Naval Facilities Engineering Command

ENGINEERING SERVICE CENTER
Port Hueneme, California 93043-4370

TECHNICAL REPORT

TR-2275-ENV

EFFECT OF BIODIESEL ON DIESEL ENGINE NITROGEN OXIDE AND OTHER REGULATED EMISSIONS PROJECT NO. WP-0308

By

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May 2006

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0811*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From – To)*
15-06-2006	Final	

4. TITLE AND SUBTITLE

EFFECT OF BIODIESEL ON DIESEL ENGINE NITROGEN OXIDE AND OTHER REGULATED EMISSIONS
PROJECT NO. WP-0308

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESSES

Commanding Officer
Naval Facilities Engineering Service Center
1100 23rd Avenue
Port Hueneme, CA 93043-4370

8. PERFORMING ORGANIZATION REPORT NUMBER

TR-2275-ENV

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Environmental Security Technology Certification Program
901 North Stuart Street, Suite 303
Arlington, VA 22203

10. SPONSOR/MONITORS ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This report summarizes the results of a 3-year project lead by the Naval Facilities Engineering Service Center (NFESC) to obtain emissions factors (i.e. tailpipe air pollution emissions data) from 10 types of Department of Defense (DoD) operated diesel powered engines. Emissions data was obtained from 8 vehicles, primarily buses and trucks, and 2 portable generators. All testing was performed with the engines installed in the vehicles/portable equipment.

Emissions factors were determined for the engines fueled with various blends/types of biodiesel as well as a baseline fuel, either California Air Resources Board (CARB) certified Ultra Low Sulfur Diesel (USLD) (15-ppm sulfur maximum) or JP-8. CARB USLD was used since it will be required within California for on-road vehicles starting in June 2006. Biodiesel blends from 20% to 70% were tested along with 100% biodiesel. For the blended biodiesel testing, the biodiesel was mixed with USLD. Although several blends were tested, the project focused on B20 (20% biodiesel) blends, since this is the primary blend of biodiesel used in military vehicles.

Testing performed on B20 fuels identified three significant results (1) There were no consistent trends over all engines tested, (2) There were no statistically significant emissions differences found between biodiesel fuels manufactured from yellow grease or soy bean oil feedstocks, and (3) An extensive statistical analyses indicated no statistically significant differences in Hydrocarbon (HC), Carbon Monoxide (CO), Nitrogen Oxides (NOx) or Particulate Matter (PM) emissions between a B20 biodiesel manufactured at Naval Base Ventura County from yellow grease and CARB ULSD petroleum diesel.

The results from this project are significantly different than those previously reported by the Environmental Protection Agency (EPA). Of particular interest is the fact that for actual DoD fleet diesel engines, there was no statistically significant increase in NOx emissions.

15. SUBJECT TERMS

Air pollution emissions, biodiesel, emission factors

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(include area code)*
U	U	U			

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Environmental Security Technology Certification Program (ESTCP)

Final Report
Effect of Biodiesel on Diesel Engine Nitrogen Oxide and Other Regulated Emissions
Project No. WP-0308

May 2006

Executive Summary

The Environmental Security Technology Certification Program (ESTCP) funded a three-year project to obtain air pollution emission factors for commonly used Department of Defense (DoD) diesel engines fueled with various types and blends of biodiesel. Biodiesel is a nontoxic, biodegradable fuel made from organic fats and oils that serves as a replacement, substitute, and enhancer for petroleum diesel. It may be blended with petroleum diesel in all existing diesel engines with little or no modification to the engines. Previous studies suggest that use of biodiesel can significantly reduce the quantity and toxicity of the air pollution produced by diesel engines.

The project included the measurement of the regulated air emissions of carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and particulate matter (PM). Testing was performed in accordance with Environmental Protection Agency (EPA) testing standards and duty cycles. The tests were performed both in the laboratory and the field. The project also included measurements of Hazardous Air Pollutants (HAPs), the evaluation of two proposed NO_x reduction fuel additives, as well as the chemical speciation of the HC emissions and characterization of the PM emissions. For the project, five fuels were tested, a soy-based biodiesel, a baseline petroleum based ultra low sulfur diesel (ULSD), JP-8, and two yellow grease based biodiesels (YGA & YGB). The biodiesel fuels were tested at the 20% (B20), 50% (B50), 70% (B70) and 100% (B100) concentration levels, with the biodiesel being mixed with the ULSD.

Ten types of DoD operated diesel engines were included in the test, including engines used for on-road, off-road, and portable power applications. Test engines were supplied by a multitude of DoD facilities. Engines were selected for inclusion in the demonstration based on their widespread use within DoD.

The primary justification for this project was to provide the biodiesel emissions data necessary to promote its increased use within DoD. Currently, there is a little emissions data in the technical literature from diesel engines of the age and types commonly used by DoD. An additional concern is the lack of data for yellow grease based biodiesel; a product manufactured using vegetable oil recycled from commercial cooking operations. It is expected that the data from this study may be incorporated with previous datasets, to provide the EPA a more detailed and comprehensive database on different varieties of biodiesel feedstocks and applications.

This project focused on B20 biodiesel blends, since this is the blend of biodiesel used in military vehicles. The project results for the regulated emissions were that at the B20 level, there were no consistent trends over all applications tested. Within the context of the test matrix, no differences were found between the different YGA, YGB, and soy-based biodiesel feedstocks. The results of more extensive statistical analyses also indicated no statistically significant differences in CO, HC, NO_x and PM emissions between the B20-YGA and the ULSD. The tested NOx reduction additives also proved to be ineffective. Thus the air pollution performance objectives outlined in the project's demonstration plan were not met. Although these results were not expected, they are not necessarily a disappointment since the baseline USLD fuel proved to be greatly superior to existing on-road Diesel No. 2.

The higher biodiesel blends (B50 to B100) were only tested on one Humvee, and with B100 on a 250 kW portable generator and a single test on the Ford F9000 tractor. On the Humvee, the higher biodiesel blends did show a trend of higher CO and HC emissions and lower PM emissions.

For the unregulated HAP emissions, no consistent trends were identified over the subset of vehicles tested. This result like those for the regulated emissions, did not meet the air pollution performance objectives outlined in the project's demonstration plan. However, it should be noted that the dataset for HAPs was smaller than that for the regulated emissions. Also, since speciation data was not available for all modes, analyses and comparisons based on weighted values could not be conducted for the species. As such, it is likely that a larger sample set would be needed to statistically evaluate the effects of biodiesel on HAPs against ULSD. While these results were not expected, it is not necessarily a disappointment since, as previously stated, the baseline ULSD fuel proved to be greatly superior to existing on-road Diesel No. 2.

Although our testing was not able to identify statistically significant air pollution benefits for the use of B20 biodiesel, from a lifecycle cost standpoint, the use of B20 is the most cost effective method for DoD fleets to meet their alternative vehicle requirements. Using B20 in place of petroleum diesel involves no new infrastructure requirements nor additional environmental compliance costs. The only cost is the $0.14 higher cost per gallon to purchase the fuel.

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List of Acronyms

AFB	Air Force Base
AFV	Alternate Fueled Vehicle
APG	Aberdeen Proving Ground
API	American Petroleum Institute
AO/AQIRP	Auto/Oil Air Quality Improvement Research Program
ARB	Air Resources Board (California)
ASTM	American Society of Testing & Materials
ATC	Aberdeen Test Center
B20	20% biodiesel by volume, 80% petroleum diesel by volume
B50	50% biodiesel by volume, 50% petroleum diesel by volume
B70	70% biodiesel by volume, 50% petroleum diesel by volume
B100	100% biodiesel by volume
BTU/GAL	British Thermal Units per Gallon
CARB	California Air Resources Board
CAT	Caterpillar Corporation
CBC	Construction Battalion Center
CBD	Central Business District
CBO	Congressional Budget Office
CCR	California Code of Regulations
CE-CERT	Bourns College of Engineering – Center for Environmental Research and Technology
CFR	Code of Federal Regulations
CH_4	Methane
CO_2	Carbon Dioxide
CO	Carbon Monoxide
CVS	Constant Volume Sampling
DENIX	Defense Environmental Network & Information Exchange
DLA	Defense Logistics Agency
DNPH	Dinitrophenylhydrazine
DoD	Department of Defense
DTBP	Ditertiary Butyl Peroxide
EC	Elemental Carbon
ECAM	Environmental Cost Analysis Methodology
EHN	Ethyl Hexyl Nitrate
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program

List of Acronyms (continued)

FTP	Federal Test Procedure
G/bhp-hr	Gram Per Brake Horsepower Hour
G/mile	Gram per mile
GC	Gas Chromatography
GC-FID	Flame Ionization Detector
GC-MS	Gas Chromatography Mass Spectroscopy
GM	General Motors Corporation
HAP	Hazardous Air Pollutant
HC	Hydrocarbon
HMMWV	Humvee
HP	Horsepower
HP LC/UV	High Performance Liquid Chromatography/Ultraviolet
ISO	International Standards Organization
JP-8	Jet Propellant No. 8
KOH	Potassium Hydroxide
KW	Kilowatt
LLC	Limited Liability Corporation
MEL	Mobile Emissions Laboratory
MSDS	Material Safety Data Sheet
MSAT	Mobile Source Air Toxics
NAAQS	National Ambient Air Quality Standards
NDIR	Non Dispersive Infrared
NFESC	Naval Facilities Engineering Service Center
NMHC	Non-Methane Hydrocarbon
NIOSH	National Institute of Occupational Safety and Health
NOx	Nitrogen Oxides Chemical Compounds Including NO and NO_2
NREL	National Renewable Energy Laboratory
NYBC	New York Bus Cycle
OC	Organic Carbon
OSHA	Occupational Safety and Health Administration

List of Acronyms (continued)

PAH	Polycyclic Aromatic Hydrocarbon
PM	Particulate Matter
PPM	Parts Per Million
POC	Point of Contact
PSI	Pounds per square inch
QA	Quality Assurance
QC	Quality Control
ROVER	Real-time On-road Vehicle Emissions Reporter
SAE	Society of Automotive Engineers
SO_2	Sulfur Dioxide
TC	Total Carbon
THC	Total Hydrocarbon
UCR	University of California, Riverside
ULSD	Ultra Low Sulfur Diesel
US06	EPA Aggressive Certification Cycle
VOC	Volatile Organic Compound
YGA	Yellow Grease Formula A
YGB	Yellow Grease Formula B

ACKNOWLEDGEMENTS:

The Project Team would like to thank the dedicated employees at the Camp Pendleton Marine Corps Base for making the arrangements to supply most of the diesel engines tested in this project. Camp Pendleton was able to supply the engines at no cost to the project and accommodate numerous delays in returning the engines. The team would also like to thank Biodiesel Industries, Inc. and the National Renewable Energy Laboratory for supplying 400 gallons of yellow grease biodiesel and emissions testing services respectfully, at no cost to the project. Finally, the Project Team would like to thank the Environmental Security Technology Certification Program office for providing the majority of the project funding. .

Contact information for the main project participants is provided in Paragraph 8. The ESTCP Cost and Performance Report may be found at their WEB site: http://www.estcp.org.

Effect of Biodiesel on Diesel Engine Nitrogen Oxide and Other Regulated Emissions

Naval Facilities Engineering Service Center

May, 2006

1. Introduction

1.1 Background

Diesel engines are widely used throughout the DoD for powering tactical and non-tactical vehicles and vessels, off-road equipment, engine-generator sets, aircraft ground-support equipment and a variety of other applications. Like gasoline engines, diesels are known to emit all of the criteria pollutants regulated by the National Ambient Air Quality Standards (NAAQS) established by the Clean Air Act. Human health concerns with diesel exhaust are; however, primarily focused on PM and HAP emissions.

Although diesels are the most efficient of internal combustion engines and have favorable characteristics in the reduction of green-house gas emissions, concerns with the health effects from PM and HAP emissions has intensified the call for cleaner burning diesels and lead to recently proposed and enacted regulations increasing restrictions on diesel exhaust emissions. Because of these developments, many control approaches are being pursued. One solution is the development of cost-effective alternative fuels, such as biodiesel, to reduce diesel engine emissions.

Biodiesel is a nontoxic, biodegradable fuel made from organic fats and oils, and serves as a replacement, substitute and enhancer for petroleum diesel. It may be used in all existing diesel engines with little or no modification to the engines. Biodiesel has been previously reported (see Reference 7.1) to reduce all regulated air pollutant emissions except for emissions of NO_x. Biodiesel may be blended with petroleum diesel at any percentage For DoD applications, it is customary to use a 20 percent by volume biodiesel 80 percent by volume petroleum diesel (B20), [pure biodiesel = (B100)] biodiesel blend. Other major biodiesel consumers commonly use B2, B5, B11 or B20 biodiesel blends, as well as neat biodiesel (B100).

Alternative fuels are mandated for all federal fleets of 20 or more vehicles and B20 is one of the options for meeting this requirement. Biodiesel has been designated as an Alternative Fuel by the Department of Energy, and has been registered with the EPA as a fuel and fuel additive. Authorization for biodiesel use by DoD in non-tactical vehicles was approved in 1999.

Although there is much support for the continued development of the biodiesel alternative, there is not currently sufficient knowledge on how various types and blends of biodiesel affect the air emissions from diesel engines of interest to DoD. Specifically, there are little data on the emission benefits of biodiesel produced from used vegetable oils. These data are important since significant quantities of used vegetable oils for the production of biodiesel are currently available near and on DoD facilities at little to no cost. It has been reported to the author that many DoD facilities are in fact, paying for the disposal of their used vegetable oil.

1.2 Objectives of the Demonstration

The objective of this project is to establish emissions factors for DoD diesel powered engines of interest fueled with various types of biodiesel. Currently, most of the available biodiesel emissions data is for older heavy-duty engines tested on an engine dynamometer and fueled with virgin soybean derived biodiesel. Although these data are important, their use in estimating DoD fleet emission factors introduces significant uncertainties. Previous Naval Facilities Engineering Service Center (NFESC) surveys have shown that although most DoD non-tactical diesel powered engines are heavy duty, a high percentage are newer engines that employ emission control technologies that are significantly different than the tested engines. In addition, it is expected that a significant portion of DoD biodiesel programs in the future will employ yellow grease derived biodiesel made from recycled vegetable oil. By targeting the emissions from actual DoD operated heavy-duty engines fueled with either soybean or yellow grease derived biodiesel, relevant DoD emissions factors can be determined.

A secondary objective of this test program is to identify and demonstrate fuel additives that reduce NO_x emissions from biodiesel. While biodiesel has been shown to reduce air emissions of the other criteria pollutants, numerous studies have shown that its use results in a slight increase in NOx emissions (i.e., < 2 percent for B20). Research at Arizona State University suggests that the addition of a cetane improver such as ethyl hexyl nitrate (EHN, 1/2 percent by volume) or ditertiary butyl peroxide (DTBP, 1 percent by volume) will reduce NOx emissions from biodiesel.

Another factor increasing the importance of this emissions testing program is the total lack of data comparing the emissions from ULSD with those from biodiesel. Starting in 2006, the EPA has mandated the use of diesel fuel with a sulfur level ≤ 15 ppm for on-highway applications. A similar requirement has been proposed for off-highway use. For this test program, NFESC will exclusively compare various types of biodiesel with ULSD for the testing of non-tactical vehicles since this test program will complete within one year of the ULSD rollout.

In addition to the measurements of currently regulated emissions, the test program will also include PM chemical analysis as well as the emissions of a number of hazardous air pollutants. This work will focus on yellow grease where the least information is available.

The testing program will include eight types of DoD operated vehicles and two portable engines. Not all the same test cycles nor fuels will be used for each test engine. Multiple testing locations with different capabilities will be used. Test results will be reported in a common format to simplify comparisons made between all the test runs.

For this project, NFESC will obtain the biodiesel emissions data necessary for DoD decision makers to intelligently plan future biodiesel implementations. Biodiesel air emissions data will be provided to the Defense Logistics Agency (DLA) along with other organizations that control specifications for DoD fuel purchases. This project will address Navy need 2.I.01.b, "Control Particulate and Other Air Emissions from Mobile and Stationary Sources", and Air Force need 506, "Eliminate NOx Emissions from Fuel-burning".

1.3 Regulatory Drivers

Mobile-source diesel emissions are regulated by both Federal (40 CFR 86, 89) and California (13 CCR Chapter 3) equipment and vehicle standards. These standards are applied to equipment and vehicles at the time of manufacture. In the last six years, EPA has pursued a program to dramatically tighten these regulations. This is illustrated in Table 1.1 below, which shows the 2007 EPA on-road heavy-duty engine standards, along with the year 2000 and 2004 standards. Likewise, the EPA has also pursued a program to dramatically tighten the regulations for non-road diesel engines. These regulations, unlike their on-road counterparts, are based on the size of the engine, with larger engines having tighter standards.

Table 1.1
Current and Future EPA Emissions Regulations [g/bhp-hr]

<table>
<tr><th colspan="2" rowspan="2"></th><th rowspan="2">2000 Standard (g/bhp –hr)</th><th rowspan="2">2004 Standard (g/bhp –hr)</th><th rowspan="2">2007 Standard (g/bhp –hr)</th><th colspan="4">Phase-In by Model Year*</th></tr>
<tr><th>2007</th><th>2008</th><th>2009</th><th>2010</th></tr>
<tr><td rowspan="5">Diesel Fleet</td><td>NO_x</td><td>4.0</td><td>N/A</td><td>0.20</td><td rowspan="3">25%</td><td rowspan="3">50%</td><td rowspan="3">75%</td><td rowspan="3">100%</td></tr>
<tr><td>HC</td><td>1.3</td><td>N/A</td><td>0.14</td></tr>
<tr><td>NMHC + NO_x</td><td>N/A</td><td>2.4</td><td>N/A</td></tr>
<tr><td>CO</td><td>15.5</td><td>15.5</td><td>15.5</td><td>100%</td><td>100%</td><td>100%</td><td>100%</td></tr>
<tr><td>PM</td><td>0.10</td><td>0.10</td><td>0.01</td><td>100%</td><td>100%</td><td>100%</td><td>100%</td></tr>
<tr><td colspan="9">* Percentages represent percent of sales</td></tr>
</table>

The 2007 heavy-duty highway diesel engine standards will reduce PM emissions by about 98 percent from a 1990 baseline and 90 percent from a 2000 baseline. Significant NO_x and non-methane hydrocarbon (NMHC) reductions, are also required for 2004 and later engines. However, because these emission decreases do not affect existing diesel engines, their full benefit will take more than 20 years to achieve. In an effort to achieve the benefits sooner, several states have proposed regulatory strategies to reduce emissions for existing engines.

In October 2000, the California Air Resources Board (CARB) finalized their *Risk Reduction Plan to Reduce Particulate Matter Emissions from Diesel-Fueled Engines and Vehicles.* The California plan calls for the use of low-sulfur fuels, retrofit requirements, or the replacement of existing engines for on-road, non-road, portable, and stationary equipment.

In 2001, Texas enacted regulatory changes to reduce emissions from diesel engines. Their plan is a comprehensive set of incentive programs. The plan includes: 1) The Retrofit and Repower Incentive Program for On-Road and Non-Road High-Emitting Engines, 2) The New Purchase and Lease Incentive Programs for Light-Duty and Heavy-Duty On-Road Vehicles, and 3) Clean diesel fuel requirements which include limitations on aromatics and sulfur in commercial diesel fuels. All of these changes will reduce both NO_x and particulate emissions.

Stationary-source diesel emissions are regulated by state and local regulations. Currently, most regulations only limit CO, NO_x, and opacity. However, CARB recently proposed guidance that if adopted by local air districts would require the reduction of HAP emissions.

In addition to the air emissions regulations, federal policymakers have also established several initiatives that require the use of alternative transportation fuels such as biodiesel. The purpose of these initiatives is to reduce the nation's oil imports. The Federal Fleet Acquisition Requirement in the Energy Policy Act (i.e., Title III) requires that 75 percent of annual DoD light duty vehicle acquisitions be capable of operating on alternative fuels. This law pertains to federal vehicle fleets consisting of 20 or more centrally fueled vehicles. Executive Order 13149, "*Greening the Government through Federal Fleet and Transportation Efficiency*," requires that federal fleets reduce petroleum consumption by 20 percent by 2005, compared with the 1999 levels.

1.4 Stakeholder/End-User Issues

As described in paragraph 1.3, DoD fleet operators are under increasing pressure to reduce both diesel air emissions and petroleum consumption. Unfortunately, many alternate fuels that have been shown to reduce emissions either have fuel costs higher than petroleum diesel or require significant engine modifications and/or infrastructure upgrades. Ideally, an alternate fuels program must be cost effective, universally applicable, and provide significant measurable environmental benefits. As demonstrated by NFESC at their Port Hueneme, California research biodiesel production facility, only biodiesel derived from yellow grease meets these requirements. It is cost effective, it can be used without any engine modifications and it does not require any infrastructure upgrades. Unfortunately, at this time, it is not available throughout the country. Also, since its raw material is limited, its supply cannot meet all of the potential DoD demand. Virgin soybean derived biodiesel, an approved alternate fuel, is more widely available and can supply all of the potential DoD demand. Unfortunately, it is more expensive to produce than petroleum based diesel. This cost difference is, however, almost completely made up by existing federal subsidies. This subsidy is not permanent and therefore could be reduced or eliminated at any time in the future.

In the last couple of years, a significant number of DoD fleets have already made the switch to B20 biodiesel. The Air Force, Marine Corps and Navy have, in fact, switched most of their non-tactical vehicles. At this time, many additional DoD fleet operators are also considering switching to B20. Many of these potential DoD B20 customers are concerned about the cost of the fuel and its effect on air pollution regulatory compliance. By providing emissions testing results for multiple types of biodiesel, this project should address these potential customer concerns.

2. Technology Description

2.1 Technology Development and Application

Biodiesel is a renewable, clean burning, oxygenated fuel for diesel powered engines or boilers made from soybean or other vegetable oils or animal fats. Chemically, biodiesel consists of a small number of alkyl esters. It contains no sulfur or aromatics and already meets the EPA's 2006 on-road standard for sulfur content in diesel fuel. Because it has properties similar to petroleum-based diesel fuel, biodiesel can be blended in any ratio with petroleum diesel and used in diesel engines without major modifications. Biodiesel is registered as a fuel and fuel additive with the EPA and meets clean diesel standards established by CARB.

Biodiesel use as a fuel is as old as the diesel engine. Rudolph Diesel, inventor of the diesel engine in 1892, used peanut oil as the original engine fuel. The use of petroleum fuels for diesel engines only came into widespread use in the 1920's. This fuel substitution was the result of a significant drop in the price of petroleum. Starting in the 1970's after the "oil crisis", interest in the use of domestically produced biofuels returned. In the 1990's, the biodiesel industry organized to promote its use. Recently, biodiesel demand has mostly come from fleet operators affected by the 1998 EPAct Amendment.

Two recent successes have helped advance the widespread use of biodiesel. First, the American Society of Testing and Materials (ASTM) issued a specification (D 6751) for biodiesel fuel in December 2001. ASTM is the premier standard-setting organization for fuels and additives in the United States. This development is crucial in standardizing fuel quality for biodiesel in the U.S. market and increasing the confidence of consumers and engine makers. The ASTM specification was developed so that approved fuels could be consistently manufactured using any vegetable oil or animal fat as the raw material. Second, biodiesel became the only alternative fuel in the country to have successfully completed the EPA's Tier I and Tier II Health Effects testing under Section 211(b) of the Clean Air Act in May 2000. The Tier I testing conclusively demonstrated biodiesel's significant reductions in most currently regulated emissions as well as most unregulated emissions—especially those associated with cancer and lung disease. Tier II testing demonstrated biodiesel's non-toxic effect on health.

The production of biodiesel is based on the process of base-catalyzed transesterification at low temperature (150 °F), low pressure (20 psi), and with a high conversion factor (98 percent). As depicted in Figure 2.1, a fat or oil is reacted with an alcohol (like methanol) in the presence of a catalyst to produce glycerine and methyl esters or biodiesel. The methanol is charged in excess to assist in quick conversion and unconverted methanol is recycled. The catalyst is usually sodium or potassium hydroxide that has already been mixed with the methanol.

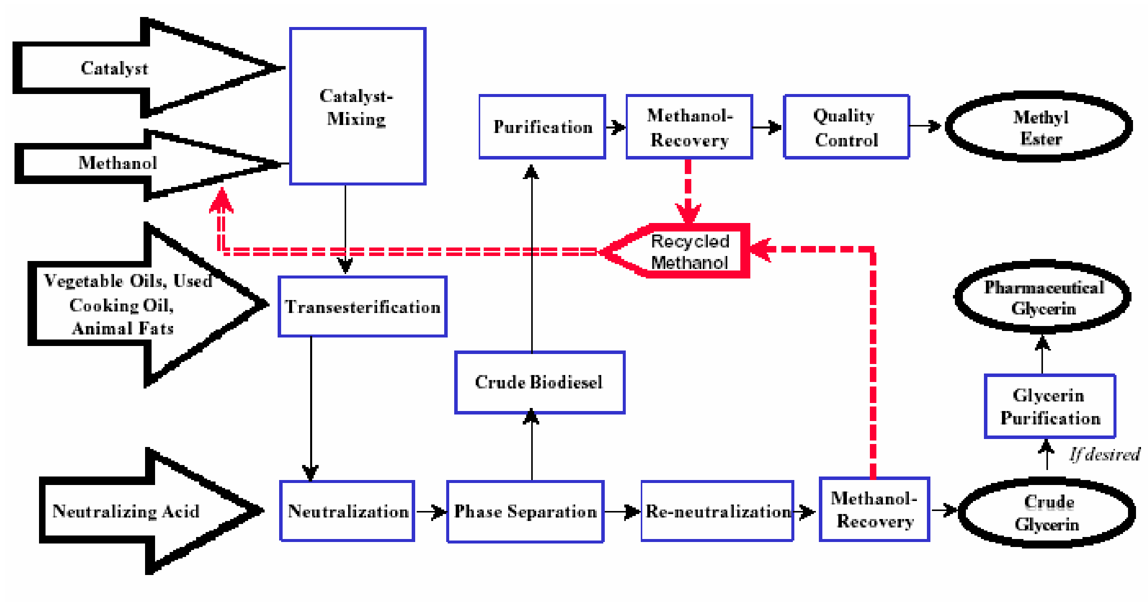
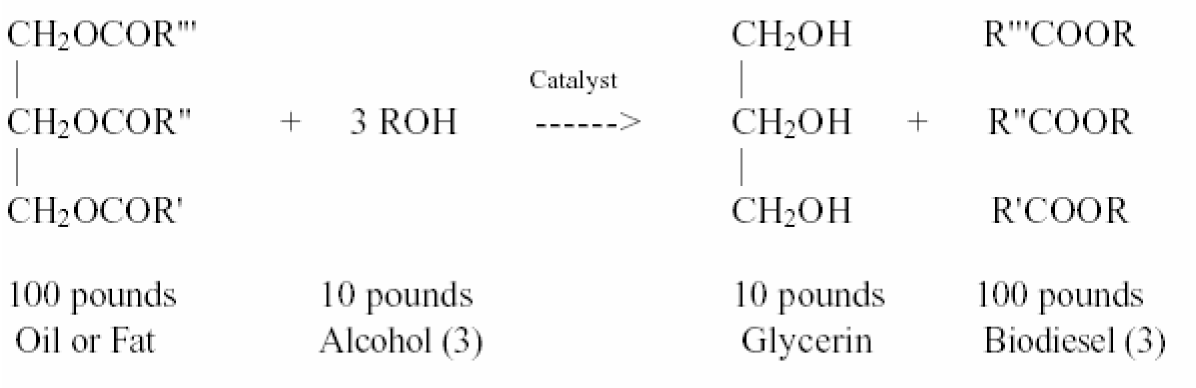


Figure 2.1
Biodiesel production diagram

The key chemical reactions are shown below:



2.2 Previous Testing of the Technology

During the past 20 years, more than 80 scientific studies have been conducted to measure the emissions from heavy-duty diesel engines fueled with biodiesel. Although the studies had many different focuses, most of the work was done using older engines (i.e., pre 1998), with testing performed on an engine dynamometer as opposed to an actual diesel powered vehicle. These studies primarily tested biodiesel derived from soybean oil since it is the most common form of the fuel.

