ESTCP
Cost and Performance Report

(WP-200728)

Demonstration of Biodiesel in Ground Tactical Vehicles and Equipment

May 2014

This document has been cleared for public release; Distribution Statement A

ESTCP

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense

COST & PERFORMANCE REPORT
Project: WP-200728

TABLE OF CONTENTS

Page

EXECUTIVE SUMMARY ES-1

1.0 INTRODUCTION 1
- 1.1 BACKGROUND 1
- 1.2 OBJECTIVES OF THE DEMONSTRATION 2
- 1.3 REGULATORY DRIVERS 3

2.0 DEMONSTRATION TECHNOLOGY 6
- 2.1 TECHNOLOGY DESCRIPTION 6
- 2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY 9

3.0 PERFORMANCE OBJECTIVES 12

4.0 SITE/PLATFORM DESCRIPTION 14
- 4.1 TEST FACILITIES & PRESENT OPERATIONS 14
  - 4.1.1 MOODY AIR FORCE BASE 14
  - 4.1.2 U.S. MARINE CORPS 29 PALMS 14
  - 4.1.3 NBVC PORT HUENEME 15
  - 4.1.4 NSWC CRANE 15
  - 4.1.5 MCBH KANEOHE BAY 15
- 4.2 SITE-RELATED PERMITS AND REGULATIONS 15

5.0 TEST DESIGN 16
- 5.1 SAMPLING PROTOCOL 16
  - 5.1.1 OIL SAMPLING PROCEDURE 16
  - 5.1.2 FUEL SAMPLING PROCEDURE 16
- 5.2 ANALYSIS OF FUEL SAMPLE 17
- 5.3 ANALYSIS OF OIL SAMPLES 18
- 5.4 OPERATIONAL TESTING 18
  - 5.4.1 VEHICLE PREPARATION 18
- 5.5 VEHICLE USAGE 19

6.0 PERFORMANCE ASSESSMENT 20
- 6.1 B20 DATA 20
- 6.2 SUMMARY OF RESULTS 20
  - 6.2.1 FUEL DATA 20
  - 6.2.2 OIL DATA 26
  - 6.2.3 TACTICAL BIODIESEL DATABASE 27
  - 6.2.4 VEHICLE OPERATOR OBSERVATIONS 27

TABLE OF CONTENTS (continued)

Page

7.0 COST ASSESSMENT 28
7.1 COST MODEL 28
7.2 COST ANALYSIS AND COMPARISON 28

8.0 IMPLEMENTATION ISSUES 32

9.0 REFERENCES XXXVI

APPENDIX A POINTS OF CONTACT A-1

LIST OF FIGURES

Page

Figure 1. Typical biodiesel production, delivery, and use chain 7
Figure 2. Fuel price per gallon over time. 9
Figure 3. B20 acid number results for the storage tank samples. 20
Figure 4. B20 acid number results for vehicle samples. 21
Figure 5. Total water content for dispenser samples. 21
Figure 6. Total water content results for the vehicle samples. 22
Figure 7. B20 particulate content results for storage tank samples. 23
Figure 8. B20 particulate content results for vehicle samples. 23
Figure 9. B20 Rancimat oxidation stability results for storage tank samples. 24
Figure 10. B20 Rancimat oxidation stability results for the vehicle samples. 25
Figure 11. Engine oil viscosity results for NSWC crane vehicles. 26
Figure 12. Engine oil water content results for NSWC crane vehicles. 27

LIST OF TABLES

Page

Table 1. Performance criteria. 12
Table 2. Delivery sample testing methods. 17
Table 3. Testing for monthly storage and vehicle tank samples 18
Table 4. Oil testing methods. 18
Table 5. Vehicle usage plan by base location. 19
Table 6. Army CONUS ground tactical vehicles and fuel use. 29
Table 7. Performance of vehicles at the five installations. 34

ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
AFPET	Air Force Petroleum Office
ASN I&E	Assistant Secretary of the Navy Installations and Environment
ASTM	American Society for Testing and Materials International
AVGP	Armored Vehicle General Purpose
CAA	Clean Air Act
CNO	Chief of Naval Operations
CONUS	Continental United States
CTC	Concurrent Technologies Corporation
DF-2	Diesel Fuel grade #2 (ASTM D975 Grade 2-D)
DLA	Defense Logistics Agency
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DS1	ULDSF Grade 1 (ASTM D975 Grade 1-D S15)
DS2	ULDSF Grade 2 (ASTM D975 Grade 2-D S15)
EMA	Truck and Engine Manufacturers Association
EO	Executive Order
EPA	U.S. Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
FY	fiscal year
GSA	General Services Administration
HEMTT	Heavy Expanded Mobility Tactical Truck
HMMWV	High Mobility Multipurpose Wheeled Vehicle (aka HUMVEE)
H.R.	House of Representatives
ID	identification
JG-PP	Joint Group on Pollution Prevention
JOAP	Joint Oil Analysis Program
JP-8	jet propulsion grade 8 fuel
LSDF	low sulfur diesel fuel
MCAGCC	Marine Corps Air Ground Combat Center
MCBH	Marine Corps Base Hawaii
mpg	miles per gallon
MTV	Medium Tactical Vehicle

ACRONYMS AND ABBREVIATIONS (continued)

MTVR	Medium Tactical Vehicle Replacement
NAVAIR	Naval Air Systems Command
NAVFAC	Naval Facilities Engineering Command
NAVFAC EXWC	Naval Facilities Engineering and Expeditionary Warfare Center
NBVC	Naval Base Ventura County
NDCEE	National Defense Center for Energy and Environment
NESDI	Navy Environmental Sustainability Development to Integration
nPAH	nitrated polycyclic aromatic hydrocarbons
NREL	National Renewable Energy Laboratory
NSWC	Naval Surface Warfare Center
O&M	operations & maintenance
OEM	Original Equipment Manufacturer
OCONUS	Outside Continental United States
PAH	polycyclic aromatic hydrocarbons
POL	Petroleum, Oil, Lubricant
RDECOM	Research, Development and Engineering Command
RFS	Renewable Fuel Standard
SERDP	Strategic Environmental Research and Development Program
SwRI	Southwest Research Institute
TARDEC	Tank Automotive Research, Development and Engineering Center
TRAM	Tractor, Rubber Tired, Articulated Steering, Multi-Purpose
ULSDF	Ultra-Low-Sulfur Diesel Fuel
U.S.	United States
USAMC	U.S. Army Material Command
USDA	U.S. Department of Agriculture

ACKNOWLEDGEMENTS

The author of this report acknowledges the following for their support:

- Dr. Jeffrey Marqusee and Bruce D. Sartwell – Strategic Environmental Research and Development Program (SERDP)/Environmental Security Technology Certification Program (ESTCP)
- Leslie A. Karr, P.E. – Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC), Navy Environmental Sustainability Development to Integration (NESDI) Program
- Kurt Bueler, P.E., David Cook, Douglas Petrie, and Jamie Lerma – NAVFAC EXWC
- Scott Mauro, P.E. – Naval Facilities Engineering Command (NAVFAC)
- Benet R. Curtis, Emilio S. Alfaro, and 2nd Lt. Irizarry C. Aurelio – Air Force Petroleum Agency
- Omar Mendoza – Air Force Research Laboratory
- Adam Watson – Naval Audit Service
- COL William M. Jr. Black, Robert W. Appleton, Jr., and Bob Lusardi – U.S. Army Material Command (USAMC) Light Armored Vehicles
- Richard A. Kamin – Chief of Naval Operations (CNO)/Naval Air Systems Command (NAVAIR)
- Sherry Williams – NAVAIR
- Luis Villahermosa and Lori Bolster – U.S. Army Research, Development and Engineering Command (RDECOM)-Tank Automotive Research, Development and Engineering Center (TARDEC)
- Edward H. Campbell and Major Alan F. Crouch – Marine Corps Base Hawaii (MCBH), Kaneohe Bay
- Phil Chambers – Marine Corps Air Ground Combat Center (MCAGCC), 29 Palms
- Richard Cramer – Naval Surface Warfare Center (NSWC) Crane
- George C. Handy II, Kevin Merichko, Leanne Debias, and Milissa Pavlik – Concurrent Technologies Corporation (CTC)
- Steven Westbrook – Southwest Research Institute (SwRI)
- Don Stits – Defense Logistics Agency (DLA)
- MSgt Donald L. Grow Jr. and Marion J. Mitchell – Moody Air Force Base (AFB)
- Hind Abi-Akar – Caterpillar Inc.
- Jenna Long and Kelly King – Pacific Biodiesel
- Reggie Kamei – Aloha Petroleum
- Russell Whang – Mid Pac Petroleum
- COL RET Howard Killian – Deputy Assistant Secretary of the Army
- SFC Juan Silva – Fort Shafter
- Leland Tong – National Biodiesel Board
- Robert L. McCormick – National Renewable Energy Laboratory (NREL)
- Naval Construction Training Center, Naval Base Ventura County (NBVC)

Technical material contained in this report has been approved for public release.
Mention of trade names or commercial products in this report is for informational purposes only; no endorsement or recommendation is implied.

This page left blank intentionally.

EXECUTIVE SUMMARY

The major objective of this project was to demonstrate and validate the use of B20 in tactical vehicles by addressing users concerns as stated in the March 2006 Position Statement written by the Tri-Service Petroleum, Oil, Lubricant (POL) Users Group – which is comprised of representatives from the Army, Navy, and Air Force.

Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC) investigated biodiesel as a usable green technology in military ground tactical vehicles. Biodiesel is a clean-burning alternative fuel, produced from domestic, renewable resources. Biodiesel contains no petroleum, but it can be blended at any level with petroleum diesel fuel to create a biodiesel blend and it can be used in compression-ignition (diesel) engines with little or no modifications. Biodiesel refers to the pure fuel before blending with diesel fuel. Biodiesel blends are denoted as, "BXX" with "XX" representing the percentage of biodiesel contained in the blend (i.e., B20 is 20% biodiesel, 80% petroleum diesel fuel). The purpose of this investigation was to analyze and compare fuel samples and oil samples from vehicles using biofuels, specifically a B20 blend, against vehicles using standard petroleum diesel or jet propulsion grade 8 (JP-8) fuels, located at five military facilities across the United States (U.S.). Oil analysis data was received from U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) and fuel analysis was conducted by Concurrent Technologies Corporation (CTC).

Three types of fuel samples were collected and analyzed from each location. The first type, delivery samples, was taken from any new shipment of fuel to the test location. At some locations, the initial storage tank fill was the only delivery sample taken for that location. The delivery samples received more extensive testing than the other samples in order to assess the quality of the fuel against the B20 specification. The second type of sample collected was the storage tank or nozzle sample. These samples were taken on a monthly basis from the storage tank, generally through the nozzle that was used to fill the vehicle fuel tank. The third and final type of fuel sample was the vehicle tank sample. This sample was also taken on a monthly basis, directly from the test vehicle's fuel tank. Engine oil was also sampled on a monthly basis. Engine oil analysis data included measurements according to the procedures outlined in the Joint Oil Analysis Program (JOAP) Manual (Department of Defense, 2005). Testing results for both fuel and oil samples, and weather data from each location, were loaded into a database for project team and stakeholder access and review. Each location was requested to report any unscheduled maintenance.

This report provides a brief overview of the five participating military installations including seasonal temperature variations, climate classification (if available), and the number of fuel and oil samples that were taken at each site. This report also presents the step-by-step fuel and oil sampling plan that was provided to each location to ensure that accurate and uniform sampling and sample labeling was conducted across the five installations. Additionally, fuel and oil sample laboratory analysis, charts, quality assurance/quality control data, and weather data are included in the Appendices of the Final Report.

The Department of Defense (DoD) does not currently authorize B20 use in Tactical Fleets. During this demonstration, Medium Tactical Vehicle Replacement (MTVR) or 7-Ton Trucks,

High Mobility Multipurpose Wheeled Vehicles (HMMWV) (aka, HUMVEES), Tractor, Rubber Tired, Articulated Steering, Multi-Purpose (TRAM), and 2 of the 3 vehicles at Moody Air Force Base (AFB) (2008 Bobtail and a Refueler Truck) did not experience maintenance breakdowns. One vehicle at Moody AFB, a 1997 Bobtail, needed its fuel tank cleaned and the fuel sending unit rebuilt and cleaned at the end of the demonstration due to fuel breakdown.

