Contractor's Report to the Board

Yosemite Closing the Loop Project

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Executive Summary

The reduction of emissions and fuel consumption using fuels that are renewable and have lower emission rates can provide considerable benefits for national parks such as Yosemite. One fuel that has shown considerable promise in meeting these needs is biodiesel. To date, a number of studies have demonstrated emissions reductions for biodiesel fuels relative to ordinary diesel fuel (U.S. Environmental Protection Agency, 2002).

Biodiesel is commercially available and also more readily implemented than other alternative fuels, such as natural gas. Biodiesel requires no modifications to the engine and only minor modifications to existing fuel practices. An added benefit of biodiesel fuels is that they can be derived from renewable, domestic resources, such as crops or waste grease. As such, biodiesel has been designated as an alternative fuel under the Energy Policy Act (EPACT). This allows fleet operators to meet the EPACT alternative fuel vehicle (AFV) acquisition requirements. Biodiesel is added to conventional diesel at blends of 20 percent and higher.

The use of biodiesel in fleet and other applications has expanded considerably in recent years, from essentially negligible levels in 1998 to 20 million gallons in 2002 (McCormick, 2003). This includes municipal fleets, military applications, postal applications, and others. The production capacity in the U.S. could be 150 million gallons per year. In Europe, production is currently at 200 million gallons, with a capacity of 600 million gallons. As the use of biodiesel continues to expand, fleets are continuing to examine potential applications of biodiesel. Yellowstone National Park has conducted a demonstration program (University of Idaho and Montana Department of Environmental Quality, 1999). Channel Island National Park is also using biodiesel on a regular basis.

Currently, DNC Parks and Resorts at Yosemite, Inc. (DNC) is considering the use of biodiesel in its fleet vehicles for applications in the park. DNC generates approximately 48 tons of used restaurant grease per year that is currently being transported back to Fresno where it is used to make biodiesel. However, the biodiesel is not returned to Yosemite for use in their fleet. The DNC goal is to make use of its restaurant grease and at the same time provide a renewable fuel for use in its fleet vehicles.

Prior to full-scale application of the biodiesel, DNC proposed a pilot program to examine the use of biodiesel in their fleet in terms of emissions benefits, maintenance, use during cold weather, and other considerations. If the application of the fuel proves to be successful, eventually the program could lead to development of a small-scale plant on the park grounds that could process the restaurant grease into biodiesel on-site.

The present project is a pilot demonstration program in the DNC fleet vehicles. The overall program included an investigation of feasibility of a biodiesel plant, emissions testing, and characterization of fuel mileage and maintenance issues with biodiesel use. The program is a collaborative effort between DNC, the California Integrated Waste Management Board, the University of California at Riverside, the Air Resources Board, Clean Air Technologies, Inc., and Biodiesel Industries.

Initially the program investigated the feasibility of a biodiesel processing plant on-site and an off-site plant to process the restaurant grease. A series of emissions tests were conducted comparing the biodiesel from the restaurant grease to the typical diesel used in the park. This included dynamometer tests at the ARB dynamometer facility in Stockton, Calif., measurements of emissions for shuttle buses during typical in-use service, and opacity tests.

Opacity reduction with the 20 percent biodiesel fuel (B20) was the only trend consistently seen for all test vehicles and test periods. Researchers observed other trends for specific vehicles and emissions components during specific test periods. Observations would need further verification using a larger sample size (that is, larger number of vehicles, increased mileage, and increased testing) and a test matrix that includes long-term reproducibility.

Aside from any benefits/liabilities in primary emissions, the CO_2 emissions generated from the biodiesel fraction of the fuel are considered to be recycled from a global perspective. Biological processes in plants use atmospheric CO_2 to produce carbon-based compounds on a much faster time scale than the processes involved in producing fossil fuels. Life-cycle analyses that account for all sources of CO_2 from both production and use as a fuel show that these factors provide a 16 percent reduction in CO_2 emissions for a B20 blend.

The in-service DNC fleet used approximately 1,000 gallons of B20 fuel during the two test periods. During these periods, the buses experienced no significant operational or maintenance problems regarding biodiesel or biodiesel storage. Since this is a relatively small operating database, further implementation of biodiesel should begin with a smaller subset of vehicles initially to further ensure operational performance before expanding to the entire fleet.

Section 1. Introduction

The use of biodiesel in fleet and other applications has expanded considerably in recent years. This is due to the potential of biodiesel to reduce emissions and its capability to be produced from renewable sources. Biodiesel has been used in several national parks, including Yellowstone and Channel Island National Parks, and the DNC Parks & Resorts at Yosemite, Inc. DNC is currently considering the use of biodiesel in its fleet vehicles for applications in the park. DNC operates the concessionary services in Yosemite National Park and generates approximately 48 tons of used restaurant grease per year.

This grease is currently being converted to biodiesel, but the biodiesel is not reused at Yosemite. The DNC goal is to make use of its restaurant grease and at the same time provide a renewable fuel for use in its fleet vehicles. Prior to full-scale application of the biodiesel, DNC proposed a pilot program to examine the use of biodiesel in their fleet in terms of emissions benefits, maintenance, use during cold weather, and other considerations. If the application of the fuel proves to be successful, eventually the program could lead to development of a small-scale plant on the park grounds that could process the restaurant grease into biodiesel on-site.

Those conducting the study began a pilot demonstration using biodiesel in the DNC fleet vehicles. The program included identifying a biodiesel production facility, investigating the feasibility of operating the facility, emissions testing, and some characterization of biodiesel use in the vehicles. The biodiesel used in this program was produced from restaurant grease from the DNC food operations in the park at a small batch biodiesel production facility operated by Biodiesel Industries, Inc. at the Naval Facilities Engineering Service Center in Port Hueneme, Ventura County, Calif.

The study included a three-fold emissions program to provide comparisons between the emissions on regular Air Resources Board (ARB) diesel and the biodiesel blend in the standard buses in the DNC fleet. The program included chassis dynamometer measurements, in-use measurements with a portable emissions measurement system, and opacity measurements. The field measurements with the on-board emissions monitor were conducted on the typical Yosemite bus route under both summer and winter conditions. Chassis dynamometer tests (measuring mechanical power) were conducted under summer and spring conditions.

The summer chassis dynamometer measurements showed statistically significant reductions in particulate matter (PM) at 10–20 percent and total hydrocarbons (THC) at 10–25 percent for one of the test buses (DNC-138). The largest reductions were found at the highest load point. Nitrogen oxide (NO_x) emissions for this bus increased for most of the test modes between 5–15 percent.

The initial round of chassis dynamometer measurements for the second bus (DNC-144) did not show any consistent trend over the entire load range. The lack of consistent test results combined with operational issues suggests that this bus was malfunctioning, perhaps with a fuel injection system problem. For the spring chassis dynamometer tests of the steady state load points, DNC-143 showed statistically significant reductions in PM for all modes ranging from 10 to 40 percent. ("State load" indicates dynamometer cycles where the speed does not change; that is, steady. Load is the amount of force applied to the dynamometer.)

The researchers observed no consistent trends for DNC-138. They found a trend of slightly increasing NO_x emissions with the B20 blend for both buses in the range of 2.5 to 6.5 percent. Under idle conditions, DNC-138 did show some trend of decreasing THC emissions on the B20 blend.

The summer field test results showed consistent reductions in PM emissions (10–17 percent) for both test buses on B20. The levels of CO and NO_x measured did not show consistent trends in either bus. Operation of the air conditioner was also found to increase emissions, particularly NO_x emissions for one of the two buses. The winter field testing results were less consistent than those found in the summer testing.

For one of the buses (DNC-143), statistically significant decrease in CO and PM emissions were observed, while statistically significant increases were found for NO_x emissions. The other bus (DNC-138) did not reveal statistically significant differences between the ARB diesel and the B20 blend. The winter tests showed greater variability in the CO_2 emissions per loop than the summer tests, suggesting greater differences in driving conditions/operation.

Opacity results for each test bus over both seasons were lower on B20 compared to ARB diesel. The reductions in opacity ranged from 10–25 percent. This could be indicative of both changes in PM mass, as well as PM composition. No differences were found between the opacity measurements made in the summer and winter seasons.

Direct comparisons between the Stockton chassis dynamometer laboratory and the on-board field testing system showed relatively good comparisons between the NO_x, CO, and CO_2 emissions. The comparisons were poor for PM and THC, however. ("Good" and "poor" are representative terms of the mathematical correlations found in the data and are represented in figures 3a-e on pages 14–16.)

The differences for PM emissions could be attributed to differences in the direct filter mass measurements made by the chassis laboratory and the light scattering devices used in the on-board system. This system measures PM mass indirectly and requires a separate calibration. The differences in the THC measurements could be related to differences in the measurement technique and/or the fact that the on-board system does not measure THC through a line heated to elevated temperatures. Based on this comparison, the field THC emissions were considered suspect.

In examining the data set as a whole, the opacity reduction with the B20 was the only trend consistently seen for all test vehicles and test periods. Other trends for specific vehicles and emissions components were only observed over specific test periods. In particular, the tests revealed no consistent trends for DNC-138 during all test periods. As such, any observations would need further verification over a larger sample size and a test matrix that includes long-term reproducibility.

Aside from any benefits/liabilities in primary emissions, the CO_2 emissions generated from the biodiesel fraction of the fuel are considered to be recycled from a global perspective. Biological processes in plants use atmospheric CO_2 to produce carbon-based compounds on a much faster time scale than the processes involved in producing fossil fuels. Life cycle analyses that account for all sources of CO_2 from both production and use as a fuel show that these factors provide a 16 percent reduction in CO_2 emissions for a B20 blend.

The in-service DNC fleet used approximately 1,000 gallons of B20 fuel during the two test periods. During these periods, the buses experienced no significant operational or maintenance problems regarding biodiesel or biodiesel storage. Since this is a relatively small operating database, further implementation of biodiesel should begin with a smaller subset of vehicles initially to further ensure operational performance before expanding to the entire fleet.

Section 2. Restaurant Grease Supply and the Biodiesel Production Facility

Restaurant Grease Production in the Park and Diesel Fuel Requirements

Yosemite National Park is one of the busiest parks in the country. In 2003 the park had a total of 3.5 million visitors. DNC is responsible for the lodging, food services, and transportation services for visitors within the park. The DNC shuttle service is the main transportation service within the park, transporting passengers between the different sites and lodging locations. The shuttle service transports 3.5 million passengers annually, with approximately 3 million of these passengers traveling between the Memorial Day and Labor Day summer high season.

During peak operation, approximately 155,000 passengers per week ride up to 10 buses in continuous service. In total, the vehicles travel the 8-mile shuttle service loop approximately 32,689 times during the year. Diesel fuel requirements for the fleet are approximately 115,000 gallons annually.

DNC services 10 restaurants throughout the park—including restaurants at the major hotels and other lodging facilities—as well as food service facilities in the village area of the park. These restaurants generate in excess of 300 tons of used grease annually. Much of this grease is generated from the runoff of the cooking grills, which includes mixtures of trap grease with large percentages of water. Collections of this grease indicated that it would not be suitable for biodiesel production due to the high water content. Of this used grease, approximately 48 tons was found to be suitable for production of biodiesel.

This grease was primarily the used vegetable oil from french fry and other frying applications. The grease from the frying applications is rotated on a regular basis and thus separated from the other grease sources. Of this 48 tons of material generated annually, approximately 70 percent is generated during the six months of highest use, the same time period when diesel fuel use is highest. The conversion of the 48 tons of useable restaurant grease to biodiesel would result in approximately 1,500 gallons per month during the high season to supplement the current diesel fuel needs in the park. Presently, the grease is transported to Fresno where it is used to make biodiesel, but the biodiesel is not returned to Yosemite for use in their fleet.

Biodiesel Production Facility

This study explored several possibilities for the processing of the restaurant grease into biodiesel. Initially the researchers considered locating an on-site facility in the park. They identified one biodiesel supplier, Biodiesel Industries, Inc., that could provide a facility of the appropriate size for Yosemite. Although sufficient funds were available for the construction of the facility, the funds required for the surrounding infrastructure were not available.