In October 2002, EPA issued the draft technical report EPA 420-P-02-001 "A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions". In this report (see Reference 7.1), EPA used various statistical analytical tools to compile the results from 39 studies. Wherever sufficient information was available, EPA attempted to develop models to predict how biodiesel emissions would be affected by various duty-cycle, engine age/type, and fuel properties. In addition, they summarized the results to identify the average expected emissions reductions. For use of B20, Table 2.1 provides the expected criteria pollutants emissions reductions for virgin soybean-based biodiesel added to an average low sulfur (i.e., <500 ppm) base fuel.

Table 2.1
Emission Impacts of B20 for Soybean-Based Biodiesel Added to an Average Base Fuel

Regulated Pollutant	Percent Change in Emissions for Soy
NO_x	+ 2.0%
PM	- 10.1 %
HC	- 21.1 %
CO	- 11.0 %

The EPA analysis noted that biodiesel impacts on emissions varied depending on the type of biodiesel (i.e., manufactured from soybean, rapeseed, or animal fats) and on the type of conventional diesel to which the biodiesel was added. For example, biodiesel based on yellow grease provided a greater environmental benefit in that the reduction was greater for CO, HC, and PM and the increase in NO_x was less than with soy-based biodiesel. With one minor exception, emission impacts of biodiesel did not appear to differ by engine model year.

2.3 Factors Affecting Cost and Performance

As presented by the National Biodiesel Board, a biodiesel industrial trade organization, at their 2006 National Biodiesel Conference & Expo, for biodiesel manufactured from virgin soybean oil, the feedstock costs account for approximately 70 percent of the direct production costs, including the plant capital costs. For example, it takes about 7.5 pounds of soybean oil costing about 21 cents per pound to produce a gallon of biodiesel, thus feedstock costs alone are at least $1.58 per gallon. With processing, marketing and overhead expenses and profit included, the price of the finished biodiesel is typically over $3 per gallon.

Biodiesel producers are trying to reduce these feedstock costs by a variety of methods including developing higher oil-content soy hybrids, using other vegetable oils with a higher oil content or using yellow grease that is often available at low (~5 cents per pound) or no cost. By employing one of these strategies, it is estimated that the future cost of the feedstock can be significantly reduced, thus making biodiesel less expensive than petroleum-based diesel fuel. The Department of Energy has forecasted that biodiesel manufactured from yellow grease will cost approximately $1.40 per gallon and mustard-based biodiesel will cost less than $1 per gallon by 2010.

Two performance issues are of primary concern with the use of biodiesel. The first concern is how it affects the emissions from diesel engines. Information on emissions affects is shown in Table 2.1. The second concern is how the use of biodiesel will affect the fuel economy of a diesel engine. As reported by the EPA in their Draft Technical Report EPA 420-P-02-001 (Reference 7.1), the average virgin soybean oil derived biodiesel has an energy content of 119k Btu/gal, compared with an average 130k Btu/gal for petroleum diesel. This basic energy content difference results in a lower fuel economy for biodiesel. The EPA in their report included a summary of 217 actual fuel economy tests. Their results showed that, the fuel economy for B20 was 0.9 – 2.1 percent less than for petroleum diesel.

2.4 Advantages and limitations of the Technology

The use of biodiesel fuel has been shown (see Reference 7.1) to reduce the overall air pollution resulting from diesel engine operations. Of the criteria pollutants regulated by the EPA, biodiesel is reported to reduce CO, HC, PM, and Sulfur Dioxide (SO_2) emissions while only causing a small increase in NO_x emissions. It also has been shown to reduce HAP and greenhouse gas emissions. In addition to its pollution reduction advantages, biodiesel also has economic and strategic advantages. Biodiesel can be made from domestically produced agricultural raw materials that are produced in surplus in the United States. The use of biodiesel will reduce the use of imported oil, much of which is supplied by potentially unstable Middle Eastern suppliers.

Although biodiesel produced from virgin raw materials such as soybean oil is more expensive than petroleum, its use has significant economic benefits. By employing the surplus of raw agricultural products, the cost of government crop support programs can be reduced. In addition, biodiesel production facilities produce employment opportunities, particularly in rural areas.

To address the raw material cost problem, the production of biodiesel manufactured from yellow grease, a food service waste product, is being greatly expanded. Currently, yellow grease is available at little to no cost. In most cases, food service operators are required to pay for the disposal of their yellow grease. Unfortunately, the supply of yellow grease is not unlimited. It is estimated that up to 800 million gallons of yellow grease may be available in the United States, a quantity sufficient to produce 700 million gallons of B100 biodiesel. This quantity cannot supply all of the potential demand. The Energy Information Administration of the Department of Energy reported in their Annual Energy Review that 2.455 million barrels per day of petroleum diesel fuel was used by the transportation sector in the United States during year 2002. If biodiesel was used for all diesel transportation needs, yellow grease could supply 9.8% of the potential B20 demand.

Three issues potentially limit the widespread and growing usage of biodiesel. The first is the cost of biodiesel and that is primarily driven by the feedstock cost. Hence in this project, we are trying to use yellow grease to reduce the fuel cost. A second potential limitation is that there has been reported a small increase in the NO_x emissions and any increase might not be acceptable in NO_x non-attainment areas. Accordingly, this project will test some additives that claim to reduce the increase in NO_x that is associated with biodiesel. The third issue is the stability and cold weather performance of biodiesel. Currently there is little information and no recognized test procedure to measure biodiesel's long-term stability. The use of acid number has however, been suggested as the best simple test method to measure biodiesel stability. Likewise, biodiesel's stability in cold weather is not well understood, although it has been shown that B100 may not be suitable in very cold weather applications, such as winter use in Minnesota. These stability concerns have currently limited DoD biodiesel usage to B20 for applications where the fuel will not be stored for extended periods.

To assess the overall potential air pollution control benefit of implementing a biodiesel program, it must be evaluated against the potential alternatives. Biodiesel is a fuel-based solution to controlling emissions from diesel engines. Alternative controls include either expensive add-on devices or replacing the engine with one that meets tougher emission standards. These emission control approaches are much more expensive than a simple fuel change; hence, biodiesel may achieve the targeted reduction in emissions at a lower total cost.

In addition to providing a low cost option to reduce diesel engine emissions, it is also the low cost option for implementing the EPAct regulations. These regulations require specified fleet operators, including most DoD fleets, to use alternate fueled vehicles (AFV) for at least 75 percent of their fleet. Using 450 gallons of B100 or 2,250 gallons of B20 earns the fleet operator one AFV credit. The Congressional Budget Office (CBO) determined in 1998 that using B20 biodiesel is the lowest cost option among the alternative fuel choices available to meet AFV requirements. The CBO predicted that the federal government would save $10 million annually by using B20 biodiesel in its fleet vehicles.

3. Demonstration Plan

3.1 Performance Objectives

Table 3.1
Performance Objectives

Type of Performance Objective	Primary Performance Criteria	Expected Performance (Metric)	Actual Performance (future) Objective Met?
Quantitative	Reduce CO Emissions	Reduce emissions by 9% minimum with B20	No
	Reduce HC Emissions	Reduce emissions by 16% minimum with B20	No
	Reduce PM Emissions	Reduce emissions by 8% minimum with B20	No
	Reduce HAP Emissions	Reduce emissions by 16% minimum with B20	No
	Minimize Increase in NO_x Emissions	Emissions increase < 3%, for B20 (Without additive)	Yes
	Reduce NO_x Emissions	Reduce emissions by 2%, minimum for B20 (With additive)	No
	Minimize Increase in Fuel Consumption	Increase fuel consumption by 3% maximum with B20	Yes
Qualitative	Drivability	No change	Yes
	Maintain Reliability	No breakdowns caused by B20 biodiesel	Yes

Note: The performance objectives are based on a comparison with ULSD.

3.2 Selecting Test Sites/ Facilities

Biodiesel emissions testing was performed at laboratory test facilities and DoD activities. The laboratory test facilities were selected based on their capabilities, proximity to NFESC, costs, and most importantly, their willingness to participate in this testing program. Field-testing sites consists of DoD facilities that operate diesel engines of interest. These sites were selected based on the availability of diesels of interest as well as their willingness to participate in the test program. The decision as to where to perform each of the emissions tests was based on many factors, including the owner's needs, the capability of the test personnel to perform field measurements, and costs.

For this emissions testing program, eight types of diesel powered vehicles and two portable engines were selected for testing. These engines were selected since they represent a good cross section of diesel engines commonly found at DoD bases as verified during previous NFESC surveys. Test engines were selected to provide the greatest possible array of equipment. They included on-highway, off-highway, military tactical, and portable power equipment. A primary consideration in the selection of the test units was the equipment operating profile and the number of units in the DoD inventory. Here emphasis was placed on equipment that normally operates at medium to high load levels, with long operating times. Information on the selected engines and the tests to be performed is provided in Table 3.2. Pictures of some of the different test engines and vehicles are provided in Appendix A.

Table 3.2
Biodiesel Emissions Test Matrix

Item No.	Test Location	Application Description	Owner/ Operator	Engine Make/Model	Model Year	Fuel Type/ Fuel Additive	Test Cycle/Load	Regulated Emissions	HC & PM Charact-erization
1	NREL UCR Mobile Lab	Thomas Bus License No. G32 001589	Cheyenne Mountain Air Station	Cummins 5.9L	2002	ULSD B20 (soy)	Cheyenne Mountain Custom Cycle	All	None
2	UCR	HMMWV (Humvee)	Camp Pendleton	GM 6.5L Model A2	2004	ULSD JP-8 B20 (YGA) B50 (YGA) B70 (YGA) B100 (YGA) B20 (soy) B100 (YGA) + Additive 1 B100 (YGA) + Additive 2	FTP, US06,	All	ULSD B20 (YGA) B100 (YGA) FTP Modes Only
	ATC		Aberdeen Proving Grounds	GM 6.2L Model A1 M998	1987	ULSD B20 (YGA)	In-use	CO, NO_x	None

Table 3.2 (Continued)
Biodiesel Emissions Test Matrix

Item No.	Test Location	Application Description	Owner/ Operator	Engine Make/Model	Model Year	Fuel Type/ Fuel Additive	Test Cycle/Load	Regulated Emissions	HC & PM Charact-erization
3	ATC	Harlan Aircraft Tug	Aberdeen Proving Grounds	Cummins C6 3.9L Engine family XCEXL0239 AAA	1999	ULSD B20 (YGA)	In-use	CO, HC, NO_x	None
4	UCR	Stake Truck, Ford F700 Series License No. G71 00341	Naval Base Ventura County	Cummins 5.9L – 175HP	1993	ULSD B20 (YGB) B20 (soy)	8-mode	All	None
5	UCR	Tractor, Ford L-9000 License No. MC 288060	Camp Pendleton	Caterpillar 3406C	1992	ULSD B20 (YGA) B20 (YGB) B100 (YGA) 49 State EPA No. 2 Diesel	8-mode	All	ULSD B20 (YGA) B100 (YGA)

Table 3.2 (Continued)
Biodiesel Emissions Test Matrix

Item No.	Test Location	Application Description	Owner/ Operator	Engine Make/Model	Model Year	Fuel Type/ Fuel Additive	Test Cycle/Load	Regulated Emissions	HC & PM Charact-erization
6	ATC	Hyster 65 Forklift Model H65XM VIN No. H177B25780 4	ATC	Perkins 2.6L - 55HP Engine family 1PKXL02.6U B1	2001	ULSD B20 (soy)	In-use	HC, CO, NO_x	None
7	UCR	Ford F-350 Pickup License No. MC 291724	Camp Pendleton	Navistar 7.3 L	1999	ULSD B20 (YGA)	FTP US06	All	None
8	UCR	Thomas Bus License No. G32 00583	Camp Pendleton	CAT 3126, 330 HP	2000 Engine 1999	ULSD B20 (YGA) B20 (soy)	8-Mode	All	All
9	UCR	Portable 250 KW Generator	Camp Pendleton	Kamatzu SA60125E-2	2000	ULSD JP-8 B20 (YGA) B100 (YGA)	5-Mode	All	ULSD B20 (YGA) B100 (YGA)

Table 3.2 (Continued)
Biodiesel Emissions Test Matrix

Item No.	Test Location	Application Description	Owner/ Operator	Engine Make/Model	Model Year	Fuel Type/ Fuel Additive	Test Cycle/Load	Regulated Emissions	HC & PM Charact-erization
10	UCR	60 KW Tactical Generator	Camp Pendleton	Lippy MEP-806A	1995	ULSD JP-8 B20 (YGA)	5-Mode	All	None

Notes:

1. The acronyms for the test locations are the National Renewable Energy Laboratory (NREL) located in Denver, CO., the University of California Riverside (UCR) located in Riverside, CA, and Aberdeen Test Center (ATC) located at Aberdeen Proving Ground (APG), MD.

2. For engine no. 2, two fuel additives are listed. The purpose of both of the additives is to reduce NOx by increasing the cetane number of the fuel. Additive no.1 is ethyl hexyl nitrate (EHN, 1/2 percent by volume) and additive no. 2 is ditertiary butyl peroxide (DTBP, 1 percent by volume).

3. Two types of yellow grease were tested, YGA and YGB. These fuels were supplied from independent sources.

4. None of engines to be tested will have Catalyzed Soot Filters installed. Some of the engines may be equipped with a Diesel Oxidation Catalyst.

3.3 Test Site/Facilities History/Characteristics

The equipment selected for testing is located at the DoD facilities described below:

U.S. Army Aberdeen Test Center (ATC), Aberdeen Proving Grounds, MD, is a temperate-climate proving ground encompassing 57,000 acres of land and water. It is DoD's lead test center for land vehicles, guns and munitions, and live-fire vulnerability and lethality testing. After more than 80 years, ATC has developed into a world-class, all-purpose test center operating as an outdoor laboratory. The comprehensive array of capabilities, unique facilities, simulators and models at ATC, combined with an experienced scientific and technical workforce, enable testing and experimentation on items ranging from components to entire systems. To support its testing mission, many of the diesel vehicles used by the DoD are found on Aberdeen Proving Grounds.

Cheyenne Mountain Air Station, Colorado Springs, CO, is buried 2,000 feet under Cheyenne Mountain. The facility is situated in underground tunnels that were bored out of the mountain. The air station is a top-secret combat operations center formerly known as the North American Air Defense Command, or NORAD. The station contains equipment that provides warning of missile or air attacks against North America and can serve as the focal point for air defense operations in the event of an attack. The station's mission is to provide Canadian and U.S. National Command authorities with accurate air, space, missile and nuclear detonation information. The major units of the station are the North American Aerospace Defense Command, U.S. Space Command, and Air Force Space Command. To access the main operational areas, diesel powered vehicles are used in the underground tunnels. Exhaust from these vehicles is the major source of contamination for the facility's air handling system. The Thomas buses selected for the demonstration are used to transport workers down the main access tunnel.

Marine Corps Base, Camp Pendleton, CA, is the site of the Corps largest amphibious assault training facility, encompassing 17 miles of Southern California coastline and 125,000 acres. The base has a population of nearly 40,000 Marines and Sailors. As such, nearly all types of equipment in the Marine Corps inventory are located at this facility. As a functioning training command, the equipment is used almost daily for training and transportation purposes. The buses and trucks selected for testing are used to transport Marines and equipment to the widely separated training ranges within Camp Pendleton, and to other Marine Corps activities. These selected buses and trucks are also commonly found at numerous other DoD facilities.

Naval Base Ventura Country, Port Hueneme Site, Port Hueneme, CA, is the home of the Construction Battalion Center (CBC), the command organization for the Navy's "Seabees". The site covers approximately 1,600 acres on the Southern California coastline and includes a deep-water port facility. To support the Seabees in their field construction mission, the CBC has a wide variety of diesel powered vehicles and equipment much of which is extensively used during training exercises. The testing of this equipment/vehicles will be a good representation of the types of diesel engines encountered at other Navy shore activities.

Laboratory testing facilities to be used for this program are described below:

University of California, Riverside (UCR), CA, Bourns College of Engineering – Center for Environmental Research and Technology (CE-CERT) is an off-campus air emissions testing and air pollution research facility of the University of California, a state supported institute of higher education. CE-CERT was founded over 12 years ago to support California's effort to understand and reduce air pollution. As part of its capabilities, CE-CERT has two emissions testing facilities that will be used during this project. One is a light-duty chassis dynamometer emissions testing facility and the other is a mobile test laboratory contained in a trailer. Both testing facilities are capable of measuring all of the criteria pollutants on various engine-operating cycles in accordance with EPA approved test methods. In addition to providing emissions rate data, these facilities can also provide HC and PM speciation measurements as well as PM size distribution measurements.

The UCR mobile laboratory was designed to be pulled by a heavy-duty tractor. This allows real on-road emissions measurements to be obtained. The mobile laboratory's design also allows it to be used to measure emissions rates from stationary diesel sources such as back-up generators.

National Renewable Energy Laboratory ReFUEL Laboratory, Denver, CO, made its debut in 2002 to provide facilities for identifying, testing, and evaluating renewable and synthetic fuels and lubricants for use in ground transportation, with a focus on enabling high efficiency operation while displacing petroleum products. The 4,500 square foot facility was previously operated by the Colorado School of Mines as the Colorado Institute for Fuels and High Altitude Engine Research. It was designated as the National High Altitude Heavy-Duty Research and Technology Center under the Clean Air Act Amendments of 1990. The facility includes a heavy-duty chassis dynamometer with tandem 40-inch rolls capable of testing single or tandem drive axle vehicles up to 80,000 lbs, and a 24-foot wheelbase. It is the only high altitude facility of its type in North America. The facility provides air pollution measurement equipment to measure all criteria pollutants using EPA approved test methods and driving cycles. In addition, it has an engine test cell for directly testing engines.

3.4 Present Operations

All 11 pieces of equipment proposed for emissions testing utilize diesel engines manufactured by various manufacturers between the years 1987 and 2004. The engines are all used at DoD facilities. Many of the engines produce visible soot during operation, making them prime candidates for application of a clean fuel program.

3.5 Pre-Demonstration Testing and Analysis

Prior to initiating the actual emissions testing program, samples of all program fuels were analytically tested for specified chemical and physical properties. Fuel analysis results are provided in Table 3.3 for biodiesel fuels and 3.4 for petroleum fuels. These tests have been selected based on the ASTM specifications for the fuels and as recommended by the EPA in Reference 7.1.

Table 3.3
B100 Biodiesel Chemical/Physical Tests

Property*	ASTM Test Method	Limits	Units	Yellow Grease A	Yellow Grease B	Soy-Biodiesel
Acid Number	D 664	0.80 max.	mg KOH/g	0.2	0.36	0.45
API Gravity	D287			29.1	29.3	28.7
Specific Gravity				0.881	0.880	0.883
Btu Content – Net Heating Value	D240		Btu/gal	126,344	122,355	121,618
Carbon Residue	D 4530	0.050 max.	% Mass	0.01%	0.013	<0.01
Cetane Number	D 613	47 min.		52.7	54.1	54.3
Cloud Point	D 2500	Report	^{o}C	4	4	-2
Copper Strip Corrosion	D 130	No. 3* max.		1a	1a	1a
Distillation at 90%	D 86	360 max.	^{o}C	352	352	352
Flash Point	D 93	130.0 min.	^{o}C	>160	200	141
Free Glycerin	D 6584	0.020	% Mass	0.000	0.012	0.004
Kinematic Viscosity, 40^{o}C	D 445	1.9 – 6.0	mm^2/s	3.807	4.464	4.086
Phosphorous Content	D 4951	0.001 max.	% Mass	0.0003	0.0000	0.0000
Sulfated Ash	D 874	0.020 max.	% Mass	0.001	0.008	0.000
Sulfur	D 5453	0.05 max.	% Mass	0.0011	0.00324	0.00005
Total Glycerin	D 6584	0.24	% Mass	0.098	0.158	0.01
Water and Sediment	D 2709	0.050 max.	% Volume	0	0	0

Note: ASTM D6751, the specification for biodiesel fuels, requires the fuel to meet the properties identified in ***Bold and Italic.*** * Comparison to a color chart for corrosion.

Table 3.4
Petroleum Diesel Chemical/Physical Tests

Property	ASTM Test Method	Limits	Units	CARB Certified ULSD	JP-8
API Gravity	D287			38.5	39.3
Specific Gravity				0.832	0.828
Aromatics	D1319		% Vol.	19.3	16.0
Btu Content – Net Heating Value	D240		Btu/gal	128,413	127,530
Rams Carbon Residue on 10% btms.	D 524	0.350 max.	% Mass	0.1	0.05
Cetane Number	D613	40 min.		54.4	36.3
Cetane Index	D976			51.92	36.4
Cloud Point	D 2500	Report	^oC	-5	<-21
Copper Strip Corrosion	D 130	No. 3* max.		1a	1a
Distillation at 90%	D 86	338 max.	^oC	328	242
Flash Point	D 93	130.0 min.	^oC	159.8	130
Kinematic Viscosity, 40^{o}C	D 445	1.9 – 6.0	mm^2/s	2.602	1.484
Ash	D 482	0.010 max.	% Mass	<0.001	<0.001
Sulfur	D 5453	0.05 max.	% Mass	0.0002	0.0461
Water and Sediment	D 2709	0.050 max.	% Volume	0	0

Note: ASTM D975, the specification for petroleum diesel fuels, requires the fuel to meet the properties identified in ***Bold and Italic.*** * Comparison to a color chart for corrosion.

3.6 Testing and Evaluation Plan

3.6.1 Demonstration Set-Up and Start-Up

The emissions testing program took place both at laboratory sites and in the field. In Table 3.2, the test location for each engine test is identified. When the testing was performed at a laboratory, the test engine was transported to the laboratory. As required, fuels were transported to the test site. Fuels and fuel additives for the testing were stored and mixed at UCR. To reduce the variability of the test results due to changes in fuel composition, all fuels required for the project were purchased and blended at the beginning of the project and stored at UCR. To ensure that the quality of the biodiesel remains the same throughout the project, 200 ppmw of Tenox 21 (active ingredient is t-butyl hydroquinone) was added to the YGA manufactured by NFESC in Port Hueneme, California as recommended by NREL.

Since similar DoD vehicles may be operated under different conditions (i.e., different loads/routes) compared to the rest of a fleet, the testing program was developed to incorporate multiple test cycles/load points for each engine tested. Generally, multiple test cycles or load points were tested using the same dynamometer, test track or load bank.

3.6.2 Period of Operation

Testing was conducted over a period of approximately one year. The testing of each individual engine took between one day and five weeks depending on the test location and the number and complexity of the testing to be performed. Standard test cycles vary from approximately 1 hour to 3 hours; however, significant additional time was required for transportation of test engines or test equipment, equipment set-up, calibration, fueling, and preliminary analysis of test results.

3.6.3 Amount/Treatment Rate of Material to be Treated

The use of biodiesel has been reported to provide significant benefits in reducing criteria pollutants from the exhaust of diesel engines. Estimates of the expected reductions were previously provided in Table 2.1. The total quantity of pollutants produced by diesel exhaust is a function of their concentration and the volume of exhaust. Both the concentration of pollutants and the exhaust flow rate continuously change based on the engine's load, speed, and environmental factors. The exhaust stream also is directly proportional to engine horsepower. As an example, a 1994 model year Caterpillar CAT3516® engine rated at 2571 horse power has a full load exhaust flow rate of 14,417 cfm at a temperature of 940 degrees Fahrenheit. Such an engine, located at Naval Public Works Center, Norfolk, and currently fueled with low-sulfur diesel, produces NO_x emissions of 414.16 lbs/kgal of fuel, CO emissions of 117.7 lbs/kgal, HC emissions of 30 lbs/kgal, and PM emissions of 33.5 lbs/kgal. Using the average reductions given in Table 2.1, along with the criteria emissions identified above, one can gain an idea of the emissions reduction potential from implementing a B20 biodiesel fueling program.

3.6.4 Residual Handling

The technology to be demonstrated by this project does not generate any residual wastes that require disposal.

3.6.5 Operating Parameters for the Technology

The factor that makes biodiesel such a valuable clean fuel for the engine owner/operator is the fact that, generally speaking, biodiesel can be used in existing diesel engines without making any engine modifications. Because biodiesel is totally compatible with petroleum diesel in any percentage, it can be used as a direct replacement for petroleum diesel. Engine pressure and temperature operating conditions are generally very close between biodiesel and petroleum diesel. One concern with neat biodiesel (B100) is its cold-flow properties. These properties can however, be modified by additives, including the amount of petroleum diesel blended into the biodiesel.

3.6.6 Experimental Design

To verify the suitability of biodiesel in reducing air emissions from in-service DoD diesel engines, a comprehensive test program was developed. As shown in Table 3.2, the proposed test program included a wide variety of test engines, fuels, operating conditions and NO_x

improvement additives. The project includes emissions testing for criteria pollutants as well as HAPs. Test methods approved by the EPA were used for applicable tests. A listing of the actual analytical testing methods is provided in Paragraph 3.7. To ensure data quality, testing using test cycles and static points were repeated, data points were recorded continuously during the tests and reported as the integrated result over the whole test period, and three testing organizations were employed. Testing results from each engine were compared with the previously completed testing and with similar work performed by other test programs.

As previously discussed, the diesel engines proposed for testing were selected based on a survey performed by NFESC for a completed ESTCP project. In this survey, DoD engines with high usage, as indicated by the number of similar engines/vehicles and by estimated hours of operation, were identified. For this project, emissions testing was performed on these high usage engines either in the field or at a laboratory. At a minimum, all engines were tested using a JP-8 or ULSD base diesel fuel and a B20 biodiesel fuel. Additional tests were performed using B20, B50, B70, and B100 biodiesel fuels manufactured from either soybean oil or yellow grease. In addition, one engine was selected for demonstrating the effectiveness of the EHN and DTBP cetane improvers in reducing NO_x emissions. These additives were chosen based on an investigation reported on in Reference 7.2.

Gaseous criteria pollutants including CO, HC, and NO_x were measured during all tests. The total weight of $PM_{2.5}$ emissions were measured for all engines tested by NREL and UCR. On a subset of engines, full chemical and physical characterization of the HAP and PM emissions were performed. Test results were reported in the form of emission factors and reported as grams per mile (g/mile), grams per gallon of fuel consumed or grams per brake horsepower hour (g/bhp-hr). The emissions tests were performed using a combination of various standardized stationary and transient driving test cycles, static and actual on-road testing. Emissions testing results reported in the scientific literature show that air emissions vary with a number of parameters, with the most important variables being the engine operating conditions. The testing conditions were chosen to come as close as possible to the expected certification or to representative in-use conditions as selected by other investigators for similar applications.

Since the purpose of our test program is to provide emissions factors for existing DoD engines installed in various types of DoD operated vehicles or equipment, all testing was performed with the engine installed in the applicable vehicle or equipment. Engine testing in an engine test cell was not part of the test program. Vehicle emission testing was performed either on-road or with the vehicle placed on a chassis dynamometer. Portable generators testing was performed using an electrical resistance load bank. The load bank was adjusted so that testing could be performed at various percentages of full engine load as specified in the EPA test method.