The data gathered by this demonstration validates the March 2006 Tri-Service Biodiesel Position Paper, although it has been demonstrated that under certain circumstances (higher Rancimat, high vehicle usage) vehicles running on B20 did not have vehicle maintenance issues that were different than vehicles running on JP-8. The Tri-Service POL membership and Defense Logistics Agency (DLA) Energy have also stated that increasing the oxidative requirement for biodiesel is not feasible and limiting the use of B20 to a limited number of Continental United States (CONUS) operations is logistically impossible. Another important fact to consider is Original Equipment Manufacturers (OEM) will not honor warranties on engine breakdowns for vehicles running on biodiesel blends above 5%, so even if the engine breakdown cannot be directly tied to the use of B20, warranties on DoD vehicles will be voided due to use of B20.

Blanket approval for the use of B20 in all tactical vehicles would not be advised because the potential for problems over and above those typically encountered with petroleum fuels is higher with the use of biodiesel. The annual fuel savings and diverted oil based fuel only make a tiny impact on overall DoD fuel usage, and the fuel cost savings are quickly negated by a small percentage of vehicles having maintenance issues.

The maximum annual DoD fuel cost saving for switching from JP-8 to B20 is calculated to be $3,385,051 and the amount of fuel diverted from oil based to renewable is 5,207,771 gallons. The overall impact to DoD would be is less than 1% of the total use of JP-8 in DoD. Also, any cost saving derived from the difference in fuel cost between B20 and JP-8 can be quickly consumed by maintenance costs.

To reduce maintenance cost issues, a conversion from JP-8 to B20 in ground tactical fleets requires adding additional requirements to the current American Society for Testing and Materials International (ASTM) D7467 B20 specification to improve the fuel quality. Adding additional requirements may not be possible under the current acquisition process and would raise the cost of B20. This additional cost would probably negate any cost savings calculated using the current acquisition process. B20 should only be used in CONUS training operations that run continuously, so that B20 is not left in storage and vehicle tanks for more than one month. These additional requirements will be difficult and according to the DoD POL Users Group, non-implementable, but necessary to reduce the occurrences of maintenance issues if DoD activities decide to implement B20 in tactical fleets.

1.0 INTRODUCTION

1.1 BACKGROUND

Biodiesel is a clean-burning alternative fuel, produced from domestic, renewable resources. Biodiesel contains no petroleum, but it can be blended at any level with petroleum diesel fuel to create a biodiesel blend. It can be used in compression-ignition (diesel) engines with little or no modifications. Biodiesel is made through the chemical process of transesterification of fats and oils from numerous sources. The process leaves behind two products – fatty acid methyl esters (the chemical name for biodiesel) and glycerin (a valuable byproduct usually sold for use in soaps, cosmetics, and other products). Biodiesel is defined as "mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats" that conform to the American Society for Testing and Materials International (ASTM) D6751 biodiesel blend stock specification (Tyson and McCormick, 2009 and 2006). Biodiesel refers to the pure fuel before blending with diesel fuel. Biodiesel blends are denoted as, "BXX" with "XX" representing the percentage of biodiesel contained in the blend (i.e., B20 is 20% biodiesel, 80% petroleum diesel fuel). Biodiesel must be produced to strict industry specifications (ASTM D6751) in order to ensure proper performance. Biodiesel is the only alternative fuel to have fully completed the health effects testing requirements of the 1990 Clean Air Act (CAA) Amendments. Biodiesel that meets ASTM D6751 and is legally registered with the United States (U.S.) Environmental Protection Agency (EPA) is a legal motor fuel for sale and distribution. Research conducted in the U.S. shows biodiesel emissions have decreased levels of all target polycyclic aromatic hydrocarbons (PAH) and nitrated PAH (nPAH) compounds, as compared to petroleum diesel fuel exhaust. PAH and nPAH compounds have been identified as potential cancer causing compounds. Targeted PAH compounds were reduced by 13 percent. Target nPAH compounds were also reduced dramatically with biodiesel fuel, with 2-nitrofluorene and 1-nitropyrene reduced by 50 percent, and the rest of the nPAH compounds reduced to trace levels. All of these reductions are due to the fact the biodiesel fuel contains no aromatic compounds (National Biodiesel Board, 2012).

Damage to the Nation's petroleum infrastructure from hurricanes Katrina and Rita were major wakeup calls for sustainable fuel production. This damage showed just how vulnerable our Nation was to even minor disruptions to petroleum production and highlighted the need to develop alternatives to petroleum for private, commercial, and military energy supplies. On 13 September 2005, the Deputy Secretary of Defense issued a memorandum requiring that Military Departments take measures that will ultimately save fuel. This requirement was driven by a Presidential Memorandum seeking to reduce both short and long-term petroleum consumption to address projected shortages due to damage to petroleum production and refining capacity caused by Hurricane Katrina. On 14 November 2005, the Assistant Secretary of the Navy Installation and Environment (ASN I&E) issued policy guidance restating that B20 be used in all non-deployable, non-emergency, diesel vehicles. The policy also called for testing of B20 in non-deployed tactical fleet vehicles and support equipment beginning in 2007. This policy clearly articulated the ASN I&E goal of switching non-deployed tactical fleets to B20 as soon as sufficient information was available to ensure a relatively trouble free conversion. Because of the need for consistent fuels and fueling policies between services, it was appropriate to address these issues using the Environmental Security Technology Certification Program (ESTCP).

Federal agencies must also comply with Executive Order (EO) 13423, which was issued by President Bush in January 2007 and revoked EO 13149. Under EO 13423, agencies are required to:

- Reduce petroleum consumption by 2% annually through fiscal year (FY) 2015 compared to their FY 2005 baseline value.
- Increase alternative fuel use by at least 10% compounded annually through FY 2015 compared to their FY 2005 baseline value.

Although numerous U.S. Department of Defense (DoD) activities have implemented biodiesel-fueling programs for their non-tactical on-road diesel vehicle fleets, a number of organizations have been reluctant to implement B20 on tactical systems and stationary engines due to technical and logistical concerns. Using B20 in tactical equipment would require a change in policy. Existing policy designates a Single Fuel on the Battlefield policy for tactical vehicles. These military fuels included jet propellant fuels (jet propulsion grade 8 [JP-8]/JP-5/Jet A-1). JP-8 is used both in training and tactical operations in the Continental United States (CONUS) and Outside Continental United States (OCONUS) to ensure the military's operational readiness is secure. All of these military fuels are produced primarily from conventional petroleum resources (crude oil) and dependent on the supply of foreign oil. Although a switch to one fuel is the ultimate goal, many installations operate ground vehicles that are non-deployed assets (vehicles and equipment that only operate in CONUS) on petroleum diesel fuel, instead of JP-8.

Biodiesel was the only alternative fuel to voluntarily perform and pass EPA Tier I and Tier II testing to quantify emission characteristics and health effects. That study found that B20 (20% biodiesel blended with 80% conventional diesel fuel) reduced total hydrocarbons by up to 20%, carbon monoxide up to 12%, and total particulate matter up to 12%.

The Tri-Service Petroleum, Oil, Lubricant (POL) Users Group, comprising representatives from the Army, Navy, and Air Force, issued a position statement in March 2006 supporting the current prohibition against the use of B20 for tactical applications. It identified the following critical issues associated with the use of B20 in such applications:

1. Stability
2. High temperature properties
3. Low temperature properties
4. Water affinity
5. Material compatibility
6. Solvency

1.2 OBJECTIVES OF THE DEMONSTRATION

The major objective of this project was to demonstrate and validate the use of B20 in tactical vehicles by addressing users concerns as stated in the Tri-Service POL Users Group, March 2006 Position Statement. The group’s concerns were the stability of the biodiesel, accelerated deterioration of the biodiesel during periods of storage at higher ambient temperatures, vehicle operation and gelling of the biodiesel in low-temperature environments, water affinity, and

possible increased fuel contamination caused by biodiesel-dissolution of contaminants and sludge.

Subset objectives were also identified to further support the initial concerns. These additional objectives included:

- Developing and demonstrating tri-service operational parameters for using B20 in DoD ground tactical vehicles and equipment:
  - fuel quality
  - vehicle age
  - vehicle usage rate
  - maximum fuel storage limits
  - climate conditions
- Determining if DoD's existing fuel management infrastructure and handling procedures can satisfy user requirements,
- Establishing a minimum set of fuel quality tests for use by tactical fleet end users,
- Establishing B20 operational parameters, procedures, validated technologies (e.g., testing methods), and
- Summarizing lessons learned within a fleet user's guide published for existing administrative (non-deployable, non-emergency) vehicle and equipment use.

1.3 REGULATORY DRIVERS

The Energy Policy Act of 2005 amended the CAA to establish a Renewable Fuel Standard (RFS) program. A renewable fuel was defined by the EPA as a motor vehicle fuel that is produced from plant or animal products or wastes, as opposed to fossil fuel sources. Renewable fuels included ethanol, biodiesel and other motor vehicle fuels made from renewable sources. The Act also required that alternative fuel procurements have lower lifecycle greenhouse gas emissions than petroleum. The program grants credit for both renewable fuels blended into conventional gasoline or diesel and those used in their neat (unblended) form as motor vehicle fuel (EPA, 2013).

President Bush signed House of Representatives (H.R.) 6, the Energy Independence and Security Act of 2007 into law, expanding the RFS and the minimum amount of biofuels that will be used in the U.S. to 36 billion gallons by 2022 (H.R.6, 2007). The expanded RFS also implements a renewable requirement, specifically the use of biomass-based diesel fuel, like biodiesel, while requiring each agency to develop fueling infrastructure. At least one renewable fuel pump must have been installed at each Federal fleet-fueling center. DoD provided an exemption for sites using less than 100,000 gallons of fuel per year. The usage requirements for biomass-based diesel began at 500 million gallons per year in 2009 and will expand to 1 billion gallons in 2012. Beyond 2012, a minimum of 1 billion gallons must be used, and the amount can be set higher by the Administrator of the EPA, in consultation with the Secretary of the U.S. Department of Agriculture (USDA) and the Secretary of the U.S. Department of Energy (DOE) (Defense Energy Support Center, 2009).

This page left blank intentionally.

2.0 DEMONSTRATION TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

Biodiesel production is a mature technology with broad commercial use. Biodiesel can be made from a variety of animal or plant sources. For further details on biodiesel production methodologies, reference the National Renewable Energy Laboratory (NREL) publication NREL/SR-510-36244 "Biodiesel Production Technology" (Gerpen et al., 2004).

ASTM is a consensus based-standards group comprised of engine and fuel injection equipment companies, fuel producers, fuel users, government representatives (both Federal and State), and other groups. Their standards are recognized in the U.S. by most government entities, including states, charged with the responsibility of ensuring fuel quality. The specification for biodiesel (B100) is ASTM D6751. This specification is intended to ensure the quality of biodiesel to be used as a blend stock with diesel fuel at 20% and lower blend levels. Any biodiesel used in the U.S. for blending should meet ASTM D6751 requirements. ASTM developed a standard specification for B6 to B20 biodiesel blends, ASTM D7467 Standard Specification for Diesel Fuel Oil, Biodiesel Blend (B6 to B20).

The Truck and Engine Manufacturers Association (EMA) has developed a test specification for biodiesel blends up to B20 (Engine Manufacturers Association, 2006). An important aspect of the EMA specification is that it contains minimum standards for fuel stability. The Original Equipment Manufacturer (OEM) specification for biodiesel blends is more stringent than ASTM.

B20 was mandated for use in administrative diesel vehicles (non-deployable, non-emergency) that represent a small percentage of the vehicles used by the DoD in CONUS. Biodiesel blend use is common throughout the U.S. and throughout the world.

B20 blends have a recommended storage life of 6 months maximum. The actual useful life of a biodiesel blend is dependent upon the fuel quality and storage tank management. The storage life of the biodiesel blends is rarely a factor in commercial use. Commercial biodiesel blends are typically consumed quickly, rarely allowing the fuel to remain in storage longer than a month or two. Expended fuel is typically restocked within a week. Though the use of biodiesel blend fuels is common throughout the U.S., few applications are similar to military operations. For example, military training operations utilize fuel in an intermittent fashion, unlike the more steady use rate for non-military users. Military use rates are also dependent upon the scope of the training operation.

