0.03	0.07	1.23	3.23	0.84	2.85	2.03	2.35	2.09	0.92	0.44
7	0.27	0.39	0.20	0.29	0.10	0.34	0.61	1.96	0.07	1.84	1.48	2.34	1.38	0.87	0.63
8	0.16	0.12	0.08	0.12	0.04	0.33	0.78	1.44	1.70	1.52	1.25	1.93	1.44	0.40	0.28
Duty Cycle Avg (Raw)	0.27	0.21	0.46	0.31	0.13	0.42	0.52	1.39	1.13	1.40	1.27	1.74	1.24	0.41	0.33
Duty Cycle Avg (Adj)	0.68	0.52	1.16	0.79	0.33	0.42	1.30	3.46	2.82	3.50	3.19	4.35	3.10	1.02	0.33

Exhaust HC Concentrations (ppm)															
Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	2/1	2/1	2/1	3 Reps	3 Reps	3 Reps	1/23	1/23	1/26	1/26	1/27	1/27	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	27	19	55	34	18.9	0.56	21	98	79	78	69	104	75	29.5	0.39
High Idle	32	38	43	38	5.51	0.15	25	57	55	77	70	79	61	20.0	0.33
Dyn Brake	---	---	---	--	--	--	29	71	62	79	92	88	70	23.0	0.33
1	8	8	19	12	6.35	0.54	30	39	26	68	79	87	55	26.4	0.48
2	8	6	13	9	3.61	0.40	27	35	39	60	52	97	52	25.2	0.49
3	4	5	13	7	4.93	0.67	20	44	36	50	60	79	48	20.3	0.42
4	5	3	7	5	2.00	0.40	20	50	23	60	64	72	48	21.9	0.45
5	5	3	8	5	2.52	0.47	21	53	28	76	54	69	50	21.8	0.44
6	8	7	8	8	0.58	0.08	26	68	18	63	45	51	45	19.9	0.44
7	7	10	5	7	2.52	0.34	16	56	2	55	46	71	41	26.4	0.64
8	4	3	2	3	1.00	0.33	22	38	45	42	36	54	40	10.7	0.27

Table F-33. Measured Particulate Matter Emission Rates for NC-1859 and B10

Time-Based PM Emission Rates (g/s)

Throttle Notch Position	Rail Yard Measurements						Over-The-Rail Measurements								
	2/1	2/1	2/1	3 Reps	3 Reps	3 Reps	1/23	1/23	1/26	1/26	1/27	1/27	6 Trains	6 Trains	6 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	0.01	0.01	0.01	0.01	0.00	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.20
High Idle	0.02	0.01	0.01	0.02	0.00	0.10	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.18
Dyn Brake	---	---	---	--	--	--	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.19
1	0.01	0.01	0.01	0.01	0.00	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.20
2	0.02	0.02	0.02	0.02	0.00	0.01	0.02	0.02	0.01	0.01	0.02	0.01	0.02	0.00	0.19
3	0.02	0.02	0.02	0.02	0.00	0.01	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.00	0.17
4	0.03	0.03	0.03	0.03	0.00	0.07	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.01	0.21
5	0.04	0.04	0.04	0.04	0.00	0.03	0.04	0.05	0.04	0.03	0.04	0.03	0.04	0.01	0.17
6	0.05	0.04	0.04	0.04	0.00	0.05	0.05	0.06	0.04	0.04	0.06	0.06	0.05	0.01	0.14
7	0.10	0.09	0.09	0.10	0.01	0.06	0.10	0.14	0.11	0.10	0.13	0.14	0.12	0.02	0.16
8	0.23	0.16	0.15	0.18	0.04	0.22	0.16	0.21	0.14	0.16	0.22	0.24	0.19	0.04	0.20

Fuel-Based PM Emission Rates (g/gal)

Throttle Notch Position	Rail Yard Measurements						Over-The-Rail Measurements								
	2/1	2/1	2/1	3 Reps	3 Reps	3 Reps	1/23	1/23	1/26	1/26	1/27	1/27	6 Trains	6 Trains	6 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	19.6	17.2	17.7	18.2	1.26	0.07	14.3	20.9	23.6	11.0	14.6	11.7	16.0	5.08	0.32
High Idle	16.0	13.5	12.9	14.1	1.60	0.11	10.1	12.3	8.19	6.86	10.6	9.76	9.63	1.89	0.20
Dyn Brake	---	---	---	--	--	--	4.29	12.3	6.73	6.71	9.64	8.70	8.07	2.79	0.35
1	5.1	5.04	4.95	5.03	0.07	0.01	5.57	8.39	4.78	4.37	5.03	5.17	5.55	1.45	0.26
2	3.98	4.01	3.92	3.97	0.04	0.01	5.23	6.37	4.03	3.44	4.96	4.07	4.68	1.05	0.23
3	3.27	3.26	3.20	3.24	0.04	0.01	4.05	4.78	3.14	2.92	3.54	3.35	3.63	0.68	0.19
4	3.30	2.88	3.13	3.10	0.21	0.07	4.06	5.18	3.25	3.37	3.71	2.99	3.76	0.79	0.21
5	3.43	3.26	3.21	3.30	0.12	0.04	3.97	4.23	3.01	2.69	3.47	2.81	3.36	0.63	0.19
6	3.04	2.79	2.88	2.91	0.13	0.04	3.81	4.29	2.99	2.95	3.86	4.10	3.67	0.57	0.15
7	4.54	4.16	4.05	4.25	0.26	0.06	4.81	6.85	5.26	4.63	6.23	6.87	5.78	1.00	0.17
8	8.39	6.07	5.78	6.75	1.43	0.21	7.15	8.28	5.58	6.10	8.35	9.54	7.50	1.50	0.20

Engine Output-Based PM Emission Rates (g/bhp-hr)

Throttle Notch Position	Rail Yard Measurements						Over-The-Rail Measurements								
	2/1	2/1	2/1	3 Reps	3 Reps	3 Reps	1/23	1/23	1/26	1/26	1/27	1/27	6 Trains	6 Trains	6 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	4.59	4.20	4.34	4.38	0.20	0.05	3.90	4.63	3.37	2.71	3.46	2.90	3.50	0.70	0.20
High Idle	6.15	5.30	5.11	5.52	0.55	0.10	4.64	5.47	3.65	3.32	4.45	4.25	4.30	0.76	0.18
Dyn Brake	---	---	---	--	--	--	4.55	5.16	3.59	2.99	4.24	3.88	4.07	0.76	0.19
1	0.25	0.25	0.24	0.25	0.00	0.02	0.26	0.34	0.21	0.20	0.23	0.22	0.24	0.05	0.20
2	0.16	0.16	0.16	0.16	0.00	0.01	0.18	0.21	0.15	0.13	0.15	0.14	0.16	0.03	0.19
3	0.12	0.12	0.11	0.11	0.00	0.01	0.13	0.15	0.11	0.10	0.11	0.11	0.12	0.02	0.17
4	0.11	0.10	0.11	0.10	0.01	0.07	0.13	0.16	0.10	0.11	0.12	0.09	0.12	0.02	0.21
5	0.12	0.11	0.11	0.11	0.00	0.03	0.12	0.14	0.10	0.09	0.11	0.09	0.11	0.02	0.17
6	0.11	0.10	0.10	0.10	0.00	0.05	0.12	0.14	0.10	0.10	0.13	0.13	0.12	0.02	0.14
7	0.15	0.14	0.14	0.14	0.01	0.06	0.22	0.19	0.15	0.13	0.17	0.19	0.17	0.03	0.19
8	0.30	0.22	0.21	0.24	0.05	0.22	0.20	0.26	0.17	0.20	0.26	0.29	0.23	0.05	0.20
Duty Cycle Avg (Raw)	0.05	0.04	0.04	0.04	0.01	0.15	0.04	0.05	0.03	0.04	0.05	0.05	0.04	0.01	0.17
Duty Cycle Avg (Adj)	0.26	0.21	0.20	0.22	0.03	0.15	0.19	0.25	0.17	0.18	0.23	0.25	0.21	0.04	0.17

Exhaust PM Concentrations (mg/m^3)

Throttle Notch Position	Rail Yard Measurements						Over-The-Rail Measurements								
	2/1	2/1	2/1	3 Reps	3 Reps	3 Reps	1/23	1/23	1/26	1/26	1/27	1/27	6 Trains	6 Trains	6 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	3.4	3.1	3.2	3.2	0.13	0.04	2.8	3.4	2.4	2.1	2.6	2.2	2.6	0.49	0.19
High Idle	3.1	2.7	2.6	2.8	0.26	0.09	2.3	2.8	1.9	1.7	2.3	2.2	2.2	0.38	0.17
Dyn Brake	---	---	---	--	--	--	2.5	2.6	1.6	1.5	2.2	2.0	2.1	0.42	0.20
1	2.4	2.4	2.3	2.4	0.04	0.02	2.4	3.2	2.1	2.0	2.3	2.2	2.4	0.44	0.19
2	2.8	2.8	2.8	2.8	0.02	0.01	3.2	3.7	2.7	2.3	2.8	2.5	2.9	0.52	0.18
3	3.0	3.0	3.0	3.0	0.02	0.01	3.4	3.9	2.8	2.7	3.0	2.9	3.1	0.46	0.15
4	3.7	3.2	3.5	3.5	0.23	0.07	4.1	5.3	3.4	3.6	4.0	3.1	3.9	0.78	0.20
5	4.2	4.0	4.0	4.1	0.14	0.03	4.3	4.8	3.4	3.2	4.0	3.3	3.8	0.64	0.17
6	3.9	3.6	3.8	3.8	0.17	0.04	4.4	5.2	3.7	3.8	5.0	5.0	4.5	0.63	0.14
7	6.7	6.2	6.1	6.3	0.34	0.05	6.8	9.2	7.6	6.7	9.0	9.9	8.2	1.36	0.17
8	13.1	9.4	8.9	10.4	2.28	0.22	9.8	11.8	7.9	9.4	13.0	14.2	11.0	2.39	0.22

Table F-34. Measured CO_2 Emission Rates for NC-1859 and B10

Time-Based CO_2 Emission Rates (g/s)															
Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	2/1	2/1	2/1	3 Reps	3 Reps	3 Reps	1/23	1/23	1/26	1/26	1/27	1/27	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	8.8	9.25	9.17	9.07	0.25	0.03	10.3	8.06	5.07	9.02	8.75	8.92	8.36	1.77	0.21
High Idle	14.5	14.8	14.8	14.7	0.18	0.01	17.4	16.7	16.7	18.0	15.6	16.1	16.8	0.85	0.05
Dyn Brake	---	---	---	--	--	--	40.6	15.5	20.0	16.5	16.2	16.4	20.9	9.77	0.47
1	36.1	35.8	35.7	35.8	0.21	0.01	33.6	29.1	32.6	33.3	32.3	30.8	32.0	1.73	0.05
2	53.1	53.2	53.3	53.2	0.14	0.00	46.9	43.9	49.3	48.8	41.7	44.5	45.8	2.98	0.07
3	91.4	92.0	92.1	91.8	0.40	0.00	85.7	83.7	89.5	90.2	83.4	83.3	86.0	3.14	0.04
4	130	130	130	130	0.32	0.00	122	120	121	122	121	119	121	1.03	0.01
5	172	174	173	173	0.73	0.00	155	159	166	164	158	162	161	4.17	0.03
6	213	211	212	212	0.67	0.00	190	201	204	208	205	196	201	6.37	0.03
7	309	310	311	310	1.15	0.00	282	281	298	286	277	282	284	7.29	0.03
8	373	373	370	372	1.57	0.00	319	358	354	369	358	350	351	17.12	0.05

Fuel-Based CO_2 Emission Rates (g/gal)															
Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	2/1	2/1	2/1	3 Reps	3 Reps	3 Reps	1/23	1/23	1/26	1/26	1/27	1/27	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	9801	9906	9797	9835	61.8	0.01	9940	9528	9283	9609	9674	9433	9578	224	0.02
High Idle	9840	9823	9845	9836	11.4	0.00	9943	9811	9829	9735	9723	9679	9787	94.9	0.01
Dyn Brake	---	---	---	--	--	--	10017	9722	9812	9701	9615	9654	9753	145	0.01
1	10045	10050	10016	10037	18.5	0.00	10009	9962	10016	9915	9874	9846	9937	70.6	0.01
2	10051	10060	10056	10056	4.86	0.00	10031	10006	10021	9977	9967	9889	9982	51.7	0.01
3	10068	10067	10061	10065	4.11	0.00	10049	10014	10034	10016	9999	9972	10014	27.0	0.00
4	10071	10070	10067	10069	1.92	0.00	10056	10026	10052	10014	10009	9996	10026	24.3	0.00
5	10069	10070	10067	10069	1.57	0.00	10054	10024	10053	10008	10020	10006	10028	21.3	0.00
6	10067	10068	10067	10068	0.32	0.00	10052	10015	10061	10023	10035	10027	10035	17.7	0.00
7	10062	10060	10066	10063	3.17	0.00	10062	10031	10073	10032	10035	10034	10044	18.3	0.00
8	10057	10066	10067	10063	5.19	0.00	10056	10045	10046	10041	10041	10030	10043	8.33	0.00

Engine Output-Based CO_2 Emission Rates (g/bhp-hr)															
Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	2/1	2/1	2/1	3 Reps	3 Reps	3 Reps	1/23	1/23	1/26	1/26	1/27	1/27	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	3161	3331	3302	3265	90.7	0.03	3720	2902	1826	3246	3150	3210	3009	638	0.21
High Idle	5221	5313	5344	5293	64.0	0.01	6257	6025	6029	6472	5625	5795	6034	305	0.05
Dyn Brake	---	---	---	--	--	--	14603	5594	7197	5946	5823	5920	7514	3518	0.47
1	684	678	676	679	4.04	0.01	637	550	617	632	613	584	605	32.8	0.05
2	546	547	549	547	1.47	0.00	483	452	507	502	429	458	472	30.7	0.07
3	487	491	491	490	2.13	0.00	457	447	478	481	445	444	458	16.7	0.04
4	469	469	467	468	1.17	0.00	438	432	435	440	435	430	435	3.70	0.01
5	477	481	480	479	2.01	0.00	429	441	461	454	438	448	445	11.6	0.03
6	479	476	477	477	1.51	0.00	428	452	459	468	460	442	452	14.3	0.03
7	463	465	467	465	1.72	0.00	376	374	397	381	370	375	379	9.71	0.03
8	497	497	494	496	2.09	0.00	383	430	425	443	430	420	422	20.54	0.05

Exhaust CO_2 Concentrations (%)															
Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	2/1	2/1	2/1	3 Reps	3 Reps	3 Reps	1/23	1/23	1/26	1/26	1/27	1/27	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 73	Train 74	Train 73	Train 74	Train 75	Train 76	Average	StDev	CV
Low Idle	0.65	0.69	0.69	0.68	0.02	0.03	0.76	0.60	0.37	0.69	0.67	0.68	0.63	0.14	0.22
High Idle	0.74	0.76	0.77	0.76	0.02	0.02	0.87	0.86	0.86	0.95	0.83	0.85	0.87	0.04	0.05
Dyn Brake	---	---	---	--	--	--	2.21	0.78	0.92	0.85	0.83	0.86	1.08	0.56	0.52
1	1.84	1.83	1.83	1.83	0.01	0.00	1.70	1.48	1.70	1.77	1.71	1.60	1.66	0.10	0.06
2	2.73	2.75	2.77	2.75	0.02	0.01	2.35	2.26	2.56	2.56	2.20	2.30	2.37	0.15	0.06
3	3.57	3.58	3.60	3.58	0.02	0.00	3.22	3.20	3.48	3.61	3.32	3.29	3.35	0.16	0.05
4	4.34	4.36	4.35	4.35	0.01	0.00	3.96	3.98	4.03	4.17	4.16	4.03	4.06	0.09	0.02
5	4.81	4.82	4.83	4.82	0.01	0.00	4.20	4.41	4.41	4.64	4.46	4.51	4.44	0.14	0.03
6	5.05	5.03	5.07	5.05	0.02	0.00	4.44	4.66	4.80	5.05	4.98	4.69	4.77	0.22	0.05
7	5.77	5.82	5.84	5.81	0.04	0.01	5.50	5.23	5.60	5.58	5.62	5.57	5.52	0.15	0.03
8	6.05	6.01	5.99	6.02	0.03	0.01	5.30	5.55	5.49	5.97	6.06	5.75	5.69	0.29	0.05

F.4 Summary of Results for NC-1859 on ULSD

The project used a PEMS to conduct RY and OTR measurements on the prime mover engine of locomotive NC-1859 (City of High Point) in August and September 2013 as it operated on ULSD. The prime mover engine was an EMD 12-710G3B. The engine was originally manufactured in 1988 and was rebuilt by AMTRAK in 2012. The 140 L engine has a peak engine output of 3000 HP at an engine speed of 900 RPM. The prime mover engine operated on ULSD.