3.6.7 Demobilization

Following completion of the emissions testing, each of the test vehicles/stationary engines was returned to its owners. During the testing process, no engine modifications were made.

3.7 Selection of Analytical/Testing Methods

3.7.1 Selection of Analytical Methods

Emissions testing for this project was performed by three testing organizations, ATC, NREL and UCR. The type of data that was collected was previously identified in Table 3.2. The analytical testing instrumentation that was used is listed in Table 3.5. Although each testing organization employs similar analytical testing instrumentation, and utilizes similar analytical testing procedures specified in federal or recognized standard publications, they each have unique testing capabilities in terms of the types of tests that they can perform. These unique capabilities have been fully exploited by this project.

For the testing of regulated pollutants, emissions testing analytical test methods approved by the EPA, and found in the Code of Federal Regulations (CFR), were used. Specifically, testing was performed using the methods contained in 40CFR86 for control of emissions from new and in-use highway vehicles and engines. The detailed emissions test procedures for diesel engines are found in 40CFR86, Subpart N – "*Emission Regulations for New Otto-Cycle and Diesel Heavy-Duty Engines; Gaseous and Particulate Exhaust Test Procedures*" and more specifically in paragraph 86.1310-2007 "*Exhaust gas sampling and analytical system for gaseous emissions from heavy-duty diesel-fueled engines and particulate emissions from all engines*."

For the non-regulated emissions, the analysis methods are not found in the CFR. Instead these analyses were performed using industrial specifications and methods that are referenced in the scientific literature. The speciated C_1-C_{12} volatile organic compounds (VOCs) were determined using methods developed in collaborative research between the automobile and petroleum industries under the Auto/Oil Air Quality Improvement Research Program (AO/AQIRP), as detailed in Reference 7.3. For the C_1-C_{12} VOCs, sample collection was performed using Carbowwax/molecular sieve packed tubes and/or Tedlar bags followed by gas chromatography – FID analysis using a modified Auto/oil protocol. The tube sample collection procedure is discussed in greater detail in Reference 7.4. Aldehydes and ketone emission rates were collected using Dinitrophenylhydrazine (DNPH) cartridges and analyzed using a high-performance liquid chromatograph with ultraviolet detection, as per an AO/AQIRP method (Reference 7.3). Elemental Carbon/Organic Carbon samples were collected on quartz filters and analyzed using a Thermooptical carbon aerosol analyzer from Sunset Laboratories, a National Institute of Occupational Safety and Health (NIOSH) recognized method (References 7.5 and 7.6). Semi-volatile hydrocarbons were collected for analysis using a PUF/XAD cartridge immediately downstream of the quartz fiber media.

To detect gaseous air emissions in the laboratory, a non-dispersive infrared (NDIR) analyzer was used to measure CO and Carbon Dioxide (CO_2), a heated probe and flame ionization detector was used to measure HC's, and a chemiluminescence analyzer was used to measure NO_x. Portable versions of these instruments were available and were employed for field measurements. The mobile instrumentation used for this project used an NDIR for CO, CO_2, and HC and a solid-state zirconia sensor for NO_x.

Characterization of gaseous HAP compounds, including the Mobile Source Air Toxics identified in Table 3.6, were performed using Gas Chromatography (GC) where the samples were collected on DNPH cartridges. Acetaldehyde, Formaldehyde, Benzene, and 1,3-Butadiene are the 4 main gas-phase HAPs specified in the Clean Air Act for mobile sources. Acrolien is another gas-phase chemical targeted by EPA for its toxicity and ambient levels. Naphthalene is the Polycyclic Aromatic Hydrocarbon (PAH) with the highest concentration in vehicle exhaust.

Table 3.5
Test Methods and Analysis of Exhaust Emissions

Instrument/Method	Measurement	Sample Duration	Lower Quantifiable Limit (Expressed in terms of fundamental measurement)
Pierburg NDIR	CO_2, CO	1 s	50 - 500 ppm
California Analytical Instruments/Flame Ionization Detection	HC, Methane	1 s	10 - 30 ppm
California Analytical Instruments/Chemiluminescence	NO, NO_2	1 s	10 ppm
Various/Filter*	$PM_{2.5}$ Mass and Chemistry-	0.25 - 2 hrs	Various
Tedlar Bag/GC-FID	VOC's (C_2 – C_{12})	0.25 - 2 hrs	10 ppb C
DNPH Cartridges/Shimadzu HPLC/UV	Aldehydes and Ketones	0.25 - 2 hrs	0.02 ug/mL

*Includes Teflon and quartz media for mass, metals, ions, elemental/organic carbon and PAHs by GC/MS on extracts from filters.

Table 3. 6
Partial List of EPA's Recognized Mobile Source Air Toxics

Acetaldehyde	Benzene	Formaldehyde
Acrolein	1,3-Butadiene	Naphthalene

The measurement of PM emissions is more difficult and consisted of mass measurements as well as chemical characterization of the particles. Mass measurements were made by collecting particulates on a filter media and weighing the media before and after exposure to the exhaust. For these measurements, it is critical that the CFR methods be applied with respect to the use of an upstream classifier to remove the large particles and that the filter face temperature be maintained at 47°C ±5°C. Chemical characterization of the PM involved chemically testing the particles collected on quartz filter media for elemental and organic carbon as these measurements can be compared with similar data from ambient monitors to determine source signatures.

The majority of the emissions testing program was performed by UCR utilizing their mobile heavy-duty testing laboratory (test trailer) (Reference 7.7). A schematic of the trailer is shown in Figure 3.1. This laboratory was designed for testing diesel powered generators and heavy-duty vehicles. The test trailer can be used for on-road tractor testing, testing of a generator connected to an electric load bank, or vehicle testing where the vehicle is placed on a separate chassis dynamometer. The UCR mobile laboratory dilutes the whole exhaust and utilizes the constant volume sampling concept of measuring the combined mass emissions of CO, CO_2, NO_x, Methane (CH_4), PM and Total Hydrocarbon (THC). Additionally, a proportional bag sampling for sample integration is used for HC, NO_x, CO, and CO_2 measurement. The mass of gaseous emissions is determined from the sample concentration and total flow over the test period. The mass of particulate emissions is determined from a proportional mass sample collected on a filter and the total flow over the test period.

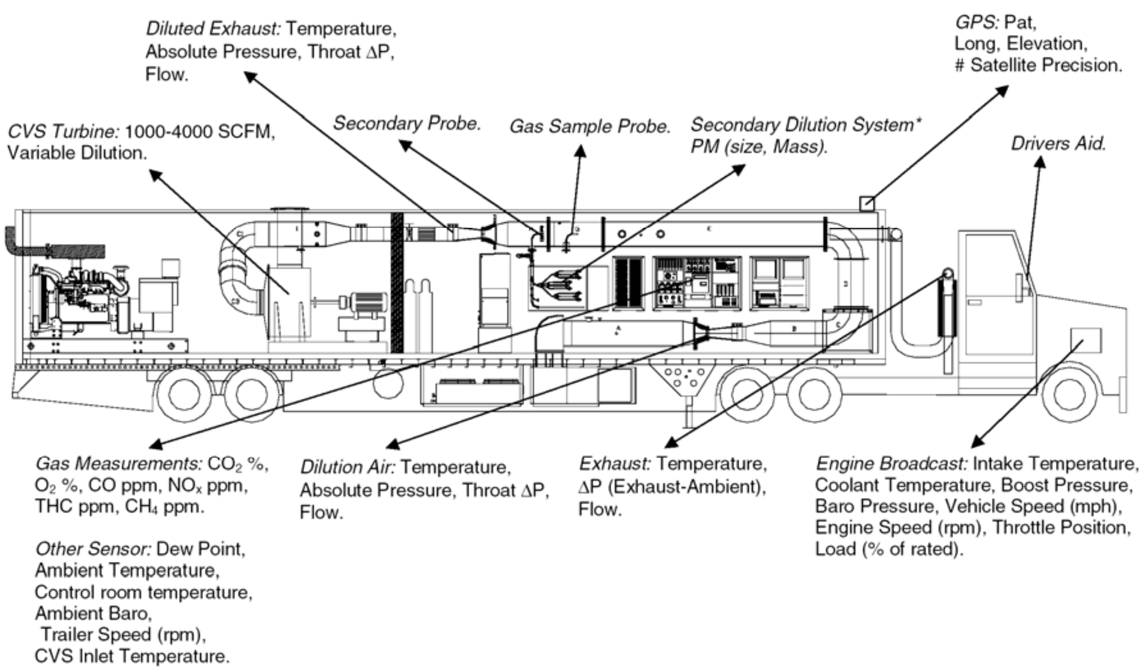


Figure 3.1

Schematic of the UCR Heavy-Duty Diesel Mobile Emissions Laboratory

For emissions measurements on light/medium duty vehicles, UCR has a Burke E. Porter 48-inch single-roll electric dynamometer. For emissions testing with this dynamometer, UCR utilizes standard bag measurements for CO, CO_2, NO_x, and THC. These measurements are conducted with a Pierburg AMA-4000 bench. THC is measured modally through a line heated to 190°C using a Pierburg AMA-2000 emission bench.

In-use testing was performed by ATC using the EPA's Real-time On-road Vehicle Emissions Reporter (ROVER). The ROVER system is presently used by ATC to perform tests for the EPA's program to monitor in-use heavy-duty diesel engines. The ROVER (including all of its components) is mounted on or in the vehicle. The data is recorded with the ROVER package computer on or in the vehicle. This data is monitored via antenna on another computer either onsite or in a chase vehicle. The main focus of the ROVER is measurement of NO_x emissions. It also records HC, CO, CO_2, exhaust temperature and pressures, torque, road speed, and the engine data stream. The engine data stream is contained in newer engines' computers systems. The ROVER system is comprised of two analyzers (both measure NO_x), a flow pipe (size determined by maximum flow of exhaust), a flow box, a pro-link tool (monitors the engine data stream), and computers containing the ROVER program. The flow pipe and box are attached directly to the engine exhaust. Sample ports in the flow pipe pull a sample and feed it to the analyzers, which are placed somewhere on or in the vehicle. The pro-link tool is set up with the analyzers and records the engine data stream to the ROVER computer. ROVER utilizes this tool with newer engines to monitor their data stream. This capability is only useful in newer vehicles containing the data stream computer system. The ROVER system records real-time data every second during the test run.

The NREL laboratory features a heavy-duty chassis dynamometer that simulates operation of a vehicle on the road. The dynamometer is connected with two 40-inch diameter rolls that are capable of testing all highway ready single or twin-axle vehicles. The distance between the rolls can be varied between 42 and 56 inches. The dynamometer will accommodate vehicles with a wheelbase between 89 and 293 inches.

In the NREL lab, simulations of vehicle loads including, rolling resistance, air resistance, desired road grade, and acceleration of vehicle inertia are performed with the dynamometer and controller software. Vehicles of weights between 8,000 to 80,000 lbs. can be simulated via electrical inertial simulation. For each vehicle test, standard or customized driving test cycles are used that match the duty-cycle of the test vehicle, ranging in speeds from idle up to 60 miles per hour. The dynamometer is equipped to run automated warm-up and coast-down routines to verify that dynamometer parasitic loads are stabilized and that road load simulations are accurate.

The NREL chassis dynamometer is supported by continuous exhaust emissions equipment similar to that previously described for the UCR Heavy-Duty Diesel Mobile Emissions Laboratory. An environmental chamber and microbalance specially designed to measure PM mass at EPA 2007 regulated levels is utilized. The lab does not, however, have the capability to chemically characterize HC and PM emissions to the extent of the UCR lab.

3.7.2 Selection of Testing Methods

3.7.2.1 Light/Medium-Duty Dynamometer Testing

The Humvee and Ford F350 were tested over the Federal Test Procedure (FTP) and US06 cycles for light-duty vehicles [Reference 7.8] using the UCR light/medium duty dynamometer. These vehicles were preconditioned prior to the first test on any new fuel by driving on the dynamometer over two back-to-back iterations of the LA4 driving schedule followed by an overnight soak at a temperature of approximately 72ºF. Each vehicle was tested twice on each of the test fuels specified. A US06 cycle was run immediately after each FTP, with a preconditioning of 5 minutes at 50 mph to warm the engine up to operating temperature.

3.7.2.2 Heavy-Duty Dynamometer Testing

The F700 stakebed truck, F9000 truck, and a bus (Engine No. 8 of Table 3.2) were all tested over the AVL 8-Mode heavy-duty test [Reference 7.9]. This cycle is a steady-state test comprised of 8 modes under speeds and load ranging from idle to full load. The cycle was designed to closely correlate with the exhaust emission results over the US FTP heavy-duty engine transient cycle. The composite value is calculated by applying weighing factors to the results for the individual modes. The load points and weighting factors are provided in Figure 3.2. These vehicles were tested on a hydrostatic chassis dynamometer at a local Caterpillar dealer in Riverside, California. An engine map for the AVL 8-mode was conducted prior to initiating the testing on any of the fuel blends.

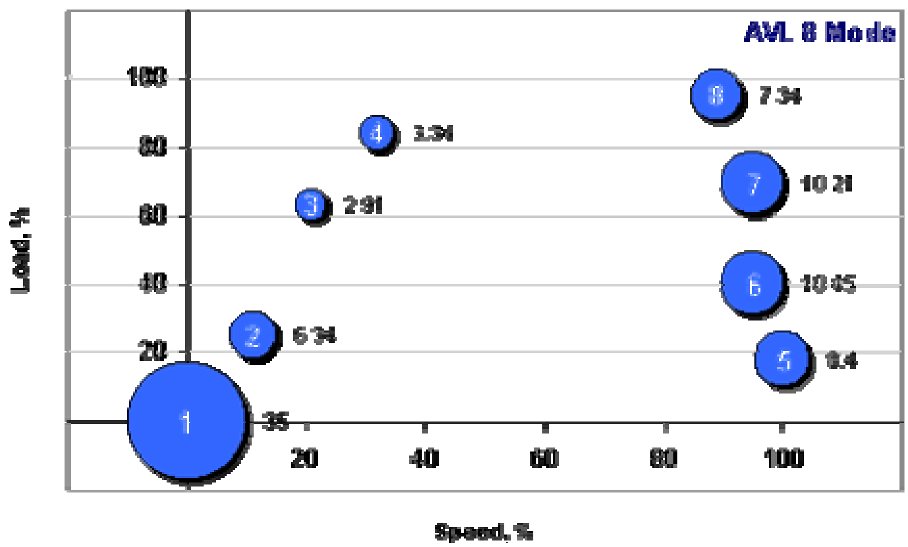


Figure 3.2
Load Points and Weighting for AVL 8-Mode Cycle

Transient chassis dynamometer testing was conducted at the NREL ReFUEL laboratory on a Cheyenne Mountain Air Force Base operated bus. The transient test was a special cycle designed to specifically simulate operation of the buses within Cheyenne Mountain. The Cheyenne Mt. Cycle is shown in Figure 3.3. This cycle was developed based on activity data monitored from actual buses operating with the Cheyenne Mt. Facility. It is composed of 6 primary events where the vehicle is accelerated to a speed of between 20 to 32 mph. A total of 2.5 miles are driven over a 1,200 second duration.

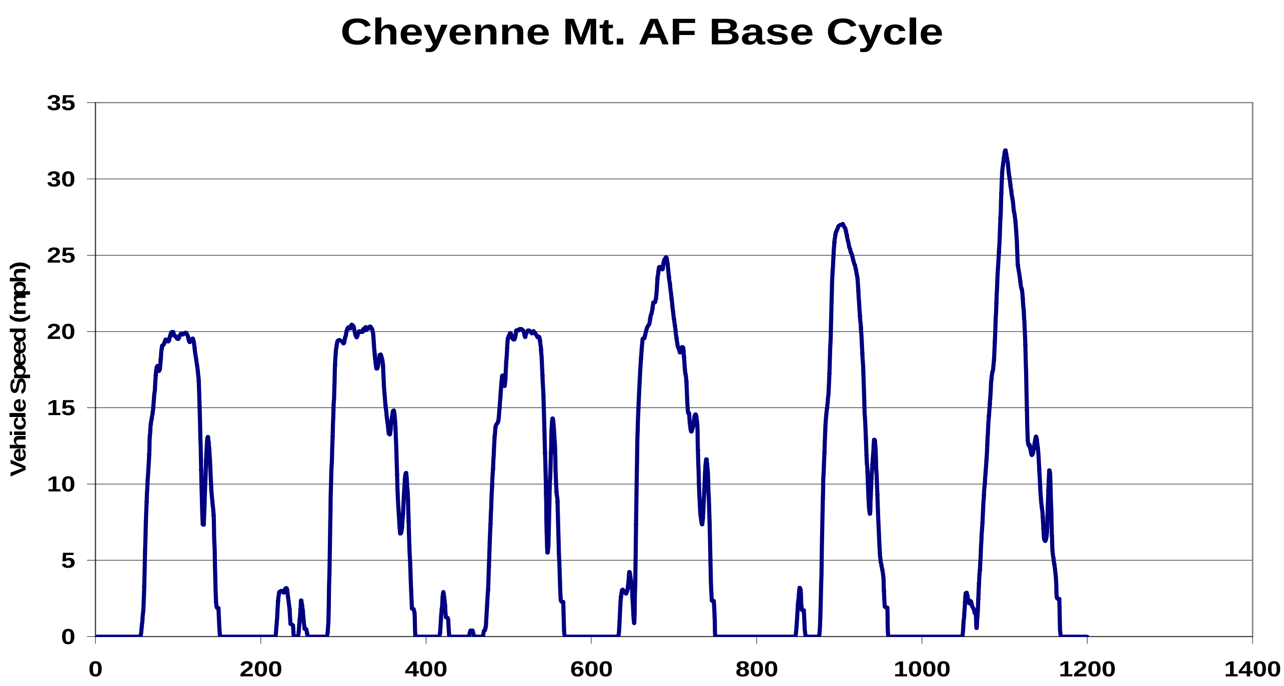


Figure 3.3.
Speed vs. Time Traces for the Cheyenne Mountain Cycle.

3.7.2.3 Portable Generator Testing

Testing for the portable generators was performed over a five-mode test cycle at steady-state conditions, as described in Table 3.7. This is a standard certification cycle for testing non-road diesel engines that is described in EPA's 40CFR Part 89 [Reference 7.10] and by the International Standards Organization (ISO) [Reference. 7.11]. While both EPA and ISO testing procedures are the same, the analysis of the results differ in that the EPA method, which was used in this study, only corrects the NO_x whereas the ISO applies a correction factor for moisture to both the PM and NO_x. The standard test protocol consists of a series of preconditioning cycles to warm and stabilize the engine followed by a sequence of stabilization and testing at five modes, each with a defined speed and load. The engine is run at rated speed for a minimum period while measuring the regulated emissions. The engine is preconditioned at idle and then full power for at least 30 minutes before measurements are made. Testing begins at the 100% mode and moves from there to the lower power modes with measurements collected for at least 10 minutes at each mode. For the duplicate run, the whole procedure is started over from the beginning. Emissions from the portable generators were measured using the UCR Heavy-Duty Laboratory.

Table 3.7
Five-Mode Test Cycle for Constant Speed Engines

Mode number	Engine Speed[1]	Observed Torque[2]	Minimum time in mode, min.	Weighting factors	Mode number
1	Rated	100	5.0	0.05	1
2	Rated	75	5.0	0.25	2
3	Rated	50	5.0	0.30	3
4	Rated	25	5.0	0.30	4
5	Rated	10	5.0	0.10	5

Notes: 1. Engine speed: ± 2 percent of point
2. Torque: Throttle fully open for 100% point. Other points: ±2% of engine maximum

3.7.2.4 In-Use Testing

In-use tests were conducted on three pieces of equipment at ATC. This included a forklift, airport tow vehicle, and a Humvee. For the forklift, the test runs simulated forklift usage include idling, hydraulic usage while idling, and driving with and without hydraulic usage over a 3.6 mile test run. In the past 2 years of EPA non-road testing, it was determined that loading the engine to simulate use of vehicles' hydraulics can be maximized by "dead heading" the hydraulics. In this case, that involves simply running the forklift's forks in a certain direction, i.e., pulling them back until they won't move anymore and holding that position. During this test, this was used to simulate the load of using the forklift's hydraulics.

The test run for the forklift with both fuels was as follows:

1. Idle time: approximately 5 minutes w/out load on engine
2. Dead head hydraulics at idle: 5 minutes of 30 seconds dead heading hydraulics while idling and 30 seconds idle w/out (normal low idle)
3. Dead head hydraulics at higher idle: 5 minutes of 30 seconds dead heading hydraulics while idling at higher RPM and 30 seconds idle w/out
4. Run included repeatable 3.6 miles with seven different periods of 15 second dead heading hydraulics at same locations on each run
5. Idle time: after run another 5 minutes of 30 seconds dead heading and 30 seconds of idle (normal low idle)

For the aircraft tow vehicle, test runs included driving the aircraft tow on the same route around the APG airfield, achieving maximum speed at the same point on each run. Each run was approximately 1.4 – 1.6 miles. The Humvee test runs were designed to simulate normal driving in fleet usage. The Humvee was operated leaving APG and driving west on Maryland RTE 40 to White Marsh, MD and back to APG. This route is stop and go due to traffic lights on Maryland RTE 40. Continuous usage with stop and go is the best representation of APG fleet usage.

3.8 Selection of Analytical/Testing Laboratory

As previously described, the emissions testing will be performed on-site and in laboratories operated by NREL and UCR. All required analytical testing of the fuels will be performed at UCR or at commercial testing laboratories under contract to UCR.

4. Performance Assessment

4.1 Performance Criteria

Table 4.1
ESTCP Performance Criteria

Performance Criteria	Description	Primary or Secondary
Criteria Air Pollutant Emissions	Reduce CO, HC & PM Air Pollutant Emissions, Minimizes NOx Emission Increases	Primary
HAP Emissions	Reduce HAP Pollutant Emissions	Primary
NOx Reduction Additive	Reduce NO_x emissions	Secondary
Fuel Economy	Maintain Fuel Economy Consistent with Energy Content of Fuel	Secondary
Drivability	Maintain Engine Performance	Secondary
Reliability	No Maintenance Increase	Secondary

4.2 Performance Confirmation Methods

Since the purpose of this demonstration is to obtain air emissions data for DoD diesel engines of interest that is not currently available in the literature, the overall success of this project will be measured in terms of the quality of data acquired and its acceptance by the scientific community. As an additional measure, this project must provide sufficient data to convince DoD diesel fleet operators and fuel suppliers to implement B20 biodiesel programs within their activities. In order for the project's test results to be accepted, standard recognized test methods must be employed and the results reported in units consistent with other investigations. In addition, the results will be compared with other previous investigations and with the emissions models provided by the EPA (see Reference 7.1).

For this project, standard EPA approved test methods have been used for both the laboratory and field measurements. To ensure the engines are consistently loaded, a chassis dynamometer or an electric load bank was used during the majority of the testing. All testing, except for those performed on-road, were performed with the engines operating on standard test cycles. All test cycles were repeated with the reported results being the average of the tests. Gaseous air emissions data was continuously measured over the test cycle, with the results reported as an integrated value. Particulate emissions were collected on a filter paper throughout a cycle and weighed after the testing is complete. The testing equipment, as previously described in paragraph 3.7 was used. All testing organizations participating in this project have extensive experience performing emissions testing. Their results from previous test efforts have been widely published in the literature.

Expected and actual engine performance from the demonstration and the applicable performance confirmation methods are shown in Table 4.2. Since emission testing provides quantitative results, this project will not have any primary qualitative performance objectives.

Table 4.2
Expected Performance and Performance Confirmation Methods

Performance Criteria	**Expected Performance (pre demo)**	**Performance Confirmation Method**	**Actual (post demo) (future)**
Primary Criteria (Performance Objects) (Quantitative)			
Reduce CO Emissions	Reduce emissions by 9% (min.) with B20	40 CFR 86	No change
Reduce HC Emissions	Reduce emissions by 16% (min.) with B20	40 CFR 86	No change
Reduce PM Emissions	Reduce emissions by 8% (min.) with B20	40 CFR 86	No change
Reduce HAP Emissions	Reduce emissions by 16% (min.) with B20	Various EPA methods	No change
Secondary Performance Criteria (Quantitative)			
Minimize increase in NO_x emissions	Emissions increase <3% for B20 (Without additive)	40 CFR 86	No change
Minimize increase in NO_x emissions	Reduce emissions by 2% (min.) for B20 (With additive)	40 CFR 86	No change
Fuel Economy	Similar to petroleum diesel	40 CFR 86	No change
Secondary Performance Criteria (Qualitative)			
Driveability	No change	Driver response	No change
Reliability	No change	Driver response	No change

4.3 Data Analysis, Interpretation and Evaluation

In this section, the emissions results for the multiple DoD operated mobile and portable diesel engines fueled with various types of biodiesel will be reported and discussed. The results are broken down for the purpose of this section into major groups corresponding to the type of diesel engine or its application. In order to present the CO, HC, NOx and PM results on the same graph, it was required to multiply the CO and HC results and divide the PM results. On each graph, the multiplication and division factors are identified. As an example, CO*5 indicates that the CO emissions factor should be multiplied by 5. Regulated and unregulated emissions are also discussed separately.

In addition to the collection of emissions data, Table 4.2 also identifies as Secondary Performance Criteria, the collection of fuel economy, drivability and reliability information. Based on energy content data reported in Reference 7.1, the project team did not expected that any fuel economy differences would be observable between the USLD, YGA and JP-8 fuels. This expectation proved to be correct. The fuel analysis reported in Tables 3.3 and 3.4 showed that the ULSD had a 1.6 percent higher energy content than the YGA fuel and the JP-8 fuel had a 0.9 percent higher energy content. These differences were less than the expected 3-5 percent difference.

For the drivability and reliability performance criteria, information was collected from fleet and vehicle maintenance management personnel at Camp Pendleton as well as from the emissions testing drivers. Based on interviews of these personnel, the project team concluded that vehicle drivers and maintenance mechanics experience no difference when operating or repairing B20 fueled vehicles. This result matched our expectation.

4.3.1 Regulated Emissions

4.3.1.1 Light/Medium-Duty Vehicles

The regulated emissions result for the 2004 Humvee and the 1999 Ford F-350 pick-up truck are presented in Figures 4.1 and 4.2 for the FTP and Figures 4.3 and 4.4 for the US06 cycle. These data represent the average of all tests conducted for each vehicle/fuel combination, with the error bars representing the standard deviation of the emissions tests.

PM emissions showed some trends with the different fuels for the Humvee over the FTP. The biodiesel blends generally showed reductions in PM. For the blends from B50 to B100, FTP PM reductions ranged from 23-42%. The B20 blends did not show as significant reductions, with the B20-YGA showing no reductions relative to the ULSD and the B20 Soy showing PM reductions of approximately 10%. PM emissions increased for the JP-8 fuel for the Humvee by approximately 10%. For the F350 over the FTP, no statistically significant differences in PM were found between the ULSD and the B20-YGA fuels.

For the more aggressive US06 cycle for the Humvee, PM emissions for nearly all fuels showed reductions relative for the ULSD. The ULSD and JP-8 PM results showed significant variability as shown by the large error bars, however, in a number of cases, the differences were within the experimental error. It is possible that more aggressive preconditioning than that used in this study might be needed to obtain more stable PM readings over the US06. The lowest overall PM emissions over the US06 were found for the higher biodiesel blends (i.e, 50-100%), consistent with the FTP results. For the F350, the B20 YGA PM results were approximately 10% lower than for ULSD.