Figure 1 shows the path that biodiesel takes from B100 producer to end user. The B100 is usually tested by the producer to confirm specification compliance. The blender may also perform minimal testing to confirm the quality of the B100. From the blenders' facility, the blend is usually trucked to the installation storage tank before it is delivered to the vehicle.

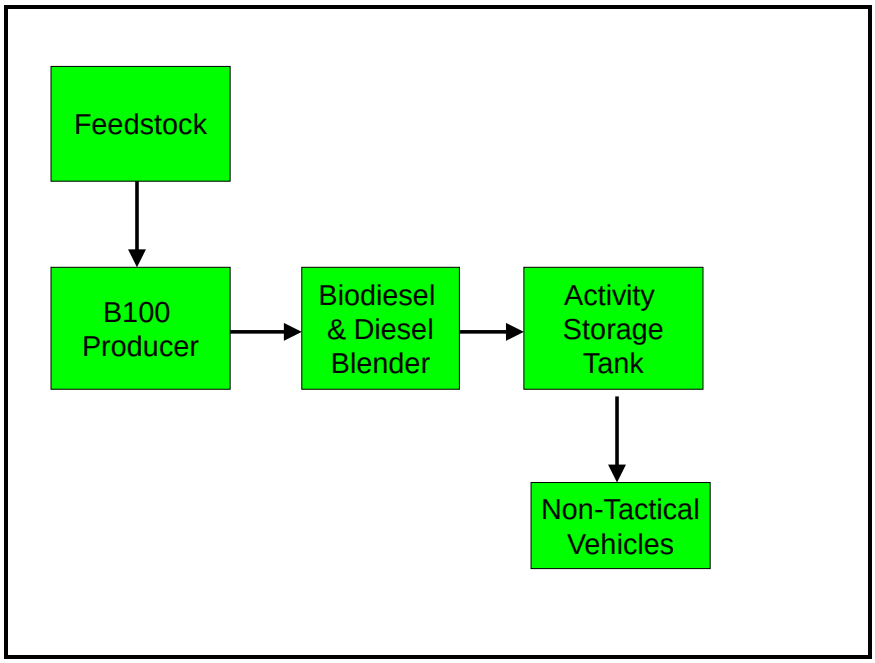

Figure 1. Typical biodiesel production, delivery, and use chain.

A 1995 Biodiesel Fuel Evaluation for U.S. Army Tactical Wheeled Vehicles compared vehicle system performance for vehicles operating with an 80/20 percent JP-8/Biodiesel fuel blend instead of neat (or 100%) JP-8 fuel (Lucas, 1995). The vehicles also operated on Diesel Fuel grade #2 (DF-2). The results of the evaluation were mixed. Vehicles generally operated equally well during acceleration and pull-bar tests. During the endurance testing some vehicle engines were running poorly shortly after the biodiesel blend was introduced into the fuel system. Plugged fuel filters were the cause of incidents. The report concluded that increased solvency of the biodiesel blend dissolved dirt deposits left behind from when the vehicles were running on DF-2. The suspended dirt became trapped in the filters, restricting fuel flow, and making the engines run inadequately. After changing the fuel filters, either as a corrective or preventive measure, the engines ran normally.

A comprehensive vehicle study examining the benefits of using a 20% soy biodiesel blend (B20) in a commercial, over-the-road trucking company is the “2 Million Mile Haul” (Heck, 2007). The study had a goal to demonstrate that a biodiesel blend can be successfully used year-round, even during winter driving conditions. The study was sponsored by the Soy Iowa Central Community College and Decker Truck Line, Inc. They have collaborated together with Renewable Energy Group, Caterpillar Engine Company, the Iowa Soybean Association, the National Biodiesel Board, and the USDA. The preliminary result of the study found that B20 can be used effectively year round, although fuel filter plugging did increase in the winter, between October 2006 and April 2007.

A NREL 2006 study, “100,000 Mile Evaluation of Transit Buses Operated on Biodiesel Blends (B20)” evaluated the emissions, fuel economy, and maintenance of five 40-foot transit buses operated on B20, compared to four buses operated on petroleum diesel fuel (Proc et al., 2006). In

the 100,000-mile evaluation of transit buses operated on B20, the following operational differences were found related:

- The fuel economy for both petroleum diesel fuel and B20 groups was 4.41 miles per gallon (mpg) based on in-use fleet data. An approximately 2% reduction in fuel economy for B20 was measured in laboratory emission testing.
- Total maintenance costs per mile were $0.54 for the diesel group and $0.51 for the B20 group, and maintenance costs specific to the engine and fuel systems were $0.05 and $0.07 per mile, respectively. Because of high variability in maintenance costs between vehicles, the engine and fuel system maintenance costs for the two groups were not significantly different.
- Miles between road calls averaged 3,197 for the diesel group and 3,632 for the B20 group. There was no evidence in the data to suggest this difference is related to fuel use.
- Fuel filter plugging on the B20 buses caused road calls, and required extra filter replacements in the B20 group. Although the additional maintenance cost was small, adding only $1,054.81 to the B20 group or $0.002 per mile, the events were significant to the transit district because of resulting disruptions to normal bus service. Fuel filter plugging may have been caused by the presence of high levels of plant sterols in the B20 or other fuel quality issues.
- Measurement of biodiesel blend level showed erratic biodiesel content for delivery load samples. Vehicle samples, however, were consistently at or near B20 indicating complete blending had occurred during delivery and offloading of the fuel.
- Oil analysis results indicated no additional metal accumulation due to wear (wear metals) from the use of B20, with similar rates of decay, oxidation, fuel dilution, and viscosity. Soot levels in the lubricant were significantly lower for the B20 vehicles.
- Laboratory chassis testing on the City-Suburban Heavy-Vehicle Cycle using the in-use fuels found that B20 reduced emissions of all regulated pollutants and caused a small fuel economy decrease.

A 1995 study, “An Alternative Fuel For Urban Buses - Biodiesel Blends,” conducted by NREL, the University of West Virginia DOE, and the University of Missouri, enabled transit operators to conduct a real-world comparison of B20 and low sulfur diesel fuel (LSDF) (sulfur level is less than 500 ppm by mass) (Schumacher et al., 1995). Performance and operational data were collected from urban mass transit buses at Bi-State Development Agency in St. Louis, Missouri. The report studied the real-world impact of a biodiesel blend on maintenance, reliability, cost, fuel economy and safety compared to LSDF. The study concluded that the buses experienced small but observable differences in fuel economy and maintenance costs. Emergency road calls were few in number for both B20 and diesel fuel control buses. An analysis of the engine lubricating oil indicated that the wear metals normally found in the B20 fueled buses were similar to the diesel control buses.

Biodiesel is the first and only alternative fuel to have a complete evaluation of emission results and potential health effects submitted to the EPA under the CAA Section 211(b) (EPA, 2002). These programs include the most stringent emissions testing protocols ever required by EPA for

certification of fuels or fuel additives. The data collected under these programs are the most thorough inventory of the environmental and human health effects attributes that current technology will allow.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

B20 remains one of the few alternative fuels that can be implemented into DoD CONUS operations with little or no cost increases related to infrastructure changes and fuel cost. Most DoD facilities have access to the fuel since the mandate to use B20 in non-tactical fleets was established. However, additional handling concerns for tactical training operations that often use tanker trucks, make the implementation for tactical fleets difficult and would increase off-road training costs. The ability to use B20 in selected tactical vehicles and equipment would improve overall fuel supply security, reduce greenhouse gas and regulated air emissions, and potentially reduce long-term fuel costs. Most tactical fleets use JP-8, which cost $0.11 per gallon more than B20. Petroleum diesel costs the same as biodiesel. Worldwide, DoD consumed 26 million barrels of JP-8 petroleum in 2010. Implementation of B20 into CONUS training operations would be a step towards developing an environmentally sustainable fueling option for tactical vehicles. Figure 2 lists the fuel prices for petroleum diesel, B20, and JP-8 for FY11 and FY12.

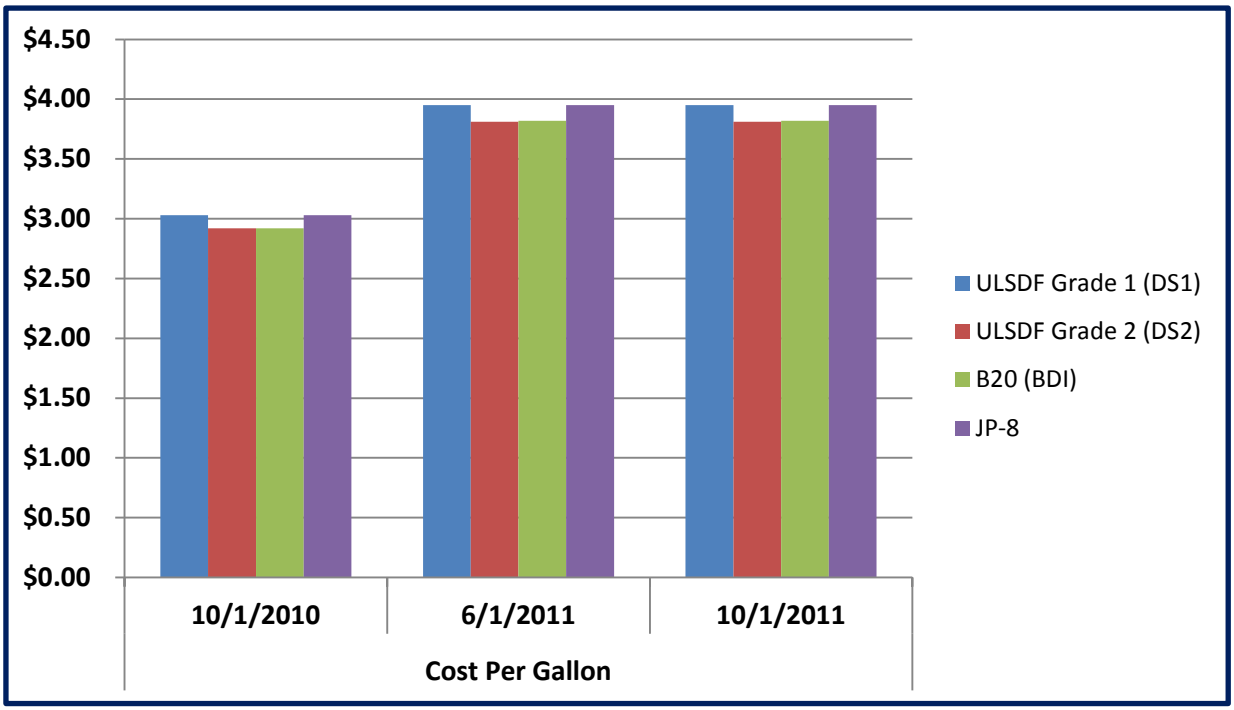

Figure 2. Fuel price per gallon over time (Defense Logistics Agency Energy, 2011).

The cost of B20 is highly dependent on the cost of ultra-low-sulfur diesel fuel (ULSDF) Grade 2 (DS2), since DS2 is 80% of the blend. Any cost savings garnered by switching from JP-8 to B20, can also be achieved by switching from JP-8 to DS2 (ASTM D975 Grade 2-D S15), without the risk presented by using B20.

B20 has combustion properties very similar to diesel and can generally be used in existing fuel dispensing systems with little or no additional modifications, although it is highly recommended that tanks be cleaned prior to conversion to B20. The use of B20 in cold weather requires additional considerations. B20 typically has poorer low-temperature properties compared to petroleum diesel fuel. Under extreme cold conditions, B20 is normally not used.

The differences between B100 and B20 are reflected in the stability requirements in the respective fuel specifications. B100 must have a minimum induction period of 3 hours for oxidation stability using the Rancimat test. B6 to B20 blends must have a minimum induction period of 6 hours per ASTM D7467. The oxidation stability of biodiesel usually does not reach the level of stability of petroleum fuel. Also, B100 oxidation stability varies with the feedstock used to produce it. Highly saturated feedstocks, such as palm or tallow, tend to be more oxidatively stable than less saturated feedstocks, such as soy. It can be argued that increased use of antioxidants in B100 accounts for most of the increased stability; although, some of the increase is undoubtedly due to increased use of feedstocks with higher inherent oxidation stability (Schneller and Gatto, 2008).