Further conversation with the biodiesel supplier indicated that a facility of the size needed for Yosemite was operating at the Port Hueneme Naval Facilities Engineering Service Center (NFESC). For this study, the researchers decided that the grease would be shipped from Yosemite to Port Hueneme and then back to Yosemite. This would demonstrate the potential for a similar facility inside the park.

The Biodiesel Industries, Inc. facility at NFESC is a modular biodiesel processing unit designed to process the cooking oil on the base into biodiesel fuel. The process uses the traditional transesterification and esterification processes for the biodiesel production. The facility ues a hybrid continuous flow/batch process that is capable of making 150 gallons of biodiesel at a time. The plant’s annual capacity is 100,000 gallons. Currently, the base is planning to use the facility to produce approximately 20,000 gallons a year, with an expansion to 1 million gallons per year during 2005. The facility is sized to fit in a typical cargo container.

Section 3. Emissions Test Program and Results

A three-fold program was used for the emissions comparisons between the regular diesel fuel and the biodiesel blend. The program included chassis dynamometer measurements, in-use measurements with a portable emissions measurement system, and opacity measurements. The purpose of the chassis dynamometer test is to measure emissions using an accepted test method, to provide a baseline for the on-board emissions tests, and to provide supporting data for the on-board emissions tests. The on-board emissions monitor was used to assess the emissions differences when the buses are operated on a typical Yosemite bus route. The opacity tests provided additional information on smoke levels.

Test Vehicles

The primary test vehicles for the chassis dynamometer and in-use testing were three 1988 Gillig Phantoms transit buses equipped with 8.3-liter 1991 Cummins engines. Buses with DNC fleet numbers 138 and 144 were used for the summer tests, while DNC 138 and 143 were used for the winter tests. These vehicles are typical of the current fleet of shuttle buses used in the park, although newer vehicles are being added to the fleet on an ongoing basis. DNC-144 was removed from the fleet between the summer and winter test periods and replaced with DNC-143.

Test Fuel

The basic test fuels for all test vehicles were a 20 percent biodiesel fuel (B20) and a 100 percent ARB diesel fuel, which served as the reference fuel. The neat biodiesel fuel used in the blending process was fully compliant with American Society for Testing Materials (ASTM) 6751 requirements. The B100 contained an anti-oxidant but no other additives, such as reduction agents for NO_x. The B20 was blended using the same ARB diesel fuel that served as the baseline diesel. A summary of the properties of the pure biodiesel fuel, the B20 blend, and the 100 percent ARB diesel fuel are provided in Table 1. Of interest is the 65.1 cetane number of the pure biodiesel fuel that is between 6–8 points higher than the baseline diesel fuel.

The biodiesel was blended separately for the summer and winter test periods. The pure biodiesel was stored in the warehouse in 55-gallon drums between the two test periods. Blended biodiesel was stored in an above-ground outdoor tank in the main Yosemite fueling area. During the winter testing, the B20 was blended at a temperature between 20°–30°F. The cloud point of the base ARB diesel fuel was 16°F. The tank temperature was approximately 30°F. A calibrated fuel can was used to ensure the proper blending ratio when preparing the biodiesel blend.

Table 1. Fuel Properties

Fuel Specifications			Summer		Winter	
Specification	**Test Method**	**B100**	**ARB**	**B20**	**ARB**	**B20**
Flash point, °F	D93-80	266	151	157	149	150
Water & sediment, vol. %	D2709	<0.005				
Carbon residue, %	D524	0.000	0.07	0.06	0.07	0.07
Sulfated ash, mass %	D874	0.006				
Viscosity at 40 C, cSt	D445-83	4.598	3.162	3.354	3.068	3.282
Sulfur content, ppm	D5453	4	143.2	114.4	125.8	101
Natural cetane number	D613-94	65.1	57.6	60.7	59.4	55.6
Cloud point, °F	D2500	36	14	19	16	19
Copper corrosion	C130	1a				
Acid number, mg KOH/gram	D664	0.36		0.07		0.07
Free glycerin	D6584	0.001				
Total glycerin	D6584	0.100				
Phosphorus, mass %	D4951					
Aromatic content, vol %	D5186-96	-	22.3	17.8	21.2	17.0
PAH, wt%	D5186-96	-	2.3	1.8	2.0	1.6
Nitrogen content, ppm	D4629-96		1.3	2.0	<1.0	1.3
Gravity, API	D287-82	28.9	38.5	36.5	38.5	36.6
Density, g/m^3		0.882	0.832	0.842	0.832	0.842
Distillation, °F	D1160					
IBP		396	302	319	312	312
10%		651	410	434	418	425
50%		658	546	572	545	568
90%		666	627	637	620	633
EP		772	669	667	661	662
Ash	D482		<0.001	<0.001	<0.001	<0.001

Chassis Dynamometer Testing

The chassis dynamometer test measurements were conducted using the Air Resources Board Mobile Source Operations Division's heavy-duty chassis dynamometer in Stockton. Each bus was tested in replicate on the 20 percent biodiesel and the 100 percent ARB diesel fuel. The buses were also tested in two periods, once in September and once in March/April.

The buses were tested at several different steady state speeds and load points. For the summer tests conducted in September, the test matrix was as follows:

1. Steady state 55 mph—25, 50, 75 percent load
2. Steady state 35 mph—25, 50 percent load

A similar test matrix was used during the spring tests, except the 55 mph, 75 percent load point was excluded and idle tests were performed both in neutral and in gear with the air conditioning (AC) on and off. The changes in the test matrix were made since the on-road tests in Yosemite indicated that most of the operation was either at lower loads or idle.

The percentage change in emissions between the baseline diesel and the B20 blend are shown in Figures 2 and 3, respectively, for the summer and spring test. The results for steady state loaded tests are based on grams per gallon measurements. The idle comparisons of emissions were made on a grams per minute basis.

Statistically significant changes are denoted as red bars (appears bold in black and white versions of report). More detailed test results are provided in Appendix A in both grams per mile, grams per gallon, and/or grams per minute. The statistical analysis results are provided in Appendix B, based on the grams per gallon or grams per minute measurements. The statistical comparisons were made using a two-tail t-test assuming equal variance within the sample subpopulations. A 90 percent confidence limit ($p = 0.10$) was used to determine statistical significance.

Summer Chassis Dynamometer Tests

For the summer testing for bus #1 (DNC-138), the most significant reductions with the B20 blend were found for PM. Statistically significant reductions in PM were found for three of the five test modes, with percentage reductions ranging from approximately 10–20 percent. This is consistent with results from previous studies (U.S. EPA, 2002). THC emissions also showed statistically significant reductions with B20 for two of the test modes, with these reductions ranging from 10–25 percent. The other modes were mixed with respect to effects on THC emissions.

The largest reductions for both PM and THC were found for the mode with the highest load (that is, 75 percent load, 55 mph). NO_x emissions showed statistically significant increases for four of the five modes, ranging in magnitude from 5–15 percent. These increases are slightly larger in magnitude than has been observed in previous studies, although NO_x may tend to show increases with biodiesel (U.S. EPA, 2002). CO emissions did not show any consistent trends for the range of test modes, although a statistically significant increase was found for the B20 at the 50 percent, 35 mph load point.

For bus #2 (DNC-143), researchers collected data for only three of the five modes, due to issues with operating the bus at the specified load points at 25 mph on the dynamometer. The results for bus #2 overall are less consistent than those for bus #1. A statistically significant reduction in PM was shown for the highest load point, but a statistically significant increase was shown at the 50 percent load point. Interestingly, a statistically significant decrease in NO_x was observed at the same load point (50 percent) where the increase in PM emissions was observed. This could be indicative of the tradeoff that is typically observed in diesel engines between PM and NO_x emissions.

THC emissions showed statistically significant increases for the two lowest power modes with the B20 blend, while a statistically significant increase in CO emissions was also found for the 50 percent load point. Given the difficulties in operating the bus over the lower range load points and the less consistent emissions test results, the conductors of the study hypothesized that bus #2 was suffering from a malfunction. A problem with the fuel injection system, either a failing fuel pump or injectors, could lead to poor fuel atomization. This bus was subsequently replaced by the Yosemite fleet prior to the second round of testing.

Spring Chassis Dynamometer Tests

For the spring tests over the steady state load points, DNC-143 showed statistically significant reductions in PM for all modes ranging from 10–40 percent. No consistent trends were observed for DNC-138. A trend of slightly increasing NO_x emissions with the B20 blend was found for both buses. The NO_x increases ranged from 2.5 to 6.5 percent. Researchers observed the increase for both buses under each load condition.

Reductions of 15–25 percent in THC emissions were found on DNC-143 for three of the four load points with the B20 blend. DNC-143 also showed an increase in CO emissions of 40–140 percent at the 25 percent load point for both the 35 and 55 mph tests. DNC-138 showed a trend of 55–66 percent lower CO emissions at the 55 mph speed and 25 and 50 percent load points. Under idle conditions, DNC-138 did show some trend of decreasing THC emissions on the B20 blend.