Emissions of NO_x did not change significantly over the range of fuels tested on the Humvee and F-350. The general lack of trends in NO_x emissions was consistent between the FTP and US06 test cycles. For the biodiesel blends, NO_x emissions were comparable with those of the ULSD within experimental variability, showing no NO_x disadvantage. The additives also did not show a strong affect on NO_x emissions compared to the baseline neat biodiesel tests. On the Humvee, slight increases in NO_x were observed for the JP-8 over both the FTP and US06 cycles. For the F350, NO_x emissions for the ULSD and B20-YGA were all comparable within the experimental variability.

THC emissions showed different trends between the two vehicles. For the Humvee, the ULSD fuel provided the lowest THC emissions of all of the fuels tested, with most fuels having 75-130% higher THC emissions over the FTP. The JP-8 showed the largest increase in THC over the FTP, with increases relative to ULSD of ~250% for the FTP. Over the US06 for the Humvee, JP-8 showed an ~80% increase in THC relative to the ULSD. There was a tendency toward higher THC emissions for the higher blend levels of biodiesel also on the US06, but these results were not statistically significant.

CO emissions also showed different trends with fuels for the two vehicles. For the Humvee, CO emissions were the lowest for the ULSD over both the FTP and US06. For the Humvee FTP tests, most fuels showed approximately a 15-30% increase in comparison with the ULSD. The increase in CO emissions for most fuels were slightly greater over the US06 relatively to the ULSD, with increases of between 20-60%. The highest CO emissions for both the FTP and US06 cycles for the Humvee were with the JP-8 fuel (110-130% higher than the ULSD). For the F-350, CO emissions showed a slight decrease over the FTP and no difference over the US06 for the B20-YGA.

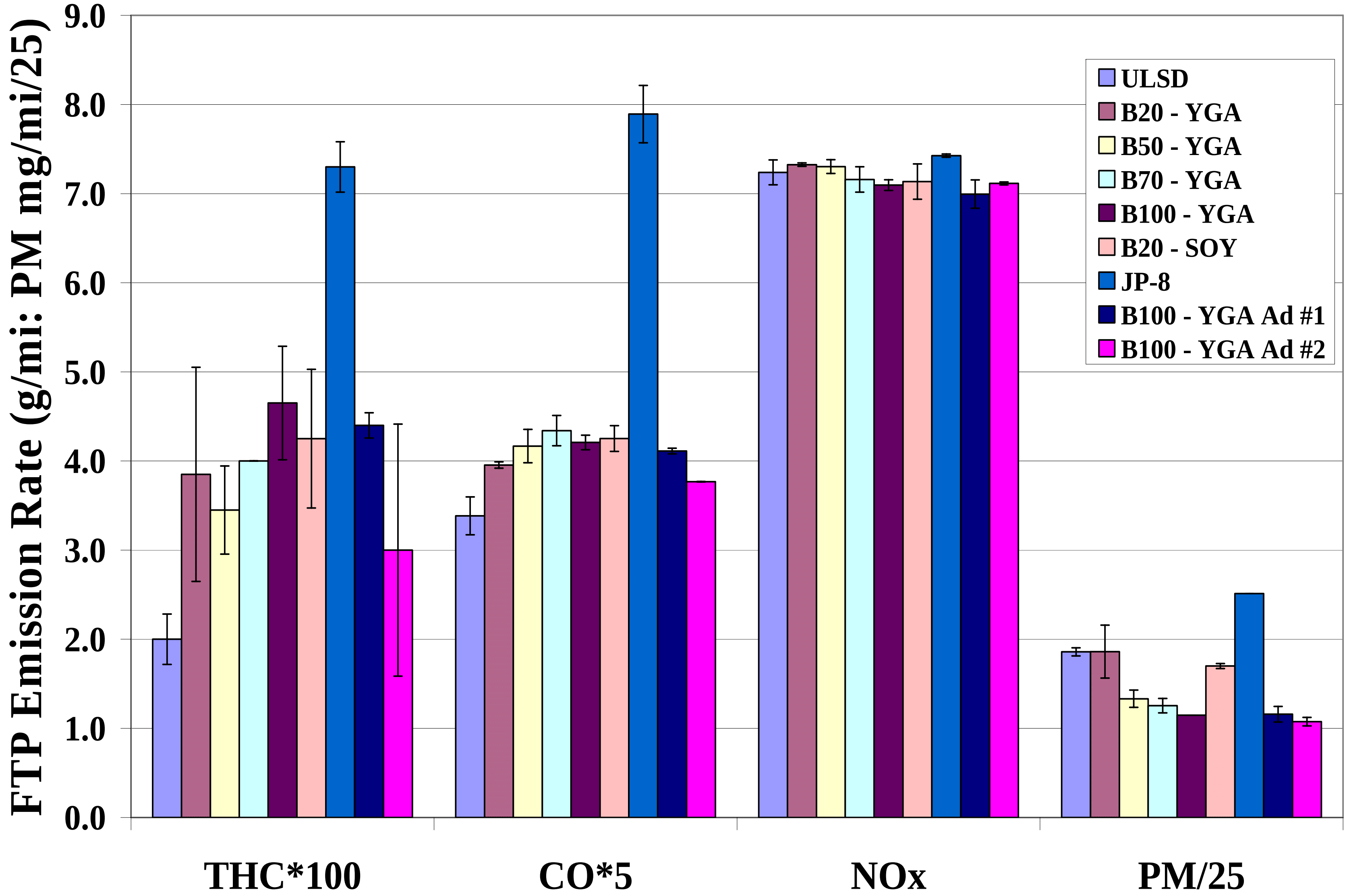


Figure 4.1.
UCR-FTP Emissions Results 2004 Humvee

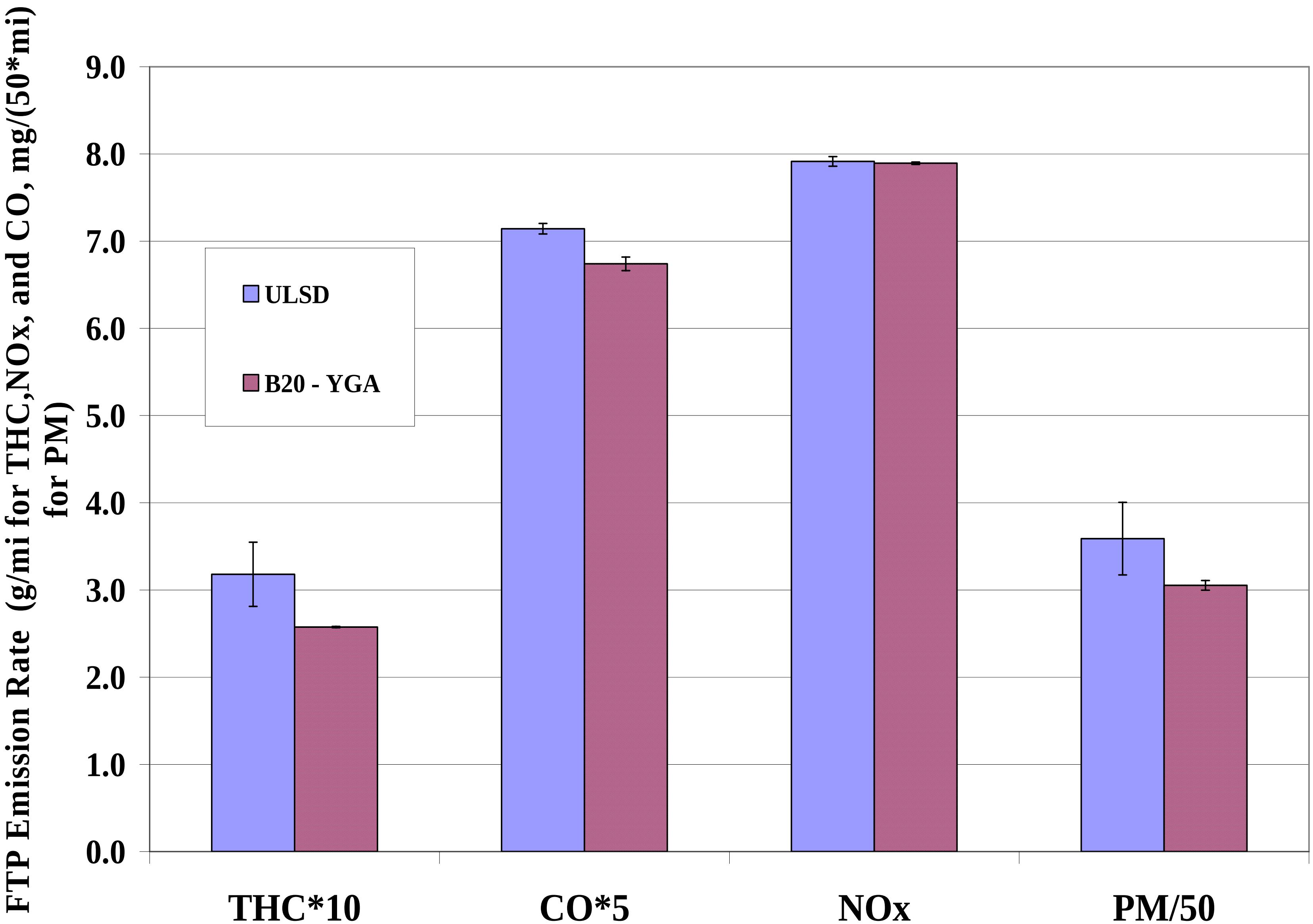


Figure 4.2.
UCR-FTP Emissions Results 1999 Ford F350 Pick-Up Truck

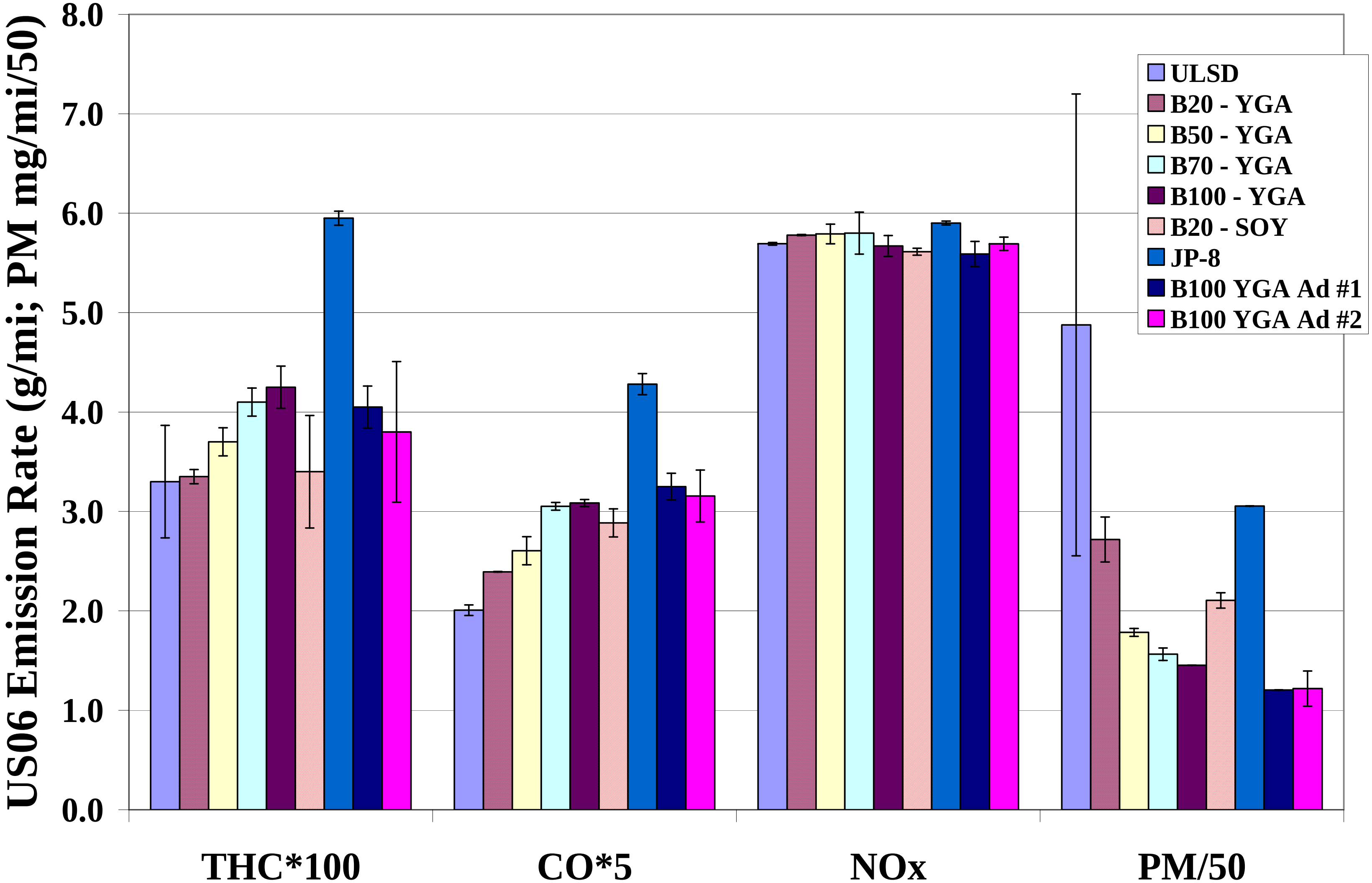


Figure 4.3.
UCR - US06 Emissions Results 2004 Humvee

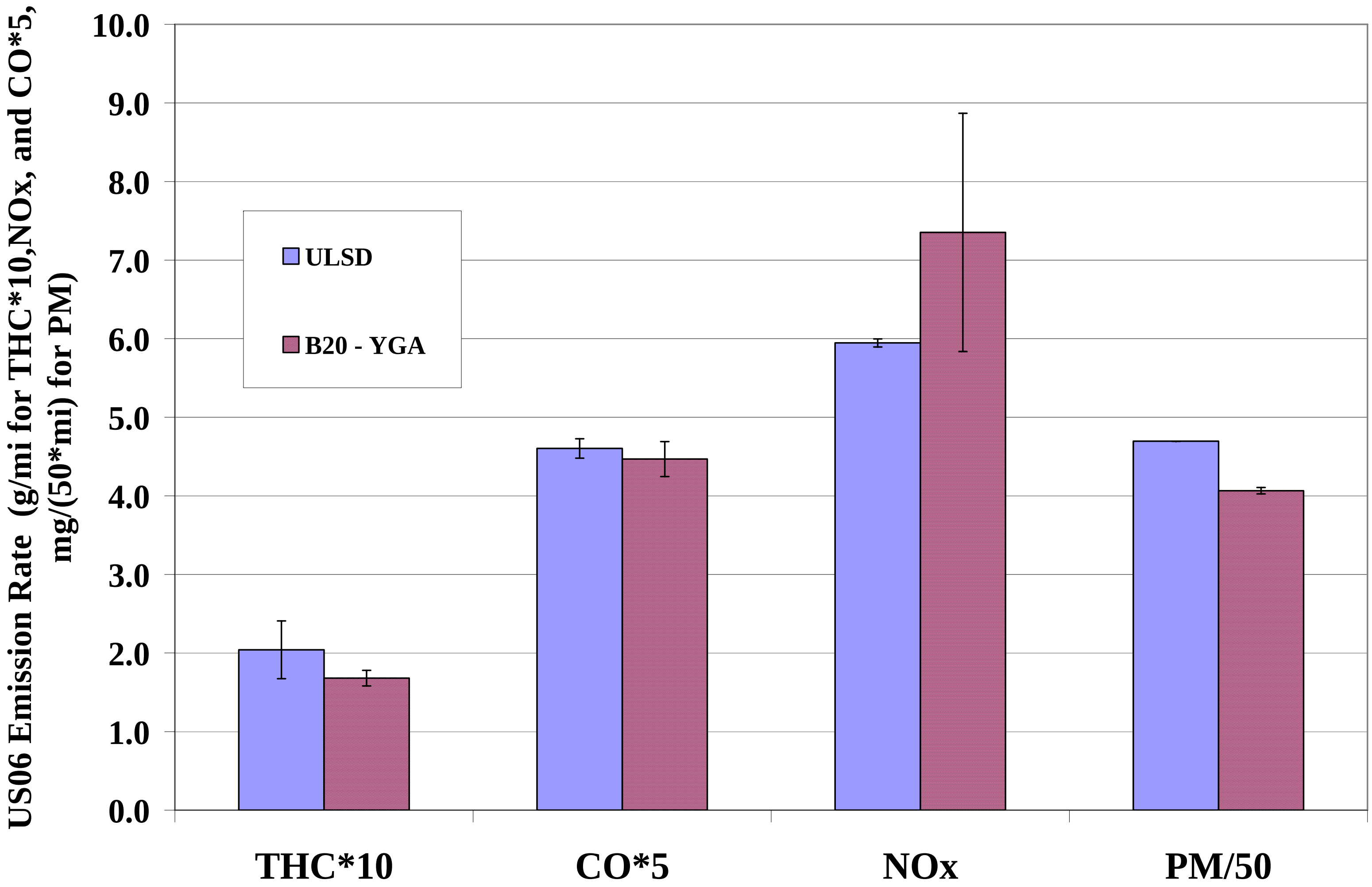


Figure 4.4.
UCR-US06 Emissions Results 1999 Ford F350 Pick-Up Truck

4.3.1.2 Heavy-Duty Vehicles

Fuels effects for the heavy-duty vehicles differed depending on the specific test vehicle. The results for the Ford F9000, Ford F700, and Pendleton Thomas bus over the AVL 8 mode cycle are shown in Figures 4.5-4.7. The results for the Cheyenne Mountain Thomas bus over the Cheyenne Mountain Cycle are shown in Figures 4.8 and 4.9, respectively, for measurements by UCR and NREL.

4.3.1.2.1 AVL 8-Mode Results

For the Ford F9000, reductions in PM relative to the ULSD were found for the B20-YGA, and B20-YGB fuels of between 20-40%. Reductions of 5-15% were also found for CO for B20-YGA and B20-YGB. The F9000 showed a trend of 30-40% lower THC and CO emissions with the B100 fuel, about a 70% reduction in PM, and a 41% increase NO_x emissions over the AVL 8-mode cycle. The Ford F700 AVL-8 mode results did not show any significant differences between the ULSD and the B20-YGA and B20-YGB fuels. The Pendleton bus over the AVL 8-mode did not show fuel differences that were statistically significant.

In summarizing the AVL 8-mode results, in a number of cases, the differences in the fuels were small for most of the emissions components. The biodiesel blends showed some reductions in PM for the F9000, but not for the other vehicles. Some slight reductions in CO were also found for the F9000. Although the B100 was tested on only one vehicle, PM, THC, and CO emissions decreased while NO_x increased, consistent with general trends for biodiesel.

4.3.1.2.2 Cheyenne Mountain Results

The trends in the Cheyenne Mountain Test results showed some differences between the measurements made by UCR and NREL. The UCR and NREL measurements were performed on the same dynamometer, with the same cycle and driver, but they were sampled at different times during the day. The results for UCR showed reductions in PM and CO for the B20-Soy compared with the ULSD. The results for the NREL measurements, on the other hand, showed no differences between the PM and CO emissions on B20-Soy and ULSD. The differences in the PM results could be due to differences in the temperatures at which the PM is measured. The UCR – Mobile Emissions Laboratory (MEL) measures PM at 47°C ±5°C, whereas the NREL PM measurements are made at room temperature. At the higher measurement temperature, the UCR PM samples would be expected to have less volatile compounds. The NREL measurements showed reductions in THC with the B20-Soy. THC emissions for the B20-soy were also lower than the ULSD for the UCR – MEL, however, this result was not statistically significant. Both UCR and NREL showed no statistically significant differences in NO_x emissions between the B20-soy and ULSD.