The biodiesel industry has grown exponentially in recent years. The conventional feedstocks are somewhat limited. The availability of acceptable feedstocks may ultimately limit future growth. Research to identify new feedstocks is increasing. As discussed earlier, the specific animal or plant fats used to manufacture B100 may significantly alter its characteristics and usability from region to region. New feedstock sources such as algae are promising, but the existing technology to produce biodiesel is limited to the most economically available feedstock in any specific region of the world (National Biodiesel Board, 2011).

Since the introduction of the $1-per-gallon biodiesel tax credit in 2005, U.S. biodiesel production climbed steadily until 2010, when Congress allowed it to lapse temporarily as the health care debate overshadowed other issues. Production immediately plummeted from a record of about 700 million gallons in 2008 to about 315 million gallons in 2010.

The industry bounced back quickly in 2011, after Congress reinstated the tax incentive in December 2010 and the EPA included biodiesel as an Advanced Biofuel in its new RFS Program, requiring minimum volumes of biodiesel use in U.S. diesel fuels. In the first six months of 2011, U.S. biodiesel production exceeded 375 million gallons.

This page left blank intentionally.

3.0 PERFORMANCE OBJECTIVES

This project was designed to address the Tri-Service POL Users Group concerns with the use of B20 in tactical vehicles and equipment including: 1) fuel stability, 2) high temperature properties, 3) low temperature properties, 4) water affinity, 5) material compatibility, and 6) solvency. The project has attempted to address these concerns by running field tests that can possibly lead to the development of specific parameters (fuel quality, fuel storage limits, vehicle usage and load, climate conditions, fuel handling, and fuel storage conditions) for using B20 in tactical vehicles. The B20 used for this demonstration was the same B20 currently used in DoD military installations for non-tactical vehicles and equipment, which may have included B20 from BQ-9000 certified facilities, B20 which is state certified, or B20 from states where no oversight exists. BQ-9000 is an industry driven accreditation program developed to increase the quality of biodiesel produced in the U.S. Fuel quality is a key factor to the successful use of B20 in tactical vehicles. To ensure quality, the fuel used was tested against ASTM D7467 and must have met B20 requirements for the duration of the demonstration as defined in Section 5.2. Joint Oil Analysis Program (JOAP) tests and specifications for used engine oil were also performed to determine engine component wear and any impact caused by using B20. The primary performance criteria that were used to demonstrate success of this project are listed in Table 1.

Table 1. Performance criteria.

Type of Performance Objective	Primary Performance Criteria	Expected Performance (Metric)	Actual Performance Objective Met?
Quantitative	1. Fuel stability	Storage time meets or exceeds 6 month storage limit for B20	Mixed (See Section 6.0)
	2. High temperature properties	Storage time meets or exceeds 6 month storage limit for B20 in hot, dry climate	Mixed
	3. Low temperature properties	Storage time meets or exceeds 6 month storage limit for B20 in cold climate	Yes*
	4. Water affinity	Storage time meets or exceeds 6 month storage limit for B20 in damp environment (climate and operation)	Mixed (See Section 6.0)
	5. Acid number	Meets or exceeds 6 month storage limit for B20	Yes
	6. Kinematic viscosity	Meets or exceeds 6 month storage limit for B20	Yes
	7. Material compatibility	No material incompatibility experienced	Mixed (See Section 6.0)
Qualitative	8. Solvency	When B20 is stable (established in quantitative tests) will pass visual appearance and sediment tests	Mixed (See Section 6.0)

**B20 used at cold site installation was automatically switched to B10 in the winter months, however only one test vehicle received B10 fuel. Switching to B10 was done outside approved procurement through Defense Logistics Agency (DLA) and obtained no energy credits. Low temperature properties of Biodiesel improved during the ESTCP investigation by the addition of the Cold Soak Filtration Test to the ASTM International D6751 for B100 specification.*

This page left blank intentionally.

4.0 SITE/PLATFORM DESCRIPTION

This section of the report provides a brief background of each location, the operational groups located on site, the vehicles that participated in the program, and the general climate at each location.

4.1 TEST FACILITIES & PRESENT OPERATIONS

Moody Air Force Base (AFB), Marine Corps Air Ground Combat Center (MCAGCC) 29 Palms, Naval Base Ventura County (NBVC) Port Hueneme, Naval Surface Warfare Center (NSWC) Crane, and Marine Corps Base Hawaii (MCBH) Kaneohe Bay were selected to participate in this task due to the varying vehicle usage, climate conditions and the potential effects of running bio-based fuels in tactical ground vehicles. Each site participated in this program for a 6 to 12 month period of performance during which fuel and oil samples were drawn monthly and shipped to the National Defense Center for Energy and Environment (NDCEE) and Tank Automotive Research, Development and Engineering Center (TARDEC), respectively, for analysis. Fuel samples were taken from test vehicles and fuel storage tanks. Oil samples were taken from both the test and control vehicles. The project used available B20 that was already being purchased to run administrative fleets; the feedstock varied from site to site.

4.1.1 MOODY AIR FORCE BASE

Moody AFB is a U.S. Air Force installation located in southern Georgia. Moody AFB is home to the 23rd Wing and the 93rd Air Ground Operations Wing which provide worldwide air support, perform combat search and rescue, and train forces to support the war on terrorism (Moody AFB, 2010A and 2010B). Moody AFB experiences warm summer months (average high of 93°F [34°C]) and mild winters (average low of 38°F [3°C]). For this task, B20 fuel samples were taken from a 2008 Bobtail, a 1997 Bobtail, an R-11 Refueler, and from a fuel dispenser (tank or nozzle sample) located on base. Soybean oil was the feedstock of the primary biodiesel producer for the B20 used at Moody AFB, but the Air Force Petroleum Office (AFPET) also reported some spot buys that may have included peanut oil as a feedstock.

4.1.2 U.S. MARINE CORPS 29 PALMS

As the world's largest Marine Corps Base, MCAGCC 29 Palms, California, is the premier training facility for Marine operations worldwide. It is essential for maintaining high levels of readiness within the U.S. Marine Corps. Each year, roughly 50,000 marines participate in the base's training exercise programs. 29 Palms is classified as having an arid, upland desert climate with high summer month temperatures (summer highs of 120°F [49°C]) and freezing winter temperature (as low as 15°F [-9°C]) (Global Security, 2010A). B20 fuel samples were drawn from a High Mobility Multipurpose Wheeled Vehicle (HMMWV) and a B20 fuel storage tank, located on base, servicing commercial vehicles. The feedstock for the 29 Palms vehicles was primarily soybean oil, but the biodiesel producer also stated that used vegetable oil was also used occasionally.

4.1.3 NBVC PORT HUENEME

NBVC is a U.S. Naval installation located in Southern California. As the only deepwater harbor between Los Angeles and San Francisco, NBVC Port Hueneme supports the current DoD logistics pre-positioning strategy, storage and deployment of heavy construction equipment. Port Hueneme experiences mild summer and winter conditions with temperatures in the 70s and mid 40s (°F respectively) (U.S. Navy, 2010A). For this task, Port Hueneme personnel drew B20 fuel samples from a Medium Tactical Vehicle Replacement (MTVR) and a B20 fuel storage tank. Oil samples from a MTVR running on JP-8 were used as a control variable when testing oil samples from the MTVR running on B20. The feedstock for the NBVC vehicles could not be determined as several biodiesel providers contributed to the B20 blend.

4.1.4 NSWC CRANE

Located in Crane, Indiana, NSWC Crane is a shore command of the U.S. Navy under the Naval Sea Systems Command. With employees deployed around the world, Crane specializes in full lifecycle support of Special Missions, Strategic Missions, and Electronic Warfare/Information Operations (U.S. Navy, 2010B). Crane, Indiana experiences hot summers (average high temperature in July of 88°F [31°C]) with several months at freezing temperature or below (average January low of 21°F [-6°C]) (U.S. Climate Data, 2010A). NSWC Crane employees took fuel samples from two Armored Vehicle General Purpose (AVGP) vehicles running on B20, and one B20 fuel storage tank. Oil samples drawn from two AVGP vehicles running on JP-8 were used as control vehicles against the two vehicles running on B20. The feedstock for the NSWC Crane was soybean oil.

4.1.5 MCBH KANEOHE BAY

MCBH Kaneohe Bay is located approximately 12 miles northeast of Honolulu and is home to the U.S. Marine Corps Pacific, 3rd Marine Regiment, 1st Radio Battalion, and the Marine Corps Air Facility (Global Security, 2010B). Kaneohe Bay experiences relatively little fluctuation in temperatures with summers averaging 80 to 85°F (27 to 29°C) and winters ranging from 70 to 76°F (21 to 24°C) (U.S. Climate Data, 2010B). B20 fuel samples were analyzed from one Tractor, Rubber Tired, Articulated Steering, Multi-Purpose (TRAM), one HMMWV, and one fuel storage tank. Oil samples were analyzed from one TRAM and HMMWV running on B20, and one TRAM and HMMWV running on JP-8. The biodiesel used at MCBH was produced using waste vegetable oil as the feedstock.

4.2 SITE-RELATED PERMITS AND REGULATIONS

Additional site-related permits and regulations were not required at any test site. B20 was already available for General Services Administration (GSA) white fleet vehicles, so no additional requirements were necessary to use the fuel in tactical vehicles.

5.0 TEST DESIGN

Tactical vehicles in military training operations do not run consistently over a long time periods, as many commercial fleets do. Prior tests on B20-powered fleet vehicles have provided positive results, with statistically insignificant operation and maintenance (O&M) cost differences compared to vehicles using petroleum diesel fuel. These results have been compared to the results of this demonstration to determine how important vehicle usage rates are.

5.1 SAMPLING PROTOCOL

5.1.1 OIL SAMPLING PROCEDURE

A sample of the fresh engine oil was taken and sent to TARDEC for analysis. Concurrent Technologies Corporation (CTC) procured 4-ounce plastic oil sample bottles and had them delivered to each sampling location. New samples were taken from the engines of both the control vehicle(s) and test vehicle(s) on a monthly basis and also sent to TARDEC for analysis. Each sample was labeled with: the location of the vehicle, date the sample was taken, supplier name (where applicable), name of the individual who took the sample and the vehicle identification (ID).

5.1.2 FUEL SAMPLING PROCEDURE

A sample of the B100 biodiesel that was used for blending with diesel to formulate the B20 used at each location was sent to TARDEC when a new shipment of B20 was received. A sample of the B20 was also taken from each location at the beginning of the study and if a new shipment was received. These samples were referred to as delivery samples and received more extensive testing in order to compare the as-delivered B20 to ASTM D7467. One-gallon tight head, 24-gauge grey epoxy phenolic lined steel cans, with ¾” bung opening and a handle (part #HMS-60390) were procured from All-Pak and delivered to each of the test sites. The sample containers were determined to be clean and dry before use, and a volume of the sample was used to rinse the container to remove any previous contamination.

Storage tank samples were taken on a monthly basis, and whenever a new delivery of B20 was received. The sample was taken from a service hose because the storage tanks/trucks had no manhole or sampling hatch/valve. In order to get a representative sample, the fuel was allowed to flow until about two times the length of the sample apparatus was flushed, and then the one gallon can was filled and immediately capped.

The test vehicle was filled with the B20 fuel and samples were taken by removing the plug in the fuel tank and allowing the fuel to flow into the one gallon sample can. Where applicable, a nozzle or dispenser sample was also taken at the time of fueling.

All samples were labeled with: the location of the vehicle, date the sample was taken, the quantity and type of fuel received, supplier name (where applicable), name of the individual who took the sample, the vehicle ID, and the sampling point (nozzle, dispenser, etc.).

5.2 ANALYSIS OF FUEL SAMPLE

Table 2 lists the testing methods used to analyze the B20 delivery samples. Much of the testing and acceptance criteria listed in the table are derived from a compilation of testing methods listed in the B20 specification (A-A-59693) (GSA, 2004) and the B6-B20 blend specification (ASTM D7467).

Table 2. Delivery sample testing methods.