Figure 1a. Summary of Emissions Results by Mode for the Stockton Summer Tests

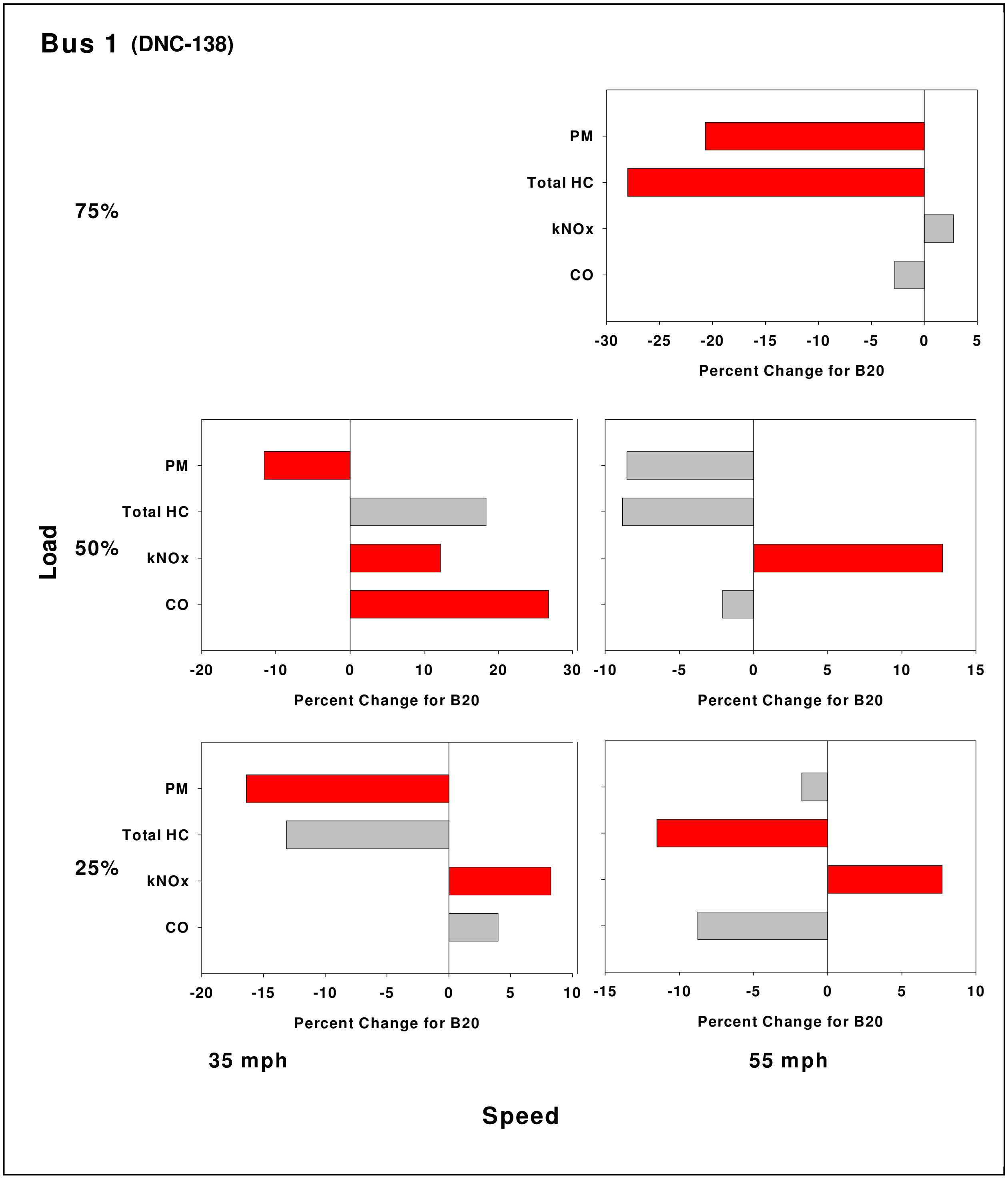


Figure 1b. Summary of Emissions Results by Mode for the Stockton Summer Tests

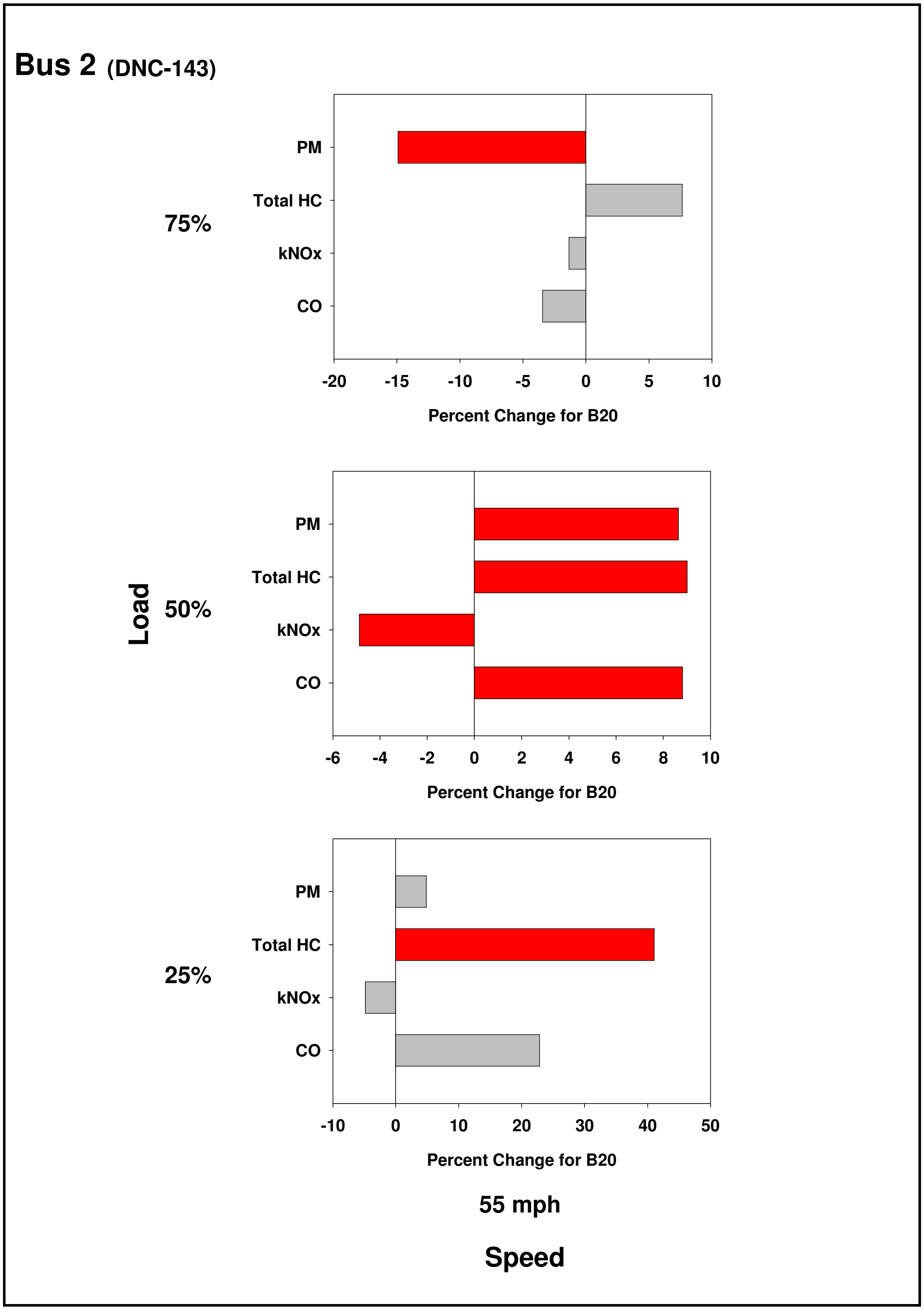
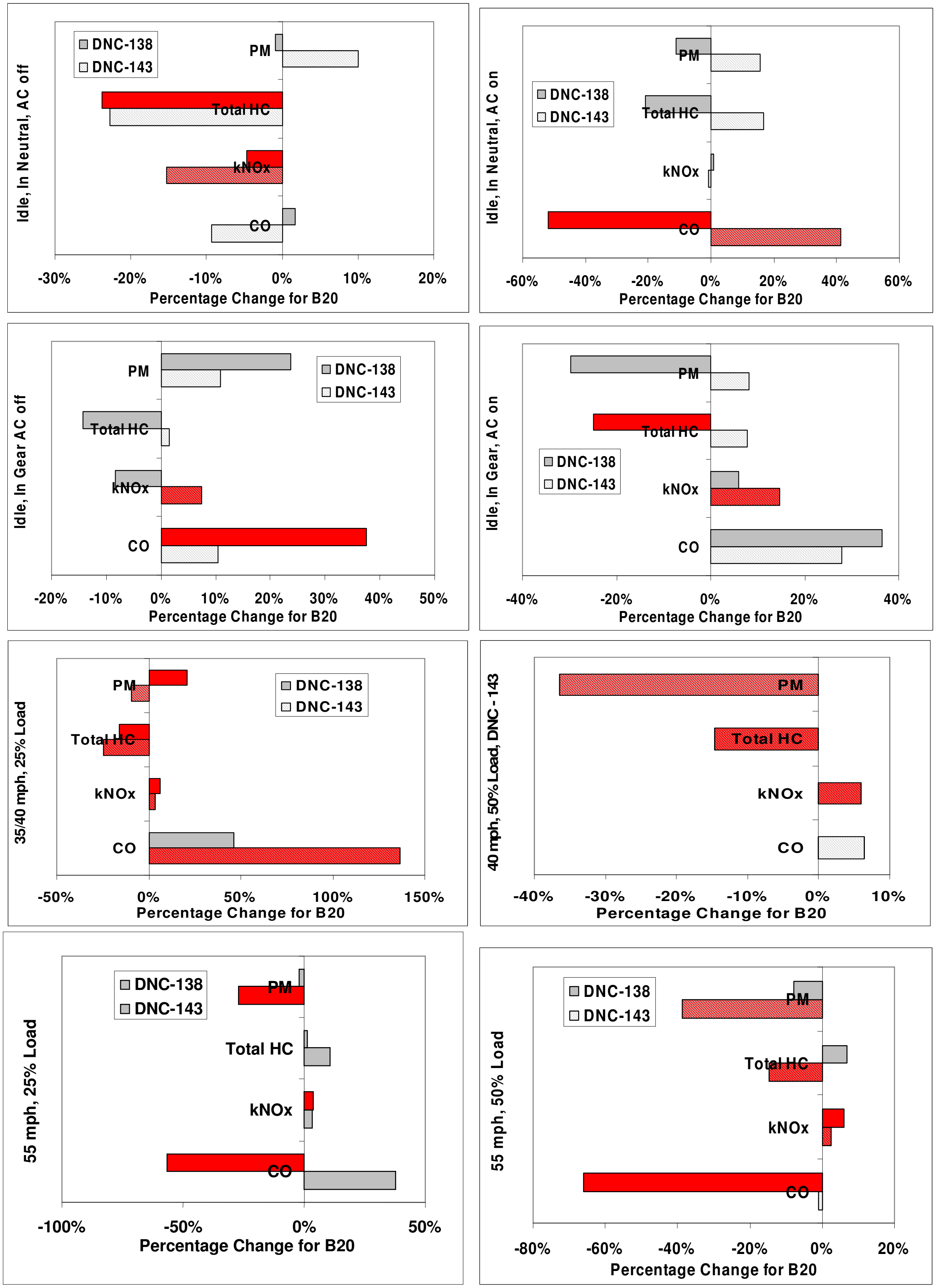


Figure 2. Summary of Emissions Results by Mode for the Stockton Spring Tests



On-Board Emissions Tests

The researchers conducted two one-week emissions tests on the vehicles driven in Yosemite National Park. For each test, exhaust emissions from two Yosemite Concession Services transit buses were tested using a Clean Air Technology, Inc. (CATI) emissions measurement system while the bus traveled its route in Yosemite National Park. The bus route is an 8-mile loop that takes approximately 50 minutes to complete.

This loop is shortened in the winter when travel demand is decreased. Passenger loading is variable, with up to 600 passengers per day loading during peak times. The field testing was separated into a summer test period that occurred the week of September 20, 2004, and a winter test period that occurred the week of January 10, 2005.

Researchers tested the transit buses using two fuels: an ARB diesel and a 20 percent biodiesel blend with the ARB base fuel. The buses were initially tested on ARB diesel followed by testing on the B20.

The emissions tests used the Clean Air Technology emissions measurement system. This unit is capable of measuring NO_x, CO_2, CO, THC, oxygen (O_2), and PM. This instrument uses an infrared analyzer for CO, CO_2, and THC measurements, an electrochemical cell for NO_x measurements, and light scattering for PM measurements. Researchers recorded all measurements in the raw exhaust.

Exhaust flow measurements for the calculation of total grams were made based on the engine revolutions per minute (RPM), engine size, and the intake air temperature and the manifold pressure. Since these buses were not equipped with an engine control module that could provide RPM, researchers mounted a PhotoTac to the engine to collect engine RPM data. They used a second Photo Tac on the driveshaft to determine the total miles traveled.

Comparisons Between the CATI Instrument and the Stockton Laboratory

Prior to performing the field tests, researchers made comparisons between the CATI instrument and the Stockton Laboratory. Figure 4 shows the results of this correlation for the NO_x, PM, CO, THC, and CO_2. The “k” for kNO_x” indicates that the NO_x values at Stockton have been corrected for humidity. The values for the CATI system are typically not corrected. The humidity correction factor ranges from 0.88 to 1.05 over the two Stockton test periods.

The quality of the comparisons between the CATI instrument and the Stockton Laboratory varied considerably depending on the pollutant measured. The best comparisons appeared in NO_x, CO, and CO_2 emissions. The slopes of the linear regression between the measurements for NO_x (slope = 0.96) and CO_2 (slope = 0.99) were relatively good, with correlation coefficients of R^2 = 0.93 for NO_x and 0.91 for CO_2. Researchers found a slightly higher slope for the linear regression for CO (slope=1.129), with an R^2 = 0.79.

The comparisons between the CATI instrument and the Stockton laboratory were poor for PM and THC. For PM, a bias of nearly an order of magnitude was found between the two measurement techniques, although the correlation between paired measurements was R^2 = 0.93. (Order of magnitude = 10 times. Two orders of magnitude = 100 times) The PM measurements for the CATI instrument were essentially an order of magnitude less than those measured with the Stockton laboratory.

The difference could be due in part to differences in the measurement techniques, with the Stockton laboratory measuring PM mass directly based on mass change on a filter and the CATI system measuring PM mass indirectly using light scattering. Under the regulations, researchers measured PM mass by weighing the filter. The Stockton laboratory uses this traditional methodology, and researchers expect that the Stockton laboratory measurements are more accurate.