Rail Yard Measurements

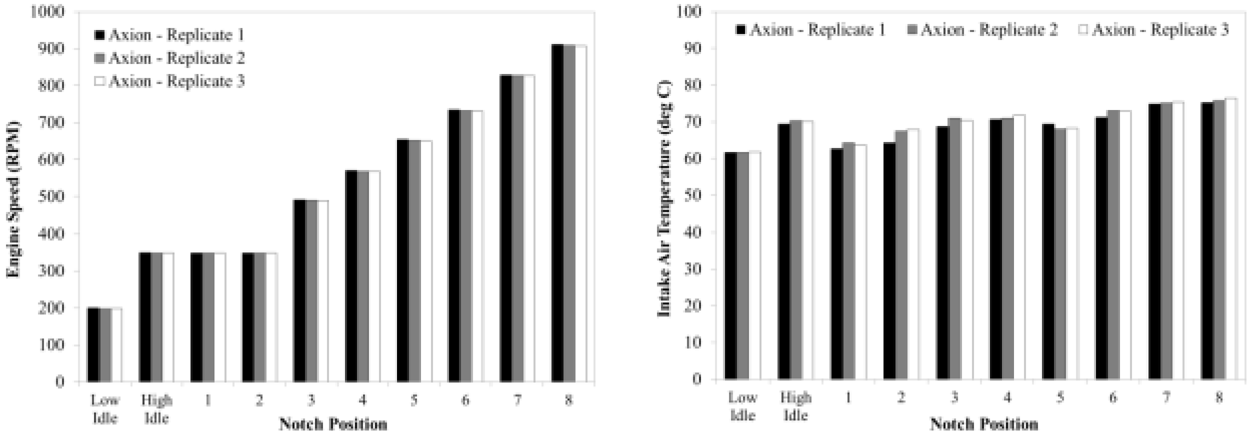
On September 1, 2013, three rail yard emissions measurement replicates were conducted on the prime mover engine of NC-1859. Results for the rail yard measurements are presented and discussed in this section. The most recent results are compared to previous measurements of the prime mover engine of NC-1859.

The cycle average emission rates for the rail yard measurements of the NC-1859 prime mover engine are shown in Table F-35. These cycle average emission rates are based on the measured engine activity data (RPM, MAP, and IAT) and measured exhaust concentrations. There was little variability between replicate measured engine activity data, given in Figure F-19. This indicates that the prime mover engine was operating consistently during all three replicate measurements.

An increasing trend in fuel use rates was apparent as notch position increased during the rail yard measurements, as shown in Figure F-20. Higher inter-replicate variability was observed at notches 7 and 8. The NO emission rates estimated with the Axion during the three replicates were fairly consistent, as shown in Figure F-21. There was variability in the estimated HC emission rates between the three replicate measurements and the two PEMS systems, as shown in Figure F-22. Inter-replicate variability in the estimated HC emission rates were, on average, 22 percent. There was also variability in the estimated CO emission rates between the three replicate measurements, as shown in Figure F-23. Inter-replicate variability in the estimated CO emission rates were, on average, 37 percent. There was variability in the measured PM concentrations between the three replicate measurements, as shown in Figure F-24. However, the PM concentrations measured were of the same magnitude as previous rail yard measurements.

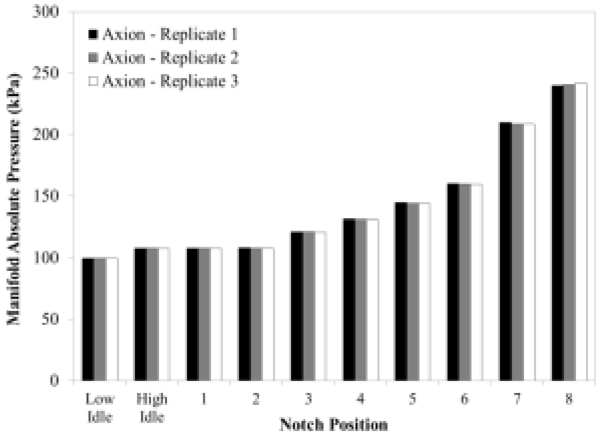
There was little variability in the NO_x and PM cycle average emission rates among the replicates. The variability amongst the three replicates for CO and HC are 15 and 18 percent, respectively. Differences in emission rates are attributable to differences in measured exhaust concentrations. Values for engine activity parameters (RPM, IAT, MAP) were similar across all measurements, as given in Figure F-19.

Figure F-19. Measured Engine Activity Data during Rail Yard Measurements of the NC-1859 Prime Mover Engine with ULSD



(a) Engine Speed

(b) Intake Air Temperature



(c) Manifold Absolute Pressure

Figure F-20. Estimated Fuel Use Rates during Rail Yard Measurements of the NC-1859 Prime Mover Engine with ULSD

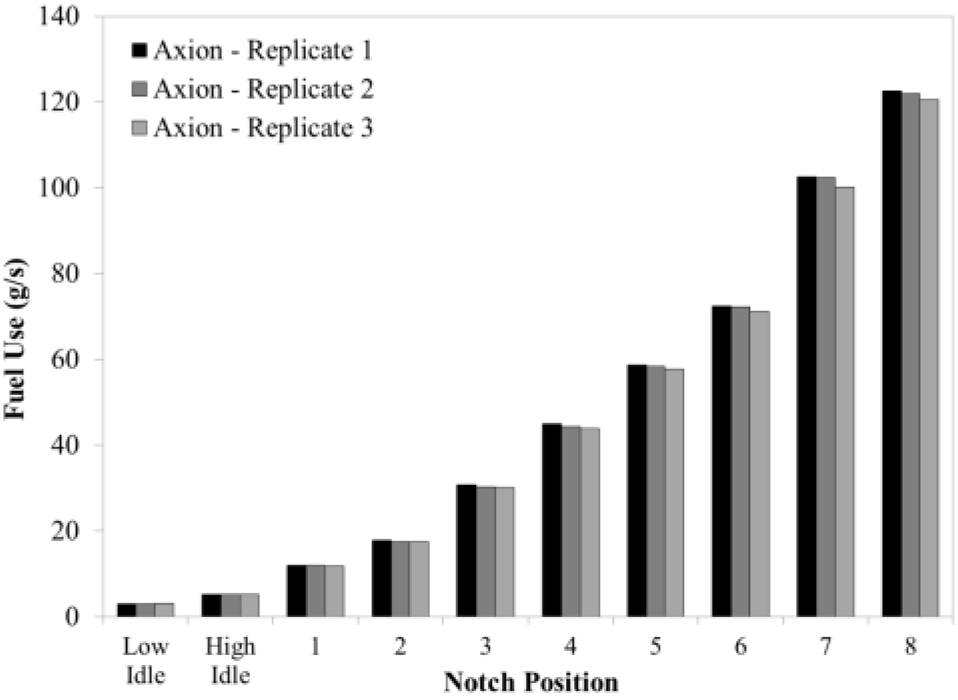


Figure F-21. Estimated NO Emission Rates during Rail Yard Measurements of the NC-1859 Prime Mover Engine with ULSD

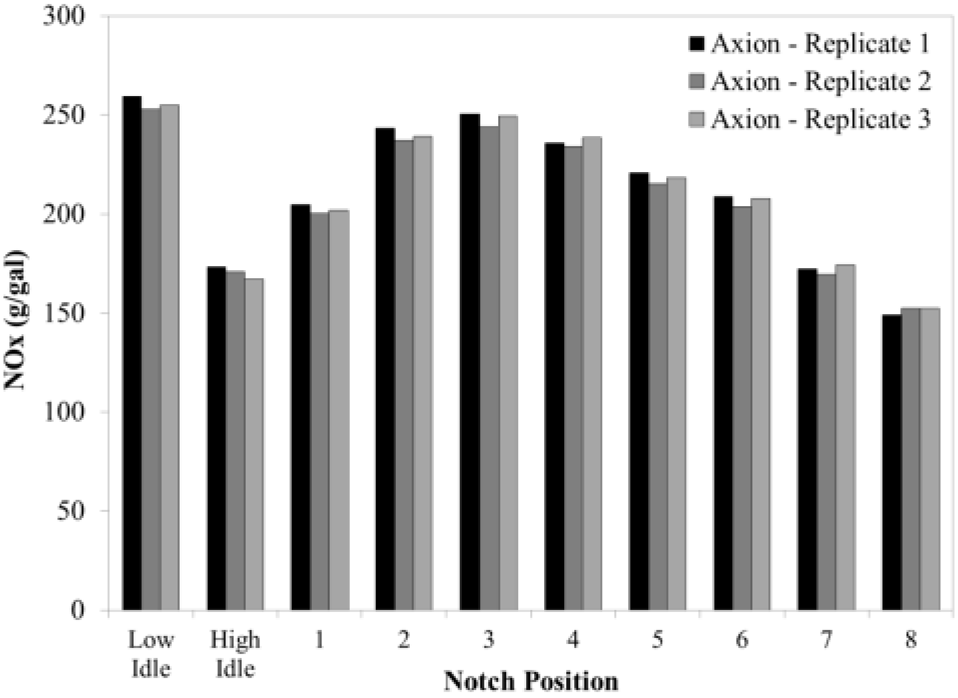


Figure F-22. Estimated HC Emission Rates during Rail Yard Measurements of the NC-1859 Prime Mover Engine with ULSD

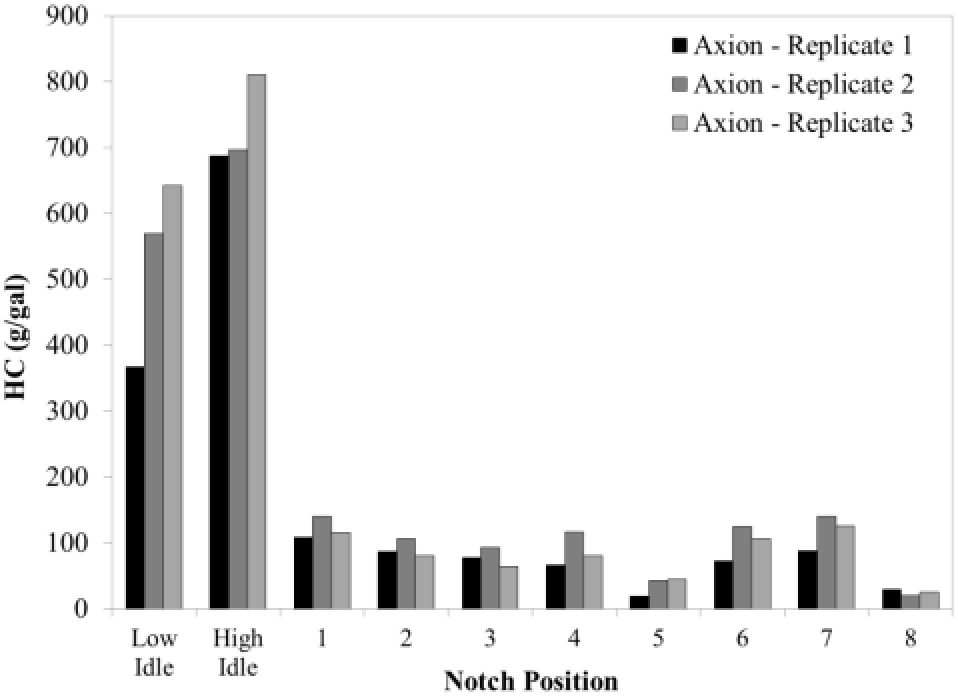


Figure F-23. Estimated CO Emission Rates during Rail Yard Measurements of the NC-1859 Prime Mover Engine with ULSD

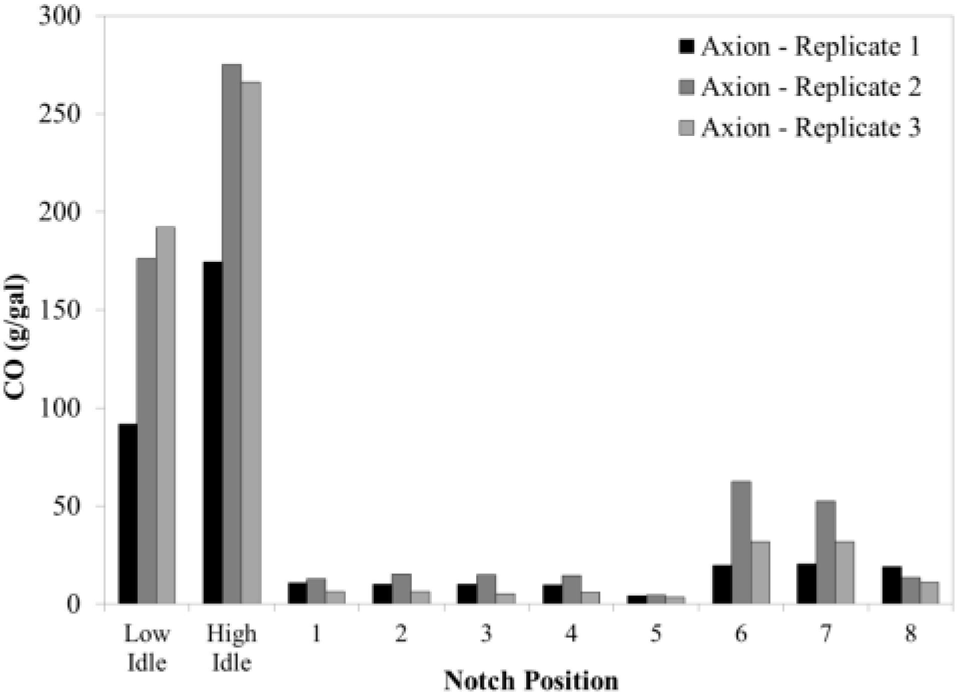


Figure F-24. Measured PM Concentrations during Rail Yard Measurements of the NC-1859 Prime Mover Engine with ULSD

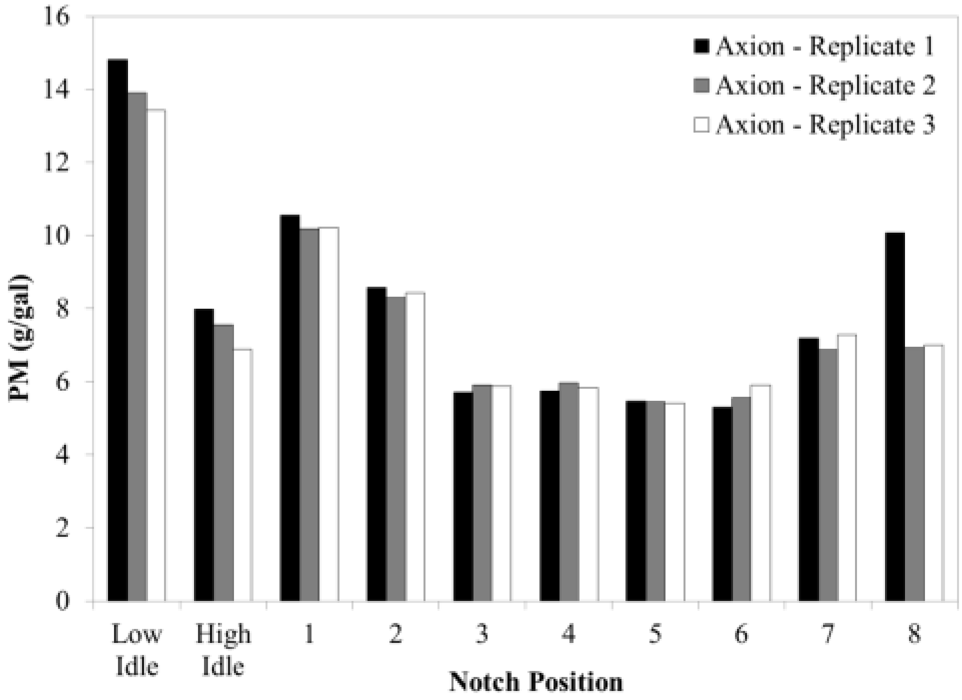


Table F-35. Cycle Average Emission Rates for Rail Yard Replicate Measurements of NC-1859 Prime Mover Engine with ULSD

	NO_x **(g/bhp-hr)**	**HC** **(g/bhp-hr)**	**CO** **(g/bhp-hr)**	**Opacity-based PM** **(g/bhp-hr)**
Replicate 1	7.0	3.62	1.6	0.38
Replicate 2	6.9	5.24	2.2	0.39
Replicate 3	7.2	4.60	1.9	0.39
Sept. 1, 2013	**7.0**	**4.49**	**1.9**	**0.39**
Coefficient of Variation	*0.02*	*0.18*	*0.15*	*0.02*

† NO_x, HC, and PM are adjusted with multipliers of 1.05, 2.5, and 5, respectively, as bias correction.