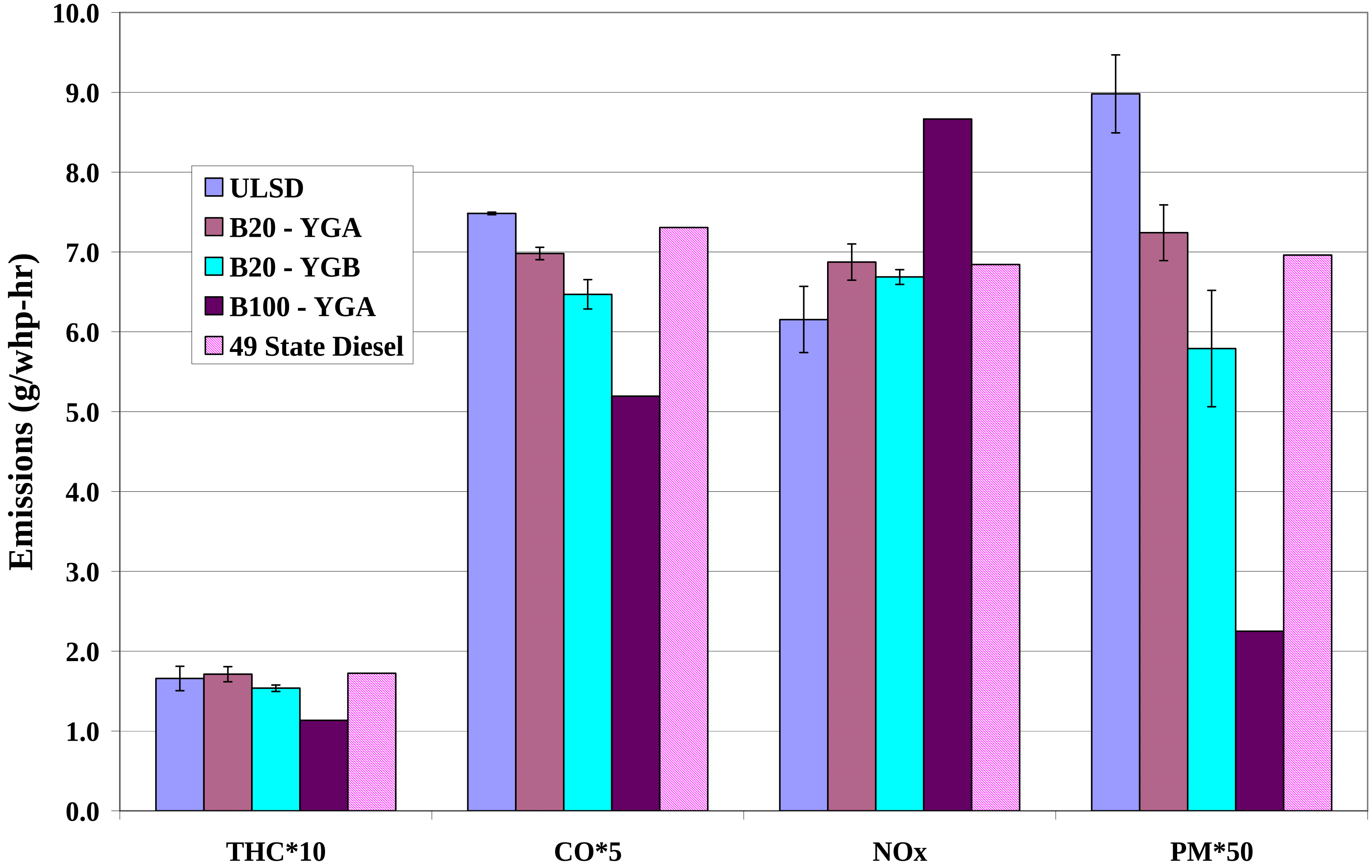


Figure 4.5.
UCR-Chassis AVL 8 Mode Results Ford F9000

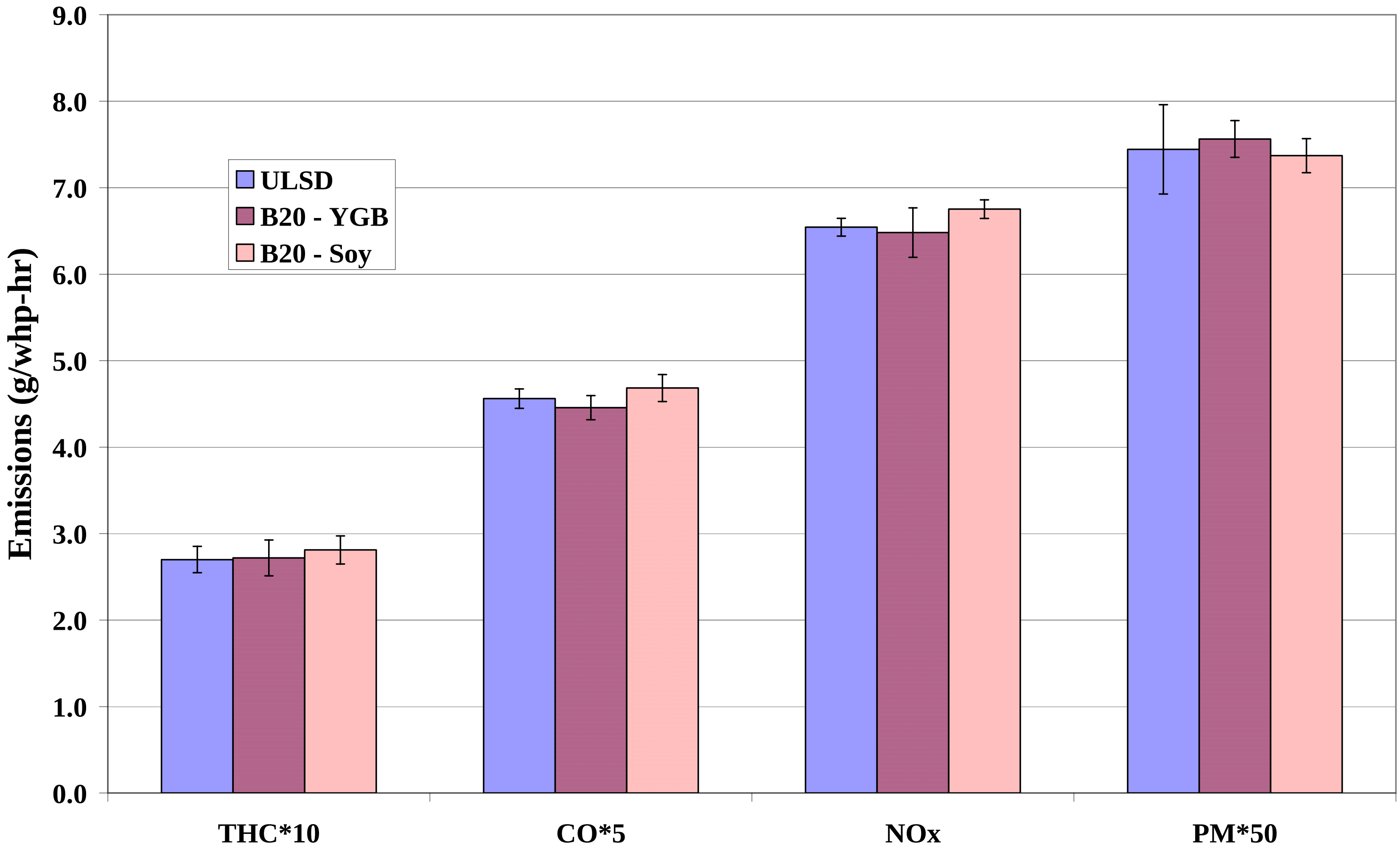


Figure 4.6.
UCR-Chassis AVL 8 Mode Results Ford F700 Stakebed Truck

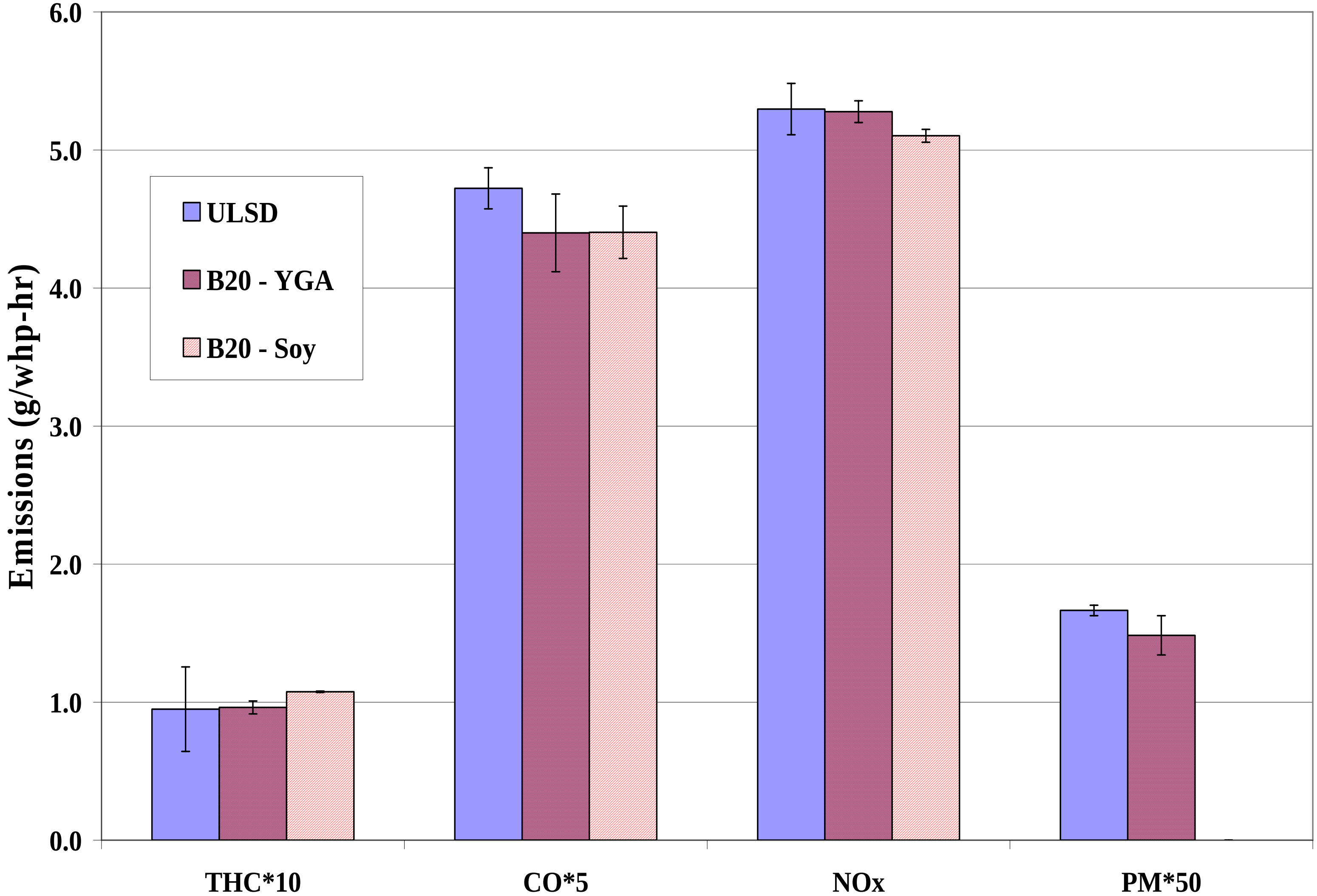


Figure 4.7.
UCR-Chassis AVL 8 Mode Bus Results

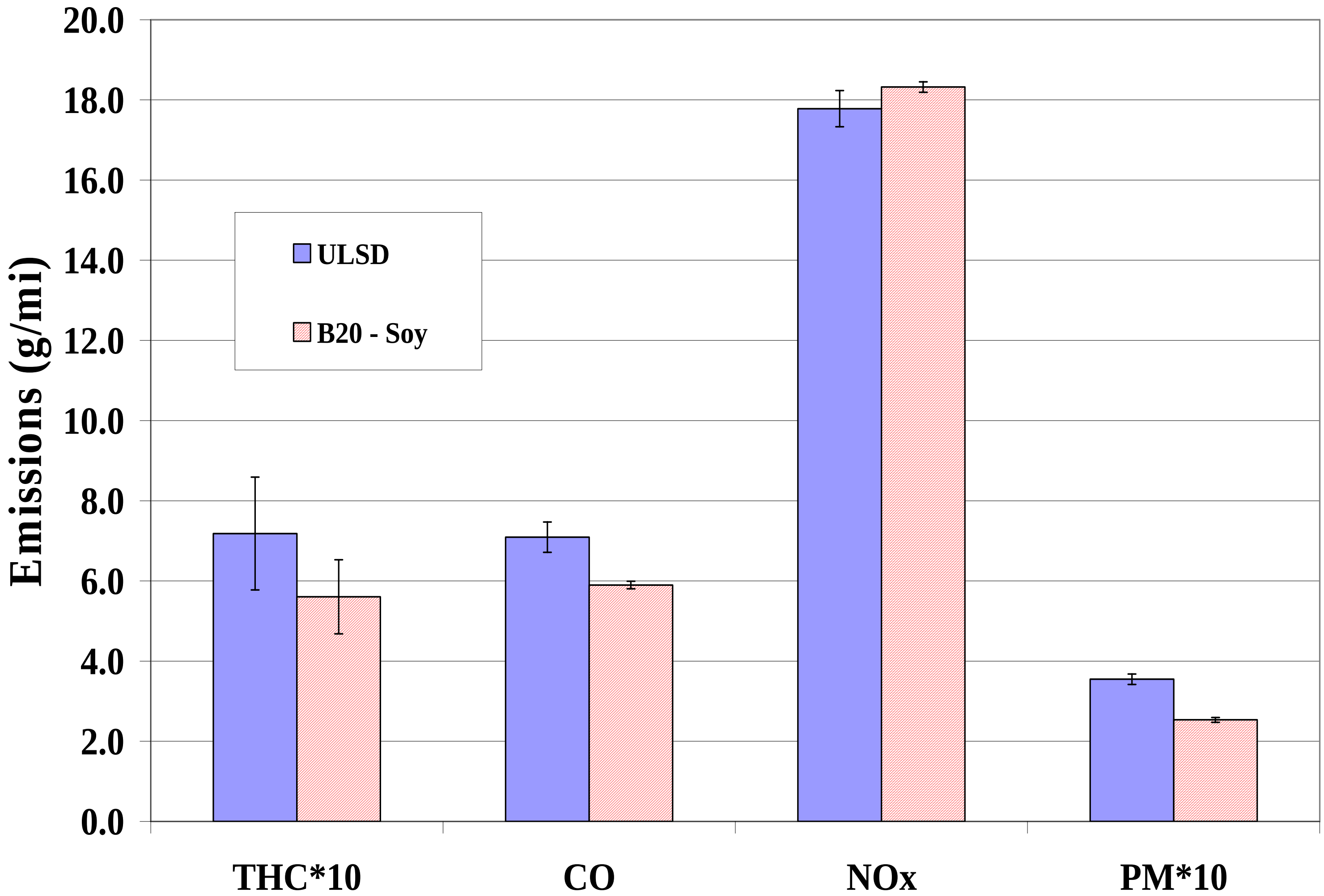


Figure 4.8.
UCR-Cheyenne Mountain Cycle Results – Cheyenne Mountain Bus

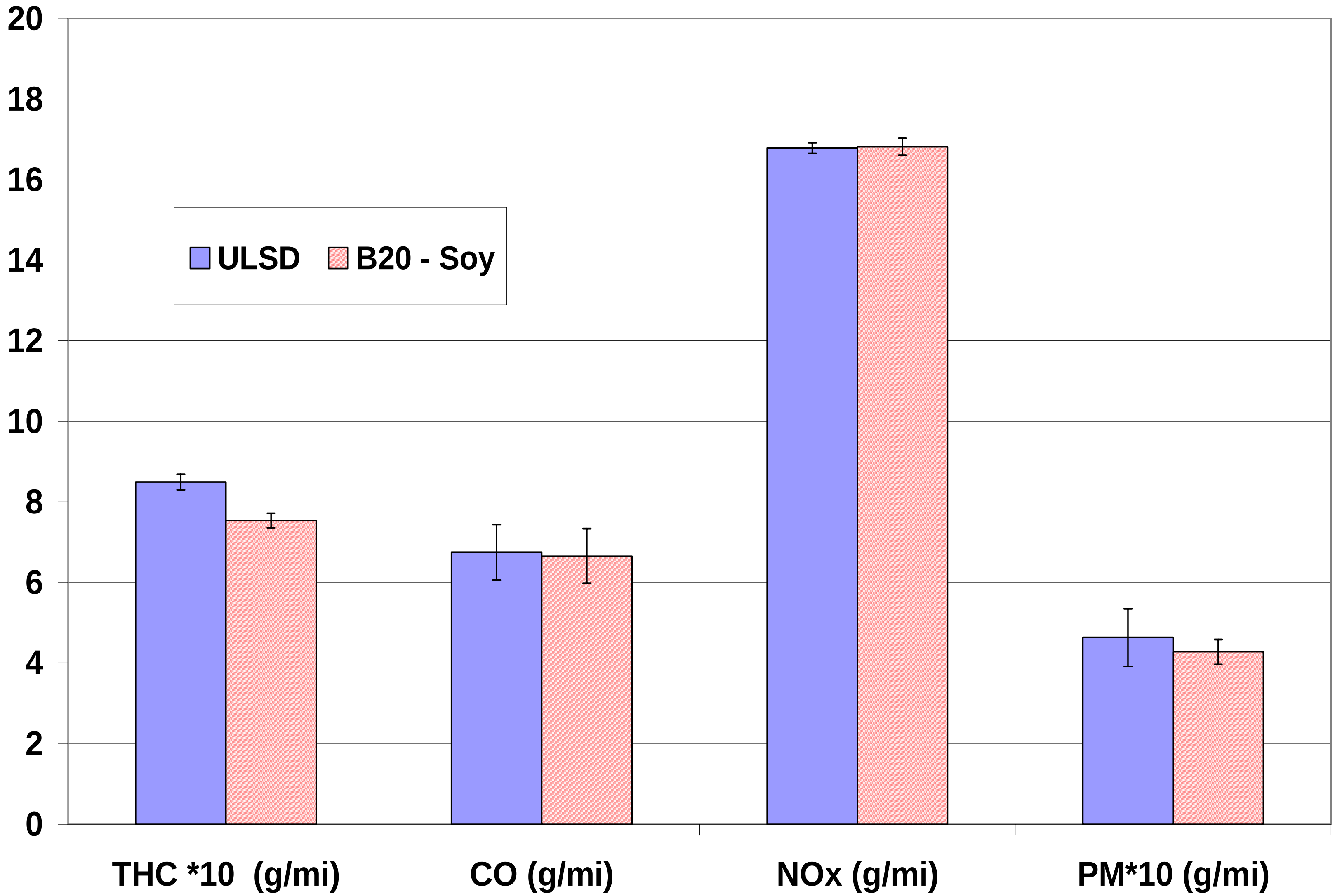


Figure 4.9.
NREL-Cheyenne Mountain Cycle Results – Cheyenne Mountain Bus

4.3.1.2.3 Portable Generator Results

The results for the 250 kW generator and a 60 kW tactical generator are shown in Figures 4.10 and 4.11, respectively. Of the fuels tested on both generators, the JP-8 showed increases in THC and CO for both generators. The JP-8 also showed about a 50% reduction in PM for the 60 kW generator. The B100 blend showed a reduction in THC for the 250 kW generator, but no other significant emissions effects. The B20 YGA showed little significant changes in any of the emissions components for either of the generators tested, with only a slight reduction in THC found for the 60 kW generator.

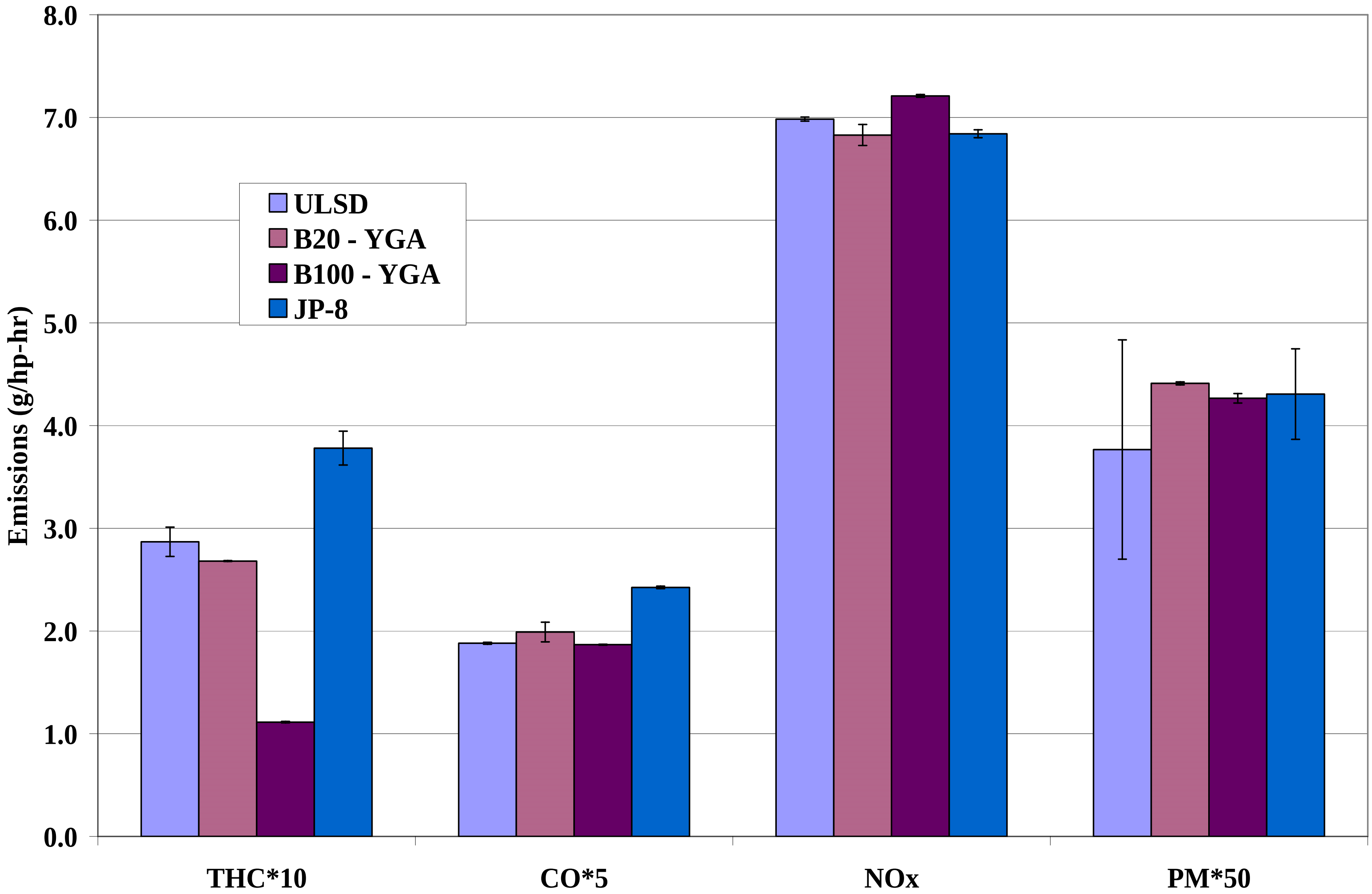


Figure 4.10.
UCR – 5-Mode Test Results – 250 kW Generator

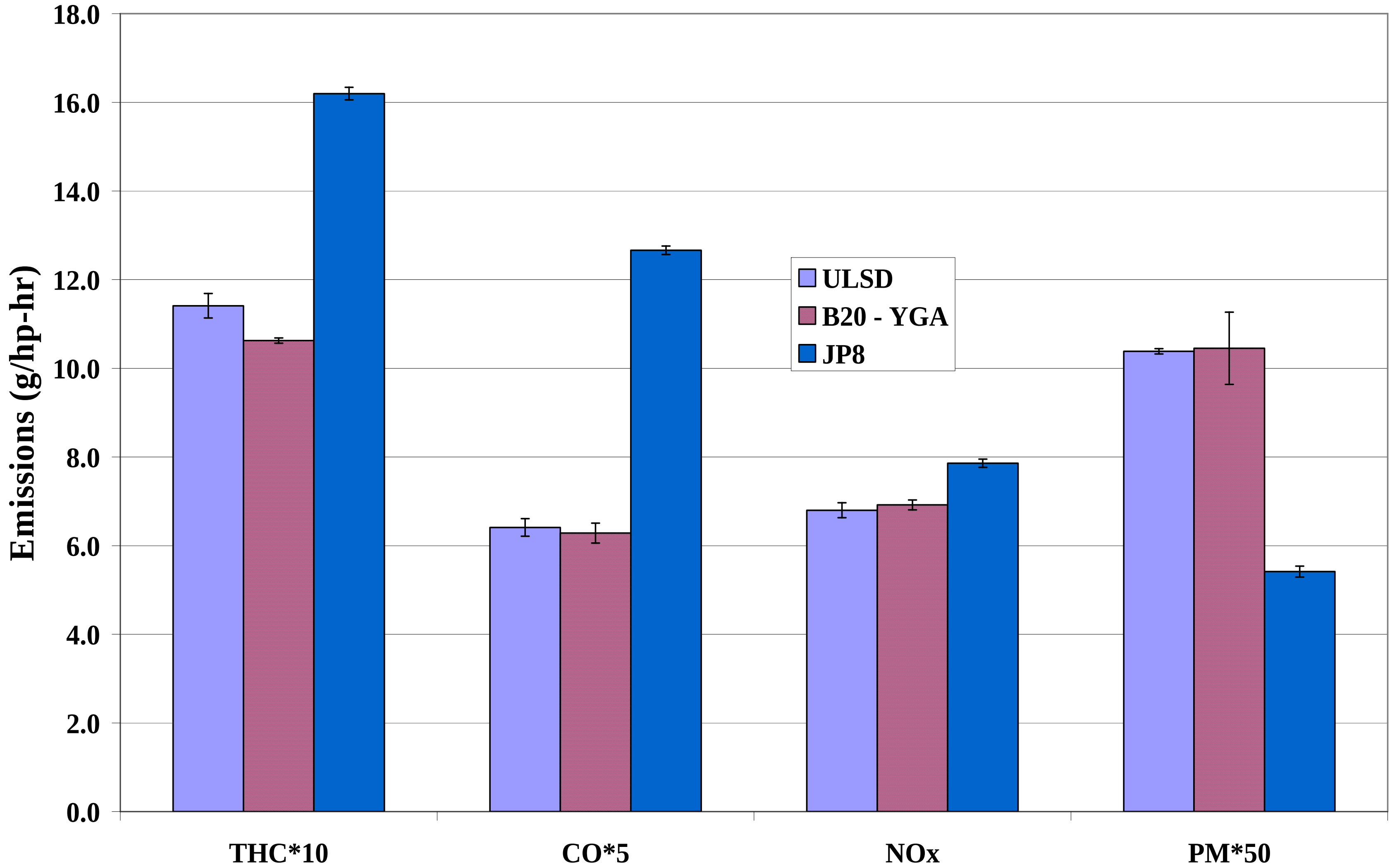


Figure 4.11.
UCR – 5-Mode Test Results – 60 kW Generator

4.3.1.2.4 In-Use Results

In-use testing results for a Hyster forklift, a Harlan aircraft tow, and a Humvee are shown in Figures 4.12 through 4.14, respectively. For the forklift, approximately a 20% increase in CO emissions was found for the B20 soy-based biodiesel fuel. As only a single test iteration is available, it is uncertain if this difference was significant or not. The differences for THC and NO_x for the forklift were small and likely within the experimental variability. For the aircraft tow vehicle, the differences between the ULSD and the B20 – YGA were all within the experimental variability. For the Humvee, only a single test iteration was available which showed little difference between the ULSD and the B20-Soy for CO and NO_x. THC was not available for the Humvee because a heated HC line was not used for these tests.