The source of the discrepancy could be related to the calibration of the light scattering measurements. The correlation between the CATI instrument and the Stockton laboratory for THC was also poor, with an $R^2 = 0.29$ and a slope of 1.26. The CATI instrument does not use a heated line (190°C) in its sampling path, as is typically used in dynamometer emissions measurements. This could lead to losses of higher hydrocarbons in the sampling line. Also, the CATI instrument uses an infrared analyzer as opposed to the flame ionization detector specified in the regulations. For these reasons, researchers expect the results for the Stockton laboratory to provide the more accurate characterization of THC emissions rather than the field THC emissions, which were suspect.

Figures 3a–e display comparison results for CATI vs. Stockton Laboratory.

Figure 3a. CATI vs. Stockton (kNO$_x$ g/s)

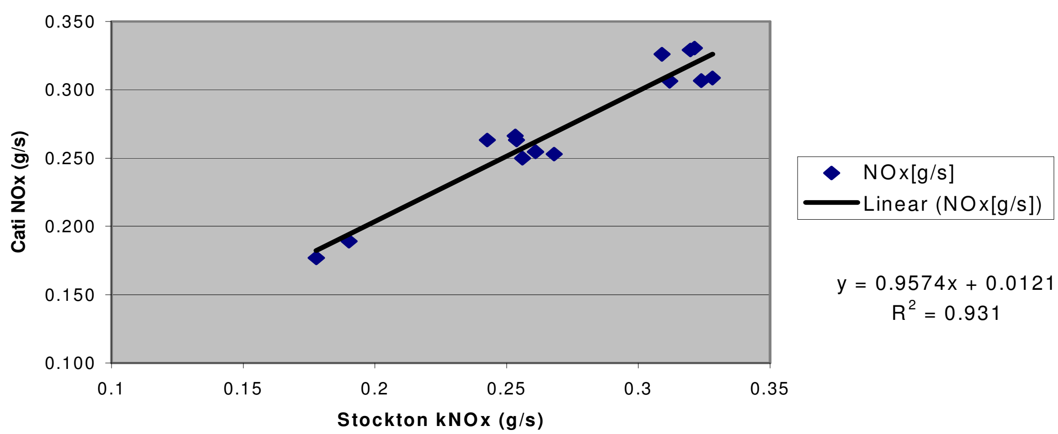


Figure 3b. CATI vs. Stockton (CO$_2$ g/s)

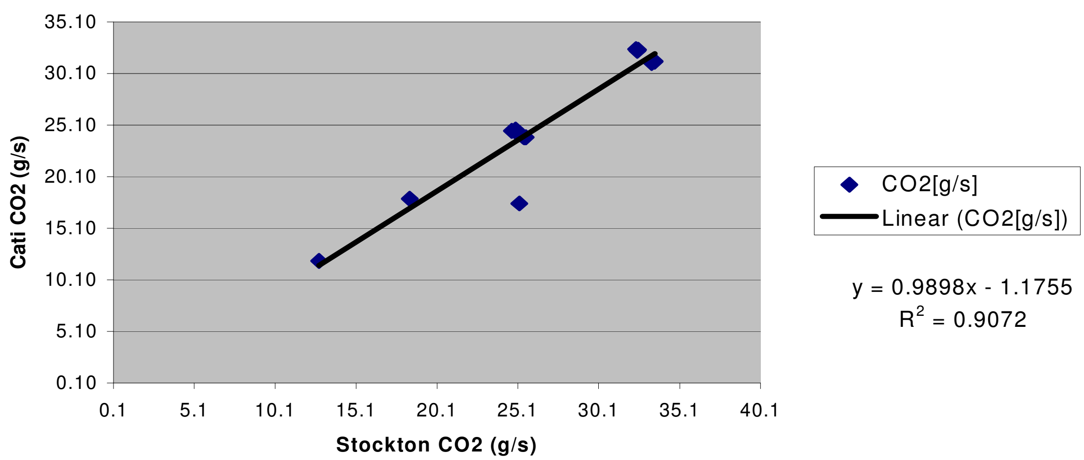


Figure 3c. Cati vs. Stockton (CO g/s)

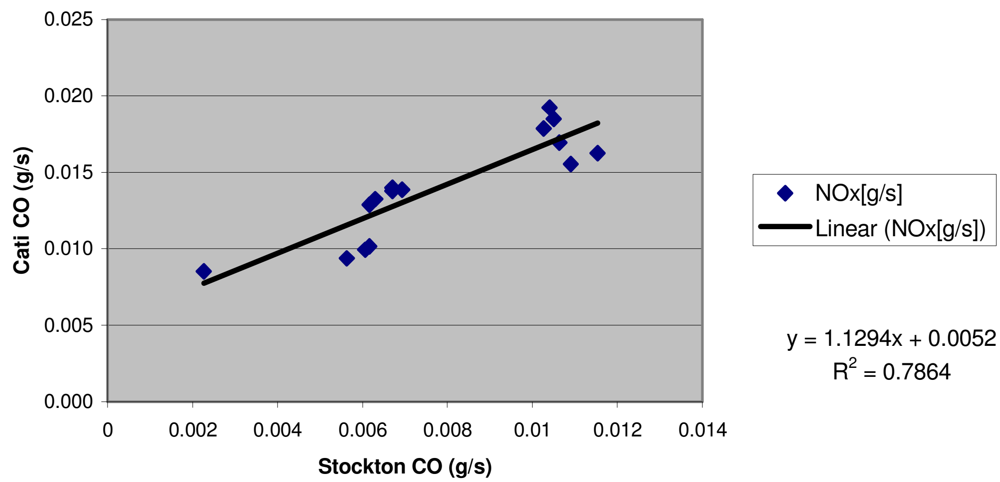


Figure 3d. Cati vs. Stockton (PM g/s)

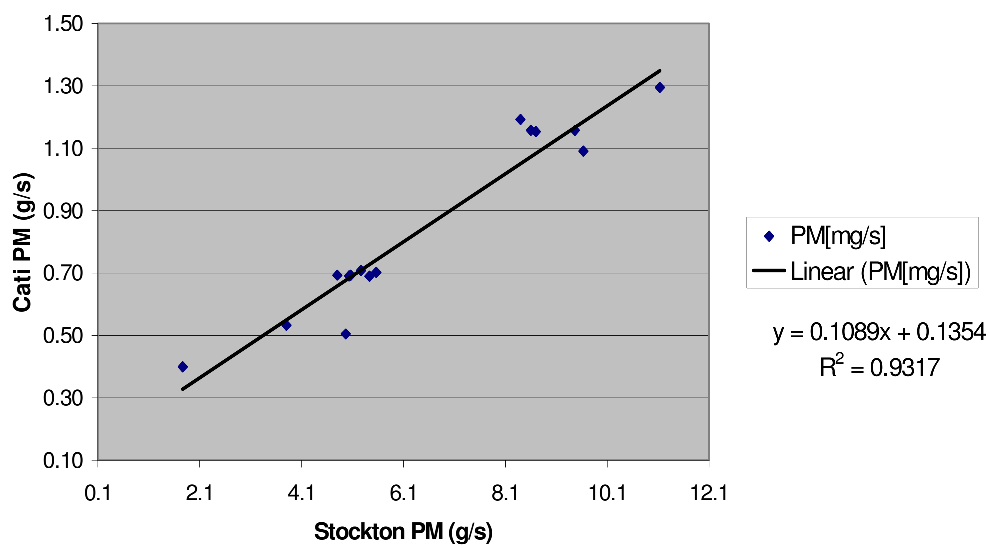
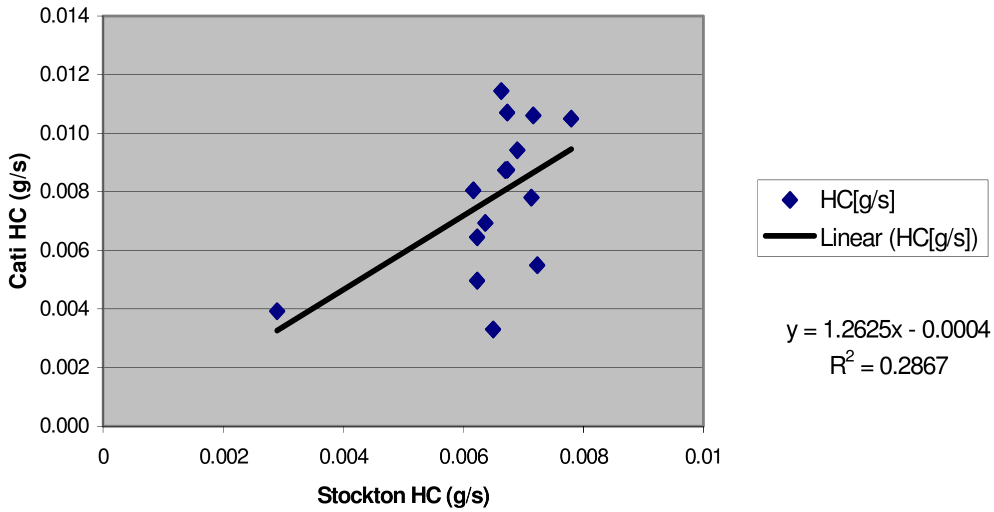


Figure 3e. CATI vs. Stockton (HC g/s)



Summer Field Emission Tests at Yosemite

The field test results for the two buses are presented in Tables 2a and 2b, respectively. Results are given both in mass of emissions per loop and per gallon of fuel consumed. Passenger loading was also noted qualitatively on a scale from one to seven. The focus for the analysis will be on the grams per gallon results, since these units better account for the variability observed between the different loop runs. Researchers conducted primary analyses on all data, with subsets of data also analyzed separately to examine effects of load.

PM emissions also showed a statistically significant reduction on both buses. PM emissions ranged from 10–17 percent lower for the two buses using the B20 fuel. Since the light scattering measurement technique is sensitive to changes in PM composition, as well as mass, these changes could also be indicative of a change in PM composition. The bias in PM measurements for the CATI, relative to the Stockton laboratory, is notable. CO and NO_x did not show consistent trends in either bus. Researchers found a statistically significant increase in NO_x for B20 on DNC-144, although this could have been due to air conditioner operation. THC emissions were 25–35 percent lower in buses using the B20 fuel, but these measurements were considered suspect due to the lack of the heated line.

Researchers conducted additional analyses to better understand the influence of load on emissions. The operation of the air conditioner was one factor that appeared to impact emissions, particularly for DNC-144, which showed increases in NO_x emissions with the air conditioner on. The increase in NO_x emissions for B20 on DNC-144 was eliminated when the air conditioning data was excluded. The PM emission reductions with B20 on DNC-144 were also greater when the air conditioning data was excluded.

The main effects on PM for DNC-138 were similar for all data and the data excluding air conditioner operation. The data set is limited for the runs with the air conditioner on compared to those with the air conditioner off. Hence, additional data is probably needed to better understand the interaction between the air conditioner load and the fuel effects. Qualitatively, the passenger loading for DNC-138 for the diesel runs appeared higher than that for the B20 fuel. More comprehensive analysis is required to better understand these effects. Different drivers operating the buses on different shifts could also have some impact on emissions.