Over-the-Rail Measurements

Three days of OTR measurements on the NC-1859 prime mover engine were conducted on August 30 and 31, 2013 and September 2, 2013. Results for the over-the-rail measurements are presented and discussed in this section, and are compared to previous measurements of the prime mover engine of NC-1859.

The cycle average emission rates for the over-the-rail measurements of the NC-1859 prime mover engine are shown in Table F-36. These cycle average emission rates are based on the measured engine activity data (RPM, MAP, and IAT) and measured exhaust concentrations. There was little variability between measured engine activity data during all three days of measurements. This indicates that the prime mover engine was operating consistently during over-the-rail measurements. Measured engine activity data during OTR measurements were similar to the measured engine activity data during RY measurements.

The cycle average OTR emission rates are quantitatively similar to the cycle average RY emission rates measured in September 2013. There was less than one percent variability amongst the six one way trips with regard to cycle average NO_x emission rates. The average cycle average over-the-rail NO_x emission rate over six one-way trips was 14 percent lower than the cycle average rail yard NO_x emission rates. There was higher variability amongst the six one-way cycle average PM (14 percent), CO (34 percent), and HC (77 percent) emission rates. The average cycle average over-the-rail CO emission rate was 60 percent lower than the cycle average CO emission rates estimated from rail yard measurements. The average cycle average over-the-rail PM emission rate was 8 percent higher than the cycle average PM emission rate estimated from rail yard measurements. The average cycle average over-the-rail HC emission rate was 19 percent lower than the cycle average rail yard HC emission rate. Differences in emission rates are attributable to differences in measured exhaust concentrations. Values for engine activity parameters (RPM, IAT, MAP) were similar across all measurements.

Table F-36. Cycle Average Emission Rates for Over-the-Rail Measurements of NC-1859 Prime Mover Engine with ULSD

	NO_x (g/bhp-hr)	**HC** (g/bhp-hr)	**CO** (g/bhp-hr)	**Opacity-based PM** (g/bhp-hr)
Aug. 30, 2013 – Train 75	6.2	3.41	0.8	0.46
Aug. 30, 2013 – Train 76	6.2	9.01	0.6	0.40
Aug. 31, 2013 – Train 73	5.6	1.42	0.6	0.40
Aug. 31, 2013 – Train 74	6.3	3.89	0.5	0.51
Sept. 2, 2013 – Train 73	6.2	2.08	1.0	0.39
Sept, 2, 2013 – Train 74	5.6	2.02	1.2	0.35
Average	**6.0**	**3.64**	**0.8**	**0.42**
Coefficient of Variation	*0.05*	*0.77*	*0.34*	*0.14*

† NO_x, HC, and PM are adjusted with multipliers of 1.05, 2.5, and 5, respectively, as bias correction.

OTR cycle average NO_x emission rates are lower than during RY measurements. Cycle average HC, CO, and PM emission rates are higher during OTR measurements. Differences in cycle average emission rates between RY and OTR measurements can be attributed to various factors. RPM and MAP was essentially the same for RY and OTR measurements. IAT differed on an absolute basis by less than 6 percent from run-to-run during OTR measurements. At notch 8, the engine output during RY measurements was 2700 horsepower, while engine output was 3000 horsepower during over-the-rail measurements. With notch 8 accounting for 16 percent of the EPA line-haul duty cycle used to estimate cycle average emission rates, higher engine output decreases engine output based emission rates and, therefore, cycle average emission rates. Finally, differences in measured exhaust concentrations between RY and OTR measurements lead to differences in fuel use and emission rates.

Throttle notch position data was obtained from the locomotive data activity recorder to measure the duty cycles for the OTR measurements. The measured duty cycles are compared to the EPA line-haul duty cycle in Table F-37. The prime mover engine operated in notch 8 during the over-the-rail tests more than double the percentage of time, on average, the EPA estimates a line-haul locomotive is operating in notch 8. The average percentage of time the prime mover engine operated in idle through notch 7 during the over-the-rail tests was lower than the percentage of time the EPA estimates a line-haul locomotive is operating in those throttle notch settings, with the exception of dynamic braking, where the amount of time spent during the six one-way trips was similar to the percentage of time allocated in the line-haul duty cycle.

Table F-37. Over-the-Rail Duty Cycles During Measurement of NC-1859 on ULSD

Notch	Percent Time in Each Notch							
	EPA Line-Haul	Measured Over-the-Rail						
		Average	8/30/2013 Train 75	8/30/2013 Train 76	8/31/2013 Train 73	8/31/2013 Train 74	9/2/2013 Train 73	9/2/2013 Train 74
Idle	38.0	27.6	33.0	36.7	22.0	15.3	28.9	28.5
DB	12.5	12.8	11.8	14.0	13.8	9.5	14.7	13.4
1	6.5	2.7	1.5	0.6	4.0	6.6	0.7	3.3
2	6.5	3.3	2.4	1.7	3.0	8.2	2.2	2.8
3	5.2	3.3	4.1	2.8	1.8	7.1	2.5	1.6
4	4.4	2.7	4.1	2.3	1.4	2.3	4.6	1.6
5	3.8	2.0	2.4	2.1	1.6	1.8	3.2	0.9
6	3.9	1.8	2.1	3.0	0.4	0.7	3.8	0.7
7	3.0	0.6	0.5	1.2	0.1	0.3	1.6	0.1
8	16.2	42.9	38.1	35.6	52.0	48.4	37.7	47.0

Supplemental tables provide the details from results of the field measurements, the fuel use, and the emission rates for RY and OTR measurements of NC-1859 using ULSD biodiesel.

Table F-38 summarizes the average measured engine speed (RPM), intake air temperature (IAT), and manifold absolute pressure (MAP) for each throttle notch position and for each replicate of the RY test and for each one-way OTR trip. Engine speed ranges from 238 to 904 RPM in both RY and OTR measurements. For the RY measurements, engine RPM was highly repeatable, with a standard deviation of less than 1 RPM for all notch positions. For the OTR measurements, the RPM was also repeatable, with a standard deviation of less than 1 RPM, except in dynamic braking, which was a transient mode of operation. The intake air temperature varies with ambient temperature and was generally in the range of 58 to 85 degrees C during all measurements. MAP was highly repeatable in the RY tests, ranging from 99 to 234 kPa with an inter-test standard deviation of less than 3 kPa for most notch settings. For OTR measurements, there was slightly more inter-run variability. However, the ratio of the standard deviation to the mean of the run average MAP values for each notch position was typically 0.02 or less. Overall, the engine activity during the measurements was consistent from test to test for the three replicates in the rail yard, and from run to run for the six one-way trips observed between Raleigh and Charlotte.

Table F-39 summarizes the estimated fuel use rates inferred from the engine data of Table F-38 and volumetric efficiency measured in dynamometer tests of a similar engine. For the RY tests, fuel use rates from 3.0 to 127 g/sec depending on notch position, and was highly repeatable, with a coefficient of variation (CV) or the standard deviation divided by the mean, of typically 0.02 or less at high engine load. The CV was slightly higher at low engine load, but the absolute variability in fuel use rates at low load was small. There was more variability in run-to-run estimates of fuel use for the OTR measurements, in part because the amount of time spent in some notch positions was low. The OTR estimated fuel use ranged from 1.6 to 119 g/sec, with CV of only 0.01 for Notch 8.

During RY measurements, the maximum engine output was 2,700 hp, whereas during OTR measurements the maximum engine output was 3,000 hp. Furthermore, as shown later in Table F-44, the average CO_2 concentrations for each notch position are lower for OTR than for RY measurements, which implies a lower fuel-to-air ratio. Because the engine activity and, therefore, engine air flow, are approximately the same for OTR versus RY measurements, the combination of higher engine output and lower fuel-to-air ratio lead to higher values of fuel-specific engine output (FSEO) in bhp-hr per gallon of fuel consumed, as shown in Table F-39. The FSEO was highly repeatable for the OTR measurements of Notch 8, which represents significant portion of the observed duty cycle. In contrast, there was large inter-run variation for some notches, such as notches 3 and 7. However, these notches were rarely used compared to other notches, and thus the apparent variation was an artifact of small sample sizes.

The measured NO exhaust concentration and the estimated NO_x emission rates are shown in Table F-40 for each notch position, each RY test replicate, and each OTR one-way run. The average measured concentrations range among notch positions from approximately 130 to 800 ppm in the RY tests, and 110 to 760 ppm in the OTR measurements. The measurements are highly repeatable for the RY and OTR measurements, with CVs typically less than 0.06 for the former and less than 0.11 for the latter. The estimated mass emission rates range from 0.2 to 4.5 g/sec for the RY measurements and 0.2 to 4.3 g/sec for the OTR measurements. Because the observed concentrations tend to be lower for the OTR versus RY measurements, the mass emission rates also tend to be slightly lower for the OTR versus RY measurements.

On a fuel basis, the average NO_x emission rates range from 100 to 220 g/gallon among notch positions for the RY measurements and 100 to 310 g/gallon for the OTR measurements. For the RY measurements, the fuel-based emission rates are highly repeatable, with CV typically less than 0.08. The OTR measurements have more run-to-run variability but are nonetheless consistent, with CVs ranging from 0.03 to 0.18 in most cases. The fuel-based emission rates tend to be lowest at high load.

On an engine output basis, the notch average NO_x emission rates range from 5.6 g/bhp-hr at Notch 8 to 10.1 g/bhp-hr at notch 1 in the RY measurements, with very high values at idle during which engine output was very low. For the OTR measurements, the notch average emission rates range from 4.9 g/bhp-hr at notch 8 to 11.2 g/bhp-hr at notch 1, with much higher values during idle and dynamic braking. In general, the emission rates on an engine output basis are lower for the OTR measurements than for the RY measurements. This results from a combination of lower exhaust concentration and higher engine output, especially at notch 8.

Results are given for exhaust concentrations and emission rates in Tables F-41, F-42, F-43, and F-44 for CO, HC, PM, and CO_2, respectively. The CO exhaust concentrations during OTR measurements tend to be lower than during RY measurements, a result of lower measured exhaust concentrations. Thus, the cycle average CO emission rates also tend to be lower for OTR than RY measurements. On average, the HC exhaust concentrations and average emission rates tend to be higher for OTR than RY. However, both the CO and HC emission rates are low on an absolute basis, and some of the measured average concentrations for a given notch position and replicate or run are below the gas analyzer detection limit. For PM, the measured exhaust levels tend to be higher for OTR than RY for a given notch position, and thus the cycle average PM emission rate tends to also be higher. The trends in CO_2 emission rates are similar to those for fuel use on a mass per time and mass per engine output basis. CO_2 emission rates are also shown on a g/gallon basis. Since typically over 99 percent of the carbon in the fuel is emitted as CO_2, the fuel-based CO_2 emission rates are approximately constant.

Differences in emission rates are attributable to differences in measured exhaust concentrations. Values for engine activity parameters (RPM, IAT, MAP) were similar across all rail yard and over-the-rail measurements.

Table F-38. Measured Engine Parameters for NC-1859 and ULSD

Engine Speed (RPM)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	9/1	9/1	9/1	3 Reps	3 Reps	3 Reps	8/30	8/30	8/31	8/31	9/2	9/2	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	239	238	238	238	0.46	0.00	238	237	237	236	238	236	237	0.63	0.00
High Idle	371	370	370	370	0.71	0.00	369	369	369	368	369	369	369	0.35	0.00
Dyn Brake	---	---	---	--	--	--	378	376	376	420	380	384	386	16.9	0.04
1	370	370	370	370	0.21	0.00	370	369	369	369	370	370	369	0.54	0.00
2	370	370	370	370	0.30	0.00	369	369	369	368	370	369	369	0.41	0.00
3	493	492	492	492	0.47	0.00	491	490	492	491	492	491	491	0.70	0.00
4	566	565	565	565	0.53	0.00	563	563	565	564	565	564	564	0.72	0.00
5	653	653	652	653	0.55	0.00	651	651	651	651	652	652	651	0.67	0.00
6	731	731	731	731	0.26	0.00	729	729	728	728	730	728	728	0.67	0.00
7	822	822	821	822	0.58	0.00	819	818	---	818	819	---	819	0.66	0.00
8	904	904	903	904	0.79	0.00	902	902	902	902	902	902	902	0.28	0.00

Intake Air Temeprature (°C)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	9/1	9/1	9/1	3 Reps	3 Reps	3 Reps	8/30	8/30	8/31	8/31	9/2	9/2	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	65	63	58	62	3.43	0.06	69	68	70	73	67	70	69	2.09	0.03
High Idle	72	73	73	73	0.68	0.01	75	75	75	78	72	76	75	1.80	0.02
Dyn Brake	---	---	---	--	--	--	76	75	75	77	71	76	75	1.86	0.02
1	67	68	65	67	1.48	0.02	75	77	74	79	76	77	76	1.67	0.02
2	67	70	70	69	1.71	0.02	74	73	74	79	71	76	74	2.77	0.04
3	70	72	72	71	1.59	0.02	76	75	71	79	72	74	75	2.86	0.04
4	71	73	73	72	1.45	0.02	77	75	77	82	69	78	76	4.11	0.05
5	70	73	73	72	1.55	0.02	76	76	78	80	73	76	77	2.42	0.03
6	74	75	74	74	0.92	0.01	74	77	75	85	73	80	77	4.47	0.06
7	75	77	77	76	1.20	0.02	75	73	---	83	75	---	77	4.58	0.06
8	78	78	79	78	0.91	0.01	79	79	78	82	76	80	79	2.00	0.03