Test Name	Test Method	Acceptance Criteria	Deviations/Comments
Appearance	ASTM D4176	Clear, bright, visually free from un-dissolved water, sediment, and suspended matter	Temperature was also measured to ensure it was near ambient prior to testing.
Acid Number	ASTM D664	0.2 mg KOH/g, max	N/A
Viscosity at 40°C	ASTM D445	1.9 – 4.1 mm^2/sec	N/A
Flash Point	ASTM D93	52°C, min	N/A
Low Temperature Properties	ASTM D2500 (Cloud Point)	Report	Dry ice used to cool the samples; temperature recorded using a calibrated digital thermometer that measured to 0.1°C.
Sulfur Content	ASTM D2622	0.0015 mass %, max	N/A
Distillation Temp, 90% Evaporated	ASTM D86	343°C, max	N/A
Ramsbottom Carbon Residue (10% bottoms)	ASTM D524	0.35 mass %, max	N/A
Cetane Index	ASTM D976	40, min	N/A
Ash content	ASTM D482	0.01 mass %, max	Open coil burner used in place of open flame burner; samples heated to the point of smoke evolution, not flames, to avoid splattering.
Water & sediment	ASTM D2709	0.05 vol %, max	N/A
Copper strip corrosion	ASTM D130	No. 3, max	NA
American Petroleum Institute Gravity	ASTM D1298	Report	N/A
Biodiesel content	ASTM D7371	20 ± 1% (by volume)	N/A
Oxidation stability, Rancimat	EN 14112 Modified (equivalent to EN 15751)	6 hours, min	N/A
Density at 15°C	ASTM D4052	Report (kg/L)	N/A
Aromaticity	ASTM D1319	35 vol%, max	N/A
Color	ASTM D1500	Rating 3, max	N/A
Particulate Contamination	ASTM D6217	10 mg/L, max	N/A
Stability	Modified ASTM D2274 (equivalent to ASTM D7462)	Total insolubles, mg/100 mL Iso-octane insolubles, mg/100 mL Acid number, mg KOH/g	2 Whatman glass microfiber filters used in place of the cellulose ester membrane filters; three washes with 50 mL of trisolvent used for total insolubles instead of 75 mL.
Trace Metals (Ca, Mg, Na, K)	EN14538	Not detectable	N/A
Total water content	ASTM D6304	Report (mg/kg)	A pyridine-free reagent, Composite 5, was used with an autotitrator, given the health concerns. The reagent was standardized and a known standard was evaluated prior to conducting sample titrations.

Table 3 lists the testing that was performed on the monthly storage tank and vehicle samples.

Table 3. Testing for monthly storage and vehicle tank samples.

Test Name	Test Method	Acceptance Criteria
Appearance	ASTM D4176	Clear, bright, visually free from un-dissolved water, sediment, and suspended matter
Acid Number	ASTM D664	0.2 mg KOH/g, max
Viscosity at 40°C	ASTM D445	1.9 – 4.1 mm^2/sec
Water & sediment	ASTM D2709	0.05 vol %, max
Total water content	ASTM D6304	Report (mg/kg)
Color	ASTM D1500	3, max
Particulate Contamination	ASTM D6217	10 mg/L, max
Oxidation Stability, Rancimat	Modified EN14112 (Equivalent to EN 15751)	6 hours, min
Stability	Modified ASTM D2274 (equivalent to ASTM D7462)	Total insolubles, mg/100 mL Iso-octane insolubles, mg/100 mL Acid number, mg KOH/g

5.3 ANALYSIS OF OIL SAMPLES

Table 4 lists oil testing methods used to analyze the oil samples from the test and control vehicles at each location. The oil testing methods are based on the methodology contained in the JOAP Manual (Department of Defense, 2005).

Table 4. Oil testing methods.

Test Name	Test Methods
Wear Metals	ASTM D5185
Total Acid Number	ASTM D664
Total Base Number	ASTM D4739
Kinematic Viscosity at 40°C and 100°C	ASTM D445
Viscosity Index	ASTM D2270
Soot Content	ASTM D7686
Percent Fuel Dilution	ASTM D3524
Water Content	ASTM D6304, Procedure C

5.4 OPERATIONAL TESTING

5.4.1 VEHICLE PREPARATION

On each base at least one vehicle was used as a control, using either JP-8 or diesel as the fuel, and at least one vehicle was used for testing, running on B20. Each of the vehicles used for this program, both control and test, had maintenance performed prior to initiating the testing. This maintenance included replacing both the oil and fuel filters and changing the engine oil. At NBVC, each vehicle was also fitted with a new fuel pump, fuel pump gasket, fuel injectors, fuel injector o-rings, and fuel lines. These components were to be examined at the end of the study for signs of degradation, scorching, scarring, and deposits.

5.5 VEHICLE USAGE

Both control and test vehicles were run in varying time increments on a monthly basis, as outlined in Table 5. The amount of hours of operation for each vehicle is listed in Appendix F in the Final Report. Vehicle operators were also asked to record observations regarding the negative performance of each vehicle such as engine knocks, tailpipe emissions, stalls, or slow starts.

Table 5. Vehicle usage plan by base location.

Military Base	Vehicle usage
NSWC Crane	One test and control AVGP vehicle run for four hours per month, One test and control AVGP vehicle run for 15 minutes per month
NBVC Port Hueneme	One test and control MTVR, or 7-ton Truck) vehicle run according to the regular Construction Engineering training schedule
Moody AFB	One test and control for two Bobtail trucks and one Refueler truck vehicle run on regular operations schedule
29 Palms	One test and control HMMWV vehicle run one day every 4 weeks
MCBH Kaneohe Bay	One test and control vehicle (TRAM) run on regular operations schedule, and one test and control vehicle (HMMWV) run on regular operations schedule

6.0 PERFORMANCE ASSESSMENT

6.1 B20 DATA

The following sections summarize, in chart format, the monthly storage tank and vehicle tank test results from each location. Details for testing results at each location can be found in the Final Report.

6.2 SUMMARY OF RESULTS

6.2.1 FUEL DATA

Visual Appearance and Water and Sediment: For the appearance test, the visual appearance of the fuel was recorded for each sample. This data cannot be trended in chart form so a brief description of the results will be provided. First, for the vehicles and storage tank at Moody AFB, vehicle # 97C00410, the 1997 Bobtail, consistently had failures in appearance due to haze or cloudiness. Then, beginning with the February 2010 samples, approximately at the half-way point in the study, the samples from the other two vehicles began to show failures due to cloudiness. These results varied from month to month. All samples received from NBVC and 29 Palms passed appearance, as well as the vehicle and storage sample from MCBH. For the vehicle and storage samples from NSWC Crane, two of the vehicle samples for the AVGP P-7 vehicle, failed appearance during the year-long trial. All samples received had water and sediment values less than the acceptance criteria of 0.05 volume percent, max.

Acid Number: As shown in Figure 3 and 4, all samples passed acid number testing, having results less than the acceptance criteria of 0.3 mg KOH/g.

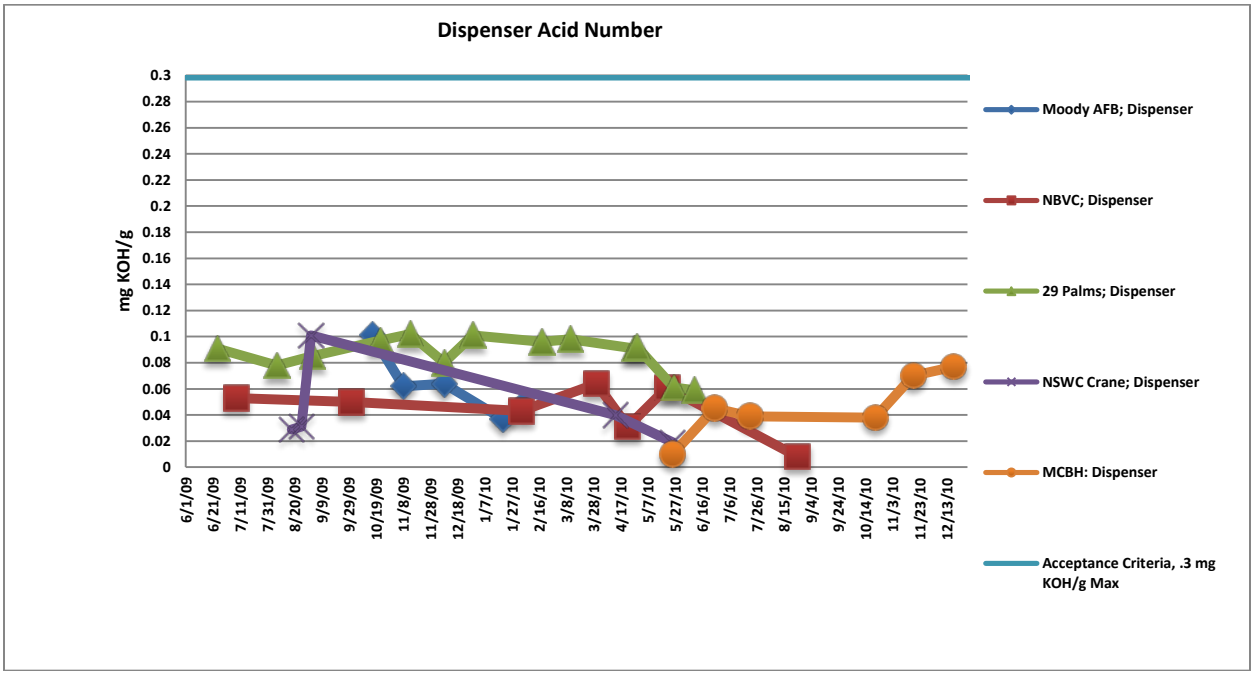

Figure 3. B20 acid number results for the storage tank samples.

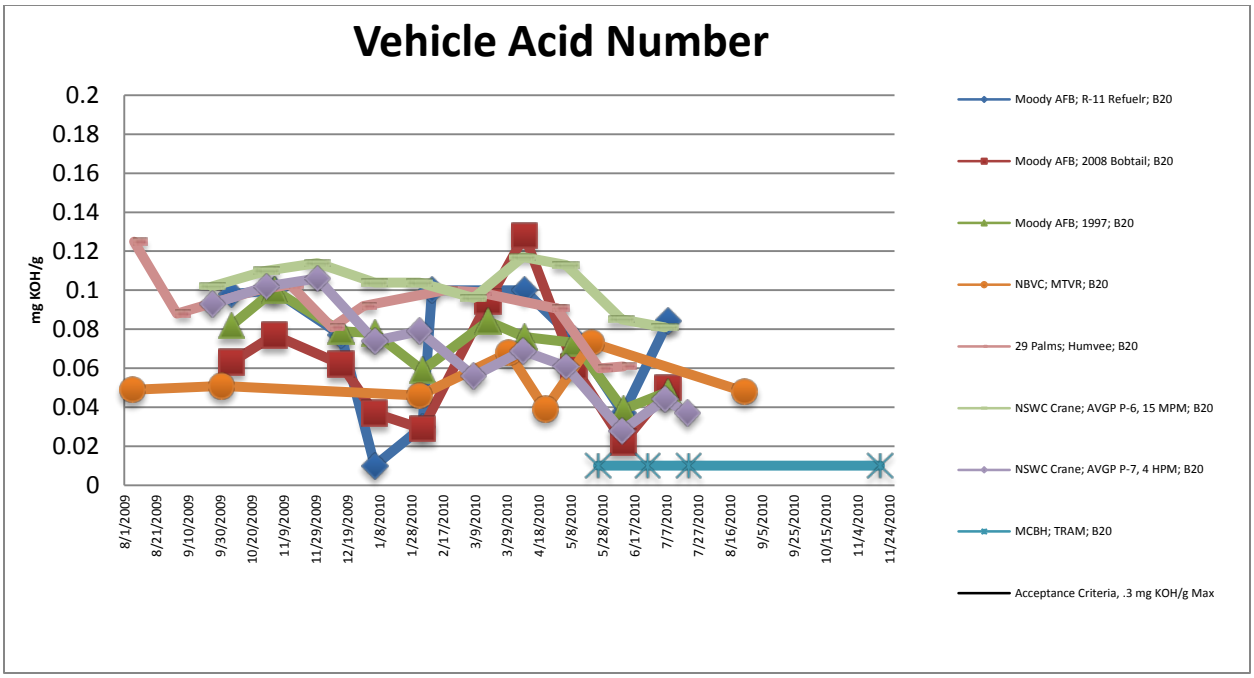

Figure 4. B20 acid number results for vehicle samples.

Kinematic Viscosity at 40°C: All samples from all locations were within the viscosity range of the acceptance criteria of 1.9 to 4.1 mm^2/sec.