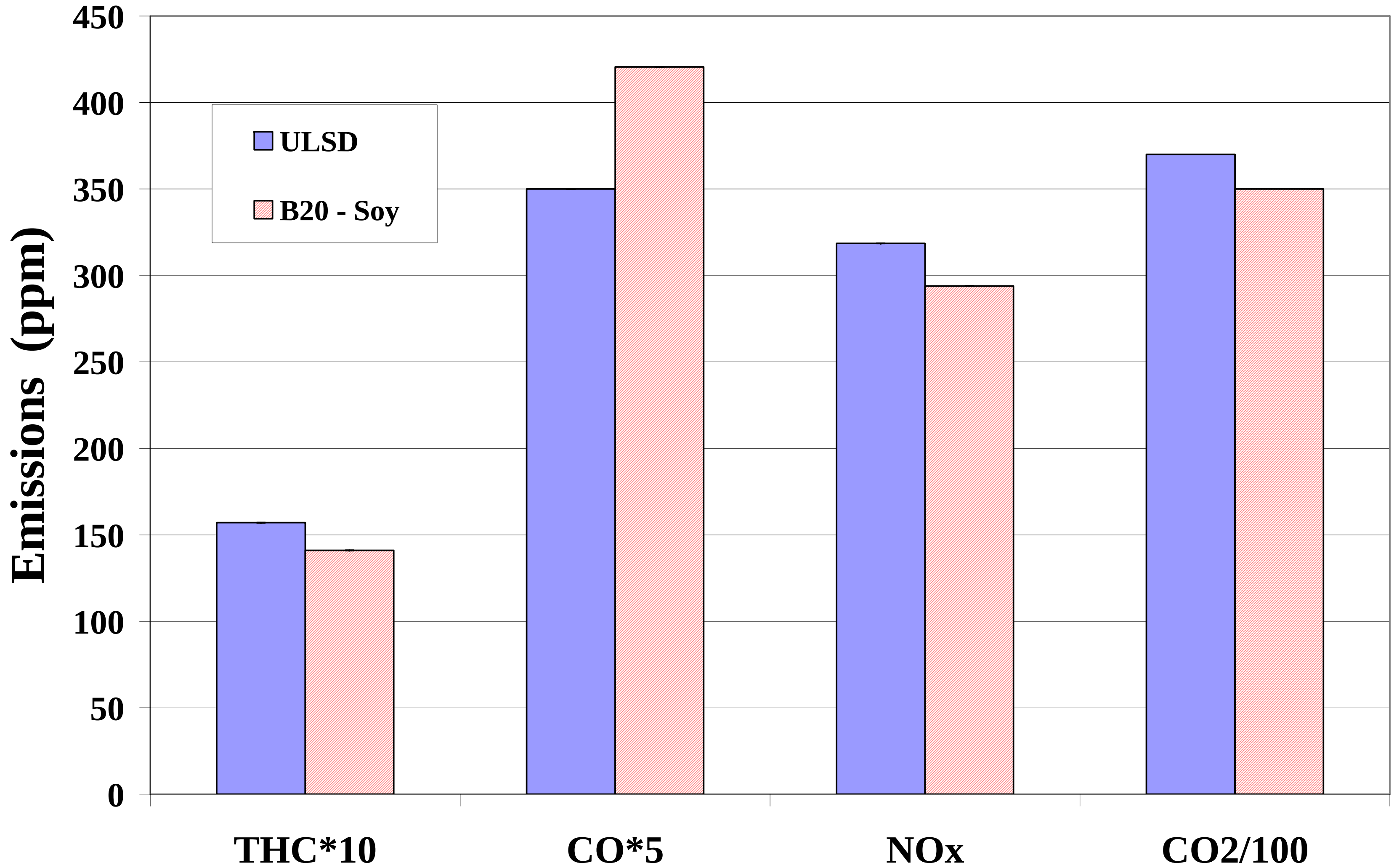


Figure 4.12.
ATC – Hyster Forklift Emissions Results

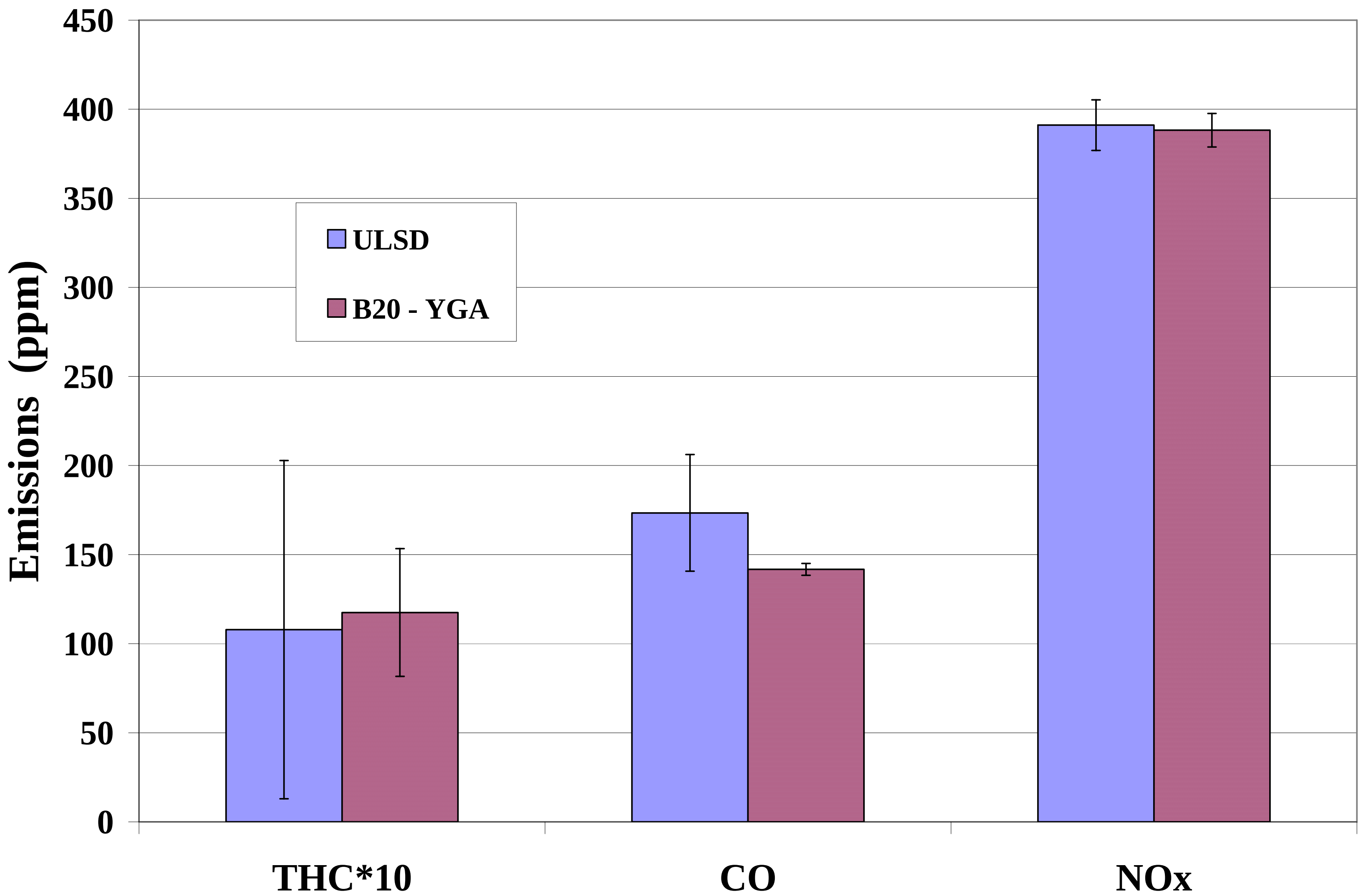


Figure 4.13.
ATC – Aircraft Tow Emissions Results

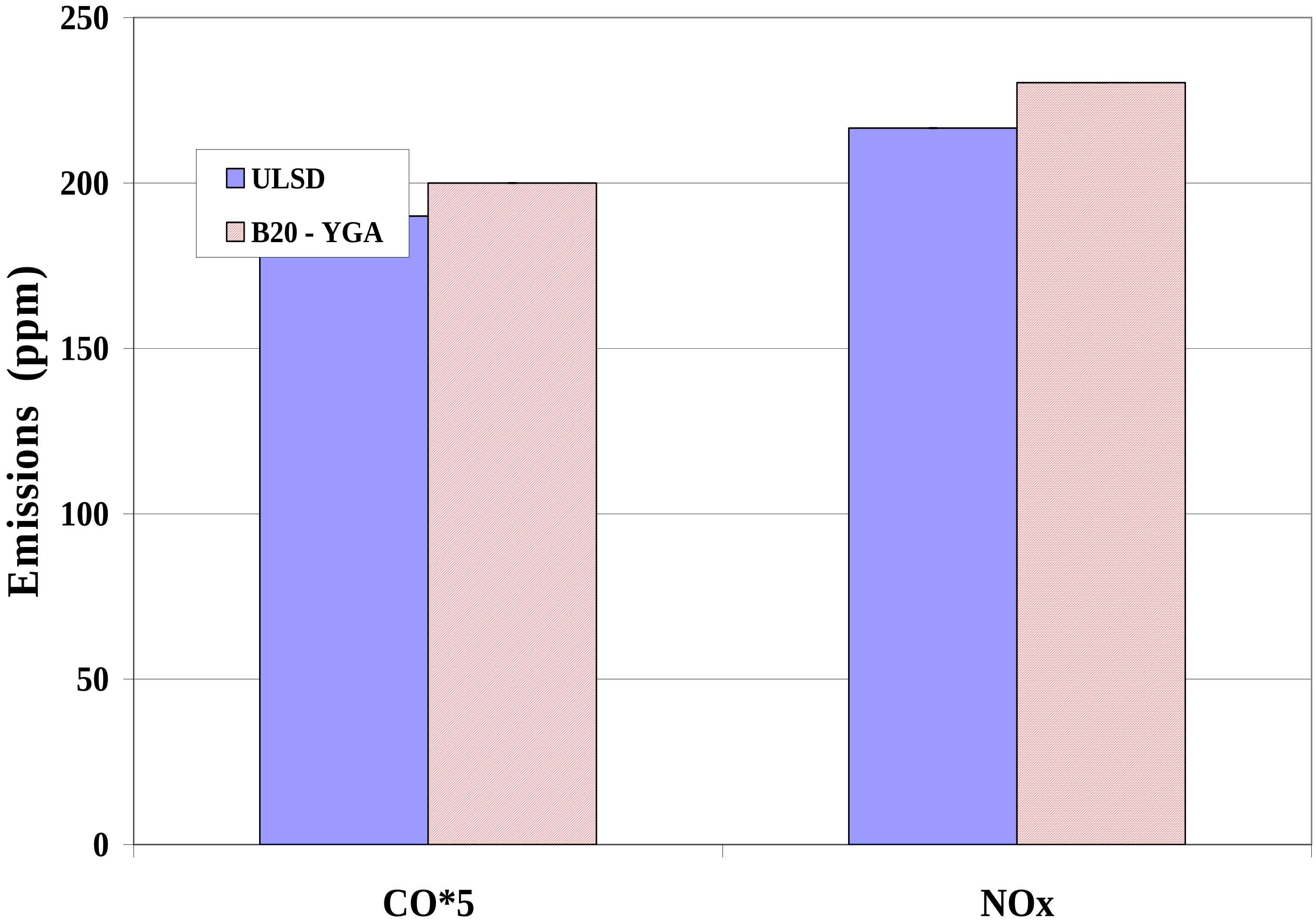


Figure 4.14.
ATC – Humvee Emissions Results

4.3.1.2.5 Discussion – Regulated Emissions

The primary fuels of interest for this study were the B20 biodiesel blends, since this is blend of biodiesel used in military vehicles. The project results for the regulated emissions were that at the B20 level, there were no consistent trends over all applications tested. Within the context of the test matrix, no differences were found between the different YGA, YGB, and Soy-based biodiesel feedstocks. The results of more extensive statistical analyses also indicated no statistically significant differences in CO, HC, NOx and PM emissions between the B20-YGA and the ULSD. The tested NOx reduction additives also proved to be ineffective. Thus the air pollution performance objectives outlined in the project's demonstration plan were not met. Although these results were not expected, they are not necessarily a disappointment since the baseline USLD fuel proved to be greatly superior to existing on-road Diesel No. 2.

The project results showed that over the range of vehicle/equipment types, emission factors could significantly vary depending on application or type of usage. A comparison of the emissions differences is provided in Table 4.3 for all vehicle/fuel combinations. Statistical comparisons between the different fuels and the ULSD using a standard t-test are also provided in Table 4.3. For this analysis, we considered $p \leq 0.05$ as statistically significant and $p \leq 0.10$ as being marginally statistically significant.

Although there were no overall trends, there were trends for individual engines. For the Ford F9000 tractor, there was a trend of lower PM emissions for the B20- YGA and B20-YGB fuels. There was some trend of higher HC emissions with the biodiesel blends for the Humvee, considering also the higher blend levels. The B20-YGA and B20 YGB also showed a trend of higher CO emissions on the Humvee.

To provide a better understanding of the effects of B20 over the entire fleet, some additional statistical analyses were performed. Since the vehicles/equipment represent a variety of applications and test protocols, the results were normalized into units of grams of emissions per either gallons of fuel used, kg of fuel used, or BTU's of fuel used. This provides a mechanism for which the results of the fleet as a whole could be compared on a consistent basis. These analyses were performed comparing ULSD to B20-YGA, since this was the blend utilized with nearly all of the test vehicles. For this analysis, a two-tailed, paired t-test was performed using only the average values for a particular vehicle/fuel combination. As such, this analysis does not account for the variability of testing within a specific vehicle/fuel combination. The results for HC, CO, NO_x and PM all showed no statistically significant differences between the ULSD and the B20-YGA for either the calculations based on gallons of fuel used, emissions per kg of fuel used, or BTU of fuel used. Statistical comparisons for fuel consumption were also made with the results showing no statistically significant difference in fuel consumption between the ULSD and the B20-YGA. A summary of these statistical analysis results is provided in Table 4.4.

Table 4.3
Summary of Emissions Changes and Statistics Relative to ULSD for Individual Vehicles

Vehicle	Cycle		YGA - B20				Soy - B20				YGB - B20				JP-8				YGA - B100			
			HC	CO	NOx	PM	HC	CO	NOx	PM	HC	CO	NOx	PM	HC	CO	NOx	PM	HC	CO	NOx	PM
F350	FTP	% change	-19%	-6%	0%	-15%																
		p-value	0.15	0.03	0.65	0.21																
	US06	% change	-18%	-3%	24%	-13%																
		p-value	0.31	0.53	0.32	NA																
Model A2 Humvee	FTP	% change	93%	17%	1%	0%	113%	26%	-1%	-9%					265%	133%	3%	35%	133%	24%	-2%	-38%
		p-value	0.17	0.06	0.48	0.99	0.06	0.04	0.61	0.05					0.00	0.00	0.20	NA	0.03	0.04	0.31	**
	US06	% change	2%	19%	2%	-44%	3%	44%	-1%	-57%					80%	113%	4%	-37%	29%	54%	0%	-70%
		p-value	0.91	0.01	0.01	0.32	0.88	0.01	0.09	0.23					0.02	0.00	0.01	NA	0.16	0.00	0.80	NA
F700	AVL 8-mode	% change					4.8%	2.7%	3.2%	5.6%	0.4%	-2.1%	-0.9%	8.4%								
		p-value					0.14	0.33	0.14	0.90	0.96	0.63	0.40	0.81								
F9000	AVL 8-mode	% change	3.2%	-6.7%	11.7%	-19.4%					-9.5%	-13.5%	8.6%	-35.5%					-31.6%	-30.6%	40.8%	-74.9%
		p-value	0.72	0.01	0.16	0.05					0.21	0.02	0.22	0.04					**	**	**	**
Camp Pendleton Bus	AVL 8-mode	% change	1.3%	-6.8%	-0.4%	-10.8%	13.3%	-6.7%	-3.7%													
		p-value	0.96	0.29	0.91	0.28	0.62	0.20	0.29													
250 kW Generator	5 -mode	% change	-6.6%	5.8%	2.3%	17.1%									31.8%	28.9%	1.5%	14.3%	-61.4%	-0.7%	8.3%	13.3%
		p-value	0.20	0.25	0.21	0.48									0.03	0.00	0.11	0.58	0.00	0.21	0.00	0.58
60 kW Generator	5-mode	% change	6.3%	13.0%	8.2%	10.9%									42.0%	97.5%	15.6%	-48.1%				
		p-value	0.69	0.41	0.40	0.57									0.00	0.00	0.02	0.00				
Cheyenne Mountain Bus – UCR	Custom	% change					-22.0%	-17%	3.0%	-29%												
		p-value					0.18	0.01	0.12	0.00												
Cheyenne Mountain Bus- NREL	Custom	% change					-11.2%	-1.3%	0.2%	-8.4%												
		p-value					0.00	0.87	0.81	0.39												
Aircraft tow	In-use	% change	9%	-18%	-1%																	
		p-value	0.91	0.31	0.83																	
Forklift	In-use	% change					-10%	20%	-8%													
		p-value					**	**	**													
Model A1 Humvee	In-use	% change	NA	5%	6%																	
		p-value	**	**	**																	

Table 4.3 (continued)
Summary of Emissions Changes and Statistics Relative to ULSD for Individual Vehicles

			YGA - B50				YGA - B70				YGA - B100 + Additive 1				YGA - B100 + Additive 2			
Vehicle	**Cycle**		**HC**	**CO**	**NOx**	**PM**	**HC**	**CO**	**NOx**	**PM**	**HC**	**CO**	**NOx**	**PM**	**HC**	**CO**	**NOx**	**PM**
Humvee	FTP	% change	73%	23%	1%	-28%	100%	28%	-1%	-33%	120%	21%	-3%	-38%	50%	11%	-2%	-42%
		p-value	0.07	0.06	0.62	0.02	0.01	0.04	0.63	0.01	0.01	0.04	0.24	0.01	0.43	0.13	0.34	0.00
	US06	% change	12%	30%	2%	-63%	24%	52%	2%	-68%	23%	62%	-2%	-75%	15%	57%	0%	-75%
		p-value	0.43	0.03	0.30	0.20	0.19	0.00	0.55	0.18	0.22	0.01	0.37	NA	0.52	0.03	0.99	0.16

**	Insufficient data for t-test calculation
(yellow)	95% confidence level - statistically significant - p ≤ 0.05
(orange)	90% confidence interval - marginally statistically significant - ≤ 0.05 p ≤ 0.10

Table 4.4
Fleetwide Statistical Analysis Results for B20-YGA vs. ULSD

		HC	CO	NO_x	PM	Fuel Use
Emissions per kg of fuel used	%	-8.6%	-5.1%	0.0%	-9.2%	
	p-value	0.14	0.28	0.97	0.27	
Emissions per gal. of fuel used	%	-7.6%	-4.1%	+1.1%	-8.2%	
	p-value	0.16	0.36	0.19	0.32	
Emissions per BTU of fuel used	%	-7.3%	-3.8%	+1.4%	-7.9%	
	p-value	0.16	0.39	0.11	0.33	
Gallons per work or activity unit						+1.7%
						0.18

The higher biodiesel blends (B50 to B100) were only tested on the Humvee, and with the B100 on the 250 kW generator and a single test on the Ford F9000. On the Humvee, the higher biodiesel blends did show a trend of higher CO emissions with the higher biodiesel blends, consistent with the B20 blends. There was also a general trend of higher HC emissions, at least on the FTP, for this vehicle. Finally, there were some trends of lower PM emissions on the Humvee for the higher biodiesel blends and on the F9000 for the B100. This is consistent with the larger body of literature, although consistent PM reductions are not found at the B20 blend levels. NO_x emissions for the single test on the F9000 with B100-YGA were also higher than that found for ULSD.

JP-8 was also tested over a range of test applications. The JP-8 showed relatively consistent higher HC emissions over the Humvee and the two generators ranging from 30 to 265%. Similarly, CO emissions increased with JP-8 on the Humvee and the two generators in the range of 30 to 130%. Some improvement in PM was found with the JP-8 on 60 kW generators.

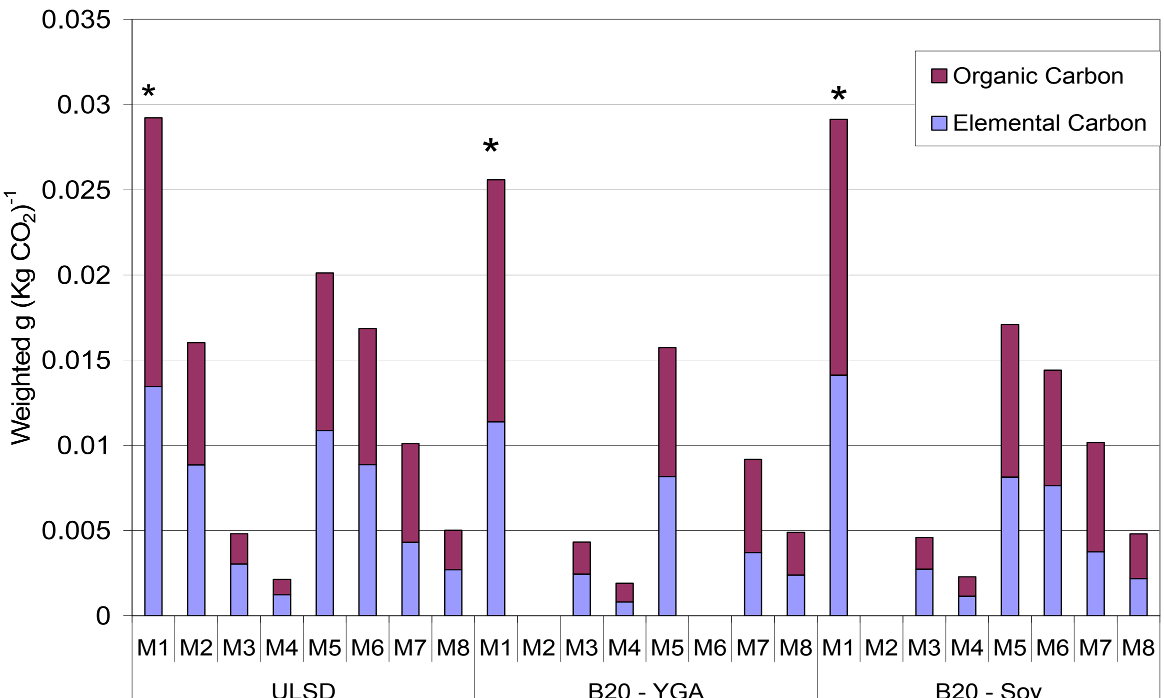
The results of this study in general show much smaller changes in emissions with B20 than previous studies. A number of other studies have found larger reductions in HC, CO, and PM emissions for biodiesel fuels [References 7.1 & 7.12 - 7.20]. There are some differences, however, between the present and previous studies. In many of the previous studies, however, comparisons were made with Federal No. 2 diesel fuels with higher aromatic contents and lower cetane numbers than the CARB fuel used in the present work [References 7.12-7.18]. Other previous studies have, however, demonstrated the emissions reduction potential of biodiesel blends in comparison with CARB fuels [References 7.19, 7.20]. It is worth noting that while ULSD will soon be implemented throughout the country, the nature of the diesel fuel could still differ significant between different regions of the country. The CARB ULSD probably represents the most stringent fuel requirements that would be met by commercial fuels. In other parts of the country where fuel specification on aromatics and other fuel properties are not as strict, some additional benefits may be found relative to those in this study.

There may also be differences in the operational load in comparison with engine dynamometer tests that affect the magnitude of the changes in emissions. Previous studies have shown that the benefits of biodiesel fuels decrease in magnitude at lower loads [References. 7.18, 7.21 & 7.22]. UCR has also observed similar results for previous tests conducted over the light-duty FTP in their laboratory for biodiesel fuels on medium-duty diesel trucks [References 7.23 & 7.24].

4.3.2 Unregulated Emissions

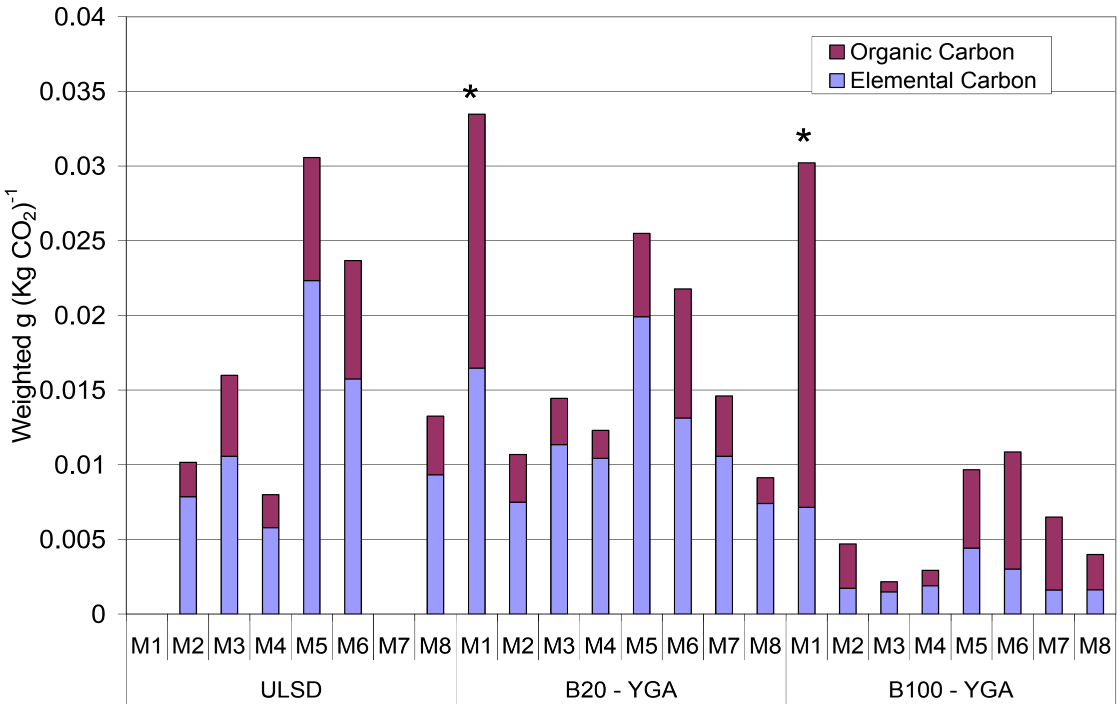
4.3.2.1 Elemental and Organic Carbon

For mobile sources, the most significant component of the PM is the elemental and organic carbon. Figures 4.15 and 4.16 provide the elemental and organic carbon data for the Camp Pendleton bus and the Ford F9000 tractor. The data for the larger engines are provided on a CO_2 basis so that comparison between vehicles can be more readily made. Also, the data are multiplied by the weighting factor to show the relative contribution on a basis of cycle weighting.



Note: Mode 1 values marked with an asterisk have been divided by 5 in order for other modes to be visible on the graph.

Figure 4.15
Bus Organic and Elemental Carbon Emission Rates Weighted by Mode



Note: Mode 1 values marked with an asterisk have been divided by 5 in order for other modes to be visible on the graph.

Figure 4.16
F9000 Organic and Elemental Carbon Emission Rates Weighted by Mode

Comparing across all fuels and tests, the ratio of elemental to organic carbon varies considerably depending on the vehicle, test mode, and fuel. Mode 1 of the AVL 8-mode cycle makes the largest contribution to the weighted average and is approximately equally weighted between elemental and organic carbon for most tests. For the F9000 operating on ULSD and YGA B20 fuel, organic carbon represented the largest fraction of the PM. On the other hand, the YGA B100 shows a larger fraction of elemental carbon on nearly all modes. Figure 4.17 and Figure 4.18 provide the relative contribution of Elemental Carbon (EC) and Organic Carbon (OC) to total Carbon (TC) for the bus and F9000, respectively.

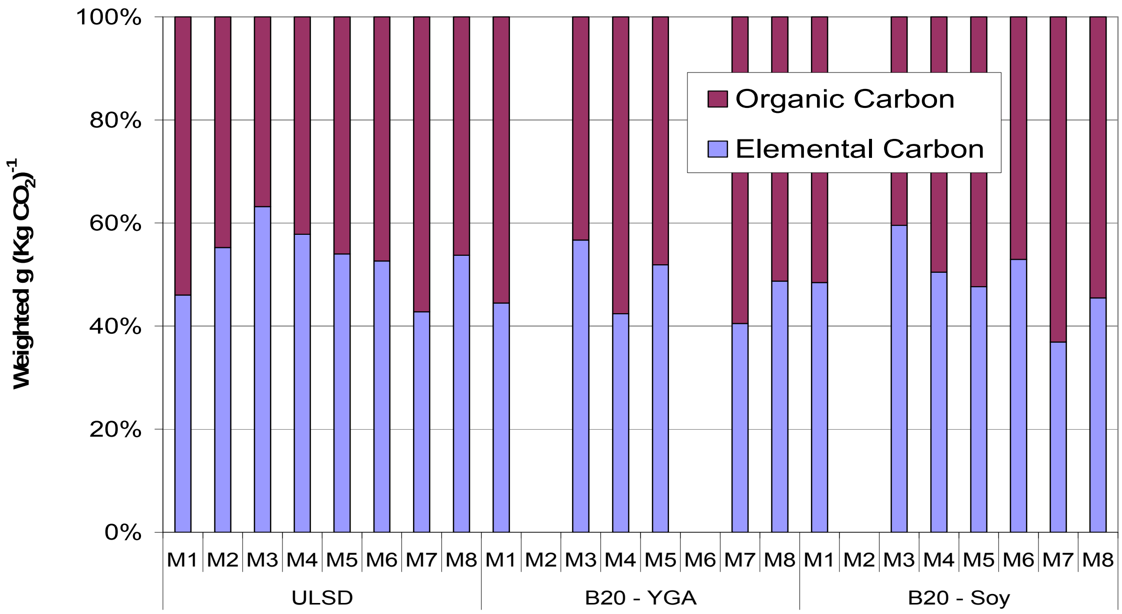


Figure 4.17
Bus Relative Organic and Elemental Carbon Emission Rates Weighted by Mode

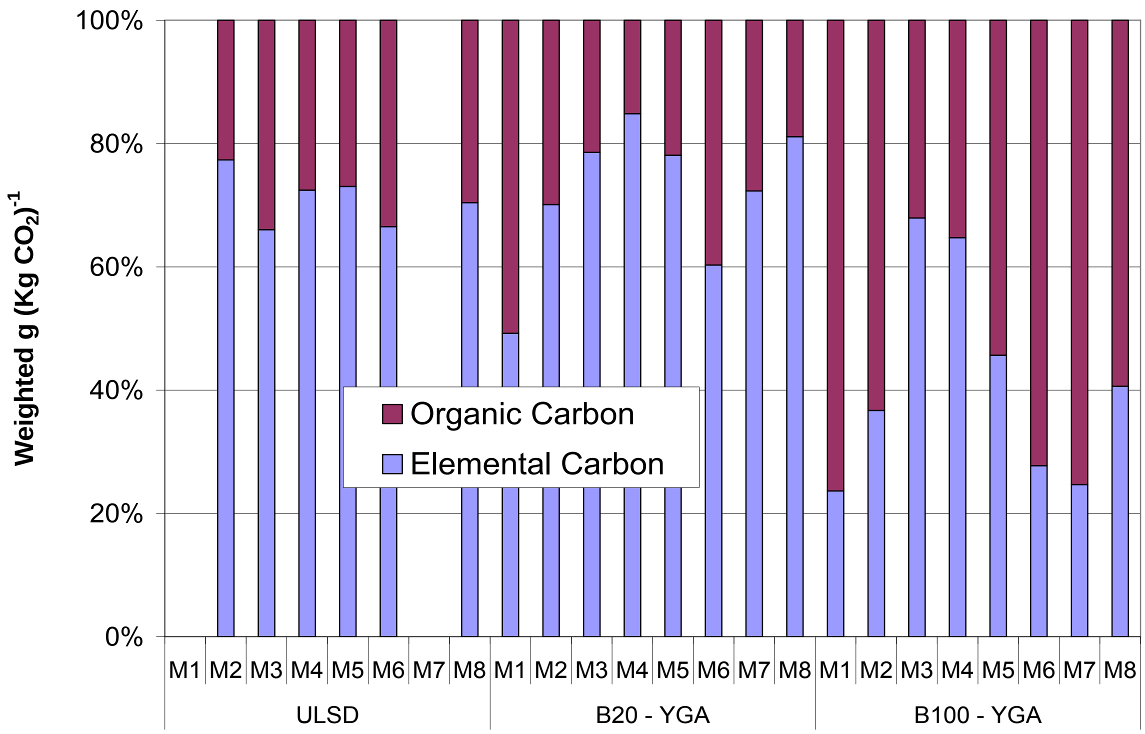
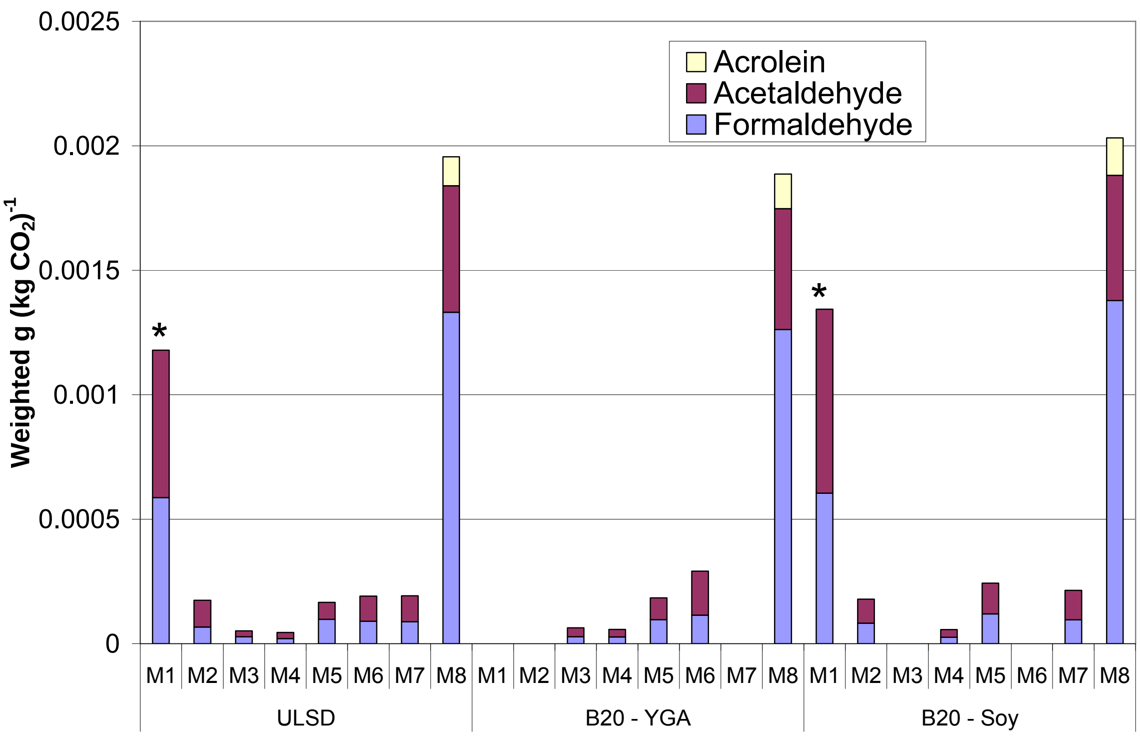


Figure 4.18
F9000 Relative Organic and Elemental Carbon Emission Rates Weighted by Mode

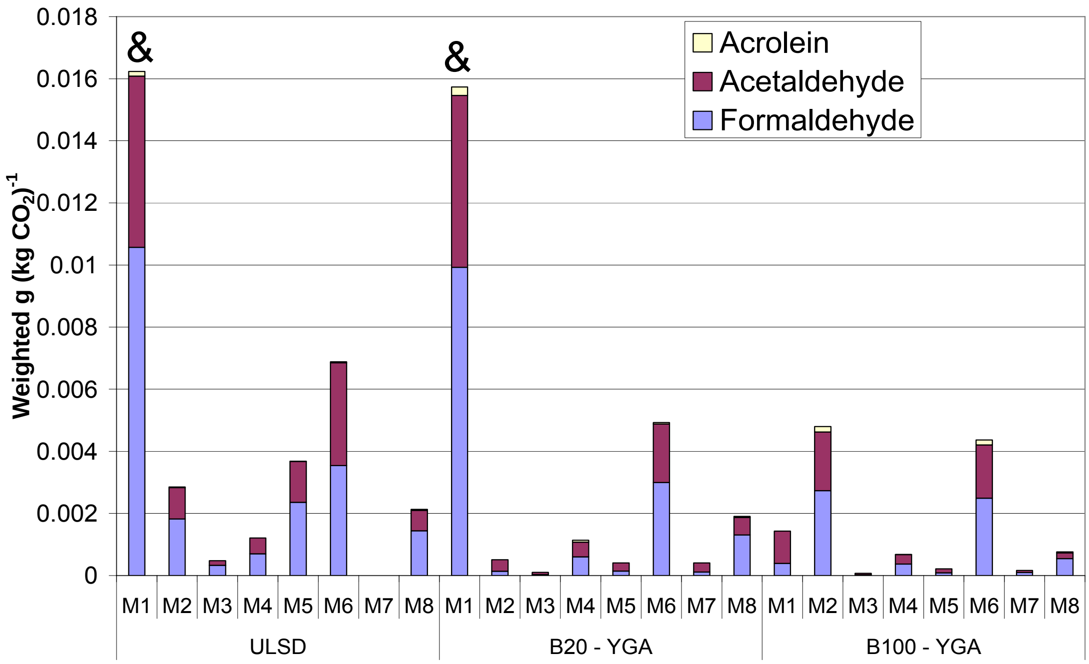
4.3.2.2 Carbonyls

Figures 4.19, 4.20, and 4.21 present the weighted modal emission factors for carbonyl compounds formaldehyde, acetaldehyde, and acrolein for the Camp Pendleton bus, Ford F9000 tractor and the 250 kW generator, respectively. Figure 4.22 presents the FTP weighted carbonyl emissions for the Humvee. From these charts, it can be seen that mode 1 for the AVL 8-mode cycle is the most significant contributor to carbonyl emissions, similar to that seen for the organic carbon and elemental carbon. Mode 8 provides the second most significant contribution to weighted carbonyl emissions. For the portable generator 5-mode cycle, a more even distribution of the carbonyl compound emissions by mode is seen.