Manifold Absolute Pressure (kPa)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	9/1	9/1	9/1	3 Reps	3 Reps	3 Reps	8/30	8/30	8/31	8/31	9/2	9/2	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	101	100	100	100	0.25	0.00	100	100	100	99	100	100	100	0.46	0.00
High Idle	109	108	108	108	0.37	0.00	108	108	109	108	108	107	108	0.60	0.01
Dyn Brake	---	---	---	--	--	--	109	108	109	112	109	109	109	1.49	0.01
1	109	108	108	108	0.31	0.00	110	110	111	110	109	109	110	0.67	0.01
2	109	109	108	109	0.36	0.00	109	108	113	110	109	109	110	1.61	0.01
3	121	120	120	120	0.57	0.00	122	120	126	122	120	124	122	2.37	0.02
4	130	129	129	129	0.80	0.01	131	130	136	135	131	130	132	2.76	0.02
5	144	143	142	143	1.01	0.01	144	145	145	152	145	143	146	3.22	0.02
6	159	158	157	158	1.15	0.01	159	160	161	164	159	157	160	2.31	0.01
7	185	180	178	181	3.18	0.02	178	179	---	177	180	---	179	1.03	0.01
8	228	231	225	228	3.13	0.01	225	225	234	227	230	223	227	4.19	0.02

Mass Air Flow (g/s)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	9/1	9/1	9/1	3 Reps	3 Reps	3 Reps	8/30	8/30	8/31	8/31	9/2	9/2	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	888	889	903	893	8.69	0.01	872	870	869	851	877	861	867	9.09	0.01
High Idle	1273	1263	1263	1267	5.67	0.00	1252	1246	1257	1239	1259	1237	1248	9.22	0.01
Dyn Brake	---	---	---	--	--	--	1280	1268	1280	1409	1300	1290	1304	52.4	0.04
1	1290	1281	1302	1291	10.6	0.01	1268	1256	1280	1253	1255	1260	1262	10.3	0.01
2	1292	1276	1290	1286	9.06	0.01	1264	1261	1297	1250	1273	1256	1267	16.7	0.01
3	1712	1687	1714	1704	14.9	0.01	1694	1669	1760	1672	1684	1719	1700	34.7	0.02
4	2000	1970	2005	1992	18.7	0.01	1973	1974	2037	1994	2011	1953	1991	30.2	0.02
5	2403	2371	2409	2394	20.7	0.01	2361	2371	2364	2431	2394	2348	2378	30.1	0.01
6	2793	2762	2827	2794	32.5	0.01	2776	2760	2796	2759	2791	2710	2766	31.1	0.01
7	3391	3312	3378	3360	42.0	0.01	3293	3326	---	3204	3316	---	3285	55.6	0.02
8	4241	4279	4296	4272	28.4	0.01	4170	4167	4316	4175	4283	4130	4207	74.1	0.02

Air to Fuel Ratio (g/g)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	9/1	9/1	9/1	3 Reps	3 Reps	3 Reps	8/30	8/30	8/31	8/31	9/2	9/2	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	290	295	302	296	6.33	0.02	308	319	534	457	280	291	365	105	0.29
High Idle	244	247	261	251	8.80	0.04	245	262	368	360	243	254	288	58.8	0.20
Dyn Brake	---	---	---	--	--	--	230	242	341	305	237	217	262	49.3	0.19
1	113	111	112	112	1.21	0.01	133	132	181	159	107	147	143	25.5	0.18
2	73.7	73.5	73.4	73.5	0.18	0.00	88.3	88.4	111	103	91.9	86.6	94.8	9.90	0.10
3	56.6	55.4	55.5	55.8	0.68	0.01	67.7	65.1	72.8	67.3	57.8	59.0	64.9	5.70	0.09
4	48.5	48.4	48.4	48.4	0.05	0.00	57.5	57.1	62.8	55.6	50.4	55.5	56.5	3.98	0.07
5	43.3	43.1	43.4	43.3	0.14	0.00	49.3	44.3	46.6	47.8	43.6	42.9	45.8	2.53	0.06
6	37.8	38.4	38.5	38.2	0.42	0.01	42.8	41.2	48.7	46.8	40.7	38.5	43.1	3.90	0.09
7	33.7	33.8	34.0	33.8	0.17	0.01	38.2	45.1	---	36.2	37.0	---	39.1	4.06	0.10
8	33.4	33.6	33.1	33.4	0.25	0.01	35.5	35.7	36.6	35.7	35.9	35.7	35.8	0.37	0.01

Table F-39. Estimated Fuel Use Rates for NC-1859 and ULSD

Time-Based Fuel Use Rates (g/s)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	9/1	9/1	9/1	3 Reps	3 Reps	3 Reps	8/30	8/30	8/31	8/31	9/2	9/2	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	3.07	3.02	2.98	3.02	0.04	0.01	2.83	2.73	1.63	1.86	3.13	2.96	2.53	0.62	0.25
High Idle	5.21	5.12	4.83	5.05	0.20	0.04	5.12	4.76	3.42	3.44	5.17	4.88	4.47	0.82	0.18
Dyn Brake	--	--	--	--	--	--	5.56	5.24	3.76	4.61	5.48	5.95	5.10	0.79	0.16
1	11.4	11.6	11.5	11.5	0.09	0.01	9.55	9.52	7.07	7.87	11.7	8.55	9.05	1.62	0.18
2	17.5	17.4	17.3	17.4	0.10	0.01	14.3	14.3	11.7	12.2	13.8	14.5	13.5	1.22	0.09
3	30.2	30.4	30.4	30.3	0.11	0.00	25.0	25.6	24.2	24.8	29.2	29.2	26.3	2.24	0.09
4	41.2	40.7	40.6	40.8	0.36	0.01	34.3	34.6	32.5	35.8	39.9	35.2	35.4	2.49	0.07
5	55.5	55.0	54.2	54.9	0.63	0.01	47.9	53.5	50.7	50.9	54.9	54.7	52.1	2.75	0.05
6	74.0	71.9	71.5	72.4	1.32	0.02	64.9	66.9	57.4	58.9	68.5	70.5	64.5	5.28	0.08
7	101	98.1	96.5	98.4	2.09	0.02	86.2	73.8	---	88.5	89.6	---	84.5	7.30	0.09
8	127	127	126	127	0.70	0.01	117	117	118	117	119	116	117	1.22	0.01

Engine Output-Based Fuel Use Rates (g/bhp-hr)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	9/1	9/1	9/1	3 Reps	3 Reps	3 Reps	8/30	8/30	8/31	8/31	9/2	9/2	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	2.64	2.68	2.71	2.68	0.04	0.01	2.85	2.96	4.96	4.33	2.58	2.73	3.40	0.99	0.29
High Idle	1.55	1.58	1.67	1.60	0.06	0.04	1.58	1.70	2.36	2.35	1.56	1.66	1.87	0.38	0.20
Dyn Brake	--	--	--	--	--	--	1.45	1.54	2.15	1.75	1.48	1.36	1.62	0.29	0.18
1	13.5	13.3	13.3	13.3	0.10	0.01	16.1	16.1	21.7	19.5	13.1	17.9	17.4	3.00	0.17
2	16.1	16.3	16.3	16.2	0.09	0.01	19.7	19.8	24.3	23.2	20.4	19.5	21.2	2.04	0.10
3	18.0	17.9	18.0	18.0	0.06	0.00	21.8	21.3	22.6	22.0	18.7	18.7	20.8	1.70	0.08
4	19.6	19.9	19.9	19.8	0.17	0.01	23.6	23.4	24.9	22.5	20.3	23.0	22.9	1.53	0.07
5	18.9	19.1	19.4	19.1	0.22	0.01	21.9	19.6	20.7	20.6	19.1	19.2	20.2	1.09	0.05
6	17.5	18.0	18.1	17.8	0.32	0.02	19.9	19.3	22.5	21.9	18.9	18.3	20.1	1.70	0.08
7	17.7	16.5	16.8	17.0	0.63	0.04	22.5	26.3	---	21.9	21.6	---	23.1	2.16	0.09
8	17.2	17.1	17.3	17.2	0.10	0.01	20.7	20.7	20.5	20.7	20.3	21.0	20.7	0.21	0.01

Table F-40. Measured NO_x Emission Rates for NC-1859 and ULSD

Time-Based NO_x Emission Rates (g/s)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	9/1	9/1	9/1	3 Reps	3 Reps	3 Reps	8/30	8/30	8/31	8/31	9/2	9/2	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	0.19	0.19	0.20	0.19	0.00	0.02	0.19	0.17	0.16	0.16	0.20	0.20	0.18	0.02	0.11
High Idle	0.23	0.23	0.23	0.23	0.00	0.00	0.26	0.29	0.22	0.23	0.26	0.24	0.25	0.02	0.10
Dyn Brake	---	---	---	--	--	--	0.28	0.29	0.23	0.28	0.27	0.29	0.27	0.02	0.08
1	0.51	0.53	0.52	0.52	0.01	0.02	0.51	0.54	0.45	0.51	0.59	0.46	0.51	0.05	0.10
2	0.89	0.94	0.96	0.93	0.04	0.04	0.77	0.81	0.83	0.85	0.84	0.80	0.82	0.03	0.04
3	1.63	1.72	1.70	1.68	0.04	0.03	1.42	1.46	1.52	1.58	1.54	1.46	1.50	0.06	0.04
4	2.17	2.17	2.24	2.19	0.04	0.02	1.93	1.92	2.11	2.25	2.13	2.19	2.09	0.13	0.06
5	2.57	2.72	2.73	2.67	0.09	0.03	2.45	2.67	2.72	2.65	2.69	2.61	2.63	0.10	0.04
6	3.09	3.36	3.46	3.30	0.19	0.06	3.17	3.29	2.72	3.40	3.11	3.25	3.16	0.23	0.07
7	3.65	3.83	3.93	3.81	0.14	0.04	3.50	2.96	---	3.42	3.51	---	3.35	0.26	0.08
8	4.53	4.16	4.39	4.36	0.19	0.04	4.29	4.30	4.21	4.16	4.05	4.05	4.18	0.11	0.03

Fuel-Based NO_x Emission Rates (g/gal)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	9/1	9/1	9/1	3 Reps	3 Reps	3 Reps	8/30	8/30	8/31	8/31	9/2	9/2	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	198	205	212	205	6.68	0.03	217	206	309	269	207	214	237	42.3	0.18
High Idle	143	144	154	147	5.79	0.04	163	196	208	214	159	161	184	25.5	0.14
Dyn Brake	---	---	---	--	--	--	163	177	201	196	158	157	175	19.4	0.11
1	144	148	145	145	2.01	0.01	171	181	205	207	163	174	184	18.3	0.10
2	164	174	179	172	7.43	0.04	173	183	229	224	195	179	197	24.0	0.12
3	174	182	181	179	4.11	0.02	183	184	202	205	170	161	184	17.3	0.09
4	170	172	178	173	4.46	0.03	181	179	209	202	172	201	191	15.2	0.08
5	149	159	162	157	6.63	0.04	165	161	173	168	158	154	163	6.92	0.04
6	135	151	156	147	11.1	0.08	157	158	153	186	146	148	158	14.3	0.09
7	117	126	131	125	7.18	0.06	131	129	---	124	126	---	128	2.99	0.02
8	115	105	112	111	5.05	0.05	118	119	115	115	109	113	115	3.33	0.03

Engine Output-Based NO_x Emission Rates (g/bhp-hr)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	9/1	9/1	9/1	3 Reps	3 Reps	3 Reps	8/30	8/30	8/31	8/31	9/2	9/2	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	67.9	69.3	70.5	69.2	1.27	0.02	68.8	63.0	56.3	56.0	72.5	70.9	64.6	7.30	0.11
High Idle	83.3	82.6	82.9	83.0	0.34	0.00	93.4	104	79.6	82.5	92.0	87.9	90.0	8.87	0.10
Dyn Brake	---	---	---	--	--	--	102	104	84.5	101	96.6	104	98.7	7.45	0.08
1	9.65	10.1	9.82	9.84	0.20	0.02	9.59	10.2	8.54	9.57	11.2	8.77	9.65	0.98	0.10
2	9.19	9.66	9.90	9.58	0.36	0.04	7.90	8.33	8.53	8.73	8.61	8.27	8.40	0.30	0.04
3	8.71	9.16	9.08	8.98	0.24	0.03	7.60	7.79	8.09	8.44	8.22	7.77	7.99	0.32	0.04
4	7.82	7.81	8.08	7.90	0.16	0.02	6.96	6.93	7.60	8.08	7.66	7.90	7.52	0.48	0.06
5	7.12	7.52	7.55	7.40	0.24	0.03	6.78	7.39	7.54	7.33	7.46	7.23	7.29	0.27	0.04
6	6.96	7.56	7.79	7.44	0.43	0.06	7.12	7.39	6.13	7.64	7.00	7.31	7.10	0.53	0.07
7	5.98	6.90	7.07	6.65	0.59	0.09	5.25	4.44	---	5.12	5.26	---	5.02	0.39	0.08
8	6.05	5.55	5.86	5.82	0.25	0.04	5.15	5.16	5.05	5.00	4.86	4.86	5.01	0.13	0.03
Duty Cycle Avg (Raw)	6.7	6.6	6.8	6.7	0.12	0.02	5.9	5.9	5.3	5.9	5.9	5.3	5.7	0.31	0.05
Duty Cycle Avg (Adj)	7.0	6.9	7.2	7.0	0.12	0.02	6.2	6.2	5.6	6.3	6.2	5.6	6.0	0.33	0.05

Exhaust NO_x Concentrations (ppm)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	9/1	9/1	9/1	3 Reps	3 Reps	3 Reps	8/30	8/30	8/31	8/31	9/2	9/2	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	132	134	134	134	1.39	0.01	137	123	111	113	143	143	128	14.7	0.11
High Idle	112	112	113	113	0.73	0.01	129	143	108	114	127	123	124	12.2	0.10
Dyn Brake	---	---	---	--	--	--	137	140	113	123	128	140	130	11.0	0.08
1	246	259	251	252	6.65	0.03	249	263	216	246	297	229	250	28.2	0.11
2	431	462	472	455	21.5	0.05	384	402	390	410	407	400	399	10.1	0.03
3	599	641	637	626	23.3	0.04	531	551	533	580	583	550	555	22.3	0.04
4	683	696	719	699	18.3	0.03	616	613	627	697	669	681	650	36.4	0.06
5	680	725	735	713	29.4	0.04	656	722	716	690	714	708	701	24.9	0.04
6	712	771	796	760	43.2	0.06	719	750	612	740	710	761	715	54.0	0.08
7	696	727	758	727	31.1	0.04	682	562	---	684	674	---	650	59.1	0.09
8	679	627	674	660	28.9	0.04	663	666	627	634	617	632	640	20.0	0.03

Table F-41. Measured CO Emission Rates for NC-1859 and ULSD

Time-Based CO Emission Rates (g/s)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	9/1	9/1	9/1	3 Reps	3 Reps	3 Reps	8/30	8/30	8/31	8/31	9/2	9/2	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	0.05	0.07	0.08	0.07	0.02	0.29	0.04	0.00	0.00	0.00	0.06	0.03	0.02	0.02	1.13
High Idle	0.94	0.90	0.34	0.73	0.34	0.46	0.10	0.04	0.03	0.01	0.16	0.20	0.09	0.07	0.82
Dyn Brake	---	---	---	--	--	--	0.09	0.03	0.00	0.00	0.14	0.19	0.08	0.08	1.03
1	0.06	0.12	0.12	0.10	0.03	0.31	0.10	0.06	0.03	0.05	0.14	0.17	0.09	0.06	0.60
2	0.15	0.17	0.16	0.16	0.01	0.04	0.11	0.02	0.09	0.09	0.08	0.21	0.10	0.06	0.63
3	0.24	0.28	0.27	0.27	0.02	0.09	0.10	0.04	0.00	0.10	0.13	0.94	0.22	0.36	1.64
4	0.27	0.55	0.41	0.41	0.14	0.34	0.14	0.10	0.14	0.09	0.00	0.28	0.12	0.09	0.73
5	0.00	0.42	0.28	0.23	0.21	0.91	0.21	0.08	0.01	0.00	0.37	0.19	0.14	0.14	0.98
6	0.37	0.22	0.31	0.30	0.08	0.25	0.08	0.18	0.28	0.00	0.33	0.27	0.19	0.13	0.68
7	0.37	2.59	1.13	1.36	1.13	0.83	0.43	0.16	---	0.00	0.15	---	0.19	0.18	0.97
8	1.52	1.54	1.44	1.50	0.05	0.04	0.65	0.58	0.60	0.61	0.73	0.76	0.66	0.08	0.11