Total Water: Figure 5 and Figure 6 summarize results for total water content. Likely most of the water was either dissolved or highly emulsified because of the biodiesel, increasing the possibility that water will move into the vehicle fuel system and aid in metal surface corrosion. Keeping the system as dry as possible has to be a priority when using biodiesel.

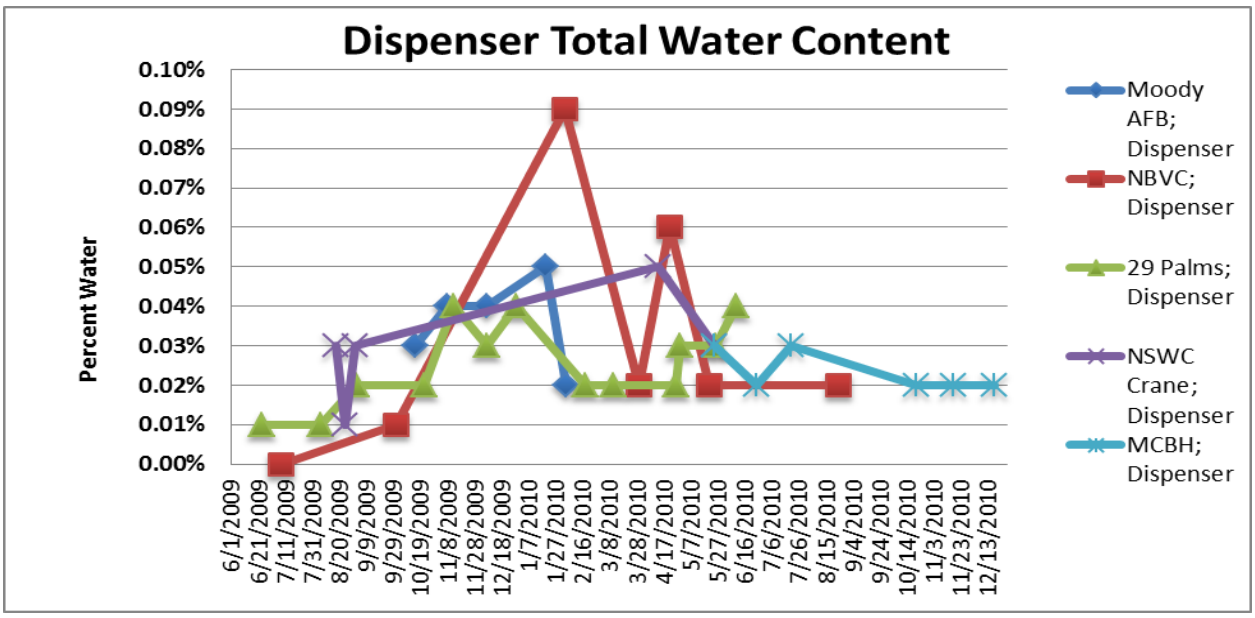

Figure 5. Total water content for dispenser samples.

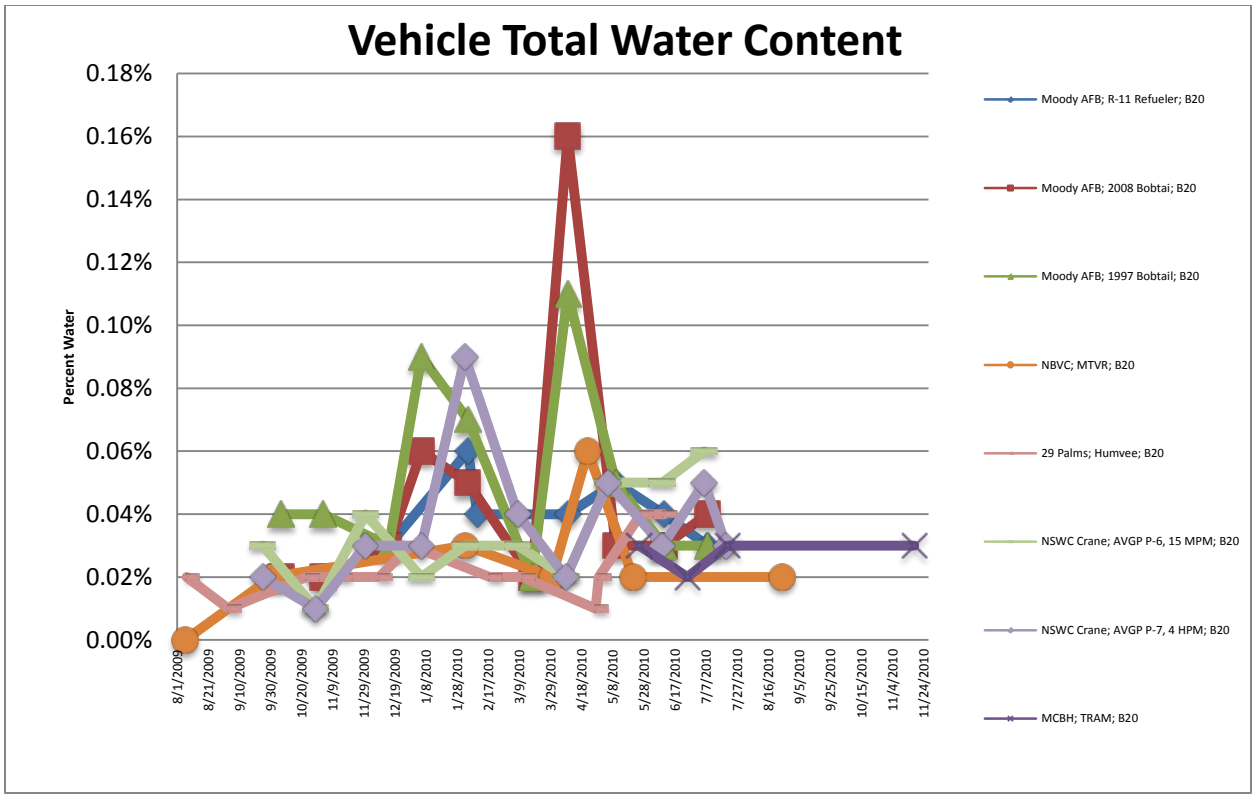

Figure 6. Total water content results for the vehicle samples.

Color: The pass/fail limit for this test is a color rating of 3 or less. All samples tested, both fuel tank and storage tank, met this requirement. In almost all instances, sample results were less than 1.5. Test results for each sample are located in tables in Appendix C in the Final Report.

Particulate Content: Figure 7 and Figure 8 show the results of the particulate content for the vehicle and storage tank samples. The acceptance criterion for this test is 10 mg/L, maximum. All storage tank samples met the test criterion, which indicates that the fuel, as delivered, and during storage, was clean. Moody AFB had two vehicles, during two different sampling events, fall outside the limits of the test. Both vehicles had results for the next month's samples within the testing limits. The periodic increases in particulates may have been caused by increased contaminants (dirt, etc.) in the fuel tanks, materials incompatibility, or they may represent anomalies in the testing process. Since fuel is filtered before passing from storage tank to vehicle, another cause of contaminates is through fuel break down in the vehicle. In general, the particulate content results show that the storage tanks and vehicle fuel tanks were relatively clean and tended to stay that way throughout the program.

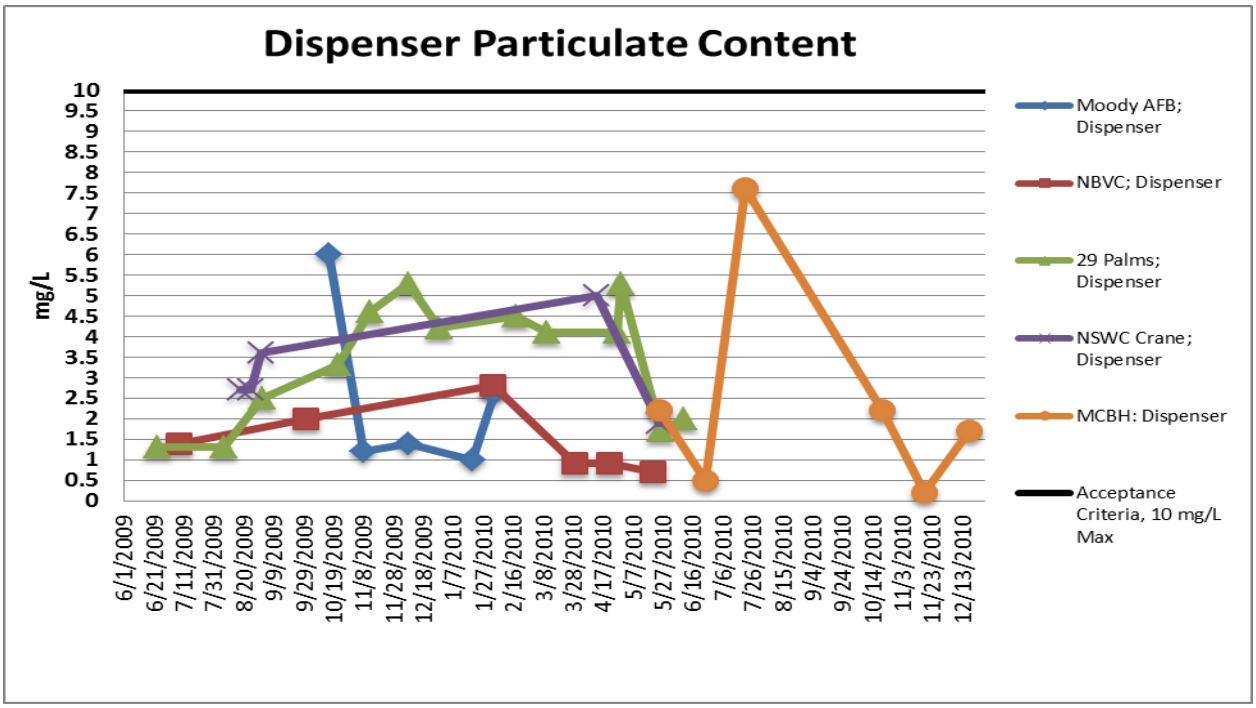

Figure 7. B20 particulate content results for storage tank samples.

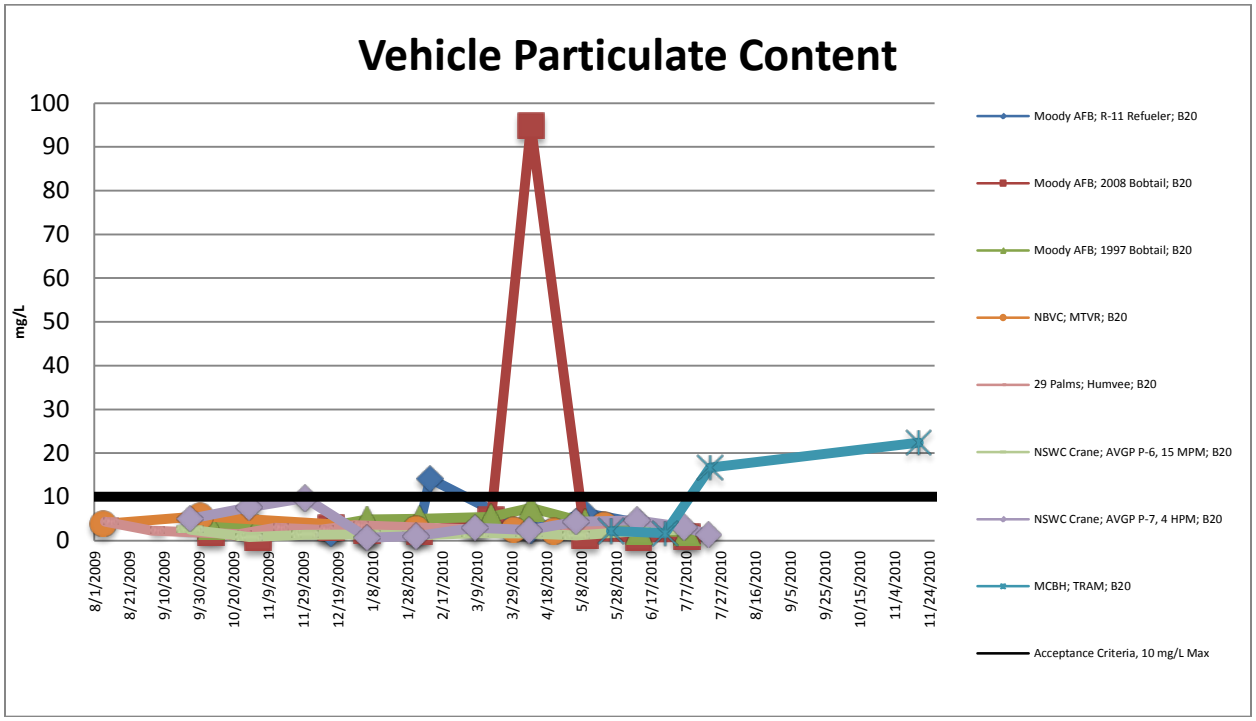

Figure 8. B20 particulate content results for vehicle samples.