Note: Mode 1 values delineated with an asterisk have been divided by 5 in order for other modal emissions to be visible on the graph.

Figure 4.19
Bus Carbonyl Emissions Weighted by Modes



Note: Mode 1 values delineated with an "&" have been divided by 10 to allow for other modal emissions to be visible.

Figure 4.20
F9000 Carbonyl Emissions Weighted by Modes

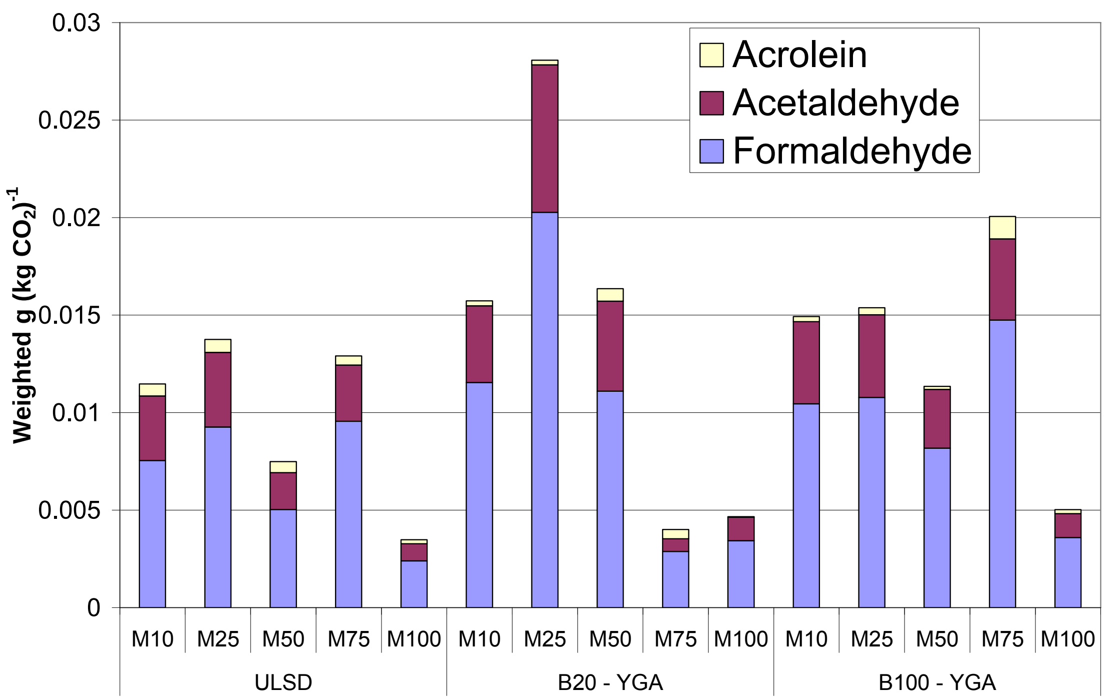


Figure 4.21
250 kW Generator Carbonyl Emissions Weighted by Modes

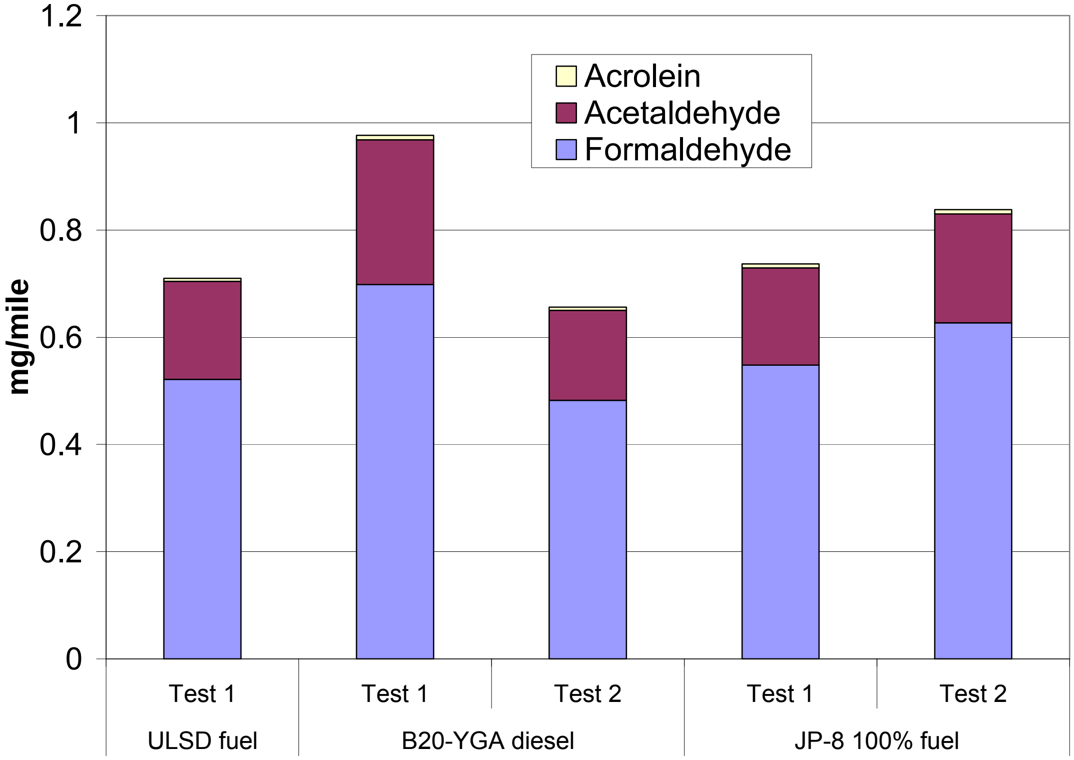


Figure 4.22
Humvee Carbonyl Emissions Over Weighted FTP Cycle in Grams Per Mile

Figures 4.23, 4.24, 4.25, and 4.26 provide the relative contributions of formaldehyde, acetaldehyde, and acrolein for the Camp Pendleton bus, Ford F9000 tractor , 250 kW generator, and Humvee respectively. For the Humvee and 250 kW generator, formaldehyde makes the largest carbonyl contribution for all test combinations. For the bus and F900, the distribution between formaldehyde and acetaldehyde is more evenly distributed with the relatively fractions differing depending on the specific test combination. Note that the relative carbonyl emissions showed good reproducibility for a specific engine, irrespective of operating mode or fuel type, especially for the FTP weighted Humvee and the 250 kW generator tests.

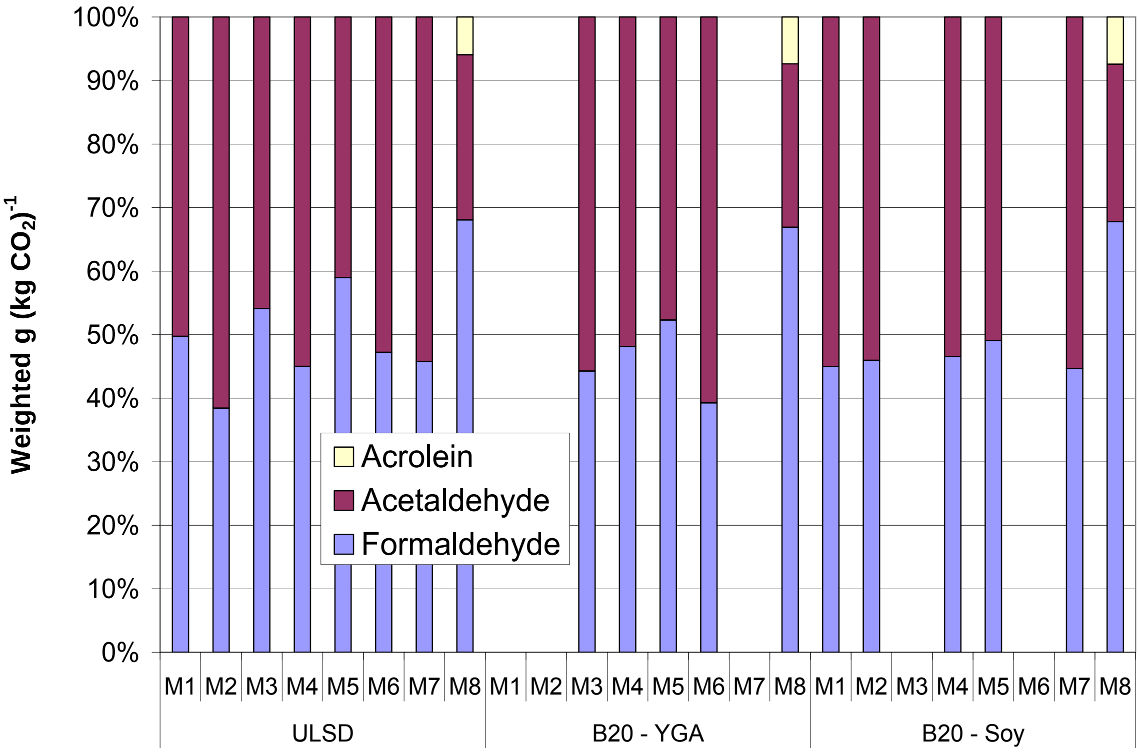


Figure 4.23
Bus Relative Carbonyl Emissions

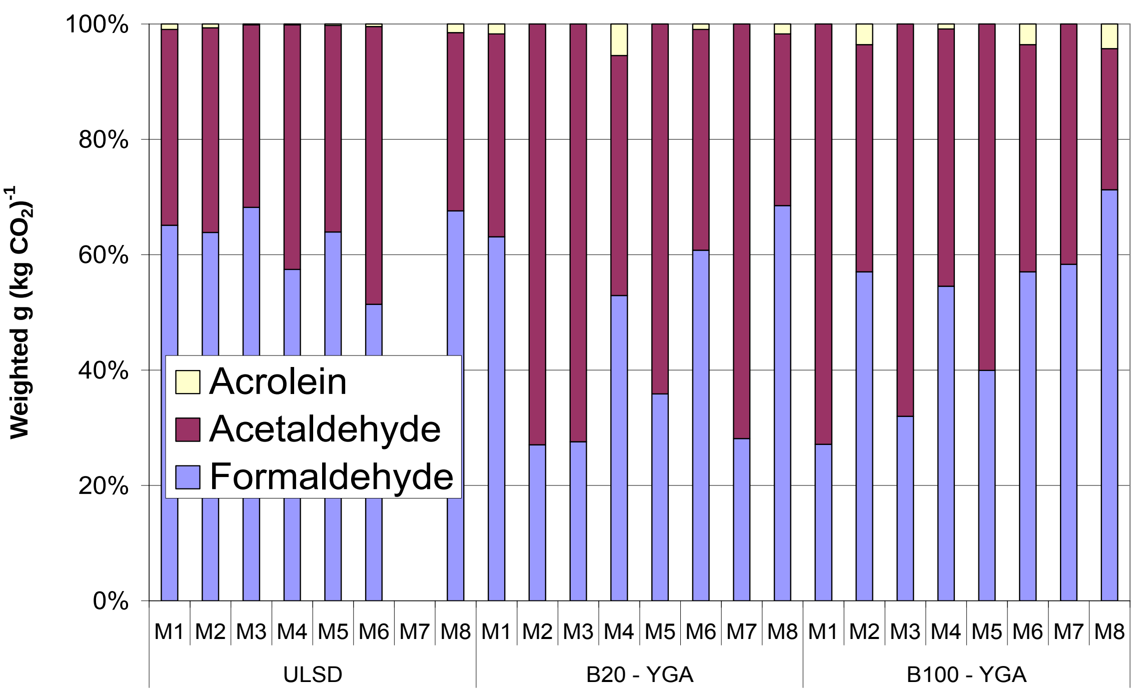


Figure 4.24
F9000 Relative Carbonyl Emissions

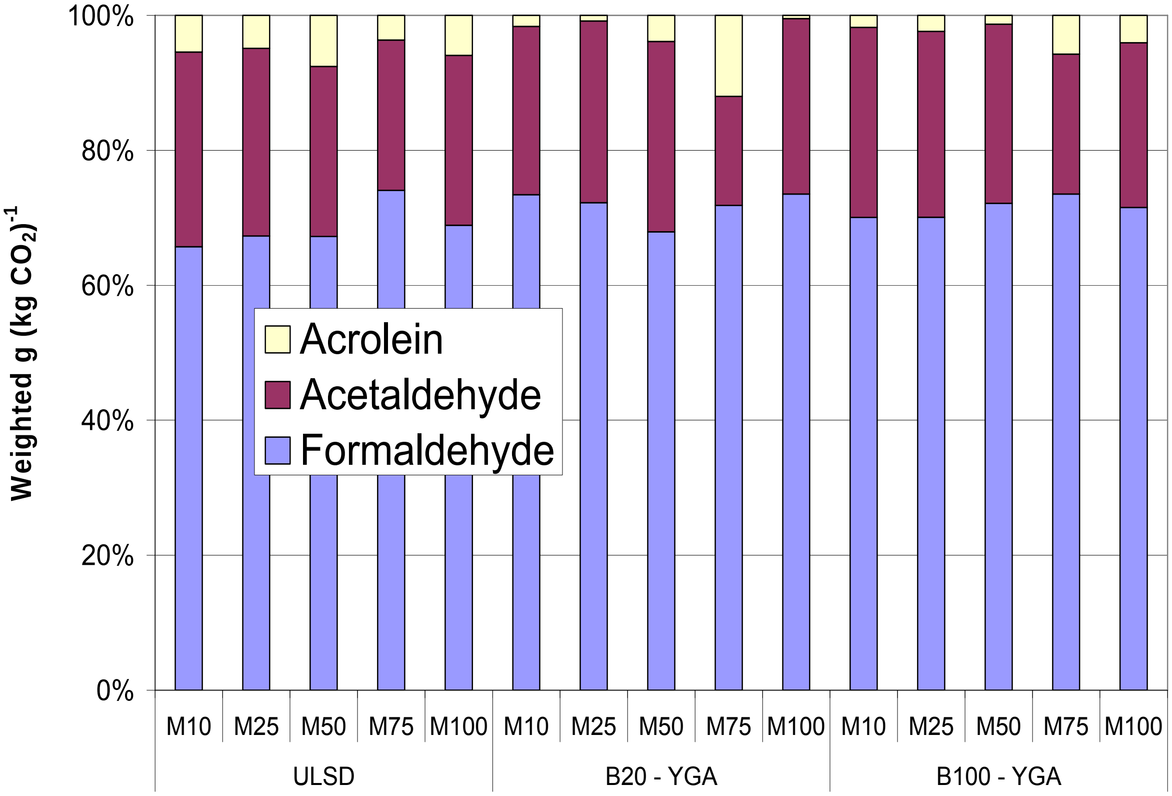


Figure 4.25
250 kW Generator Relative Carbonyl Emissions

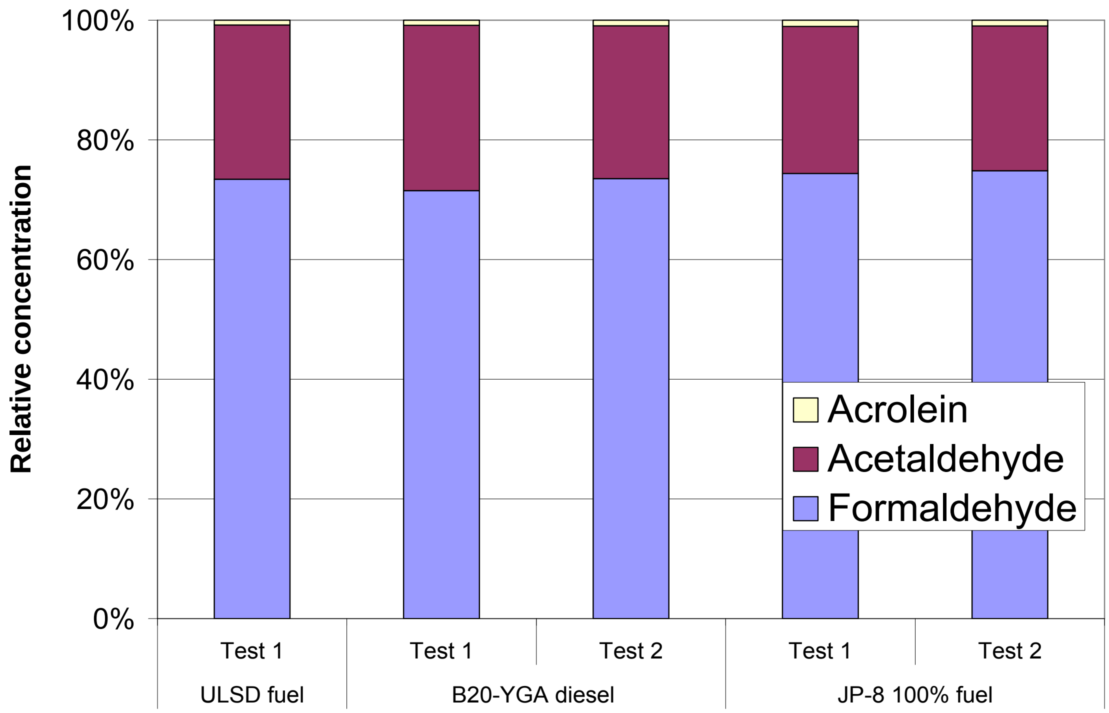


Figure 4.26
Humvee Relative Carbonyl Emissions

4.3.2.3 Gas-Phase Hydrocarbon Species

Additional speciation was performed on the light hydrocarbons. Weighted benzene emissions (Figure 4.27) for the Ford F9000 tractor is provided to demonstrate that other individual species also follow similar emission trends to those compounds already discussed, with Mode 1 dominating the net weighted emissions with mode 8 providing the second most important bin. Figure 4.28 presents the weighted FTP benzene and 1,3-butadiene emission rates for the Humvee for ULSD, YGA B20, YGA B100, and JP8. The emissions of 1,3-butadiene are seen to slightly increase in the YGA fuels as compared with ULSD. The 1,3-butadiene emissions are also measured to be higher in JP-8 as compared with the base ULSD fuel, although greater variability in 1,3 butadiene measurements is noted for the JP8 fuel as compared with the YGA fuels and ULSD fuel. No clear trends are noted for benzene across fuels tested for the Humvee.

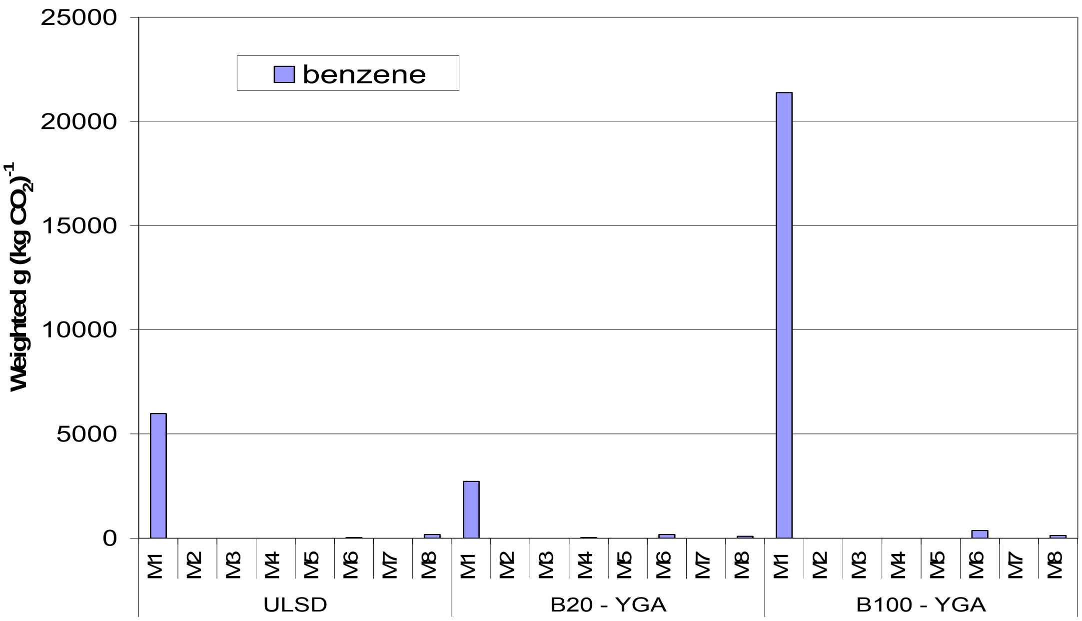


Figure 4.27
F9000 Modal Benzene Emissions Weighted by Mode

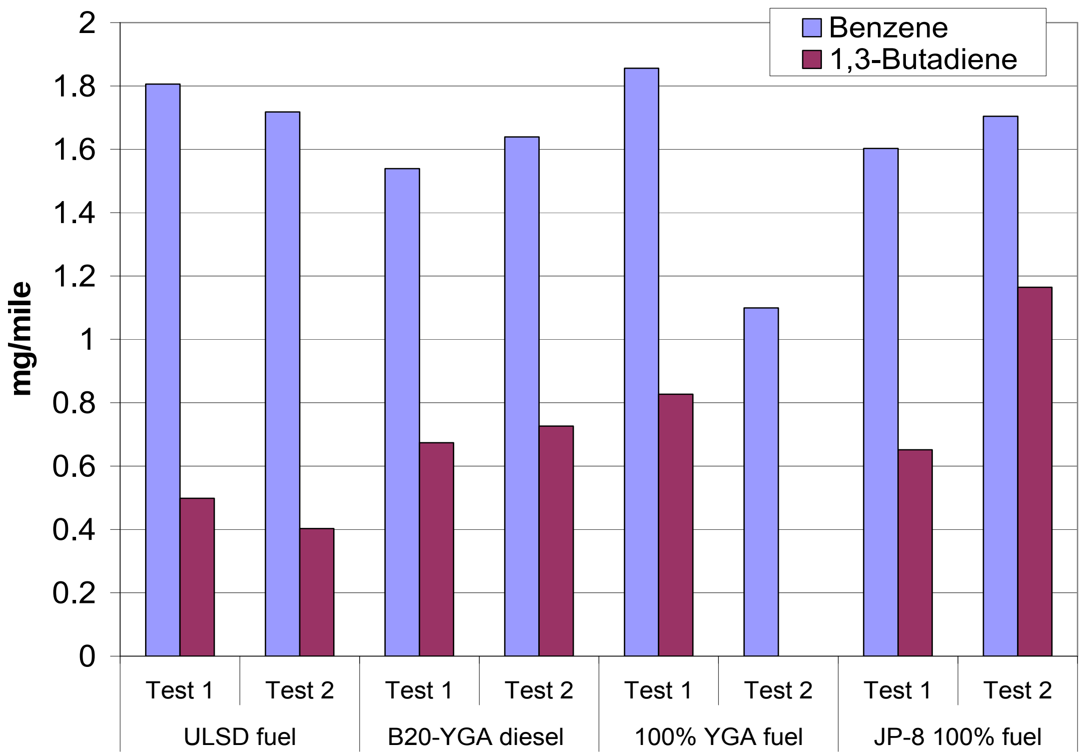


Figure 4.28
Humvee FTP Weighted Benzene and Butadiene Emissions on a Per Mile Basis

Detailed modal Naphthalene measurements were acquired for the 250 kW generator. Weighted emission factors for this generator are found in Figure 4.29. For the 250 kW generator, naphthalene emissions tend to be lower on a CO_2 basis for the higher load point, although it is expected that the absolute emissions would be greater under these conditions. A peak in the weighted emissions for Naphthalene is noted at 50% power for YGA B20 and YGA B100 for the 250 kW generator. The data for the 250 kW generator show some differences in tests run on different fuels, but the data are limited. Additional measurements of Naphthalene weighted emissions for a subset of modes are provided in Figures 4.30 and 4.31 for the Camp Pendleton bus and Ford F9000 tractor, respectively. For the bus, data are only available for Mode 8. For the F9000, Mode 1 appears to continue to be the most significant mode for weighted mobile source air toxic emissions for YGA B20 following the trends for carbonyl compounds as well as EC and OC. Relatively high naphthalene emissions were also found for the YGA B100 on Mode 6. As these data are relatively limited on the individual vehicles, there are no conclusive fuel trends.