Fuel-Based CO Emission Rates (g/gal)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	9/1	9/1	9/1	3 Reps	3 Reps	3 Reps	8/30	8/30	8/31	8/31	9/2	9/2	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	48.0	78.9	90.6	72.5	22.0	0.30	42.1	1.31	8.81	0.00	61.9	28.2	23.7	24.9	1.05
High Idle	583	568	226	459	202	0.44	63.8	27.4	32.1	13.0	98.8	130	60.8	45.7	0.75
Dyn Brake	---	---	---	--	--	--	50.2	19.1	2.34	1.23	85.0	103	43.5	43.5	1.00
1	18.3	33.4	33.2	28.3	8.66	0.31	34.7	20.8	13.3	20.5	39.0	63.8	32.0	18.3	0.57
2	28.1	30.9	29.2	29.4	1.42	0.05	24.4	3.73	24.3	23.8	19.4	46.4	23.7	13.7	0.58
3	25.5	30.1	29.1	28.2	2.45	0.09	12.5	5.57	0.00	12.6	14.5	104	24.9	39.2	1.58
4	21.2	43.6	32.1	32.3	11.2	0.35	13.5	9.13	13.5	7.95	0.25	25.6	11.7	8.37	0.72
5	0.00	24.5	16.8	13.8	12.5	0.91	13.9	4.99	0.70	0.00	21.4	11.3	8.72	8.36	0.96
6	16.1	9.8	14.1	13.4	3.23	0.24	3.86	8.64	15.9	0.00	15.3	12.4	9.35	6.41	0.69
7	11.8	85.0	37.8	44.9	37.1	0.83	16.1	7.04	---	0.00	5.41	---	7.14	6.69	0.94
8	38.5	38.9	36.7	38.0	1.15	0.03	17.7	16.1	16.4	16.8	19.8	21.2	18.0	2.09	0.12

Engine Output-Based CO Emission Rates (g/bhp-hr)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	9/1	9/1	9/1	3 Reps	3 Reps	3 Reps	8/30	8/30	8/31	8/31	9/2	9/2	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	16.5	26.6	30.2	24.4	7.12	0.29	13.4	0.40	1.60	0.00	21.7	9.33	7.73	8.72	1.13
High Idle	340	325	122	262	122	0.46	36.5	14.6	12.3	5.00	57.1	70.9	32.7	26.8	0.82
Dyn Brake	---	---	---	--	--	--	31.2	11.2	0.98	0.64	52.1	68.9	27.5	28.4	1.03
1	1.23	2.27	2.25	1.92	0.60	0.31	1.95	1.17	0.55	0.95	2.69	3.21	1.75	1.05	0.60
2	1.57	1.71	1.62	1.63	0.07	0.04	1.11	0.17	0.90	0.93	0.86	2.15	1.02	0.64	0.63
3	1.28	1.52	1.46	1.42	0.13	0.09	0.52	0.24	0.00	0.52	0.70	5.02	1.17	1.91	1.64
4	0.98	1.98	1.46	1.47	0.50	0.34	0.52	0.35	0.49	0.32	0.01	1.00	0.45	0.33	0.73
5	0.00	1.16	0.78	0.65	0.59	0.91	0.57	0.23	0.03	0.00	1.01	0.53	0.40	0.39	0.98
6	0.83	0.49	0.71	0.68	0.17	0.25	0.18	0.40	0.64	0.00	0.73	0.61	0.43	0.29	0.68
7	0.60	4.66	2.04	2.43	2.06	0.85	0.65	0.24	---	0.00	0.23	---	0.28	0.27	0.97
8	2.02	2.05	1.91	2.00	0.07	0.04	0.77	0.70	0.72	0.73	0.88	0.92	0.79	0.09	0.11
Duty Cycle Avg (Raw)	1.6	2.2	1.9	1.9	0.29	0.15	0.8	0.6	0.6	0.5	1.0	1.2	0.8	0.26	0.34
Duty Cycle Avg (Adj)	1.6	2.2	1.9	1.9	0.29	0.15	0.8	0.6	0.6	0.5	1.0	1.2	0.8	0.26	0.34

Exhaust CO Concentrations (%)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	9/1	9/1	9/1	3 Reps	3 Reps	3 Reps	8/30	8/30	8/31	8/31	9/2	9/2	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	0.006	0.009	0.010	0.008	0.00	0.28	0.005	0.000	0.001	0.000	0.007	0.003	0.003	0.00	1.12
High Idle	0.079	0.076	0.029	0.061	0.03	0.46	0.009	0.003	0.003	0.001	0.014	0.017	0.008	0.01	0.82
Dyn Brake	---	---	---	--	--	--	0.007	0.003	0.000	0.000	0.012	0.016	0.006	0.01	1.03
1	0.005	0.010	0.010	0.008	0.00	0.31	0.009	0.005	0.002	0.004	0.012	0.014	0.008	0.00	0.60
2	0.013	0.014	0.013	0.013	0.00	0.05	0.009	0.001	0.007	0.008	0.007	0.018	0.008	0.01	0.64
3	0.015	0.018	0.018	0.017	0.00	0.10	0.006	0.003	0.000	0.006	0.009	0.062	0.014	0.02	1.64
4	0.015	0.031	0.022	0.023	0.01	0.35	0.008	0.005	0.007	0.005	0.000	0.015	0.007	0.00	0.73
5	0.000	0.019	0.013	0.011	0.01	0.91	0.010	0.004	0.001	0.000	0.017	0.009	0.007	0.01	0.97
6	0.015	0.009	0.013	0.012	0.00	0.26	0.003	0.007	0.011	0.000	0.013	0.011	0.008	0.01	0.68
7	0.012	0.085	0.038	0.045	0.04	0.82	0.015	0.005	---	0.000	0.005	---	0.006	0.01	0.97
8	0.039	0.040	0.038	0.039	0.00	0.02	0.017	0.016	0.015	0.016	0.019	0.021	0.017	0.00	0.12

Table F-42. Measured Hydrocarbon Emission Rates for NC-1859 and ULSD

Time-Based HC Emission Rates (g/s)

Throttle Notch Position	Rail Yard Measurements						Over-The-Rail Measurements								
	9/1	9/1	9/1	3 Reps	3 Reps	3 Reps	8/30	8/30	8/31	8/31	9/2	9/2	6 Trains	6 Trains	6 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	0.19	0.19	0.30	0.23	0.06	0.26	0.04	1.07	0.00	0.00	0.19	0.00	0.22	0.43	1.97
High Idle	1.76	1.69	0.81	1.42	0.53	0.37	0.96	1.49	0.36	0.41	0.31	0.31	0.64	0.49	0.76
Dyn Brake	---	---	---	--	--	--	0.80	1.65	0.30	0.36	0.24	0.42	0.63	0.54	0.85
1	0.41	0.47	0.55	0.47	0.07	0.15	0.81	1.97	0.35	0.96	0.24	0.03	0.73	0.70	0.97
2	0.73	0.76	0.85	0.78	0.06	0.08	0.46	0.49	0.03	0.75	0.03	0.51	0.38	0.29	0.77
3	1.21	1.18	1.37	1.25	0.10	0.08	0.87	2.47	0.38	1.36	0.22	0.71	1.00	0.82	0.82
4	1.26	1.63	1.80	1.56	0.28	0.18	0.93	2.64	0.81	1.29	0.57	0.15	1.06	0.86	0.81
5	0.00	1.47	1.25	0.91	0.79	0.87	0.62	2.69	0.56	3.09	1.27	0.38	1.43	1.17	0.82
6	0.00	0.00	0.00	0.00	0.00	#DIV/0!	0.92	3.25	0.00	2.68	1.58	1.19	1.60	1.19	0.74
7	0.03	4.46	1.54	2.01	2.26	1.12	2.06	3.80	---	0.00	0.44	---	1.57	1.73	1.10
8	2.77	3.45	2.76	2.99	0.39	0.13	2.13	3.78	1.09	2.14	1.08	1.57	1.97	1.01	0.51

Fuel-Based HC Emission Rates (g/gal)

Throttle Notch Position	Rail Yard Measurements						Over-The-Rail Measurements								
	9/1	9/1	9/1	3 Reps	3 Reps	3 Reps	8/30	8/30	8/31	8/31	9/2	9/2	6 Trains	6 Trains	6 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	201	208	321	243	67.5	0.28	39.9	1267	0.00	0.00	197	1.03	251	504	2.01
High Idle	1085	1064	541	896	308	0.34	601	1011	338	387	191	207	456	310	0.68
Dyn Brake	---	---	---	--	--	--	463	1014	260	253	143	226	393	322	0.82
1	115	131	153	133	19.2	0.14	273	666	160	395	66.9	10.1	262	242	0.92
2	135	141	157	144	11.6	0.08	103	112	7.81	199	6.37	114	90	73.4	0.81
3	129	125	145	133	10.8	0.08	112	310	50.2	176	24.6	78.5	125	105	0.84
4	98.4	129	143	123	22.8	0.18	87.0	246	80.1	115	45.9	13.7	98.0	80.4	0.82
5	0.00	86.1	74.0	53.4	46.6	0.87	41.4	162	35.4	195	74.6	22.5	88.5	72.7	0.82
6	0.00	0.00	0.00	0.00	0.00	#DIV/0!	45.5	156	0.00	146	74.4	54.6	79.5	60.8	0.76
7	0.87	146	51.5	66.3	73.9	1.12	76.9	166	---	0.00	15.7	---	64.7	75.3	1.16
8	70.4	87.2	70.5	76.0	9.67	0.13	58.5	104	29.6	59.0	29.2	43.8	54.0	27.8	0.52

Engine Output-Based HC Emission Rates (g/bhp-hr)

Throttle Notch Position	Rail Yard Measurements						Over-The-Rail Measurements								
	9/1	9/1	9/1	3 Reps	3 Reps	3 Reps	8/30	8/30	8/31	8/31	9/2	9/2	6 Trains	6 Trains	6 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	68.9	70.2	107	82.0	21.7	0.26	12.7	387	0.00	0.00	68.9	0.34	78.1	153	1.97
High Idle	632	608	292	511	190	0.37	344	538	129	149	111	113	231	175	0.76
Dyn Brake	---	---	---	--	--	--	288	594	109	130	87.8	150	227	193	0.85
1	7.69	8.94	10.4	9.00	1.34	0.15	15.3	37.3	6.64	18.3	4.61	0.51	13.8	13.3	0.97
2	7.56	7.82	8.72	8.03	0.61	0.08	4.72	5.09	0.29	7.76	0.28	5.30	3.91	3.00	0.77
3	6.44	6.32	7.31	6.69	0.54	0.08	4.66	13.2	2.01	7.23	1.19	3.79	5.34	4.39	0.82
4	4.54	5.87	6.48	5.63	0.99	0.18	3.34	9.49	2.91	4.63	2.05	0.54	3.82	3.09	0.81
5	0.00	4.07	3.45	2.51	2.19	0.87	1.71	7.45	1.54	8.55	3.52	1.06	3.97	3.25	0.82
6	0.00	0.00	0.00	0.00	0.00	#DIV/0!	2.06	7.30	0.00	6.02	3.56	2.69	3.61	2.67	0.74
7	0.04	8.04	2.78	3.62	4.06	1.12	3.09	5.71	---	0.00	0.65	---	2.36	2.60	1.10
8	3.70	4.60	3.67	3.99	0.53	0.13	2.56	4.54	1.30	2.57	1.30	1.89	2.36	1.21	0.51
Duty Cycle Avg (Raw)	1.45	2.10	1.84	1.80	0.33	0.18	1.37	3.60	0.57	1.56	0.83	0.81	1.46	1.12	0.77
Duty Cycle Avg (Adj)	3.62	5.24	4.60	4.49	0.81	0.18	3.41	9.01	1.42	3.89	2.08	2.02	3.64	2.79	0.77

Exhaust HC Concentrations (ppm)

Throttle Notch Position	Rail Yard Measurements						Over-The-Rail Measurements								
	9/1	9/1	9/1	3 Reps	3 Reps	3 Reps	8/30	8/30	8/31	8/31	9/2	9/2	6 Trains	6 Trains	6 Trains
	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	30	31	46	36	9.00	0.25	6	170	0	0	31	0	34	67.5	1.96
High Idle	191	186	90	156	57.2	0.37	107	166	40	46	34	36	72	54.0	0.76
Dyn Brake	---	---	---	--	--	--	88	181	33	36	26	45	68	59.5	0.87
1	44	52	60	52	7.73	0.15	90	218	38	106	27	3	80	77.6	0.97
2	80	84	94	86	7.08	0.08	52	55	3	82	3	58	42	32.2	0.76
3	100	100	115	105	9.12	0.09	73	210	30	112	19	60	84	69.9	0.83
4	89	118	130	112	20.9	0.19	67	189	54	90	40	11	75	61.9	0.82
5	0	88	76	55	47.8	0.87	37	164	33	181	76	23	86	69.8	0.81
6	0	0	0	0	0.00	#DIV/0!	47	167	0	132	81	63	82	59.9	0.73
7	1	191	67	86	96.2	1.12	90	163	---	0	19	---	68	74.2	1.09
8	94	117	95	102	13.0	0.13	74	132	36	73	37	55	68	35.4	0.52

Table F-43. Measured Particulate Matter Emission Rates for NC-1859 and ULSD

Time-Based PM Emission Rates (g/s)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	9/1	9/1	9/1	3 Reps	3 Reps	3 Reps	8/30	8/30	8/31	8/31	9/2	9/2	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	0.02	0.02	0.02	0.02	0.00	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.08
High Idle	0.02	0.02	0.02	0.02	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.11
Dyn Brake	---	---	---	--	--	--	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.09
1	0.03	0.03	0.03	0.03	0.00	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.00	0.08
2	0.04	0.03	0.03	0.03	0.00	0.01	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.00	0.09
3	0.05	0.05	0.05	0.05	0.00	0.02	0.06	0.06	0.07	0.07	0.05	0.07	0.06	0.01	0.10
4	0.07	0.07	0.07	0.07	0.00	0.02	0.09	0.08	0.12	0.11	0.08	0.09	0.09	0.02	0.17
5	0.10	0.09	0.09	0.09	0.00	0.02	0.12	0.11	0.13	0.15	0.11	0.11	0.12	0.02	0.13
6	0.13	0.13	0.13	0.13	0.00	0.02	0.17	0.14	0.15	0.27	0.14	0.15	0.17	0.05	0.29
7	0.21	0.21	0.20	0.21	0.00	0.02	0.25	0.14	---	0.26	0.23	---	0.22	0.06	0.25
8	0.27	0.27	0.28	0.28	0.01	0.02	0.36	0.31	0.32	0.40	0.29	0.29	0.33	0.04	0.13