Rancimat Oxidation Stability: The summarized stability test results are shown in Figure 9 and Figure 10. This test measures the rate at which volatile compounds (mostly acids and peroxides) are formed during the oxidation of the test sample. When evaluating the results of this test, it is

important to remember that the 6-hour minimum is a specification requirement. Based upon test measurements in the vehicle fuel tanks in this study, blends with less than 6-hour induction periods are still useful fuels that will likely cause no problem if used in the near future. A reduction in the measured induction period of fuel in storage means that the fuel has been oxidized to some degree; but, that oxidation may have caused no appreciable degradation to the fuel. In some cases, oxidation of biodiesel causes an increase of particulates, acid number, or water shedding characteristics. Only measurement of these properties will determine if such changes have indeed occurred. So, it should be remembered that changes in Rancimat induction period do indicate some change in the fuel but do not necessarily mean the fuel is no longer usable.

In general, the vehicle samples failed to meet the minimum acceptance requirement in a number of cases, as compared with their respective storage tank samples. These reductions in induction period may be the result of storage time, or storage conditions (heat, water, contaminants, etc.), or both. The reductions in the induction periods of the vehicle samples could be mitigated by quicker turnover of the fuel in the vehicle, diluting contaminants and/or addition of antioxidants to the blend. Note in Figure 9 and Figure 10 that many of the samples showed varying results throughout the program. The longer induction periods tended to be in the colder times of the year. Replenishing fuel in vehicles with fresh fuel will also improve the oxidation stability of the fuel in the tank.

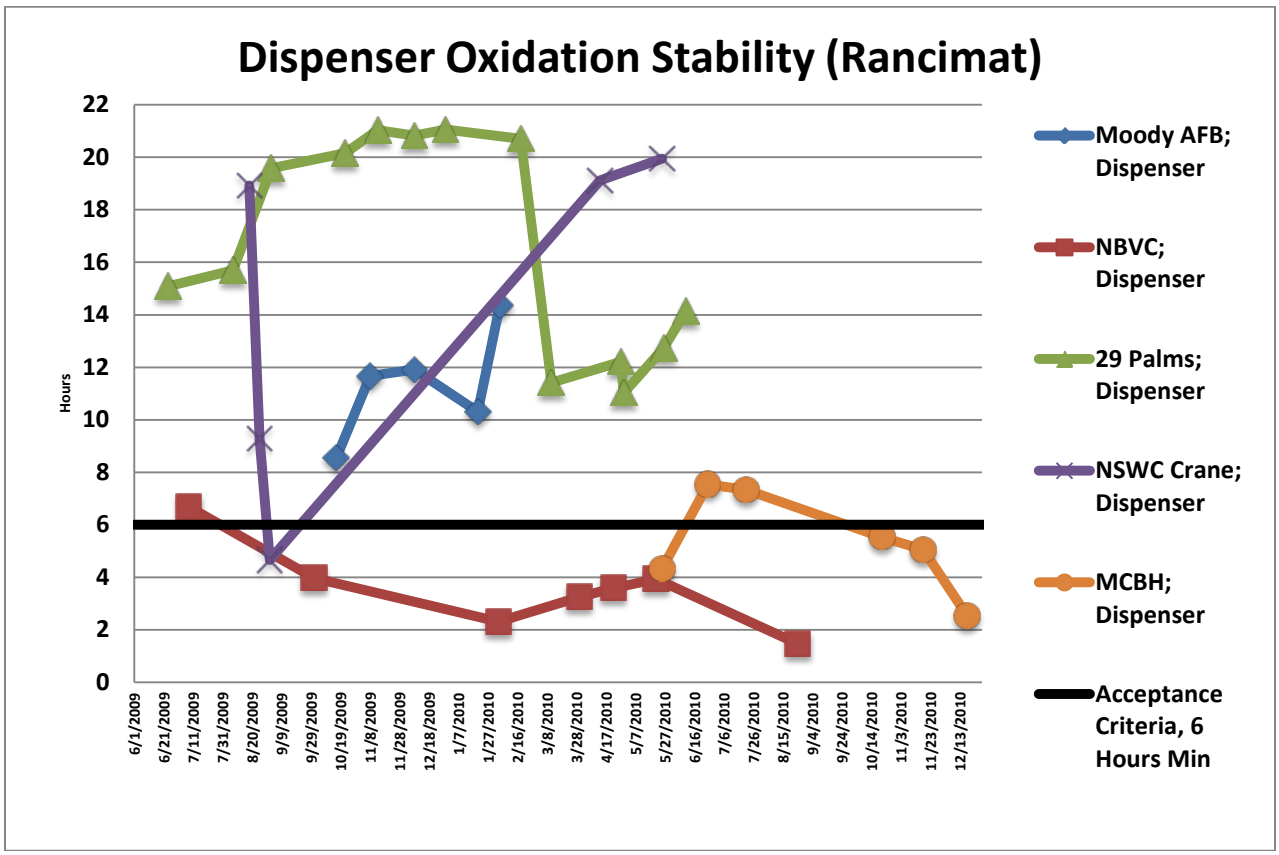

Figure 9. B20 Rancimat oxidation stability results for storage tank samples.

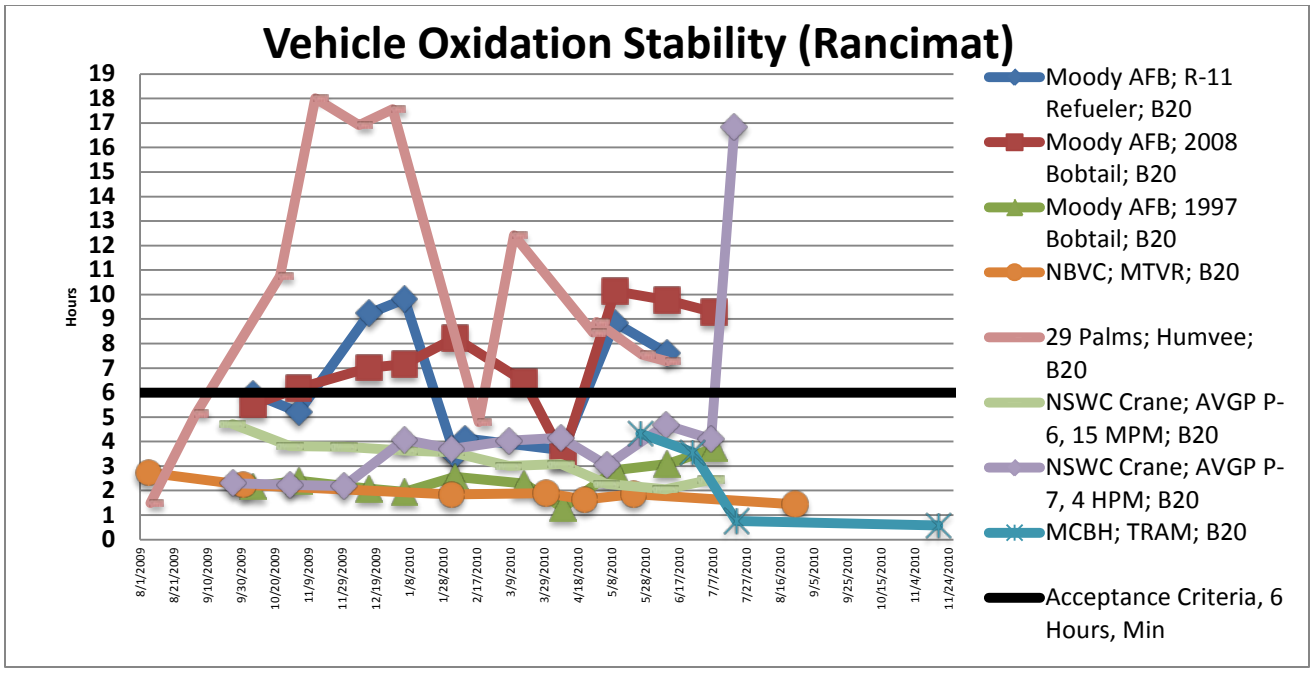

Figure 10. B20 Rancimat oxidation stability results for the vehicle samples.

Modified ASTM D2274 Oxidation Stability Test: By the time of this writing, this procedure has been published at ASTM D7462. This test method has no generally-accepted pass/fail limits. It is useful as an indicator of the tendency of a given biodiesel/biodiesel blend to form insoluble material during oxidation.

The samples from Moody AFB show that the 1997 Bobtail consistently had the highest concentrations of filterable materials throughout the trial; this same vehicle had high water content and failing Rancimat stability results. The other two vehicles at Moody and the storage tank samples all had comparable results. The initial vehicle sample at 29 Palms had high results for insoluble content, but then all remaining samples were consistently low. Both the storage tank and vehicles samples for NBVC showed very high levels of insolubles, which match the trends of failing Rancimat oxidation stability values for these same samples. NSWC Crane storage tank samples all had low results for concentrations of filterable solids, yet samples from the two vehicles had consistently higher results, by at least one order of magnitude, in insoluble content than the storage tank samples. The large change in stability between the storage tank and the vehicle tank may be due to residual contamination or water in the vehicle tank that could assist with premature breakdown of the biodiesel component of the fuel, but the fuel may break down even in the absence of water or residual contamination. One thing is clear: the fuel does break down faster in the vehicle tank than in the storage tank.

An overall summary of the fuel results show that, in most cases, the B20 with good initial stability (as shown by Rancimat results) does not deteriorate over time in the storage tanks. Generally, the fuel properties remained consistent throughout the test, with some locations, such as 29 Palms, having consistently high-performing fuel, while other locations had a lesser-performing blend. Also, it appears that, in some instances, the fuel sitting in the vehicle tanks did deteriorate. For the locations that measured very high Rancimat results (Crane and 29 Palms), the

fuel in the vehicles did not have visible breakdown during the duration of the demonstration. Two locations, Port Hueneme and Kaneohe Bay, had only one delivery during the total and iso-octane insolubles fuel test. Consequently the fuel tests showed more deterioration (more insoluables), including very high counts in the vehicle.

6.2.2 OIL DATA

Please see Appendix D in the Final Report for raw oil data submitted by TARDEC. As noted in the test methodology section, there were no acceptance criteria listed for the oil analyses. Testing was conducted for comparison purposes only.

Vehicles from 29 Palms had consistently higher levels of boron, magnesium, molybdenum, zinc, and silicon than the other locations. Samples from NSWC Crane had the highest boron content, while the NBVC samples had the highest silver and copper content. There were no significant trends or differences between test and control vehicles at any of the locations, with the exception of the HMMWVs at 29 Palms. The control vehicle running on JP-8 had consistently higher levels of zinc, silicon, and sodium than the test vehicle.

At Moody AFB, the R-11 Refueler and both the control and test vehicles had consistently lower viscosity values and higher fuel dilution percentages than the Bobtail vehicles at that location. The control Refueler running on diesel generally had lower viscosity and higher fuel dilution values than the test vehicle operating on B20. Otherwise, the testing results for the Bobtail control and test vehicles were comparable. At 29 Palms, the test and control vehicles had comparable engine oil test results with the exception of one outlier for the test vehicle, potentially due to water contamination in that particular sample. For NBVC, the test and control vehicle results were very comparable, especially toward the end of the trial. There were increased fuel dilution percentages in the test vehicle engine oil at the beginning of the trial. For the NSWC Crane vehicles, all results trended similarly, with viscosity decreasing as water content and fuel dilution increased. Figure 11 and Figure 12 below show the trends for these samples.