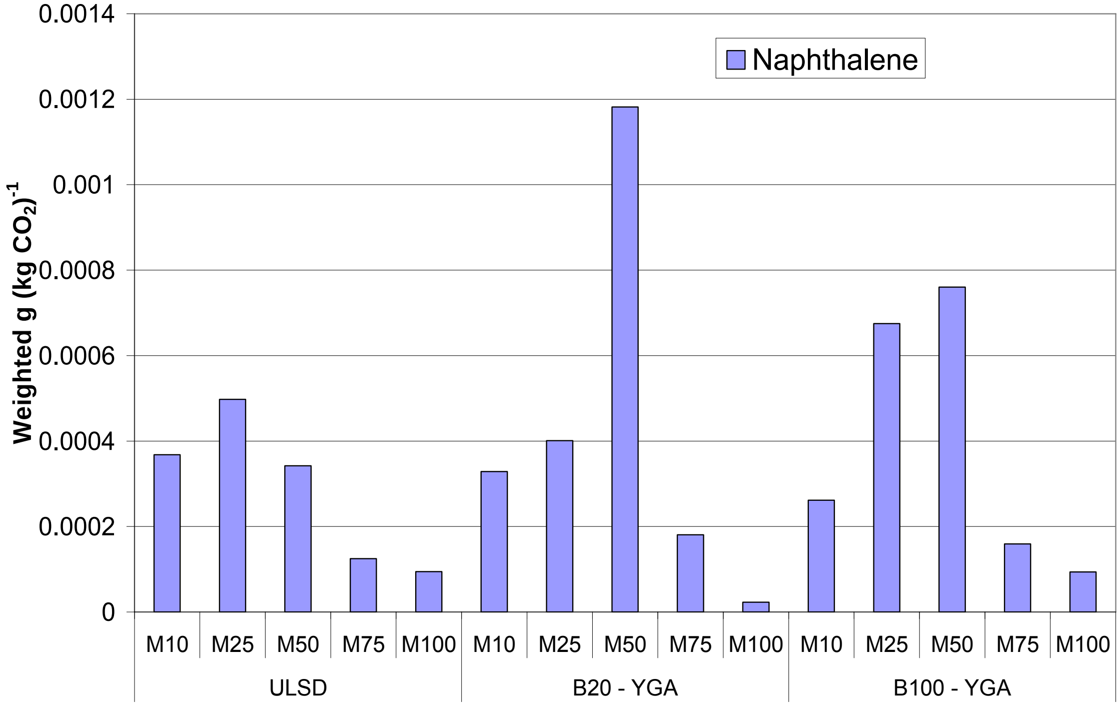
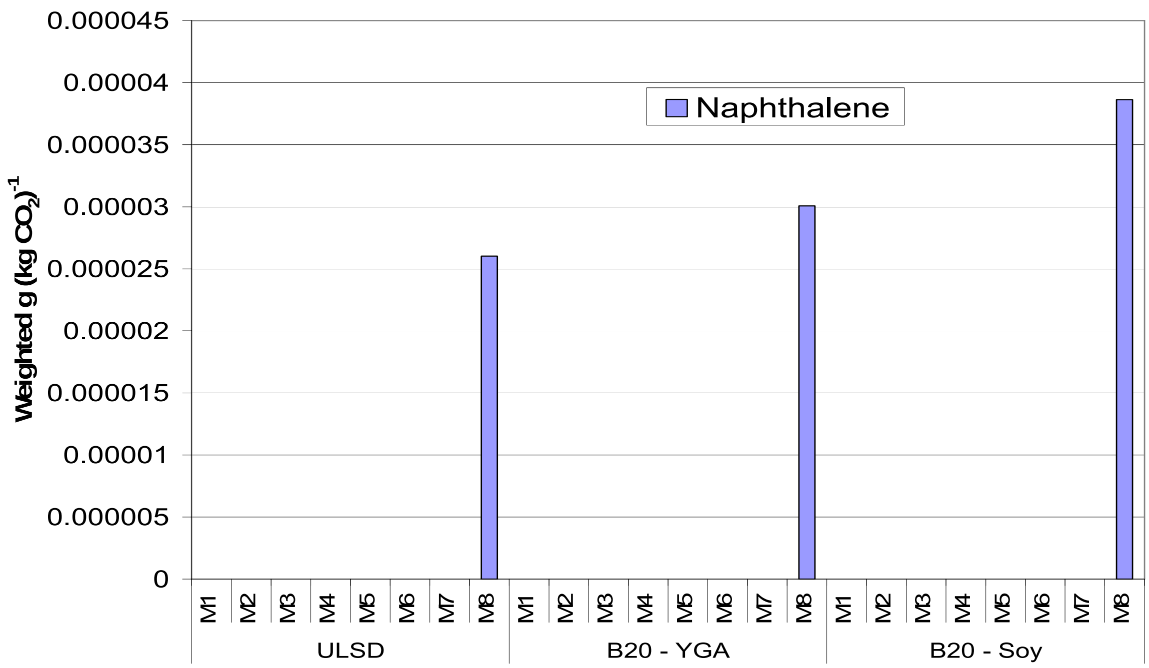


Figure 4.29
250 kW Generator Modal Naphthalene Emissions Weighted by Mode



Note: Only mode 8 emissions are reported

Figure 4.30
Bus Modal Naphthalene Emissions Weighted by Mode

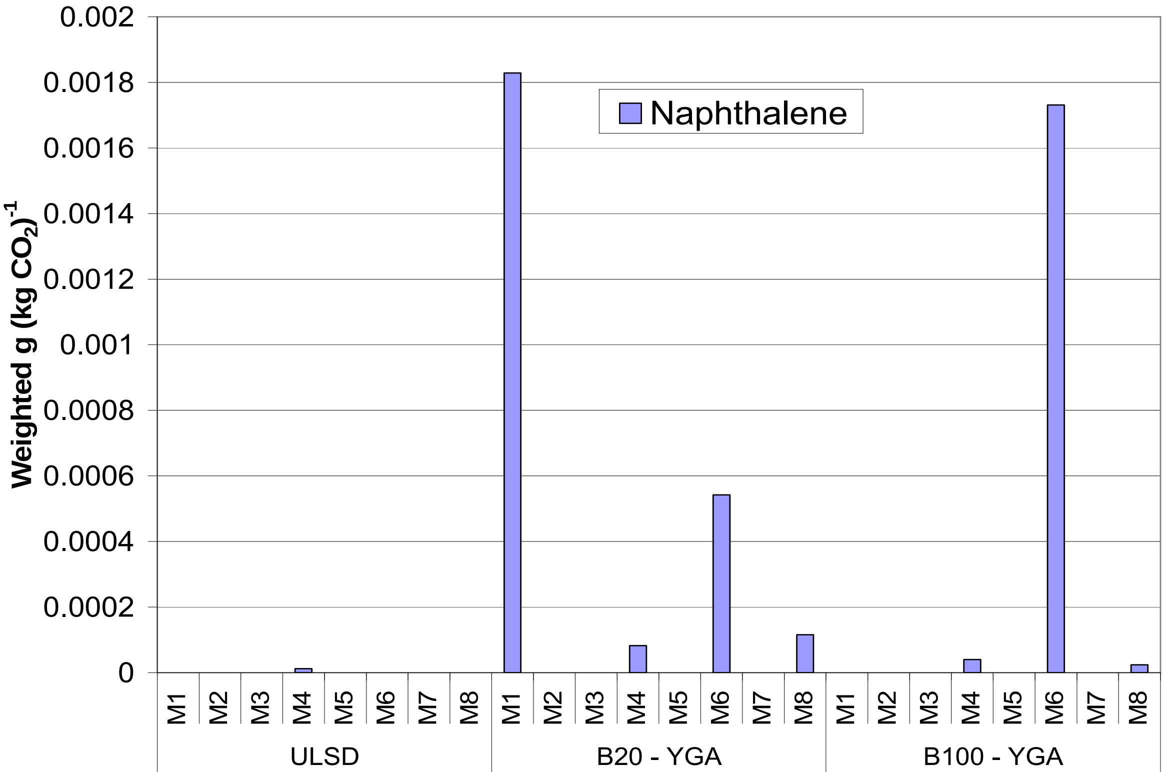


Figure 4.31
F9000 Modal Naphthalene Emissions Weighted by Mode

4.3.2.4 Statistical Analysis of Fuel Effects for Unregulated Emissions

A detailed statistical analysis was performed to determine the significance of measured fuel effects. Since speciation data is not available for all modes, analyses and comparisons based on weighted values could not be conducted for the species. To provide some understanding of potential trends, a paired t-test was conducted using all the data modes with the vehicle/fuel average data for each mode. Since the analyses are conducted over a wider range of mode representing different operating conditions, a more stringent criteria for statistical significance of p=0.01 was applied for statistically significant differences, p=0.05 used for marginally statistically significant results. Table 4.5 below summarizes the findings for the three engines. Cells blacked out indicate that insufficient data was collected for analyses of fuel effects, cells highlighted in yellow are those compounds that have a fuel effect (>95% confidence). All white cells indicate that measured fuel effects were ***not*** statistically significant. An insufficient number of FTP tests were performed to report significant statistical information on the Humvee. Although some differences were found to exist for specific vehicle/fuel combination comparisons, no consistent trends were observed for the data.

Table 4.5
Summary of Emissions Changes and Statistics Relative to ULSD for HAPs

	Engine		EC	OC	TC	Acet-aldehyde	Acrolein	Benzene	Buta-diene	Formald-ehyde	Naph-thalene
YGA 20%	Camp Pendleton Bus	% change	-11.834	4.459	-3.697	21.702				14.704	
		t-test	0.124	0.792	0.158	0.232				0.018	
	F9000	% change	5.808	-16.481	-1.979	-36.934	1110.738	538.116		-46.037	547.751
		t-test	0.637	0.178	0.694	0.043	0.195	0.456		0.018	**
	250 kW Generator	% change				44.218	-39.649			36.667	36.767
		t-test				0.239	0.117			0.411	0.819
	Humvee	% change				19.59	24.65	-9.8	55.31	13.28	
		t-test						0.014	0.002		
YGA 100%	F9000	% change	-79.174	-31.298	-64.190	-47.235	235.889	411.028		-53.932	214.207
		t-test	0.006	0.171	0.022	0.264	0.193	0.360		0.271	**
	250 kW Generator	% change				36.300	-6.526			44.306	31.096
		t-test				0.016	0.552			0.015	0.631
	Humvee	% change						-16.13	83.48		
		t-test						0.533			
Soy B20	Camp Pendleton Bus	% change	-11.834	4.459	-3.697	21.702	29.551			14.704	48.443
		t-test	0.124	0.792	0.158	0.232	**			0.018	**

** Only one mode acquired, insufficient data for t-test calculation
99% confidence level – statistically significant - $p \leq 0.05$
95% confidence level – marginally statistically significant - $\leq 0.05\ p \leq 0.10$
data insufficient for statistical analysis

5. Cost Assessment

5.1 Cost Reporting

Implementing a biodiesel fueling program represents new additional operational costs over existing petroleum diesel fueling activities. The advantage of implementing a biodiesel program over other potential alternative fuels is that biodiesel can be used in most existing diesel engines without modifications to either the engine or fuel storage system and that the fuel can be dispensed from existing fueling stations. Thus a biodiesel program should have very small start-up costs. These benefits are not available for competing alternate fuels such as hydrogen or compressed natural gas. The only direct cost for implementing a biodiesel program is the price difference of the fuel, taking into account the slight decrease in fuel economy with biodiesel, which for most fleets will not be noticeable. As of the preparation date of this Final Report, the average national difference between the commercial price of petroleum diesel and B20 is $0.17 per gallon of fuel. For federal government fleets, the Defense Energy Support Center currently charges a $0.14 per gallon premium for B20.

In terms of indirect environmental costs, NFESC has not been able to identify any costs that would change with biodiesel use. For example, permitting and spill plan requirements for fuel dispensing and storage operations would be the same. The only way that biodiesel use will affect environmental compliance costs is in the area of AFV credits. Since the federal government is mandated to purchase AFVs, satisfying this requirement through the use of biodiesel can minimize this program's compliance costs. Assigning a value to an AFV is, however, very difficult. NFESC is not aware of any value assigned to an AFV credit that has been reported in the literature.

Since the fuel cost is the only identified cost difference between the use of petroleum and biodiesel, this is the only cost information that has been entered into Table 5.1. No attempt has been made in the table to use the Environmental Cost Analysis Methodology (ECAM) developed by the National Defense Center for Environmental Excellence. The reasons the ECAM was not used is that it is not required for incorporating the fuel cost information. Cost information for competing alternate fuels will not be incorporated into Table 5.1 since the purpose of this ESTCP project is to obtain air emissions data for biodiesel, and not to justify its use in place of another alternative fuel.

Table 5.1
Types of Costs by Category

Direct Environmental Activity Process Costs				**Indirect Environmental Activity Costs**		**Other Costs**	
Start-Up		**Operation & Maintenance**					
Activity	$	Activity	$/gal	Activity	$	Activity	$
		Fuel Purchase (Price Difference)	$0.14				

5.2 Cost Analysis

Currently many DoDoperated non-tactical diesel powered engines are fueled with low sulfur diesel fuel made from petroleum. This is rapidly changing as new B20 biodiesel programs are rolled out throughout DoD. Tactical engines are fueled with JP-8, a higher sulfur containing fuel also derived from petroleum. Starting in 2006, the EPA has mandated that on-road diesel powered vehicles use ULSD. Since this new mandate will be implemented after the completion of this project, the costs for biodiesel will be not be compared to ULSD. As previously discussed in paragraph 5.1, cost information for competing alternate fuels will not be incorporated into the final reports since the purpose of this ESTCP project is to obtain air emissions data for biodiesel, and not to justify its use in place of another alternate fuel.

The retail price of biodiesel reflects its distribution and manufacturing costs, the profit for the distributors and producers as well as the fact that given the current biodiesel demand/supply balance, buyers are generally willing to pay a premium over the price of petroleum diesel. The manufacturing costs are primarily driven by the cost of the raw material vegetable oil. At current soybean oil prices, the oil costs a little over one half the retail price of biodiesel. Generally, the manufacturing cost for making the biodiesel is proprietary information, however, it is believed to be decreasing in recent years as the biodiesel market has developed. This trend is expected to continue for, at least, the next few years.

The costs and differences in cost between petroleum diesel and biodiesel continuously change over the course of time. Petroleum diesel costs are driven by the world cost of crude oil, the oil refining markup and any local supply/demand imbalances. Since biodiesel consumed in the United States is primarily made from virgin soybean oil, its cost is driven by this commodity's price, as well as any local supply/demand imbalances. Currently, the cost of soybean oil for use in the manufacture of biodiesel has been lowered through a $1.00 per gallon direct federal subsidy. The duration and extent of future subsidies is unknown.

In summary, the life-cycle costs for implementing a biodiesel fueling program are totally dependant on the difference in cost between the two fuels. Assuming that the cost for crude oil increases faster than that of soybean oil, the price premium for biodiesel should decrease in the future. This cost difference between petroleum diesel and biodiesel may or may not be important based on any future mandates to use alternate fuels. In this case, the costs for biodiesel must be compared to that of the other alternate fuels.

6. Implementation Issues

6.1 Environmental Checklist

Performance of a biodiesel emissions testing or implementation program for diesel-powered vehicles is not expected to require any new environmental permits nor permit changes since no existing pollution control equipment will be modified or removed. This lack of requirements for permitting actions may not be the case for stationary engines. Stationary-source diesel emissions are regulated differently from mobile sources. Generally, they are permitted by state and local air pollution control agencies with unique requirements. Depending on the use of the engine (prime power or standby) and whether or not it is located within a designated air pollution non-attainment area, the switch to biodiesel could potentially trigger a requirement for a permit change. Since each permit is unique, an assessment must be made on a case-by-case basis prior to testing or implementing a biodiesel project on a stationary diesel-powered engine. The project team will work with the owners of stationary diesel engines to be tested to ensure that any required air emissions permit changes are approved prior to initiating testing.

6.2 Other Regulatory Issues

At the beginning of the project CARB and EPA were given a chance to review our project demonstration plan and make suggestions on changes that would provide significant value to their organizations. Both agencies were invited to attend the project's kickoff meeting. At the conclusion of this demonstration project, these same organizations will be given a copy of the ESTCP final report.

In addition to the planned coordination with the environmental regulatory agencies, NFESC also plans to work with the National Biodiesel Board. The purpose of this coordination is to ensure that this ESTCP project does not duplicate other current industry or academic efforts and to assist with the dissemination of project results to interested parties in the biodiesel industry. The participation of other non-government organizations will be encouraged and is actively being investigated.

6.3 End-User Issues

The end users of this project will be DoD diesel-powered fleet operators and the DoD diesel fuel suppliers, primarily DLA. Their primary focus with implementing biodiesel fueling programs concern the issues of fuel availability, cost, performance, and environmental regulation. Negative results in any of these areas, will stop an implementation program in its tracks.

Biodiesel may be manufactured from a multitude of agricultural raw materials; however, biodiesel fuel made from virgin soybean oil is the most common type. Although this fuel is overwhelmingly manufactured in the midwestern states, near where the soybeans are grown, it is widely available throughout the continental United States. Significant increases in DoD use of this fuel are not expected to greatly change its supply/demand balance. Unfortunately, at this time, virgin soybean biodiesel costs more than petroleum diesel.

Another potential source of biodiesel is that made from yellow grease. This fuel has an advantage in that it is currently cost competitive with petroleum. As the market for yellow grease is in its early stage of development, this fuel is not widely available. It is generally not used by DoD even though its use have been approved by the Defense Energy Support Center, the primary DoD fuel supplier.

Since B20 biodiesel has an approximately 1.7 % lower fuel energy content per gallon of fuel than petroleum diesel, a small decrease in fuel economy, as measured in miles per gallon, may occur with its use. Fleet operators do not; however, expect any noticeable decrease in engine performance nor any increase in required maintenance. Based on previous biodiesel implementation efforts these performance expectations should be met.

In the area of environmental regulatory compliance, the DoD fleet operator is not expected to face any implementation barriers, just benefits. DoD fleet operators are required to purchase 75 percent of their light duty vehicles capable of operating on alternative fuels. For every 2,250 gallons of B20 biodiesel fuel used on vehicles weighing more that 8,500 pounds, one AFV credit is allowed. Since the use of biodiesel will not require any infrastructure upgrades, its widespread implementation is an easy way to earn AFV credits and thus avoid other costly options such as the use of natural gas powered vehicles.

In addition to these current regulatory issues, it is expected that some form of air pollution reductions will be mandated for existing diesel engines particularly in the area of PM emissions. Since B20 biodiesel has been reported to reduce PM emissions when compared with current low sulfur Diesel Fuel No. 2 (see Table 2.1), the DoD fleet operator may avoid other more costly retrofit requirements.

To ensure that project results are transitioned to DoD fleet operators, the transition plan for this project will involve publicizing the test results in various forms that are readily available to DoD and regulatory decision makers. This publicizing effort will include providing a copy of the final report to the National Biodiesel Board as well as making a presentation of the results at the National Biodiesel Board annual brainstorming session. Since the DLA controls the accepted DoD buy list, NFESC will work with that organization to ensure that potential biodiesel users fully understand its potential benefits.

To reach potential DoD interested parties, NFESC has presented project results at the annual Joint Service Environmental Management Conference as well as a regional Air and Waste Management Association and Federal Laboratory Consortium Conference. Currently, NFESC produces a number of products supporting the transition of technologies to the Navy and other DoD customers. These products include generating environmental quality initiative fact sheets, Currents Magazine articles, Pollution Prevention Technical Library data sheets, pocket cards, user data packages, technical reports, technology implementation plans and a point of contact (POC) list of potential customers. Project results will also be posted on the Defense Environmental Network & Information Exchange (DENIX). Potential non-DoD interests will be informed of the results of the project by submitting articles for publication in applicable trade publications and technical journals, as well as using the National Biodiesel Board to disseminate information.

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8. Points of Contact

Table 8.1
Points of Contact

POINT OF CONTACT Name	ORGANIZATION Name Address	Phone/Fax/Email	Role in Project
Bruce Holden	NFESC 1100 23RD Avenue Port Hueneme, CA. 93043	(805) 982-6050 (voice) (805) 982-1409 (fax) bruce.holden@navy.mil	Principal Investigator
Dr. Norman Helgeson	NFESC 1100 23RD Avenue Port Hueneme, CA. 93043	(805) 982-1335 (voice) (805) 982-4832 (fax) norman.helgeson@navy.mil	Quality Assurance Officer
Jason Jack	U.S. Army Aberdeen Test Center CSTE-DTC-AT-SL-S 400 Colleran Road APG, MD. 21005-5059	(410) 278-4045(voice) (410) 278-1589(fax) Jason.jack@atc.army.mil	Environmental Scientist
Dr. Wayne Miller	University of California, Riverside CE-CERT 1084 Columbia Ave. Riverside, CA. 92507	(909) 781-5579 (voice) (909) 781-5590 (fax) wayne@cert.ucr.edu	Director Emissions & Fuels Research Laboratory
Dr. Tom Durbin	University of California, Riverside CE-CERT 1084 Columbia Ave. Riverside, CA. 92507	(909) 781-5794 (voice) (909) 781-5590 (fax) durbin@cert.ucr.edu	Associate Research Engineer
Bob Hayes	ReFUEL Lab - National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401	(303) 275-3143 (voice) (303) 275-3147 (fax) Bob_Hayes@nrel.gov	Senior Engineer

Appendix A
Photographs of Test Engines and Equipment

Military Humvee in the UCR Vehicle Emissions Research Laboratory

Ford F350 Pick-up Truck in the UCR Vehicle Emissions Research Laboratory

Ford F9000 Truck Pulling the CE-CERT Mobile Emissions Laboratory

Camp Pendleton Bus at Heavy-Duty Chassis Facility

Ford F700 Truck at Heavy-Duty Chassis Facility

Military Generator Testing with CE-CERT Mobile Emissions Laboratory

Aircraft Tow Tractor Testing with ATC Rover System

Cheyenne Mountain Air Force Base Bus Being Tested at the National Renewable Energy Laboratory in Denver, CO

Hyster Forklift Being Tested at ATC

Appendix B
Data Quality Assurance/Quality Control Plan

B.1 Purpose and Scope of the Plan

The purpose of the Quality Assurance (QA) plan is to ensure that the data collected during this demonstration project is of sufficient quality to fulfill the project objectives.

B.2 Quality Assurance Responsibilities

The primary responsibility for Quality Assurance belongs to each project performer. However, Dr. Norman Helgeson, an NFESF engineer will serve as the project's Quality Assurance Officer. A NFESC senior engineer, not directly involved in the project, will provide peer review of the final report.

B.3 Data Quality Parameters

Gaseous air emissions will be collected using electronic instruments with the results directly transferred to a computer. For the ATC tests utilizing the EPA's ROVER system, two NOx gas analyzers are employed. Data averaging and integration functions will be performed within the computer. Emission results for each of the gaseous criteria pollutants will be transferred to and stored in a laboratory notebook maintained for this project. Since the measured quantities are time sensitive, sample storage and re-testing is not possible. Weight records for PM collections will likewise be recorded in the project's laboratory notebook. At each test condition, a minimum of two tests will be performed. If the results from any test differ more than the expected standard deviation from an equivalent previous test, an investigation will be performed to try and identify any test equipment or other problems.

The chosen test cycles must satisfy two needs. They must closely represent the actual duty cycle placed on the engine while also being a cycle commonly reported in the literature so that testing results can be compared with those from other investigations. Since these two needs are not equivalent, the chosen test cycle(s) represents a compromise.

B.4 Calibration Procedures, Quality Control Checks, and Corrective Action

All the project's air emissions measuring instruments including the gaseous sampling equipment and the analytical balances used for weighing the PM samples are maintained under calibration programs run by the respective testing organizations. Quality inspections that are mandated by the CFR, such as propane balances within the CVS system, are run weekly and corrective actions taken as needed. Prior to each test performed by ATC using the ROVER, gas calibrations and pressure checks are completed and recorded to verify accurate installation of the system and accuracy of its components. In addition to the test instruments calibration, the dynamometers and electric load banks used to set the engine load points will be checked prior to each use. As previously stated, testing at each testing condition will be repeated a minimum of two times. Most test data will be collected electronically with a computer integrating and averaging the data. Other data will be directly recorded in a laboratory notebook. Data will be reported in tabular format using standard units so that it can easily be compared with results from other investigations

B.5 Demonstration Procedures

The test of each engine will begin with either the vehicle being transported to the testing laboratory or field-testing instruments brought to the engine to be tested. It is expected, that in total, testing can be completed on each engine within a five week time period. Problems with the testing equipment or the engine will be addressed on a case-by-case basis.

Since multiple fuels will be tested on each engine, the testing organizations will be required to mix and store fuels as well as performing multiple filling and draining of fuel systems. All fuels for the project will be distributed out of a central storage location. Commercial fuel transporters will be used.

B.6 Calculation of Data Quality Indicators

Data quality will be determined by comparing test results from identical test conditions, by comparing the results with those from previous investigations, and finally by comparing the results with the EPA models (see Reference 7.1). In addition, UCR maintains quality control charting of the calibration gases for both the light- and heavy-duty emissions laboratories. Such charts allow for the taking of corrective actions when the system is out of control as defined in the quality manuals. For example, five points in a row below the mean value will require a corrective action, even though the measured value is within the upper and lower control limits.

B.7 Performance and System Audits

To ensure that the collected data represents the actual system conditions, an NFESC engineer/scientist, Dr. Norman Helgeson will independently audit the emissions measuring techniques. The purpose of this audit is to ensure that the measuring method accurately reflects the actual demonstration conditions. The audit will consist of laboratory and field measurement reviews, review of instrument calibration certifications and a specific review of the air emissions measuring procedure. It is expected that one audit will be completed.

During 2002, the EPA conducted a quality audit of the light- and heavy-duty laboratories at UCR and both were found to conform within the expected specifications for QA/QC. Additionally, the light-duty laboratory participates in an annual cross-laboratory round robin wherein a vehicle is tested at up to 25 laboratories. In each of the last two years, the UCR laboratory has measured values well within the variation of all the participating laboratories. In addition, the heavy-duty laboratory was verified by comparing the values obtained in the CARB heavy-duty laboratory with those of the UCR laboratory. Agreement was within the values found in a recent publication for a round robin study.

B.8 Quality Assurance Reports

It is expected that one audit will be completed. Any significant results from the Performance and System Audit will be incorporated into the final project reports. Quality assurance status reports will not be prepared. This decision is based on the testing organizations long history of successfully performing similar testing operations.

B.9 ISO 14001

NFESC, the principle organization responsible for this demonstration, is not ISO 14001 certified. UCR likewise is not ISO 14001 certified, however, it has a Quality Plan prepared for its organization, and the light-duty and heavy-duty laboratories have a number of SOPs and quality control practices that are followed for all test programs. ATC is in the process of obtaining ISO 14001 certification. At the time of the preparation of this demonstration plan it is not known when the certification will be obtained.

B.10 Data Format

Test data will be acquired both electronically and on paper. At UCR, gaseous emissions are measured continuously from a number of instruments and the results stored on a computer disk within the light- and heavy-duty laboratories. These data are stored along with frequent calibrations of the instruments using calibration gases that are generated in a gas divider. Other data for the integrated PM mass or for HAPs are measured off-line and then integrated into the data page where the averages for the continuous gaseous measurements.

ATC ROVER test data is electronically generated in spreadsheet format. A data point is generated for each second of the test. This raw data will be submitted along with a separate ATC test record to the principal investigator for review.

B.11 Data Storage and Archiving Procedure

All correspondence, documentation, raw data, and records generated as a result of this demonstration project will be maintained on site by the Principal Investigator for a period of one year after projection completion. The information will be collected in its originally generated form (i.e. paper or electronic). The ESTCP Final Report, in paper and electronic versions, will be maintained by the NFESC Technical Information Center. The POC for the Technical Information Center is Bryan Thompson at (805) 982-1124