Fuel-Based PM Emission Rates (g/gal)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	9/1	9/1	9/1	3 Reps	3 Reps	3 Reps	8/30	8/30	8/31	8/31	9/2	9/2	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	26.2	29.0	28.3	27.9	1.45	0.05	34.8	36.1	62.4	44.1	30.8	29.6	39.6	12.3	0.31
High Idle	15.3	14.9	16.3	15.5	0.74	0.05	20.9	20.8	31.4	28.5	17.2	16.3	22.5	6.12	0.27
Dyn Brake	---	---	---	--	--	--	20.4	19.2	29.1	22.2	16.7	15.2	20.5	4.92	0.24
1	10.9	10.3	10.3	10.5	0.33	0.03	14.3	14.2	21.9	19.2	11.8	14.5	16.0	3.76	0.23
2	8.93	8.94	8.85	8.91	0.05	0.01	12.9	13.4	17.7	17.0	12.6	11.5	14.2	2.54	0.18
3	7.43	7.65	7.51	7.53	0.11	0.01	10.9	10.6	12.3	12.6	8.26	10.7	10.9	1.56	0.14
4	7.73	7.73	7.54	7.67	0.11	0.01	11.4	10.2	16.3	13.2	8.84	11.3	11.9	2.62	0.22
5	7.69	7.64	7.61	7.65	0.04	0.01	10.9	9.55	11.3	13.5	9.14	8.99	10.6	1.72	0.16
6	7.60	8.09	7.92	7.87	0.25	0.03	11.4	9.65	11.8	20.6	9.02	9.59	12.0	4.34	0.36
7	9.29	9.55	9.41	9.42	0.13	0.01	13.0	8.33	---	13.1	11.6	---	11.5	2.22	0.19
8	9.50	9.56	9.99	9.68	0.27	0.03	13.7	12.0	12.2	15.1	10.7	11.0	12.5	1.69	0.14

Engine Output-Based PM Emission Rates (g/bhp-hr)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	9/1	9/1	9/1	3 Reps	3 Reps	3 Reps	8/30	8/30	8/31	8/31	9/2	9/2	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	6.50	7.08	6.81	6.80	0.29	0.04	7.97	7.95	8.21	6.64	7.79	7.07	7.60	0.61	0.08
High Idle	6.43	6.17	6.37	6.32	0.14	0.02	8.66	7.99	8.66	7.93	7.19	6.41	7.81	0.88	0.11
Dyn Brake	---	---	---	--	--	--	9.16	8.13	8.84	8.26	7.37	7.31	8.18	0.75	0.09
1	0.53	0.50	0.51	0.51	0.01	0.02	0.58	0.57	0.66	0.64	0.59	0.53	0.60	0.05	0.08
2	0.36	0.36	0.35	0.36	0.00	0.01	0.43	0.44	0.48	0.48	0.40	0.38	0.44	0.04	0.09
3	0.27	0.28	0.27	0.27	0.00	0.02	0.33	0.32	0.36	0.37	0.29	0.37	0.34	0.03	0.10
4	0.26	0.25	0.25	0.25	0.01	0.02	0.31	0.29	0.43	0.38	0.28	0.32	0.34	0.06	0.17
5	0.27	0.26	0.26	0.26	0.00	0.02	0.33	0.32	0.36	0.43	0.31	0.31	0.34	0.05	0.13
6	0.28	0.29	0.29	0.29	0.01	0.02	0.37	0.33	0.34	0.61	0.31	0.34	0.38	0.11	0.29
7	0.34	0.38	0.37	0.36	0.02	0.05	0.38	0.21	---	0.39	0.35	---	0.33	0.08	0.25
8	0.36	0.36	0.38	0.37	0.01	0.02	0.43	0.38	0.39	0.48	0.34	0.34	0.39	0.05	0.13
Duty Cycle Avg (Raw)	0.08	0.08	0.08	0.08	0.00	0.02	0.09	0.08	0.08	0.10	0.08	0.07	0.08	0.01	0.14
Duty Cycle Avg (Adj)	0.38	0.39	0.39	0.39	0.01	0.02	0.46	0.40	0.40	0.51	0.39	0.35	0.42	0.06	0.14

Exhaust PM Concentrations (mg/m^3)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	9/1	9/1	9/1	3 Reps	3 Reps	3 Reps	8/30	8/30	8/31	8/31	9/2	9/2	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	4.9	5.3	5.1	5.1	0.22	0.04	6.2	6.0	6.3	5.2	6.0	5.5	5.9	0.41	0.07
High Idle	3.4	3.3	3.4	3.3	0.07	0.02	4.7	4.3	4.6	4.3	3.8	3.5	4.2	0.45	0.11
Dyn Brake	---	---	---	--	--	--	4.8	4.3	4.6	3.9	3.8	3.8	4.2	0.43	0.10
1	5.2	5.1	5.0	5.1	0.11	0.02	5.9	5.8	6.5	6.4	6.0	5.3	6.0	0.42	0.07
2	6.6	6.7	6.6	6.6	0.05	0.01	8.0	8.3	8.5	8.8	7.4	7.2	8.0	0.60	0.08
3	7.2	7.6	7.4	7.4	0.21	0.03	8.9	8.9	9.1	10.0	7.9	10.3	9.2	0.85	0.09
4	8.7	8.8	8.6	8.7	0.13	0.01	10.8	9.8	13.7	12.8	9.7	10.8	11.3	1.64	0.15
5	9.8	9.8	9.7	9.8	0.07	0.01	12.2	12.1	13.1	15.6	11.6	11.6	12.7	1.52	0.12
6	11.3	11.6	11.4	11.4	0.17	0.01	14.6	12.9	13.3	23.0	12.3	13.8	15.0	4.02	0.27
7	15.5	15.5	15.3	15.4	0.14	0.01	19.0	10.2	---	20.2	17.4	---	16.7	4.50	0.27
8	15.7	16.0	16.8	16.2	0.59	0.04	21.7	18.9	18.7	23.5	16.9	17.4	19.5	2.58	0.13

Table F-44. Measured CO_2 Emission Rates for NC-1859 and ULSD

Time-Based CO_2 Emission Rates (g/s)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	9/1	9/1	9/1	3 Reps	3 Reps	3 Reps	8/30	8/30	8/31	8/31	9/2	9/2	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	9.7	9.48	9.27	9.48	0.20	0.02	8.79	7.88	5.09	5.83	9.59	9.22	7.73	1.87	0.24
High Idle	14.0	13.8	14.3	14.0	0.27	0.02	15.3	13.9	10.4	10.5	15.8	14.8	13.4	2.39	0.18
Dyn Brake	---	---	---	--	--	--	16.8	15.3	11.6	14.2	16.8	18.1	15.5	2.32	0.15
1	35.9	36.3	36.1	36.1	0.20	0.01	29.2	28.5	21.9	23.9	36.3	26.5	27.7	5.02	0.18
2	55.0	54.5	54.4	54.6	0.34	0.01	44.3	44.3	36.3	37.5	43.2	44.7	41.7	3.78	0.09
3	94.1	94.8	94.4	94.4	0.32	0.00	77.6	78.6	75.4	76.7	90.9	89.3	81.4	6.82	0.08
4	128	126	126	126	1.44	0.01	106	106	101	111	124	109	110	7.99	0.07
5	173	170	168	170	2.54	0.01	149	166	158	157	171	171	162	8.48	0.05
6	229	222	221	224	3.97	0.02	202	207	179	183	213	219	201	16.3	0.08
7	309	296	295	300	8.17	0.03	268	228	---	277	280	---	263	23.9	0.09
8	384	385	381	383	1.75	0.00	365	362	368	364	371	360	365	4.11	0.01

Fuel-Based CO_2 Emission Rates (g/gal)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	9/1	9/1	9/1	3 Reps	3 Reps	3 Reps	8/30	8/30	8/31	8/31	9/2	9/2	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	9875	9823	9735	9811	71.1	0.01	9984	9294	10060	10074	9856	10029	9883	299	0.03
High Idle	8492	8528	9386	8802	506	0.06	9605	9411	9816	9816	9802	9743	9699	163	0.02
Dyn Brake	---	---	---	--	--	--	9711	9422	9911	9917	9853	9773	9764	186	0.02
1	9975	9941	9928	9948	24.2	0.00	9852	9633	9955	9800	9972	9968	9863	133	0.01
2	9947	9939	9932	9939	7.81	0.00	9973	10000	10031	9914	10040	9931	9982	51.7	0.01
3	9955	9950	9939	9948	8.17	0.00	9986	9875	10043	9947	10036	9863	9958	77.9	0.01
4	9981	9926	9936	9948	28.9	0.00	10000	9909	10004	9991	10046	10026	9996	46.9	0.00
5	10074	9983	10002	10020	48.1	0.00	10027	9967	10051	9954	9995	10043	10006	40.4	0.00
6	10049	10059	10052	10053	5.07	0.00	10040	9965	10049	9984	10004	10021	10011	32.6	0.00
7	10055	9851	9983	9963	104	0.01	10002	9961	---	10074	10056	---	10023	51.6	0.01
8	9970	9960	9973	9968	7.21	0.00	10011	9985	10030	10012	10025	10014	10013	15.8	0.00

Engine Output-Based CO_2 Emission Rates (g/bhp-hr)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	9/1	9/1	9/1	3 Reps	3 Reps	3 Reps	8/30	8/30	8/31	8/31	9/2	9/2	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	3484	3411	3339	3411	72.7	0.02	3164	2837	1832	2099	3452	3319	2784	672	0.24
High Idle	5031	4962	5153	5049	97.1	0.02	5498	5008	3752	3777	5671	5317	4837	859	0.18
Dyn Brake	---	---	---	--	--	--	6040	5518	4165	5114	6033	6504	5562	836	0.15
1	681	688	685	685	3.87	0.01	554	540	414	454	687	502	525	95.0	0.18
2	566	561	560	562	3.53	0.01	456	456	374	386	444	460	429	38.9	0.09
3	502	505	504	504	1.69	0.00	414	419	402	409	485	476	434	36.4	0.08
4	485	476	502	488	13.2	0.03	383	383	363	400	448	394	395	28.8	0.07
5	479	470	484	478	6.84	0.01	413	458	438	435	472	472	448	23.5	0.05
6	515	501	498	504	8.92	0.02	455	466	403	411	479	494	451	36.7	0.08
7	506	532	531	523	14.6	0.03	401	342	---	416	420	---	395	35.8	0.09
8	512	513	508	511	2.33	0.00	438	435	441	436	446	432	438	4.93	0.01

Exhaust CO_2 Concentrations (%)

Throttle	Rail Yard Measurements						Over-The-Rail Measurements								
Notch	9/1	9/1	9/1	3 Reps	3 Reps	3 Reps	8/30	8/30	8/31	8/31	9/2	9/2	6 Trains	6 Trains	6 Trains
Position	Axion REP1	Axion REP2	Axion REP3	Average	StDev	CV	Train 75	Train 76	Train 73	Train 74	Train 73	Train 74	Average	StDev	CV
Low Idle	0.72	0.71	0.68	0.70	0.02	0.03	0.69	0.61	0.40	0.47	0.75	0.74	0.61	0.15	0.24
High Idle	0.73	0.73	0.76	0.74	0.02	0.02	0.84	0.76	0.56	0.57	0.86	0.82	0.73	0.13	0.18
Dyn Brake	---	---	---	--	--	--	0.90	0.82	0.61	0.68	0.88	0.96	0.81	0.13	0.17
1	1.88	1.92	1.89	1.90	0.02	0.01	1.58	1.54	1.16	1.28	2.00	1.44	1.50	0.29	0.19
2	2.87	2.90	2.89	2.89	0.01	0.00	2.44	2.42	1.88	2.00	2.31	2.45	2.25	0.25	0.11
3	3.77	3.87	3.86	3.83	0.05	0.01	3.18	3.26	2.92	3.09	3.78	3.71	3.33	0.35	0.10
4	4.43	4.43	4.42	4.42	0.01	0.00	3.74	3.73	3.30	3.80	4.31	3.74	3.77	0.32	0.09
5	5.05	5.01	5.00	5.02	0.03	0.01	4.40	4.93	4.58	4.51	4.98	5.10	4.75	0.29	0.06
6	5.85	5.67	5.66	5.72	0.11	0.02	5.06	5.20	4.44	4.39	5.35	5.66	5.01	0.51	0.10
7	6.59	6.27	6.35	6.40	0.17	0.03	5.73	4.77	---	6.11	5.92	---	5.63	0.59	0.11
8	6.47	6.52	6.59	6.53	0.06	0.01	6.21	6.18	6.03	6.10	6.22	6.18	6.15	0.07	0.01

Appendix G.
Evaluation of NO_x to NO Ratio and Total Hydrocarbon to Hydrocarbon Ratio

G.1 Introduction

This project measured multiple pollutants from railroad locomotive prime mover diesel engines with a PEMS in both OTR and RY settings. For over-the-rail applications, the team needed to employ a PEMS that was compact, lightweight, highly portable, and that did not require use of hazardous materials, and they decided to use the Axion PEMS manufactured by Clean Air Technologies International, Inc. The Axion PEMS measures NO using electrochemical cells and CO_2, CO, and HC using non-dispersive infrared (NDIR) detection. Diesel engines emit $NO_{x,}$ which was typically comprised (by volume) of approximately 95 percent of NO and 5 percent NO_2. To account for total NO_x, a correction factor based on the expected ratio of total NO_x (NO + NO_2) to NO was used in combination with the measured NO concentration. If 5 volume percent of NO_x is NO_2, then the NO_2/NO ratio is 0.053 and the NO_x to NO ratio is 1.053.

However, there was a need to verify if these estimated ratios are reasonable and accurate when applied to diesel prime mover engines, and determine if these ratios might vary depending on the fuel used as the team compared ultra-low sulfur diesel (ULSD) and various biodiesel blends. Thus, we conducted supplemental measurements during static load tests in the rail yard of prime mover NO and NO_2 exhaust concentrations using a larger, less portable PEMS, the Sensors, Inc. SEMTECH-DS, which was capable of measuring both NO and NO_2 using non-dispersive ultraviolet (NDUV) detection.

With regard to HC concentrations, NDIR is known to respond well to straight-chain alkanes but its response decreases for other types of hydrocarbons. Because diesel exhaust HC is a mixture of various types of compounds, the average response of NDIR is expected to be biased low. Total HC can be detected using flame ionization detection (FID), which requires use of a “FID fuel” containing hydrogen that is used to combust the hydrocarbon followed by detection of the resulting emitted carbon. Based on measurements made by others, a typical correction factor for total HC measured with FID compared to HC detected by NDIR was approximately 2.5. The SEMTECH-DS was capable of making HC measurements using both FID and NDIR, and thus can be used to evaluate the FID/NDIR ratio. Because FID requires a hydrogen-laden FID fuel, which is hazardous, we do not use this method in over-the-rail measurements.

G.2 Methods

The multiplicative correction factors for NO_x/NO and FID/NDIR for HC might be different for different fuels. Therefore, measuring the prime mover engine NC-1797 in the rail yard was done with four different fuels: (1) ultra-low sulfur diesel (ULSD); (2) 10 percent soy-based biodiesel and 90 percent ULSD blend (B10); (3) 20 percent soy-based biodiesel and 80 percent ULSD blend (B20); and (4) 40 percent soy-based biodiesel and 60 percent ULSD blend (B40). For each fuel, we measured the steady state exhaust concentrations of NO and NO_2 using NDUV, and HC using both FID and NDIR for each throttle notch position. The fuels used and measurement dates are summarized in Table 1.

Table G-1. Fuels and Measurement Dates for NC-1797 Rail Yard Measurement

Fuel Used	Measurement Dates
ULSD	10/22/2013
B10	3/10/2014
B20	4/14/2014
B40	7/21/2014

For each measurement, the SEMTECH was placed on a portable table near the locomotive. The heated exhaust line was connected to the locomotive engine exhaust. A laptop was used to control the SEMTECH and record the data. To protect the PEMS from weather conditions, a pop-up tent was set up to cover the SEMTECH.

For each measurement day, the SEMTECH was warmed up, zero-spanned and calibrated in the field. The zero-span process uses zero gas. The calibration process uses a BAR-97 Low gas mixture and a standard 94 ppm NO_2 calibration gas. When the zero-span and calibration are completed, the SEMTECH was ready for data collection.