Table 2a. Yosemite Summer Field Test Results for Bus DNC-138

Diesel 9/21/2004	**Passenger load**	**Miles**	**NO_x g/loop**	**HC g/loop**	**CO g/loop**	**CO_2 kg/loop**	**PM g/loop**	**Gals. /loop**	**NO_x g/gal**	**HC g/gal**	**CO g/gal**	**PM G/gal**
9:00 AM	2.5–4.5	8.85	263.7	4.37	43.7	20.5	1.22	2.08	126.6	2.10	21.0	0.58
11:00 AM	2–6	8.82	241.5	4.69	33.2	18.0	1.07	1.83	132.1	2.56	18.2	0.59
12:00 AM	2–3	8.83	253.5	5.25	18.0	17.5	0.67	1.78	142.7	2.95	10.1	0.38
1:00 PM	2–6	8.79	278.8	6.57	22.5	19.1	0.79	1.93	144.3	3.40	11.6	0.41
2:00 PM	2–5	8.75	268.7	5.25	17.1	18.0	0.78	1.82	147.4	2.88	9.4	0.43
3:00 PM	2–6	8.83	263.3	4.51	21.0	18.1	0.81	1.84	143.3	2.45	11.4	0.44
4:00 PM	2–6	8.80	286.8	5.03	25.4	19.3	0.87	1.95	146.9	2.57	13.0	0.44
Avg		8.81	265.1	5.09	25.8	18.6	0.89		140.5	2.70	13.5	0.47
St Dev		0.03	15.1	0.74	9.5	1.0	0.19		7.95	0.42	4.4	0.08
B-20 9/22/2004	**Passenger load**	**Miles**	**NO_x g/loop**	**HC g/loop**	**CO g/loop**	**CO_2 kg/loop**	**PM g/loop**	**Gals. /loop**	**NO_x g/gal**	**HC g/gal**	**CO g/gal**	**PM G/gal**
8:30 AM	2	8.12	214.0	2.43	23.0	16.1	0.66	1.65	130.0	1.47	14.0	0.40
9:30 AM	2–3	8.82	256.2	2.75	27.5	18.1	0.72	1.85	138.1	1.48	14.8	0.39
10:30 AM	2	8.81	235.0	4.80	25.7	16.7	0.68	1.71	137.2	2.81	15.0	0.40
11:30 AM	1–2	8.81	285.2	4.29	26.6	19.2	0.71	1.97	144.8	2.18	13.5	0.36
12:30 PM	2	8.80	249.9	2.99	26.3	17.2	0.61	1.76	141.8	1.70	14.9	0.35
1:30 PM	2–5 / AC	8.84	332.8	4.71	47.7	21.8	0.98	2.24	148.5	2.10	21.3	0.44
2:30 PM	2–6 / AC	8.80	265.9	5.15	35.2	19.4	0.77	1.99	133.6	2.59	17.7	0.39
Avg		8.71	262.7	3.87	30.3	18.4	0.73		139.1	2.05	15.9	0.39
St Dev		0.3	38.2	1.1	8.5	2.0	0.1		6.4	0.5	2.7	0.0
All Data												
B-20 / D		-1.1%	-0.9%	***-23.9%***	17.2%	-1.5%	-17.1%		-0.9%	***-24.3%***	17.5%	***-16.6%***
t-test		0.352	0.876	***0.033***	0.375	0.752	0.101		0.739	***0.024***	0.247	***0.040***
Tests on partial data set, according to shading next to the runs												
B-20 / D		0.04%	-3.3%	***-28.9%***	16.1%	-2.8%	***-17.8%***		-1.6%	***-27.2%***	18.6%	***-16.2%***
t-test		0.819	0.475	***0.024***	0.258	0.381	***0.072***		0.489	***0.032***	0.197	***0.095***

Red/italicized entries indicate differences that were statistically significant at greater than a 90 percent confidence level. Passenger Load Scale: 1—driver and study team; 3—all seats w/ 1 person; 5—aisle starts filling; 7—passengers left at stop. AC—Denotes use of conditioner unit; gals. = gallons

Table 2b. Yosemite Summer Field Test Results for Bus DNC-144

Diesel 9/23/2004	Passenger Load	Miles	NO_x g/loop	HC g/loop	CO g/loop	CO_2 kg/loop	PM g/loop	Gals. /loop	NO_x g/gal	HC g/gal	CO g/gal	PM g/gal
7:30 AM	1.5–2	NA	278.9	6.46	47.9	20.3	1.21	2.06	135.2	3.13	23.2	0.59
8:30 AM	1.5–2.5	8.71	213.7	4.16	42.4	16.4	1.16	1.67	128.3	2.50	25.5	0.70
9:30 AM	1.5–3	8.65	226.9	5.72	40.4	16.8	1.22	1.70	133.1	3.36	23.7	0.72
10:30 AM	1.5–2	6.96	214.7	8.56	38.9	15.0	1.04	1.53	140.5	5.60	25.5	0.68
11:30 AM	1.5–2	7.84	208.2	6.19	35.7	15.4	0.85	1.57	132.7	3.95	22.8	0.54
12:30 PM	1.5–3	8.62	255.7	7.69	37.4	18.1	0.94	1.84	139.2	4.19	20.4	0.51
1:30 PM	2–5.5/AC	8.56	316.6	8.49	45.0	21.8	1.25	2.22	142.8	3.83	20.3	0.56
2:30 PM	1.5–3.5/AC	8.63	319.8	7.20	48.8	21.4	1.21	2.18	147.0	3.31	22.4	0.55
Avg		8.28	254.3	6.81	42.1	18.2	1.11		137.4	3.73	23.0	0.61
St Dev		0.7	46.1	1.5	4.8	2.7	0.2		6.1	0.9	2.0	0.1
B-20 9/24/2004	**Passenger Load**	**Miles**	**NOx g/loop**	**HC g/loop**	**CO g/loop**	**CO_2 kg/loop**	**PM g/loop**	**Gals. /loop**	**NO_x g/gal**	**HC g/gal**	**CO g/gal**	**PM g/gal**
7:45 AM	1.5–2	8.72	195.0	4.45	30.3	14.6	0.81	1.49	130.5	2.98	20.3	0.54
8:45 AM	1.5–6	8.72	228.3	4.64	36.1	16.1	0.86	1.65	138.5	2.81	21.9	0.52
9:30 AM	2–4	8.71	231.2	5.39	32.6	16.4	0.90	1.68	137.2	3.20	19.3	0.54
10:30 AM	1.5–3/AC	8.72	312.9	4.47	49.3	19.9	1.14	2.05	152.9	2.18	24.1	0.56
11:30 AM	1.5–5/AC	8.71	324.0	4.47	46.9	20.1	1.15	2.07	156.9	2.16	22.7	0.55
12:30 PM	1–2/AC	8.71	323.9	4.15	43.9	20.2	1.07	2.07	156.2	2.00	21.2	0.52
1:30 PM	2–5/AC	8.72	397.4	5.00	54.2	24.3	1.44	2.49	159.3	2.01	21.7	0.58
2:30 PM	1.5–3/AC	8.70	358.5	5.52	52.0	22.1	1.27	2.27	158.2	2.44	22.9	0.56
Avg		8.71	296.4	4.76	43.2	19.2	1.08		148.7	2.47	21.8	0.55
St Dev		0.01	70.7	0.49	9.1	3.3	0.21		11.4	0.47	1.5	0.02
All Data												
B-20 / D		5.2%	16.5%	***-30.1%***	2.6%	5.8%	-2.8%		***8.3%***	***-33.7%***	-5.2%	***-10.1%***
t-test		0.084	0.181	***0.002***	0.771	0.493	0.744		***0.026***	***0.004***	0.196	***0.054***
Tests on partial data set, according to shading next to the runs												
B-20 / D		8.4%	***6.4%***	-18.6%	***-12.8%***	2.1%	-17.6%		3.1%	-21.9%	***-15.4%***	***-19.8%***
t-test		0.334	***0.082***	0.455	***0.100***	0.619	0.204		0.333	0.442	***0.042***	***0.094***
Tests on partial data set, according to shading next to the runs												
B-20 / D		1.3%	7.9%	***-39.8%***	5.0%	-1.3%	-1.3%		***8.2%***	***-39.5%***	5.5%	-1.2%
t-test		0.002	0.378	***0.002***	0.495	0.847	0.884		***0.003***	***0.001***	0.305	0.711

Red/Italicized entries indicate differences that were statistically significant at greater than a 90% confidence level. Passenger Load Scale: 1—driver and study team; 3—all seats w/ 1 person; 5—aisle starts filling; 7—passengers left at stop

AC—Denotes use of air conditioner unit; gals. = gallons

Winter Field Emission Tests at Yosemite

The field test results for the two buses field-tested in the winter are presented in Tables 3a and 3b, respectively. For the winter tests, the driveline sensor was not consistently operational due to problems with the driveline tachometer such as contamination with snow and mud. Also, drivers used snow chains on the buses during the first day of testing on January 11, 2005. The PM sampling line was also found to freeze for several runs invalidating those specific test runs.

The DNC-138 bus was tested in both the summer and winter field studies. The results showed the NO_x and THC emissions were comparable between the two periods. CO and PM emissions on a grams per gallon basis were consistently higher during the winter months.

The results for the winter testing were less consistent than those found in the summer testing. For bus DNC-138, no statistically significant differences were found between the ARB diesel and the B20 blend. For bus DNC-143, researchers observed statistically significant decreases in CO and PM emissions, along with a statistically significant increase for NO_x.

The winter runs also showed statistically significant differences in CO_2 emissions per driving loop. These differences ranged from 10 to 15 percent for the ARB diesel and B20 runs. CO_2 emissions per loop for the summer tests were much more consistent, and they did not show statistically significant differences between fuels for either bus. This suggests less consistency between the runs for the winter months due to factors such as changing the loop course, different drivers, or different driving conditions.

Table 3a. Yosemite Winter Field Test Results for Bus DNC-138

Diesel 1/12/2005	Passenger load	NO_x g/loop	HC g/loop	CO g/loop	CO_2 kg/loop	PM g/loop	Gals.	NO_x g/gal	HC g/gal	CO g/gal	PM g/gal
3:45 PM	1–2	188.6	3.45	27.2	13.8	2.11	1.40	134.7	2.47	19.4	1.50
4:30 PM	1–2	181.0	2.85	23.6	12.9	1.89	1.31	138.4	2.18	18.0	1.44
6:00 PM	1–2	190.2	3.41	21.7	13.5	1.41	1.37	138.4	2.48	15.7	1.03
6:45 PM	1–5	197.4	2.85	25.5	13.8	2.33	1.40	141.0	2.03	18.2	1.66
7:30 PM	1	167.8	3.12	21.3	11.8	1.34	1.19	140.5	2.61	17.9	1.12
Avg		185.0	3.14	23.8	13.2	1.81	1.34	138.6	2.35	17.8	1.35
St Dev		11.2	0.3	2.5	0.9	0.4	0.1	2.5	0.2	1.3	0.3
B20 1/13/2005	**Passenger load**	**NO_x g/loop**	**HC g/loop**	**CO g/loop**	**CO_2 kg/loop**	**PM g/loop**	**Gals.**	**NO_x g/gal**	**HC g/gal**	**CO g/gal**	**PM g/gal**
12:40 PM	2–5	226.3	2.96	32.9	15.9	3.58	1.61	140.3	1.83	20.4	2.22
1:25 PM	1–3	219.0	2.70	29.0	15.1	2.28	1.53	143.1	1.77	19.0	1.49
2:15 PM	1–2	200.6	4.10	24.3	13.6	1.50	1.38	145.4	2.97	17.6	1.08
3:00 PM	1–5	225.5	2.50	31.2	14.9	2.23	1.51	149.4	1.66	20.6	1.48
3:45 PM	1–5	218.7	1.58	23.9	16.0	2.75	1.62	134.9	0.97	14.7	1.69
4:25 PM	1–2	203.1	2.59	32.0	15.0	2.89	1.52	133.7	1.70	21.0	1.90
5:10 PM	1–2	200.7	2.56	31.5	14.3	2.13	1.45	138.6	1.77	21.8	1.47
5:50 PM	1–2	187.9	2.97	23.2	12.7	1.43	1.29	145.2	2.30	17.9	1.10
6:40 PM	1–3	199.0	4.10	17.6	12.7	1.63	1.29	154.7	3.19	13.6	1.27
Avg		209.0	2.90	27.3	14.5	2.27	1.47	142.8	2.02	18.5	1.52
St Dev		13.6	0.8	5.3	1.2	0.7	0.1	6.8	0.7	2.8	0.4
B-20 / D		13.0%	-7.7%	14.5%	***9.8%***	25.0%		3.0%	-14.3%	3.8%	12.7%
t-test		0.006	0.533	0.197	***0.060***	0.224		0.211	0.320	0.624	0.384