For each day of measurement, 3 replicates of a test procedure were conducted to ensure data quality. For each replicate, the prime mover engine was operated at notches 1 through 8 and idle for at least 5 minutes each. Each replicate test procedure measurement takes approximately an hour. Data from the SEMTECH were synchronized with data from the Axion PEMS that was used simultaneously. The Axion includes an engine sensor array for key engine variables from which mass air flow to the engine can be estimated. These variables include engine speed (RPM), manifold absolute pressure (MAP), and intake air pressure (IAT). To eliminate the effect of transient operation when the engine activity and exhaust concentrations were unstable, seconds when the change of engine speed was greater than 10 RPM were excluded when developing average engine activity and emission concentrations for each notch.

G.3 Results

This section describes the results for: (1) the ratio of NO_2 versus NO; and (2) the ratio of FID versus NDIR for HC.

NO_2/NO Ratio

Figure G-1 shows the NO_2/NO ratios for the three different biodiesel fuels by notch position. Results are not shown for ULSD because there was a problem with calibration that rendered those results invalid.

The exhaust NO_2 concentrations typically range from 20 to 100 ppm for the three biodiesel fuels, depending on notch positions. Typically the NO_2/NO ratios for the three biodiesel fuels follow a similar trend over notch positions. The NO_2/NO ratios are typically higher at idle than any other throttle position. For each biodiesel blend, the highest NO_2/NO ratios were at idle, decreased with engine load to notch 3, slightly increased with further engine load to notches 4 or 4, reaching a minimum at notch 7, and increasing slightly at notch 8. The inter-replicate variability for a given notch and fuel was generally low. The ratios of mean to standard deviation (coefficient of variation) were used to quantify the inter-replicate variability. The coefficient of variation for the NO_2/NO ratio for each notch for each fuel was typically less than 0.10.

The NO_2 and NO emission rates for each throttle setting are weighted based on the EPA line haul freight duty cycle to estimate cycle average NO_2 and NO emission rates. The cycle average NO_2/NO ratios are estimated based on cycle average NO_2 and NO emission rates. The cycle average NO_2/NO ratios are 0.069, 0.076, and 0.104 for B10, B20, and B40, respectively. These ratios imply that NO comprises 90.6 to 93.5 vol-% of NO_x, depending on the fuel. Based on these results, the initial assumption that NO comprises 95 vol-% of total NO_x was shown to be reasonable.

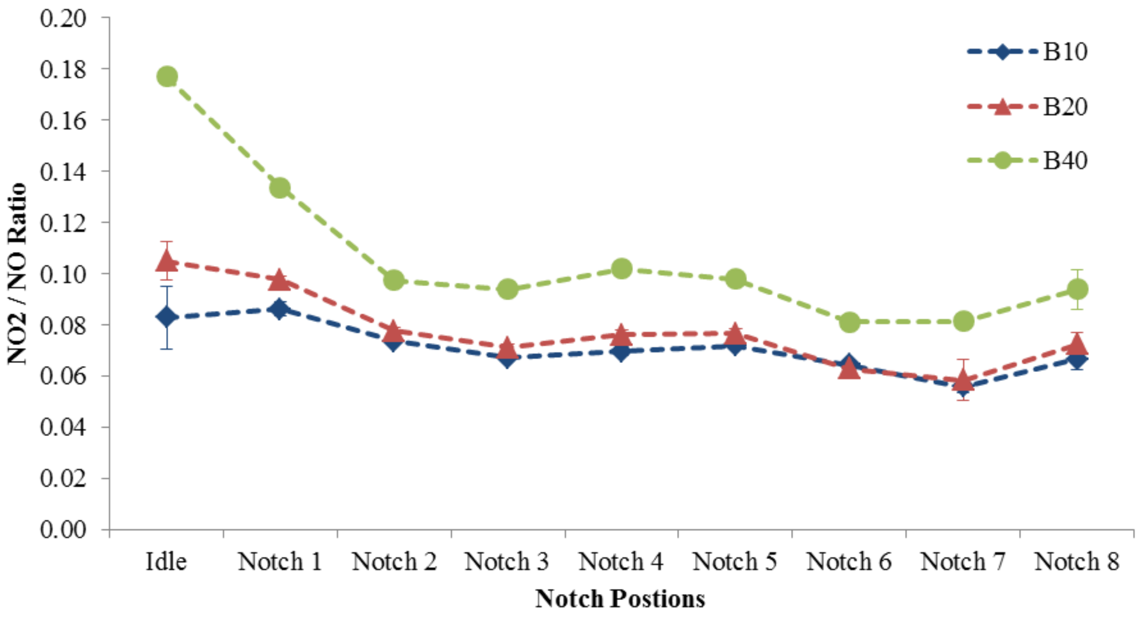


Figure G-1. Ratios of NO_2 versus NO for Different Fuels by Notch Positions for Locomotive Prime Mover Engine NC-1797. Error Bars Indicate Standard Deviations.

Table G-2 summarizes the cycle average NO_2/NO ratios for all measured locomotive prime mover engines and fuels. Measurements were made on ULSD for all locomotives, but the results were not valid for NC-1797. Valid measurements were made on B10, B20, and B40 for NC-1797 and NC-1859. Valid measurements were made on NC-1810 for B60, B80, and B100. The cycle average NO_2/NO ratios appear to differ depending on the fuel and between locomotives. For NC-1810 and NC-1859 prime mover engines, the cycle average NO_2/NO ratios for ULSD are lower compared to biodiesel blends. For the biodiesel blends, the cycle average NO_2/NO ratios range from 0.06 to 0.08, except for NC-1797 on B40. These ratios imply that NO comprises 92.6 to 94.3 vol-% of total NO_x, for biodiesel blends.

Table G-2. Cycle Average Ratios of NO_2 versus NO for Different Fuels and Locomotive Prime Mover Engines.

Fuel/Locomotive	NC-1797	NC-1810	NC-1859
ULSD	n/a	0.056	0.054
B10	0.069	-	0.077
B20	0.076	-	0.071
B40	0.104	-	0.063
B60	-	0.073	-
B80	-	0.061	-
B100	-	0.068	-

"n/a" indicates measurement was attempted, but the results were invalid; "-" indicates no measurement was done.

FID/NDIR Ratio for HC

Figure G-2 shows the FID/NDIR HC ratios for the four different fuels by notch positions. Results are not shown for B20 because the NDIR reported concentration was unrealistically and consistently low at less than 2 ppm, indicating a sensor or calibration problem. Results for the other fuels did not have this problem.

Typically, the FID/NDIR ratios for the three fuels follow a similar trend over notch positions. For each fuel, the FID/NDIR ratios decrease from Idle to approximately notch 4, and then increase to notch 8. There was relatively little variability in results between the replicates for a given fuel and notch position, as the coefficients of variation for the FID/NDIR ratio for each notch position for each fuel were typically less than 0.10.

The FID HC and NDIR HC emission rates for each throttle setting are weighted based on the EPA line haul freight duty cycle to estimate cycle average FID HC and NDIR HC emission rates. The cycle average FID/NDIR ratios are estimated based on cycle average FID HC and NDIR HC emission rates. These cycle average FID/NDIR ratios are 4.1, 3.0, and 2.4, for ULSD, B10, and B40, respectively. The FID/NDIR ratio was highest for ULSD. Among the biodiesel fuels, the FID/NDIR ratios are similar. The average ratio among the biofuels was 2.7, which was 8 percent higher than the previously assume ratio of 2.5. Thus, the previously assume ratio was shown to be reasonable.

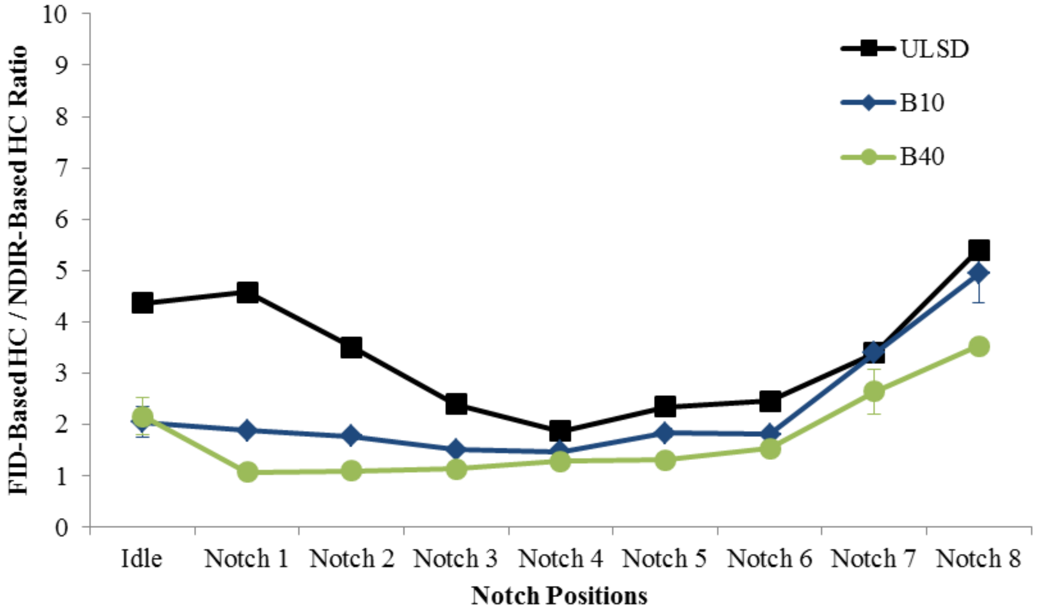


Figure G-2. Ratios of Flame Ionized Detection versus Non-Dispersive Infrared Hydrocarbon for Different Fuels by Notch Position for Locomotive Prime Mover Engine NC-1797. Error Bars Indicate Standard Deviations.

Table G-3 summarizes the cycle average FID/NDIR ratios for all measured locomotive prime mover engines and fuels. Measurements were made on ULSD for all three locomotives, on B10, B20, and B40 for NC-1797 and NC-1859, and on B60, B80, and B100 for NC-1810. However, the result for NC-1797 on B20 was not valid and, therefore, was not reported. The cycle average FID/NDIR ratios differ by locomotive and fuel. For ULSD, the cycle average FID/NDIR ratios range from 4.1 to 6.0. For the biodiesel blends from B10 through B60, the cycle average FID/NDIR ratios were lower than ULSD, ranging from 1.9 to 3.7. For B80 and B100 measured on NC-1810, the cycle average FID/NDIR ratio was 4.0 and 5.5, respectively. The assumption that actual total hydrocarbons are approximately 2.5 times greater than the NDIR measurement appears to be reasonable in many cases, such as for B10, B20, B40, and B60. These results indicate that this assumption may be low particularly for ULSD, B80, and B100. However, there was substantial variability in the results.

Table G-3. Cycle Average Ratios of Flame Ionized Detection versus Non-Dispersive Infrared Hydrocarbon for Different Fuels and Locomotive Prime Mover Engines.

Fuel/Locomotive	NC-1797	NC-1810	NC-1859
ULSD	4.1	6.0	5.7
B10	3.0	-	3.7
B20	n/a	-	2.0
B40	2.4	-	2.9
B60	-	1.9	-
B80	-	4.0	-
B100	-	5.5	-

“n/a” indicates measurement was attempted, but the results were invalid; “-” indicates no measurement was done.

SUPPLEMENTAL INFORMATION

NO_2/NO Ratio

Tables G-4 and G-5 summarize the engine output based NO_2 and NO emission rates, respectively, for each notch position for each replicate for all fuels. For each fuel, averages and standard deviation from three replicates were calculated for each notch position. For each fuel, the notch coefficients of variation for the NO_2 emission rates were typically less than 0.15, indicating some variability. The NO emission rates were highly repeatable, with coefficients of variation typically less than 0.08.

Table G-6 summarizes the engine output based NO_2/NO ratios for each notch position for each replicate. Average NO_2/NO ratios are calculated for each notch position for each replicate. For all biodiesel fuels, the NO_2/NO ratios range from approximately 0.03 to 0.17. Based on EPA line haul freight duty cycle, the cycle average NO_2/NO ratios are 0.069, 0.076, and 0.104 for B10, B20, and B40, respectively.

Table G-4. Engine Output Based Nitrogen Dioxide (NO_2) Emission Rates for each Notch Position for each Replicate for Locomotive Prime Mover Engine NC-1797.

Engine Output-Based NO2 Emission Rates (g/bhp-hr)												
Throttle	**ULSD**						**B10**					
Notch	**10/22**	**10/22**	**10/22**	**3 Reps**	**3 Reps**	**3 Reps**	**3/10**	**3/10**	**3/10**	**3 Reps**	**3 Reps**	**3 Reps**
Position	**REP1**	**REP2**	**REP3**	**Average**	**StDev**	**CV**	**REP1**	**REP2**	**REP3**	**Average**	**StDev**	**CV**
Idle	0.00	0.00	0.00	0.00	0.00	--	12.53	17.55	18.90	16.33	3.35	0.21
1	0.00	0.00	0.00	0.00	0.00	--	1.87	2.12	2.16	2.05	0.15	0.08
2	0.00	0.00	0.00	0.00	0.00	--	1.38	1.58	1.63	1.53	0.13	0.09
3	0.00	0.00	0.00	0.00	0.00	--	0.81	0.98	0.94	0.91	0.09	0.10
4	0.00	0.00	0.00	0.00	0.00	--	0.65	0.82	0.79	0.76	0.09	0.12
5	0.00	0.00	0.00	0.00	0.00	--	0.69	0.85	0.81	0.79	0.09	0.11
6	0.00	0.00	0.00	0.00	0.00	--	0.60	0.59	0.66	0.61	0.04	0.06
7	0.00	0.00	0.00	0.00	0.00	--	0.37	0.40	0.44	0.40	0.03	0.09
8	0.00	0.00	0.00	0.00	0.00	--	0.44	0.52	0.56	0.51	0.06	0.13
Throttle	**B20**						**B40**					
Notch	**4/14**	**4/14**	**4/14**	**3 Reps**	**3 Reps**	**3 Reps**	**7/21**	**7/21**	**7/21**	**3 Reps**	**3 Reps**	**3 Reps**
Position	**REP1**	**REP2**	**REP3**	**Average**	**StDev**	**CV**	**REP1**	**REP2**	**REP3**	**Average**	**StDev**	**CV**
Idle	15.28	16.37	17.15	16.27	0.94	0.06	29.25	28.75	29.40	29.14	0.34	0.01
1	1.72	1.77	1.78	1.76	0.03	0.02	2.42	2.42	2.42	2.42	0.00	0.00
2	1.24	1.27	1.29	1.27	0.03	0.02	1.57	1.61	1.57	1.59	0.02	0.01
3	0.71	0.73	0.76	0.74	0.02	0.03	0.95	0.96	0.95	0.95	0.00	0.00
4	0.60	0.62	0.63	0.62	0.02	0.03	0.80	0.81	0.81	0.80	0.00	0.00
5	0.63	0.66	0.67	0.65	0.02	0.03	0.84	0.83	0.84	0.84	0.01	0.01
6	0.46	0.49	0.50	0.49	0.02	0.04	0.64	0.63	0.64	0.64	0.01	0.01
7	0.29	0.39	0.37	0.35	0.05	0.15	0.42	0.40	0.41	0.41	0.01	0.02
8	0.45	0.42	0.47	0.45	0.03	0.07	0.62	0.54	0.55	0.57	0.04	0.08

Table G-5. Engine Output Based Nitric Oxide (NO) Emission Rates for Each Notch Position for Each Replicate for Locomotive Prime Mover Engine NC-1797.