Red/italicized entries indicate differences that were statistically significant at greater than a 90 percent confidence level

Passenger Load Scale: 1—driver and study team; 3—all seats w/ 1 person; 5—aisle starts filling; 7—passengers left at stop

Table 3b. Yosemite Winter Field Test Results for Bus DNC-143

Diesel 1/11/2005	Passenger load	NO_x g/loop	HC g/loop	CO g/loop	CO_2 kg/loop	PM g/loop	Gals.	NO_x g/gal	HC g/gal	CO g/gal	PM g/gal
8:15 AM	1–2	192.0	2.42	84.5	16.2	1.45	1.65	116.3	1.47	51.2	0.88
9:00 AM	2	196.7	2.08	88.0	15.8	1.39	1.62	121.8	1.29	54.5	0.86
9:45 AM	1–2	195.5	1.72	82.5	15.5	1.31	1.58	123.6	1.09	52.2	0.83
10:30 AM	1–2	184.4	2.77	70.0	14.3	0.98	1.45	126.8	1.90	48.1	0.67
11:15 AM	1–2	188.1	2.35	94.3	14.7	1.11	1.50	125.4	1.57	62.8	0.74
12:00 PM	1–3	191.9	2.26	94.5	15.1	1.15	1.54	124.6	1.47	61.4	0.75
12:45 PM	2–3	186.6	1.93	95.6	14.8	1.05	1.51	123.2	1.28	63.1	0.69
Avg		190.7	2.2	87.1	15.2	1.2	1.6	123.1	1.44	56.2	0.77
St Dev		4.6	0.3	9.1	0.7	0.2	0.1	3.4	0.3	6.2	0.1
B20 1/11-12/05	**Passenger Load**	**NO_x g/loop**	**HC g/loop**	**CO g/loop**	**CO_2 kg/loop**	**PM g/loop**	**Gals.**	**NO_x g/gal**	**HC g/gal**	**CO g/gal**	**PM g/gal**
5:50 PM	1–5	188.5	3.05	75.8	13.5	1.05	1.38	136.8	2.21	55.0	0.76
6:40 PM	1–5	183.2	3.43	67.0	13.0	0.92	1.33	138.0	2.59	50.5	0.70
7:25 PM	1–2	176.6	1.90	45.0	12.1	0.63	1.23	143.9	1.55	36.7	0.51
8:15 PM	1–5	182.9	1.65	55.0	12.9	0.81	1.32	138.7	1.25	41.7	0.61
8:57 PM	1	164.2	2.69	43.9	11.3	0.57	1.15	143.0	2.34	38.2	0.50
8:20 AM	1–4	199.8	4.51	60.0	13.8	0.76	1.41	142.1	3.21	42.7	0.54
9:45 AM	1–4	192.7	3.02	68.0	13.4	NA	1.37	140.8	2.20	49.7	NA
10:30 AM	1–3	186.8	3.17	55.0	12.6	NA	1.29	145.1	2.46	42.8	NA
Avg		184.3	2.93	58.7	12.8	0.79	1.31	141.1	2.23	44.7	0.60
St Dev		10.7	0.9	11.2	0.8	0.2	0.1	3.0	0.6	6.4	0.1
B-20 / D		-3.4%	***31.9%***	***-32.6%***	***-15.6%***	***-34.4%***		***14.6%***	***55.0%***	***-20.5%***	***-22.0%***
t-test		0.166	***0.072***	***0.000***	***0.000***	***0.002***		***0.000***	***0.007***	***0.004***	***0.007***

Red/italicized entries indicate differences that were statistically significant at greater than a 90 percent confidence level

Passenger Load Scale: 1—driver and study team; 3—all seats w/ 1 person; 5—aisle starts filling; 7—passengers left at stop

Opacity Tests

Researchers conducted opacity measurements in conjunction with each of the test buses used in the field tests. "Opacity" means the degree of light-obscuring capability of emissions of visible air contaminants expressed as a percentage. Complete obscuration is expressed as 100 percent opacity. They used the Snap and Idle test procedure, according to the SAE J1667 standard, to record opacity measurements. A Wager (MDL 650) smoke meter was used for all testing. For each day of testing, researchers conducted three Snap and Idle tests on the fuel/vehicle combination used that day. The tests were conducted at the end of the road testing with the engines warmed up to operational temperature. Each vehicle was subjected to three “clean-out” engine accelerations to the maximum governed engine RPM for approximately 3 seconds, followed by a return to idle.

Researchers conducted tests by placing the sensor head across the exhaust stream, accelerating the engine to the maximum governed engine RPM for approximately 3 seconds and returning it to idle. This procedure was repeated for two additional Snap and Idle sequences. To be accepted, a given test sequence needed to demonstrate a span deviation of less than 5 percent.

The results of the opacity measurements for both the summer and winter tests are presented in Table 4. The results showed that for all bus/season combinations, opacity was lower for the buses operated on B20 fuel, with reductions ranging from 10–25 percent. The reductions in opacity with B20 were also statistically significant for all bus/season combinations at 99 percent or higher confidence level.

Since opacity can vary as a function of PM composition, as well as PM mass, these changes could indicate both a change in PM mass and composition. The opacity results for bus DNC-138 were consistent between the two seasons for both fuels, with no statistically significant differences observed between the seasons for either fuel ($p = 0.25$ for both fuels). Average opacity between the seasons ranged from 22.0 to 23.4 for the RFD and from 19.6 to 20.8 for B20.

Table 4. Test Results for Opacity Measurements for RFD and Biodiesel Blends

	Summer Tests				**Winter Tests**			
	Bus #1 DNC-138		**Bus #2 DNC-144**		**Bus #1 DNC-138**		**Bus #2 DNC-143**	
	RFD	B20	RFD	B20	RFD	B20	RFD	B20
Test #1	19	20	20	16	22	21	23	19
	21	19	20	17	23	19	26	18
	20	21	19	15	22	19	24	18
Avg #1	20	20	19.7	16	22.3	19.7	24.3	18.3
Test #2	22	21	20	16	24	22	26	20
	20	21	20	17	24	24	24	19
	23	18	19	17	23	22	28	19
Avg #2	21.7	20.0	19.7	16.7	23.7	22.7	26.0	19.3
Test #3	24	19	21	17	25	19	-	19
	24	20	20	15	24	20	-	20
	25	17	23	15	24	21	-	21
Avg #3	24.3	18.7	21.3	15.7	24.3	20.0	-	20.0
Avg.all tests	***22.0***	***19.6***	***20.2***	***16.1***	***23.4***	***20.8***	***25.2***	***19.2***
Stand dev	2.1	1.4	1.2	0.9	1.0	1.7	1.8	1.0
P-values		0.012		0.000		0.012		0.000

Operational Performance

The B20 biodiesel blend was tested in the field during the one-week summer and winter field testing periods, and for 1–2 weeks after the field tests while the tank was being emptied. Approximately 500 gallons of biodiesel were consumed during each of the test periods, with 100 gallons of B20 being used for the dynamometer testing.

The B20 biodiesel blend was stored in an above-ground tank outdoors in the main Yosemite fueling area. During the two test periods, researchers saw no significant issues with the operation of the buses on biodiesel or with biodiesel storage. Biodiesel use required no extra maintenance. Since this is a relatively small operating database, further implementation of a biodiesel program should begin with a smaller subset of vehicles initially to further ensure operational performance before expanding to the entire fleet.

Section 4. Summary and Conclusions

This pilot demonstration included use of biodiesel in the fleet vehicles of DNC Parks and Resorts at Yosemite, Inc. The program included an investigation of the feasibility and identification of a biodiesel production facility, emissions testing, and some characterization of biodiesel use in the vehicles. The biodiesel used in this program was produced from restaurant grease from the DNC food operations in the park.

The biodiesel was produced at a small batch biodiesel production facility operated by Biodiesel Industries, Inc. at the Naval Facilities Engineering Service Center in Port Hueneme, Calif. A three-fold emissions program provided comparisons between the emissions on regular ARB diesel and the biodiesel blend in the standard buses in the DNC fleet.

The program included chassis dynamometer measurements, in-use measurements with a portable emissions measurement system, and opacity measurements. The researchers measured the on-board emissions of the typical Yosemite bus route under both summer and winter conditions. They conducted chassis dynamometer tests under summer and spring conditions.

Following are the major results of these analyses:

- The summer chassis dynamometer measurements showed statistically significant reductions in PM (10–20 percent) and THC (10–25 percent) for one of the test buses (DNC-138), with the largest reductions found at the highest load point. NO_x emissions for this bus increased between 5–15 percent for most of the test modes.
- The summer chassis dynamometer measurements for the second bus (DNC-144) did not show any consistent trend over the entire load range. The lack of consistent test results combined with operational issues suggests that this bus was malfunctioning, perhaps with a fuel injection system problem.
- For the spring chassis dynamometer tests of the steady state load points, DNC-143 showed statistically significant reductions in PM for all modes ranging from 10–40 percent. Researchers observed no consistent trends for DNC-138. A trend of slightly increasing NO_x emissions with the B20 blend was found for both buses in the range of 2.5 to 6.5 percent. Under idle conditions, DNC-138 did show some trend of decreasing THC emissions on the B20 blend.

- The summer field test results showed consistent reductions in PM emissions (10–17 percent) for both test buses using B20 fuel. CO and NO_x did not show consistent trends in either bus. Operation of the air conditioner was also found to increase emissions, particularly NO_x, for one of the two buses.

- The winter field testing results were less consistent than those found in the summer testing. For bus DNC-143, researchers observed statistically significant decreases in CO and PM emissions. They found statistically significant increases for NO_x emissions. For DNC-138, no statistically significant differences were found between the ARB diesel and the B20 blend. The winter tests showed greater variability in the CO_2 emissions per loop than the summer tests, suggesting greater differences in driving conditions/operation.

- Opacity results for each test bus over both seasons were lower on B20 compared to ARB diesel fuel. The reductions in opacity ranged from 10–25 percent. This could be indicative of both changes in PM mass, as well as PM composition. Researchers found no differences between the opacity measurements made in the summer and winter seasons.

- Direct comparisons between the Stockton chassis dynamometer laboratory and the on-board field testing system showed relatively good comparisons between the NO_x, CO, and CO_2 emissions. The comparisons were poor for PM and THC, however. The differences for PM emissions could be attributed to differences in the direct filter mass measurements made by the chassis laboratory and the light scattering device used in the on-board system.

  This device measures PM mass indirectly and requires a separate calibration. The differences in the THC measurements could be related to differences in the measurement technique and/or the fact that the on-board system does not measure THC through a line heated to elevated temperatures. Based on this comparison, the field THC emissions were considered suspect.

- In examining the data set as a whole, the opacity reduction with the B20 was the only trend consistently seen for all test vehicles and test periods. Researchers observed other trends for specific vehicles and emissions components during specific test periods. They found no consistent trends for DNC-138 during any test period. As such, any observations would need further verification using a larger sample size and a test matrix that includes long-term reproducibility.

- Aside from any benefits/liabilities in primary emissions, the CO_2 emissions generated from the biodiesel fraction of the fuel are considered to be recycled from a perspective of global CO_2 emissions. This is related to the biological processes in plants that use atmospheric CO_2 to produce carbon-based compounds on a much faster time scale than the processes that produce fossil fuels. Life cycle analyses that account for all sources of CO_2 from both production and use as a fuel show that these factors provide a 16 percent reduction in CO_2 emissions for a B20 blend (Sheehan et al., 1998).

- The project included use of approximately 1,000 gallons of B20 fuel in the DNC service fleet during the two test periods. During these periods, researchers observed no significant operation issues with the operation or maintenance of the buses on biodiesel or with biodiesel storage. Since this is a relatively small operating database, further implementation of biodiesel should begin with a smaller subset of vehicles initially to further ensure operational performance before expanding to the entire fleet.

Section 5. Cost Summary

Some cost estimates were made for the preparation and installation of a biodiesel production facility on location at Yosemite National Park. The cost estimates included costs for the construction of the facility, preparation of a facility to house the production plant, and storage facilities for the materials used for the production of biodiesel and for the biodiesel and other by-products of the processing.

This included installation of a new fuel tank for the storage/dispensing of the biodiesel. DNC estimated total expenditures for the installation of an operating biodiesel production plant to be approximately $53,000. The plant would be comparable to size of the one at the Port Hueneme NFESC base. These costs cannot necessarily be considered representative of the installation costs of a biodiesel plant at other locations, since a considerable fraction of the costs are attributed to modification of the site.

The production cost per gallon was not determined as part of these estimates. Alternatively, DNC could purchase biodiesel directly from a supplier, with only expenses for suitable fuel storage required. Compared with diesel fuel, 100 percent biodiesel on the open market is currently priced at $2.62 per gallon. This price, as of the summer of 2005, includes a $0.50 per gallon Blender's Tax Credit and a $0.40 per gallon USDA Bioenergy Subsidy.

References

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United States Environmental Protection Agency, *A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions—Draft Technical Report*, 2002.

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Appendix A. Individual Emissions Test Results for Stockton

Table A-1. Stockton Summer Test Results (Bus 139)

Test No:	Bus	Test Type:	CO g/mi	kNOx g/mi	Total HC g/mi	PM g/mi	CO g/gal	kNO xg/gal	Total HC g/gal	PM g/gal
2489	138	Bus 1, Diesel, 75% Load, 55 MPH, Filter (Makeup)	0.21	21.43	0.23	0.62	1.07	110.59	1.19	3.18
2488	138	Bus 1, Diesel, 75% Load, 55 MPH, Filter 1	0.21	20.17	0.24	0.58	1.11	104.89	1.27	3.00
2488	138	Bus 1, Diesel, 75% Load, 55 MPH, Filter 2	0.14	18.94	0.20	0.45	0.94	125.56	1.34	2.98
2506	138	Bus 1, B20, 75% Load, 55 MPH, Filter 1	0.19	22.42	0.18	0.47	1.00	117.13	0.92	2.45
2506	138	Bus 1, B20, 75% Load, 55 MPH, Filter 2	0.20	22.40	0.17	0.46	1.03	116.50	0.90	2.40
2490	138	Bus 1, Diesel, 50% Load, 55 MPH, Filter 1	0.15	16.17	0.23	0.24	1.01	109.42	1.55	1.61
2490	138	Bus 1, Diesel, 50% Load, 55 MPH, Filter 2	0.15	16.46	0.23	0.19	1.00	111.12	1.55	1.29
2490	138	Bus 1, Diesel, 50% Load, 55 MPH, Filter 3	0.15	16.31	0.23	0.18	1.02	110.81	1.56	1.24
2507	138	Bus 1, B20, 50% Load, 55 MPH, Filter 1	0.15	18.75	0.25	0.18	1.02	123.71	1.65	1.17
2507	138	Bus 1, B20, 50% Load, 55 MPH, Filter 2	0.14	18.83	0.20	0.21	0.94	124.71	1.34	1.40
2507	138	Bus 1, B20, 50% Load, 55 MPH, Filter 3	0.15	18.72	0.19	0.18	1.01	125.14	1.25	1.23
2491	138	Bus 1, Diesel, 25% Load, 55 MPH, Filter 1	0.20	10.40	0.26	0.17	1.92	99.36	2.45	1.63
2491	138	Bus 1, Diesel, 25% Load, 55 MPH, Filter 2	0.21	10.38	0.26	0.15	2.01	98.83	2.51	1.44
2491	138	Bus 1, Diesel, 25% Load, 55 MPH, Filter 3	0.22	10.38	0.26	0.16	2.10	98.99	2.51	1.57
2508	138	Bus 1, B20, 25% Load, 55 MPH, Filter 1	0.18	11.57	0.22	0.15	1.69	109.47	2.09	1.43
2508	138	Bus 1, B20, 25% Load, 55 MPH, Filter 2	0.19	11.34	0.23	0.16	1.80	107.95	2.22	1.55
2508	138	Bus 1, B20, 25% Load, 55 MPH, Filter 3	0.21	10.88	0.24	0.17	2.01	102.69	2.31	1.58
2492	138	Bus 1, Diesel, 50% Load, 35 MPH, Filter 1	0.10	22.69	0.12	0.20	0.71	154.49	0.81	1.36

Test No:	Bus	Test Type:	CO g/mi	kNOx g/mi	Total HC g/mi	PM g/mi	CO g/gal	kNO xg/gal	Total HC g/gal	PM g/gal
2492	138	Bus 1, Diesel, 50% Load, 35 MPH, Filter 2	0.09	24.03	0.09	0.21	0.61	163.29	0.62	1.41
2492	138	Bus 1, Diesel, 50% Load, 35 MPH, Filter 3	0.09	22.51	0.08	0.20	0.59	150.59	0.56	1.33
2509	138	Bus 1, B20, 50% Load, 35 MPH, Filter 1	0.13	27.67	0.19	0.19	0.87	178.59	1.21	1.21
2509	138	Bus 1, B20, 50% Load, 35 MPH, Filter 2	0.13	27.33	0.10	0.19	0.82	175.90	0.62	1.25
2509	138	Bus 1, B20, 50% Load, 35 MPH, Filter 3	0.11	26.72	0.08	0.18	0.73	171.01	0.51	1.17
2493	138	Bus 1, Diesel, 25% Load, 35 MPH, Filter 1	0.08	14.11	0.13	0.12	0.79	139.99	1.30	1.18
2493	138	Bus 1, Diesel, 25% Load, 35 MPH, Filter 2	0.08	13.96	0.15	0.14	0.85	141.01	1.47	1.39
2493	138	Bus 1, Diesel, 25% Load, 35 MPH, Filter 3	0.10	13.61	0.16	0.13	1.00	138.18	1.61	1.36
2510	138	Bus 1, B20, 25% Load, 35 MPH, Filter 1	0.10	16.19	0.11	0.10	0.93	153.51	1.05	0.95
2510	138	Bus 1, B20, 25% Load, 35 MPH, Filter 2	0.09	15.42	0.14	0.12	0.89	148.59	1.32	1.13
2510	138	Bus 1, B20, 25% Load, 35 MPH, Filter 3	0.10	15.70	0.15	0.12	0.93	151.66	1.45	1.20

Table A-2. Stockton Summer Test Results (Bus 144)

Test No:	Bus	Test Type:	CO g/mi	kNOx g/mi	Total HC g/mi	PM g/mi	CO g/gal	kNOx g/gal	Total HC g/gal	PM g/gal
2532	144	Bus 2, Diesel, 75% Load, 55 MPH, Filter 1	0.75	20.98	0.47	0.72	3.76	105.60	2.36	3.63
2532	144	Bus 2, Diesel, 75% Load, 55 MPH, Filter 2	0.71	21.28	0.43	0.61	3.54	106.75	2.18	3.08
2532	144	Bus 2, Diesel, 75% Load, 55 MPH, Filter 3	0.67	20.24	0.43	0.62	3.34	101.56	2.16	3.13
2525	144	Bus 2, B20, 75% Load, 55 MPH, Filter 1	0.69	20.15	0.51	0.55	3.48	101.11	2.55	2.75
2525	144	Bus 2, B20, 75% Load, 55 MPH, Filter 2	0.69	20.91	0.47	0.57	3.42	104.05	2.32	2.83
2525	144	Bus 2, B20, 75% Load, 55 MPH, Filter 3	0.68	21.01	0.47	0.56	3.38	104.49	2.33	2.80
2533	144	Bus 2, Diesel, 50% Load, 55 MPH, Filter 1	0.40	17.02	0.41	0.31	2.61	110.65	2.65	2.04
2533	144	Bus 2, Diesel, 50% Load, 55 MPH, Filter 2	0.40	16.69	0.40	0.33	2.60	107.79	2.60	2.13
2533	144	Bus 2, Diesel, 50% Load, 55 MPH, Filter 3	0.41	17.48	0.41	0.33	2.65	112.88	2.62	2.12
2526	144	Bus 2, B20, 50% Load, 55 MPH, Filter 1	0.44	16.57	0.44	0.35	2.82	106.47	2.83	2.27
2526	144	Bus 2, B20, 50% Load, 55 MPH, Filter 2	0.44	16.53	0.44	0.34	2.82	106.25	2.83	2.21
2526	144	Bus 2, B20, 50% Load, 55 MPH, Filter 3	0.45	15.88	0.45	0.36	2.92	102.45	2.92	2.35
2534	144	Bus 2, Diesel, 25% Load, 55 MPH, Filter 1	0.39	16.76	0.41	0.32	2.60	110.20	2.73	2.12
2527	144	Bus 2, B20, 25% Load, 55 MPH, Filter 1	0.37	12.49	0.43	0.25	3.17	106.74	3.64	2.14
2527	144	Bus 2, B20, 25% Load, 55 MPH, Filter 2	0.39	11.42	0.45	0.27	3.36	99.67	3.96	2.32
2527	144	Bus 2, B20, 25% Load, 55 MPH, Filter 3	0.41	10.81	0.48	0.28	3.71	97.10	4.35	2.55
2528	144	Bus 2, B20, 45HP Load, 40 MPH, Filter 1	0.21	16.69	0.27	0.16	1.87	146.56	2.40	1.45
2528	144	Bus 2, B20, 45HP Load, 40 MPH, Filter 2	0.22	17.72	0.26	0.19	1.85	151.11	2.18	1.62
2528	144	Bus 2, B20, 45HP Load, 40 MPH, Filter 3	0.21	17.69	0.25	0.19	1.79	150.28	2.12	1.59

Table A-3. Stockton Spring Test Results (DNC-138)

Test	ARB		kNO$_X$ g/mi	CO g/mi	CO$_2$ g/mi	THC g/mi	kNO$_X$ g/gal.	CO g/gal.	CO$_2$ g/gal.	THC g/gal.	NO$_X$ g/min	CO g/min	CO$_2$ g/min	THC g/min	KNO$_X$ g/mi	KNO$_X$ g/min
2796	Idle, AC off, neut	Avg									1.76	0.17	86.26	0.10		1.673
		Std Dev									0.01	0.02	0.82	0.01		0.028
2798	Idle, AC on, neut	Avg									2.79	0.14	137.67	0.10		2.684
		Std Dev									0.01	0.03	0.15	0.01		0.014
2800	Idle, AC off, in gear	Avg									2.56	0.16	120.00	0.10		2.446
		Std Dev									0.35	0.03	19.71	0.01		0.349
2801	Idle, AC on, in gear	Avg									3.50	0.12	170.84	0.12		3.342
		Std Dev									0.46	0.03	13.39	0.02		0.438
2803	35 mph, 50HP 25%	Avg	18.04	0.21	1304.62	0.19	148.90	1.57	9881.03	1.45	12.27	0.13	814.61	0.12	18.04	11.262
		Std Dev	0.53	0.04	16.21	0.01	2.97	0.33	0.56	0.08	0.10	0.03	9.94	0.01	0.53	0.152
2804	55 mph, 50HP, 25%	Avg	10.73	11.78	0.50	1240.32	93.75	4.02	9873.04	2.75	11.13	0.48	1172.08	0.33	10.73	10.141
		Std Dev	0.16	0.05	19.92	0.00	0.72	0.44	0.77	0.04	0.23	0.05	33.33	0.01	0.16	0.278
2805	55 mph, 100HP, 50%	Avg	16.11	0.63	1798.31	0.28	97.30	3.45	9877.72	1.56	17.02	0.60	1728.44	0.27	16.11	15.485
		Std Dev	0.34	0.09	18.98	0.01	2.24	0.47	0.67	0.06	0.22	0.09	17.47	0.01	0.34	0.334
2806	35 mph, 100 HP, 35%	Avg	26.19	0.46	1901.86	0.11	148.42	2.37	9882.49	0.59	17.82	0.28	1186.42	0.07	26.19	16.337
		Std Dev	0.10	0.08	7.29	0.01	1.16	0.42	0.78	0.04	0.14	0.05	1.08	0.00	0.10	0.119
	B20															
2808	Idle, AC off, neut	Avg									1.76	0.17	93.01	0.07		1.593
		Std Dev									0.01	0.02	0.59	0.01		0.014
2810	Idle, AC on, neut	Avg									2.90	0.07	155.48	0.08		2.707
		Std Dev									0.06	0.02	0.88	0.01		0.043
2819	Idle, AC off, in gear	Avg									2.48	0.21	129.97	0.09		2.242
		Std Dev									0.30	0.02	17.06	0.01		0.275