Engine Output-Based NO Emission Rates (g/bhp-hr)												
Throttle	ULSD						B10					
Notch	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	3/10	3/10	3/10	3 Reps	3 Reps	3 Reps
Position	REP1	REP2	REP3	Average	StDev	CV	REP1	REP2	REP3	Average	StDev	CV
Idle	174.67	170.32	172.09	172.36	2.18	0.01	183.50	198.44	209.45	197.13	13.03	0.07
1	0.00	22.09	21.18	21.81	0.55	0.03	22.54	24.10	24.67	23.77	1.10	0.05
2	20.28	20.07	20.83	20.39	0.39	0.02	19.13	21.31	22.12	20.85	1.55	0.07
3	13.62	13.44	13.72	13.59	0.14	0.01	12.36	14.38	14.05	13.59	1.08	0.08
4	10.66	10.56	10.70	10.64	0.07	0.01	9.63	11.68	11.18	10.83	1.07	0.10
5	11.39	11.15	11.11	11.22	0.15	0.01	9.78	11.81	11.15	10.91	1.03	0.09
6	9.65	10.80	10.69	10.38	0.63	0.06	9.23	9.24	10.11	9.53	0.50	0.05
7	7.80	7.91	7.95	7.88	0.08	0.01	6.80	7.22	7.43	7.15	0.32	0.04
8	7.70	7.88	8.07	7.88	0.18	0.02	6.96	7.83	7.97	7.59	0.55	0.07
Throttle	B20						B40					
Notch	4/14	4/14	4/14	3 Reps	3 Reps	3 Reps	7/21	7/21	7/21	3 Reps	3 Reps	3 Reps
Position	REP1	REP2	REP3	Average	StDev	CV	REP1	REP2	REP3	Average	StDev	CV
Idle	158.01	152.96	154.03	155.00	2.66	0.02	167.90	160.73	164.77	164.47	3.60	0.02
1	17.80	18.04	18.08	17.97	0.16	0.01	17.98	18.01	18.28	18.09	0.17	0.01
2	16.21	16.33	16.35	16.30	0.08	0.00	16.12	16.49	16.22	16.28	0.19	0.01
3	10.23	10.31	10.46	10.34	0.11	0.01	10.17	10.20	10.12	10.16	0.04	0.00
4	8.05	8.09	8.17	8.10	0.06	0.01	7.87	7.93	7.85	7.89	0.04	0.01
5	8.46	8.50	8.58	8.52	0.06	0.01	8.61	8.52	8.50	8.54	0.06	0.01
6	7.74	7.68	7.74	7.72	0.04	0.00	8.00	7.79	7.77	7.85	0.13	0.02
7	5.92	6.10	5.87	5.96	0.12	0.02	5.08	5.06	5.01	5.05	0.04	0.01
8	6.19	6.11	6.17	6.16	0.04	0.01	5.98	6.06	6.02	6.02	0.04	0.01

Table G-6. Ratios of Nitrogen Dioxide (NO_2) versus Nitric Oxide (NO) for Each Notch Position for Each Replicate for Locomotive Prime Mover Engine NC-1797.

Engine Output-Based Emission Rates (g/bhp-hr) NO2/NO Ratio												
Throttle	ULSD						B10					
Notch	10/22	10/22	10/22	3 Reps	3 Reps	3 Reps	3/10	3/10	3/10	3 Reps	3 Reps	3 Reps
Position	REP1	REP2	REP3	Average	StDev	CV	REP1	REP2	REP3	Average	StDev	CV
Idle	0.000	0.000	0.000	0.000	0.00	--	0.068	0.088	0.090	0.083	0.01	0.15
1	0.000	0.000	0.000	0.000	0.00	--	0.083	0.088	0.088	0.086	0.00	0.03
2	0.000	0.000	0.000	0.000	0.00	--	0.072	0.074	0.074	0.074	0.00	0.01
3	0.000	0.000	0.000	0.000	0.00	--	0.066	0.068	0.067	0.067	0.00	0.02
4	0.000	0.000	0.000	0.000	0.00	--	0.068	0.070	0.071	0.070	0.00	0.02
5	0.000	0.000	0.000	0.000	0.00	--	0.070	0.072	0.073	0.072	0.00	0.02
6	0.000	0.000	0.000	0.000	0.00	--	0.065	0.064	0.065	0.064	0.00	0.01
7	0.000	0.000	0.000	0.000	0.00	--	0.054	0.055	0.059	0.056	0.00	0.04
8	0.000	0.000	0.000	0.000	0.00	--	0.063	0.066	0.071	0.067	0.00	0.06
Throttle	B20						B40					
Notch	4/14	4/14	4/14	3 Reps	3 Reps	3 Reps	7/21	7/21	7/21	3 Reps	3 Reps	3 Reps
Position	REP1	REP2	REP3	Average	StDev	CV	REP1	REP2	REP3	Average	StDev	CV
Idle	0.097	0.107	0.111	0.105	0.01	0.07	0.174	0.179	0.178	0.177	0.00	0.01
1	0.097	0.098	0.099	0.098	0.00	0.01	0.134	0.134	0.132	0.134	0.00	0.01
2	0.076	0.078	0.079	0.078	0.00	0.02	0.098	0.098	0.097	0.097	0.00	0.00
3	0.070	0.071	0.073	0.071	0.00	0.02	0.094	0.094	0.094	0.094	0.00	0.00
4	0.074	0.077	0.078	0.076	0.00	0.02	0.102	0.102	0.103	0.102	0.00	0.01
5	0.075	0.077	0.078	0.077	0.00	0.02	0.098	0.098	0.098	0.098	0.00	0.00
6	0.060	0.064	0.065	0.063	0.00	0.04	0.080	0.081	0.083	0.081	0.00	0.02
7	0.049	0.063	0.063	0.058	0.01	0.14	0.083	0.079	0.082	0.081	0.00	0.02
8	0.072	0.068	0.077	0.072	0.00	0.06	0.103	0.089	0.091	0.094	0.01	0.08

FID/NDIR Ratio

Tables G-7 and G-8 summarize the engine output based HC emission rates measured using FID and NDIR, respectively, for each notch position for each replicate for each fuel. Data from replicate 1 was excluded because the FID had not been adequately warmed up, but it was warmed up by replicate 2. For each fuel, averages, standard deviations, coefficients of variation from the available replicates were calculated for each notch position.

For each fuel, there were variations for the HC emission rates using FID and NDIR for each notch position. The coefficients of variation were typically less than 0.15 for the former and less than 0.40 for the latter.

Table G-9 summarizes the FID/NDIR ratios for engine output based HC emission rates for each notch position for replicates 2 and 3 for each fuel. For all fuels excluding B20, the FID/NDIR ratios typically range from approximately 1.1 to 5.4. Based on the EPA line haul freight duty cycle, the cycle average FID/NDIR ratios are 4.1, 3.0, and 2.4 for ULSD, B10, and B40, respectively.

Table G-7. Engine Output Based Flame Ionized Detection (FID) Hydrocarbon Emission Rates for Each Notch Position for Each Replicate for Locomotive Prime Mover Engine NC-1797.

Engine Output-Based FID HC Emission Rates (g/bhp-hr)										
Throttle	**ULSD**					**B10**				
Notch	**10/22**	**10/22**	**2 Reps**	**2 Reps**	**2 Reps**	**3/10**	**3/10**	**2 Reps**	**2 Reps**	**2 Reps**
Position	**REP2**	**REP3**	**Average**	**StDev**	**CV**	**REP2**	**REP3**	**Average**	**StDev**	**CV**
Idle	35.57	30.03	32.80	3.91	0.12	20.34	22.81	21.58	1.74	0.08
1	1.48	1.40	1.44	0.06	0.04	1.07	1.09	1.08	0.01	0.01
2	0.83	0.92	0.87	0.06	0.07	0.62	0.63	0.62	0.00	0.01
3	0.54	0.46	0.50	0.06	0.12	0.41	0.41	0.41	0.00	0.01
4	0.45	0.36	0.41	0.06	0.15	0.37	0.38	0.38	0.01	0.02
5	0.48	0.39	0.44	0.07	0.15	0.38	0.36	0.37	0.01	0.03
6	0.45	0.38	0.42	--	--	0.26	0.31	0.29	0.03	0.12
7	0.45	0.43	0.44	--	--	0.40	0.44	0.42	0.03	0.07
8	0.55	0.46	0.51	--	--	0.58	0.51	0.54	0.05	0.09
Throttle	**B20**					**B40**				
Notch	**4/14**	**4/14**	**2 Reps**	**2 Reps**	**2 Reps**	**7/21**	**7/21**	**2 Reps**	**2 Reps**	**2 Reps**
Position	**REP2**	**REP3**	**Average**	**StDev**	**CV**	**REP2**	**REP3**	**Average**	**StDev**	**CV**
Idle	25.26	27.46	26.36	1.55	0.06	28.86	24.86	26.86	2.82	0.11
1	1.05	--	1.05	--	--	0.64	--	0.64	--	--
2	0.60	--	0.60	--	--	0.37	--	0.37	--	--
3	0.39	--	0.39	--	--	0.30	--	0.30	--	--
4	0.36	--	0.36	--	--	0.32	--	0.32	--	--
5	0.32	--	0.32	--	--	0.29	--	0.29	--	--
6	0.27	0.17	0.22	0.07	0.33	0.28	0.27	0.27	0.01	0.04
7	0.36	0.31	0.33	0.04	0.11	0.36	0.30	0.33	0.05	0.14
8	0.44	0.37	0.40	0.05	0.13	0.41	0.38	0.39	--	--

Table G-8. Engine Output Based Non-Dispersive Infrared (NDIR) Hydrocarbon Emission Rates for Each Notch Position for Each Replicate for Locomotive Prime Mover Engine NC-1797.

Engine Output-Based NDIR HC Emission Rates (g/bhp-hr)										
Throttle	ULSD					B10				
Notch	10/22	10/22	2 Reps	2 Reps	2 Reps	3/10	3/10	2 Reps	2 Reps	2 Reps
Position	REP2	REP3	Average	StDev	CV	REP2	REP3	Average	StDev	CV
Idle	--	7.51	7.51	--	--	8.86	12.21	10.53	2.37	0.23
1	--	0.31	0.31	--	--	0.56	0.59	0.57	0.02	0.04
2	--	0.25	0.25	--	--	0.34	0.36	0.35	0.02	0.05
3	--	0.21	0.21	--	--	0.27	0.27	0.27	0.00	0.01
4	--	0.22	0.22	--	--	0.26	0.26	0.26	0.00	0.00
5	--	0.19	0.19	--	--	0.20	0.20	0.20	0.00	0.02
6	--	0.17	0.17	--	--	0.15	0.17	0.16	0.02	0.10
7	--	0.13	0.13	--	--	0.12	0.13	0.12	0.01	0.07
8	--	0.09	0.09	--	--	0.11	0.11	0.11	0.00	0.03
Throttle	B20					B40				
Notch	4/14	4/14	2 Reps	2 Reps	2 Reps	7/21	7/21	2 Reps	2 Reps	2 Reps
Position	REP2	REP3	Average	StDev	CV	REP2	REP3	Average	StDev	CV
Idle	0.47	0.54	0.50	0.05	0.10	11.88	12.95	12.41	0.76	0.06
1	0.00	0.00	0.00	0.00	--	0.59	0.60	0.59	0.01	0.02
2	0.00	0.01	0.00	0.00	0.22	0.34	0.34	0.34	0.00	0.00
3	0.01	0.02	0.01	0.00	0.35	0.26	0.27	0.26	0.01	0.03
4	0.01	0.02	0.02	0.01	0.30	0.24	0.25	0.25	0.01	0.03
5	0.01	0.02	0.01	0.01	0.40	0.21	0.23	0.22	0.01	0.06
6	0.01	0.02	0.02	0.01	0.46	0.18	0.18	0.18	0.00	0.02
7	0.02	0.02	0.02	0.00	0.00	0.12	0.13	0.12	0.00	0.02
8	0.02	0.01	0.02	0.01	0.48	0.11	0.11	0.11	--	--

Table G-9. Ratios of Flame Ionized Detection versus Non-Dispersive Infrared for Engine Output Based Hydrocarbon Emission Rates for Each Notch Position for the Second and Third Replicates for Locomotive Prime Mover Engine NC-1797.

Engine Output-Based HC Emission Rates (g/bhp-hr) FID/NDIR Ratio										
Throttle	**ULSD**					**B10**				
Notch	**10/22**	**10/22**	**2 Reps**	**2 Reps**	**2 Reps**	**3/10**	**3/10**	**2 Reps**	**2 Reps**	**2 Reps**
Position	**REP2**	**REP3**	**Average**	**StDev**	**CV**	**REP2**	**REP3**	**Average**	**StDev**	**CV**
Idle	--	4.0	4.4	--	--	2.3	1.9	2.0	0.30	0.15
1	--	4.4	4.6	--	--	1.9	1.9	1.9	0.05	0.03
2	--	3.7	3.5	--	--	1.8	1.7	1.8	0.08	0.04
3	--	2.2	2.4	--	--	1.5	1.5	1.5	0.03	0.02
4	--	1.7	1.9	--	--	1.5	1.5	1.5	0.02	0.02
5	--	2.1	2.3	--	--	1.9	1.8	1.8	0.09	0.05
6	--	--	2.5	--	--	1.8	1.8	1.8	0.04	0.02
7	--	--	3.4	--	--	3.4	3.4	3.4	0.01	0.00
8	--	--	5.4	--	--	5.3	4.5	4.9	0.57	0.12
Throttle	**B20**					**B40**				
Notch	**4/14**	**4/14**	**2 Reps**	**2 Reps**	**2 Reps**	**7/21**	**7/21**	**2 Reps**	**2 Reps**	**2 Reps**
Position	**REP2**	**REP3**	**Average**	**StDev**	**CV**	**REP2**	**REP3**	**Average**	**StDev**	**CV**
Idle	53.9	50.9	52.3	2.12	0.04	2.4	1.9	2.2	0.36	0.17
1	--	--	--	--	--	1.1	--	1.1	--	--
2	161.5	--	136.6	--	--	1.1	--	1.1	--	--
3	41.4	--	31.1	--	--	1.2	--	1.1	--	--
4	23.9	--	18.9	--	--	1.3	--	1.3	--	--
5	35.0	--	25.0	--	--	1.4	--	1.3	--	--
6	24.8	7.9	13.6	11.92	0.88	1.6	1.5	1.5	0.09	0.06
7	16.0	13.6	14.8	1.66	0.11	2.9	2.3	2.6	0.43	0.16
8	19.5	33.1	24.0	9.63	0.40	--	3.3	3.5	--	--

Abbreviations and Acronyms

B10	Blend of 90 percent, by volume, ULSD and 10% biofuel blend stock
B100	100% biofuel blend stock, no ULSD.
B20	Blend of 80 percent, by volume, ULSD and 20% biofuel blend stock
B40	Blend of 60 percent, by volume, ULSD and 40% biofuel blend stock
B60	Blend of 40 percent, by volume, ULSD and 60% biofuel blend stock
B80	Blend of 20 percent, by volume, ULSD and 80% biofuel blend stock
CO	Carbon monoxide
CO_2	Carbon dioxide
EMD	Electro Motive Division
ETV	Environmental Technology Verification program of the US EPA
FID	Flame Ionization Detection
GPS	Global Position System
HC	Hydrocarbons
HEP	Head End Power engine
IAT	Intake Air Temperature
LCI	Life Cycle Inventory
LHV	Lower Heating Value
MAP	Manifold Absolute Pressure
NAAQS	National Ambient Air Quality Standards
NCDOT	North Carolina Department of Transportation
NCSU	North Carolina State University
NDIR	Non-dispersive infrared
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
OTR	Over the Rail
PEMS	Portable Emissions Measurement System
PM	Particulate matter
$PM_{2.5}$	Particulate Matter less than 2.5 micro-meters in aerodynamic diameter
PME	Prime Mover Engine

RPM	Revolutions per Minute
RY	Rail yard
ULSD	Ultra Low Sulfur Diesel
US EPA	United States Environmental Protection Agency
USDOT	United States Department of Transportation
VOC	Volatile Organic Compounds
WHO	World Health Organization