Test	ARB		kNO_X g/mi	CO g/mi	CO_2 g/mi	THC g/mi	kNO_X g/gal.	CO g/gal.	CO_2 g/gal.	THC g/gal.	NO_X g/min	CO g/min	CO_2 g/min	THC g/min	KNO_X g/mi	KNO_X g/min
2822	Idle, AC on, in gear	Avg									3.89	0.16	186.48	0.09		3.541
		Std Dev									0.64	0.04	19.28	0.02		0.579
2824	35 mph, 50HP, 25%	Avg	18.38	0.29	1239.71	0.15	158.54	2.30	9780.32	1.22	12.54	0.18	773.36	0.10	18.38	11.466
		Std Dev	0.33	0.07	9.48	0.00	1.15	0.59	0.97	0.03	0.14	0.04	12.37	0.00	0.33	0.124
2825	35 mph,100HP, 50%	Avg	27.02	0.40	1890.81	0.11	154.26	2.04	9782.76	0.57	18.70	0.25	1186.15	0.07	27.02	16.951
		Std Dev	0.43	0.06	30.99	0.01	1.17	0.27	0.53	0.05	0.19	0.03	2.82	0.01	0.43	0.208
2826	55 mph, 50HP	Avg	10.67	0.22	1218.53	0.35	97.23	1.75	9776.22	2.79	11.40	0.21	1146.58	0.33	10.67	10.038
		Std Dev	0.16	0.06	12.69	0.01	0.65	0.44	0.66	0.03	0.18	0.05	17.53	0.01	0.12	0.145
2829	55 mph, 100HP	Avg	15.45	0.20	1663.87	0.28	103.30	1.18	9780.66	1.67	16.70	0.19	1581.88	0.27	15.45	14.686
		Std Dev	0.15	0.05	16.26	0.02	1.57	0.31	0.33	0.07	0.11	0.05	25.43	0.02	0.15	0.118

Table A-4. Stockton Spring Test Results (DNC-143)

Test No.	Test Type		kNO_X g/mi	CO g/mi	CO_2 g/mi	THC g/mi	kNO_X g/gal	CO g/gal	CO_2 g/gal	THC g/gal	NO_X g/min	CO g/min	CO_2 g/min	THC g/min	KNO_X g/mi	KNO_X g/min
2713-2716	Idle, in neutral, AC off	Average									1.45	0.22	74.96	0.07		1.38
		Std Dev									0.02	0.04	1.81	0.02		0.02
2718-20	Idle in neutral, AC on	Average									2.30	0.16	125.04	0.07		2.22
		Std Dev									0.05	0.03	1.90	0.02		0.04
2725-27	Idle in gear, AC off	Average									2.36	0.15	120.88	0.07		2.20
		Std Dev									0.01	0.03	0.46	0.02		0.01
2729-31	Idle in gear, AC on	Average									2.83	0.09	147.19	0.07		2.63
		Std Dev									0.02	0.04	0.24	0.02		0.02
2732	40 mph, 50 HP, 25%	Average	12.47	0.04	1083.88	0.18	113.68	0.40	9882.17	1.67	9.06	0.03	728.30	0.12	12.47	8.38
		Std Dev	1.12	0.01	86.62	0.03	2.85	0.06	0.70	0.19	0.99	0.01	76.33	0.02	1.12	0.96
2739	40 mph, 100 HP, 50%	Average	14.70	0.10	1223.07	0.10	118.79	0.83	9884.21	0.81	11.09	0.07	834.40	0.07	14.70	10.03
		Std Dev	0.07	0.01	2.73	0.01	0.81	0.06	0.33	0.07	0.19	0.01	5.94	0.01	0.07	0.14
2740	55 mph, 50 HP, 25%	Average	6.54	0.10	744.37	0.16	86.76	1.28	9879.16	2.18	6.25	0.08	639.90	0.14	6.54	5.62
		Std Dev	0.05	0.00	0.79	0.02	0.78	0.06	0.78	0.22	0.04	0.00	0.84	0.01	0.05	0.06
2741	55 mph, 100 HP, 50%	Average	8.85	0.13	947.48	0.22	92.31	1.33	9878.69	2.31	9.24	0.12	871.68	0.20	8.85	8.15
		Std Dev	0.16	0.00	10.47	0.01	0.64	0.02	0.33	0.10	0.16	0.00	9.33	0.01	0.16	0.14
B20																
2743-45	Idle, in neutral, AC off	Average									1.33	0.20	64.43	0.05		1.17
		Std Dev									0.06	0.04	2.54	0.01		0.05
2751-54	Idle, in neutral, AC on	Average									2.37	0.22	112.61	0.08		2.19
		Std Dev									0.46	0.03	24.18	0.01		0.43
2757-59	Idle in gear, AC off	Average									2.57	0.17	118.00	0.07		2.36
		Std Dev									0.01	0.02	0.26	0.01		0.02
2761-63	Idle in gear, AC on	Average									3.37	0.11	150.86	0.08		3.01
		Std Dev									0.01	0.02	0.49	0.01		0.01

Test No.	Test Type		kNO_X g/mi	CO g/mi	CO_2 g/mi	THC g/mi	kNO_X g/gal	CO g/gal	CO_2 g/gal	THC g/gal	NO_X g/min	CO g/min	CO_2 g/min	THC g/min	KNO_X g/mi	KNO_X g/min
2768	40 mph, 50 HP, 25%	Average	13.79	0.11	1144.79	0.15	117.80	0.94	9782.33	1.26	10.64	0.08	789.89	0.10	13.79	9.51
		Std Dev	0.21	0.01	5.74	0.01	1.36	0.09	0.30	0.05	0.07	0.01	2.03	0.00	0.21	0.10
2769	40 mph, 100 HP, 50%	Average	22.44	0.16	1743.70	0.12	125.91	0.89	9784.21	0.69	17.21	0.11	1196.37	0.08	22.44	15.40
		Std Dev	0.15	0.07	8.53	0.01	0.20	0.40	0.69	0.03	0.14	0.05	7.51	0.00	0.15	0.12
2771	55 mph, 50HP, 25%	Average	10.00	0.20	1089.33	0.27	89.76	1.76	9777.36	2.42	10.30	0.18	993.67	0.25	10.00	9.12
		Std Dev	0.24	0.03	4.84	0.02	1.83	0.29	1.06	0.19	0.12	0.03	7.44	0.02	0.24	0.12
2772	55 mph, 100 HP, 50%	Average	15.48	0.21	1600.42	0.32	94.62	1.31	9779.51	1.96	16.14	0.20	1491.06	0.30	15.48	14.43
		Std Dev	0.05	0.00	6.05	0.00	0.08	0.02	0.06	0.02	0.08	0.00	5.54	0.00	0.05	0.05

Appendix B. Statistical Analysis Results for the Stockton Emission Tests

Table B-1. Statistical Analysis Results for Stockton Summer Tests (P Values)

Bus		Speed, MPH	Load, %	CO	kNO_x	Total HC	PM
138	P-value	55	75	0.700	0.720	0.009	0.005
	% change for B20			-2.8	2.8	***-28.0***	***-20.7***
138	P-value	55	50	0.452	0.000	0.321	0.432
	% change for B20			-2.1	***12.7***	-8.8	-8.5
138	P-value	55	25	0.174	0.021	0.000	0.738
	% change for B20			-8.8	***7.7***	***-11.5***	-1.7
138	P-value	35	50	0.038	0.012	0.625	0.007
	% change for B20			***26.8***	***12.2***	18.3	***-11.6***
138	P-value	35	25	0.608	0.002	0.267	0.101
	% change for B20			4.0	***8.3***	-13.1	***-16.4***
144	P-value	55	75	0.383	0.497	0.164	0.050
	% change for B20			-3.4	-1.4	7.7	***-14.9***
144	P-value	55	50	0.004	0.052	0.002	0.021
	% change for B20			***8.8***	***-4.9***	***9.0***	***8.6***
144	P-value	55	25	0.123	0.258	0.092	0.468
	% change for B20			22.8	-4.8	***41.0***	4.9

Values in italics/red (online) are statistically significant with at least 90 percent confidence level
Student t-test—two-sample equal variance, two-tailed distribution

Table B-2. Statistical Analysis Results for Stockton Spring Tests, by Idle Condition (P-Values)

Bus		Idle Condition	CO	KNO_x	Total HC	PM
138	P-value	Idle, in neutral, AC off	0.856	0.012	0.076	0.958
	% change for B20		1.7%	***-4.8%***	***-23.8%***	-0.9%
138	P-value	Idle in neutral, AC on	0.019	0.438	0.143	0.666
	% change for B20		***-51.9%***	0.8%	-20.9%	-11.2%
138	P-value	Idle in gear, AC off	0.044	0.470	0.229	0.329
	% change for B20		***37.5%***	-8.4%	-14.3%	23.7%
138	P-value	Idle in gear, AC on	0.201	0.659	0.086	0.660
	% change for B20		36.4%	6.0%	***-24.9%***	-29.8%
143	P-value	Idle, in neutral, AC off	0.546	0.001	0.209	0.448
	% change for B20		-9.3%	***-15.2%***	-22.7%	10.0%
143	P-value	Idle in neutral, AC on	0.042	0.938	0.307	0.626
	% change for B20		***41.4%***	-0.9%	16.8%	15.6%
143	P-value	Idle in gear, AC off	0.512	0.000	0.929	0.539
	% change for B20		10.3%	***7.4%***	1.5%	10.8%
143	P-value	Idle in gear, AC on	0.349	0.000	0.729	0.729
	% change for B20		28.0%	***14.7%***	7.8%	8.3%

Table B-3. Statistical Analysis Results for Stockton Spring Tests, by Speed (P-Values)

Bus		Speed, MPH	Load, %	CO	kNO_x	Total HC	PM
138	P-value	35 mph	50 HP 25%	0.135	0.006	0.012	0.958
	% change for B20			46.4%	***6.5%***	***-15.8%***	-0.9%
138	P-value	55 mph	50 HP, 25%	0.003	0.003	0.299	0.666
	% change for B20			***-56.5%***	***3.7%***	1.2%	-11.2%
138	P-value	55 mph	100 HP, 50%	0.002	0.019	0.120	0.329
	% change for B20			***-66.0%***	***6.2%***	7.0%	23.7%
							0.660
143	P-value	40 mph	50 HP, 25%	0.000	0.072	0.017	-29.8%
	% change for B20			***136.2%***	***3.6%***	***-24.7%***	
143	P-value	40 mph	100 HP, 50%	0.830	0.000	0.064	0.448
	% change for B20			6.5%	***6.0%***	***-14.7%***	10.0%
143	P-value	55 mph	50 HP, 25%	0.050	0.059	0.230	0.626
	% change for B20			***37.8%***	***3.5%***	10.8%	15.6%
143	P-value	55 mph	100 HP, 50%	0.466	0.003	0.004	0.539
	% change for B20			-1.1%	***2.5%***	***-14.8%***	10.8%

Values in italics/red (online) are statistically significant with at least 90 percent confidence level
Student t-test—two-sample equal variance, two-tailed distribution