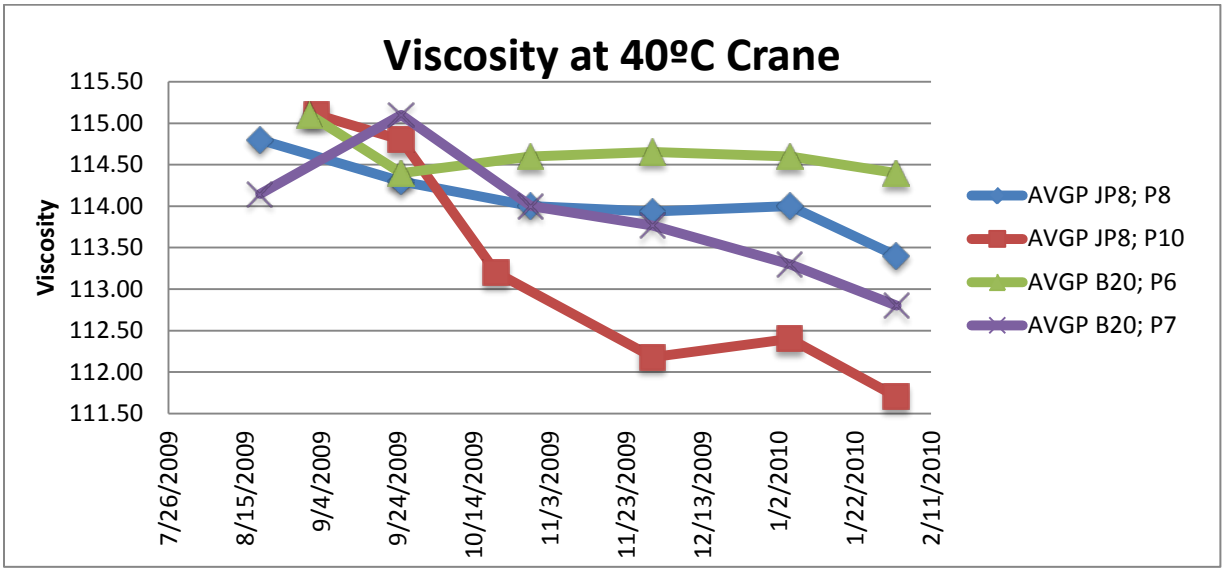

Figure 11. Engine oil viscosity results for NSWC crane vehicles.

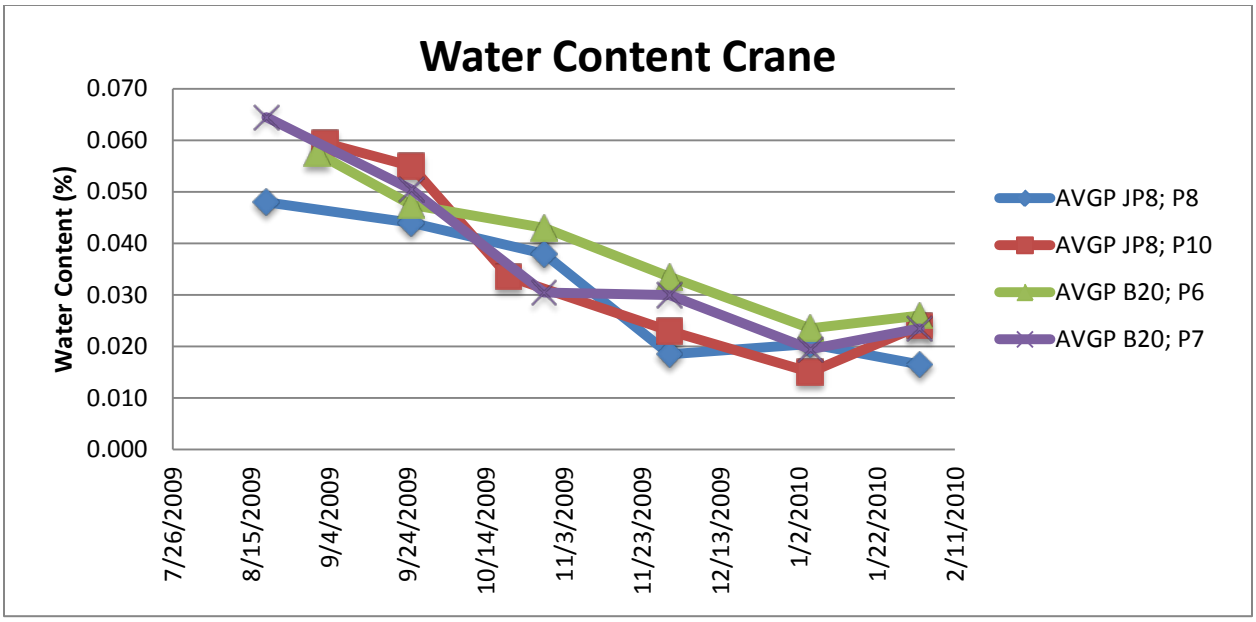

Figure 12. Engine oil water content results for NSWC crane vehicles.

Limited sampling conducted at MCBH does not show any significant trend. Only two data points are currently available for each vehicle.

The overall conclusion from review of the summarized engine oil data shows that B20 does not have an effect on the engine, as can be seen in changes in the engine oil itself. Generally, the test and control vehicle data trended similarly.

6.2.3 TACTICAL BIODIESEL DATABASE

All B20 biodiesel, engine oil, and weather data tested or collected was entered into the Tactical Biodiesel Database developed for easy data extraction and trend analysis. The database is located at https://tacticalbiodieseluse.ctc.com/. For access to the data, a user name and password can be obtained at this website. See deliverables "Draft Biofuels Database Layout and Overview" and "Draft Technical Data Package (Database Systems and Operation Manual)" for additional database resources.

6.2.4 VEHICLE OPERATOR OBSERVATIONS

Vehicle operators from each of the demonstration sites reported no performance differences between test and control vehicles.

7.0 COST ASSESSMENT

Since B20 is largely derived from petroleum, it was expected that its cost would parallel that of petroleum crude and diesel. However, Congress had provided a biodiesel excise tax credit of up to $1.00/per gallon per percentage of biodiesel in the fuel blend. DLA Energy costs for the last few years indicate that DoD pays the same for DS2 and B20 (Defense Logistics Agency Energy, 2011).

Biodiesel quality has a direct impact on O&M costs. Biodiesel that falls outside of ASTM specifications has led to an increase in engine component breakdown. Improved quality of biodiesel through more stringent specifications may be required to expand the use of biodiesel to tactical fleets (Barker, 2009). This will increase the cost of the fuel but will reduce the risk of maintenance issues. In addition to fuel quality, vehicle performance may be affected by vehicle age, accumulated vehicle mileage and a history of diesel use. Vehicles built prior to 1994 may have components that are not compatible with B20, such as rubber hoses or gaskets. Vehicles that have run diesel for many years may have deposits that act as a seal on engine components. The solvency of B20 causes these deposits to break down leading to leaks. As stated earlier, this breakdown of diesel deposits also occurs when switching from diesel to JP-8.

7.1 COST MODEL

The FY12 Rates for Fuel (per gallon) listed by DLA Energy are: B20 – $3.69, ULDSF Grade 1 (DS1) (ASTM D975 Grade 1-D S15) – $3.82, DS2 – $3.69, JP-8 - $3.82. There is no fuel cost saving switching vehicles currently running on DS2 to B20, and maintenance costs and storage tank maintenance would rise. For vehicles currently running on JP-8 or DS1, there could be a fuel cost saving based upon the number of vehicles that could be switched over.

7.2 COST ANALYSIS AND COMPARISON

The Army is the largest DoD owner of ground tactical vehicles and would have the largest economic outcome switching from JP-8 to B20. The Army operates 387,981 CONUS ground tactical vehicles that use 23 million gallons of JP-8. Of these vehicles, HMMWVs constitute 49.6% of the total, although it is not the largest ground tactical fuel user. The Heavy Expanded Mobility Tactical Truck (HEMTT) series uses 25% of all the fuel used by ground tactical vehicles for the Army, or 5.9 million gallons of fuel even though it makes up only 10% of the CONUS ground tactical fleet. Table 6 lists the Top 5 Army CONUS ground tactical vehicles and the amount of fuel used by each series (not including the HEMTT). These vehicles make up 88.3% of all Army CONUS ground tactical vehicles and use 62.4% of fuel used by Army CONUS ground tactical vehicles.

Table 6. Army CONUS ground tactical vehicles and fuel use.

Ground Tactical Vehicle	Number of Ground Tactical Vehicle Series	Percentage of Total Ground Tactical Vehicles	Amount of Fuel (JP-8) Used	Percentage of Total Fuel Used
HMMWV	192,608	49.6%	5,018,946	21.2%
Light Medium Tactical Vehicle (MTV)	47,625	12.2%	3,559,232	15.0%
"M" Series Truck	38,347	9.9%	2,433,063	10.3%
MTV	51,630	13.3%	3,763,572	15.9%
Palletized Load	12,813	3.3%	2,368,414	10.0%

The annual fuel cost savings of switching from JP-8 to B20 for HMMWV series in the Army is calculated to be $770,917 based upon the difference in cost per gallon, $0.13, between JP-8 and B20. The HMMWVs tested in this program did not produce any maintenance issues that could be differentiated from the control vehicles running on JP-8. The annual amount of fuel diverted from an oil based fuel to a renewable fuel is 1,186,025 gallons. Although the different series of vehicles were not specifically tested in this program we can still calculate the fuel cost saving and amount of fuel diverted for all CONUS Army vehicles. The annual fuel cost savings of switching from JP-8 to B20 for all Army CONUS ground tactical vehicles is calculated to be $2,999,536 and the amount of oil based fuel diverted is calculated to be 4,614,671 gallons each year.

The impact of switching from JP-8 to B20 for HMMWVs and MTVRs in the Navy and Marine Corps would not have the amount of fuel savings as the Army since they drive fewer CONUS ground tactical vehicles. The estimated annual amount of JP-8 consumed by ground tactical vehicles for the Navy and Marine Corps is 2,965,500 gallons. The Marine Corps owns approximately 42,000 ground tactical vehicles; 24,000 of these are HMMWVs and 9,000 are MTVRs. This makes up 79% of the ground tactical fleet. If these vehicles switched to B20 the annual fuel cost saving would be $304,557 with 486,549 gallons of oil based fuel diverted.

The overall impact of switching CONUS Air Force ground tactical vehicles from JP-8 to B20 would be minimal for a couple of reasons. First, the Air Force defines a Tactical Vehicle differently than the other services. Every vehicle on the flight line is considered tactical. The Army, Navy, and Marines generally define tactical as transport vehicles such as MTVRs and Humvees. Additionally, a vast majority of the CONUS Air Force bases already use B20 for the vehicles that they consider appropriate for use. Since the Air Force has already defined which of their tactical vehicles should and should not use B20, a DoD change in policy for B20 would not increase the amount of biodiesel purchased and consumed.

The total annual DoD fuel cost saving for switching from JP-8 to B20 is calculated to be $3,385,051 and the amount of fuel diverted from oil based to renewable is 5,207,771 gallons. The overall impact to DoD would be very small considering that DoD consumes nearly 5 trillion gallons of fuel each year. Of this total, JP-8 makes up 64%. The percentage of fuel diverted from JP-8 oil based fuel to renewable biodiesel would be just 0.17%.

The cost for an increase in maintenance when switching from JP-8 to B20 is difficult to estimate since only one vehicle had unusual maintenance costs associated with it. At best it can be calculated at which point the fuel savings cost would equal the maintenance cost. The cost to repair the gas tank and replacement unit for 1997 Bobtail was $917. Although this vehicle would not be defined as a ground tactical for the other services, it does provide a data point for repair cost. The number of vehicles that would need to have this service done to equal the amount of fuel cost savings is 3,691 or 1% of the total vehicles. The cost to change the oil and replace a fuel filter for a MTVR is $502. The number of MTVRs that would need to have this service done to equal the amount of fuel cost savings is 6,743 vehicles or 11% of the total MTV and MTVRs in DoD. The cost to change the oil and replace a fuel filter for a HMMWV is $147. The number of HMMWVs that would need to have this service done to equal the amount of fuel cost savings is 23,028 vehicles or 11% of the total number of HMMWVs in DoD.

This page left blank intentionally.

8.0 IMPLEMENTATION ISSUES

Critical issues for stakeholders and end users include fuel stability and its use in extreme climates. The Tri-Service POL Users Group, comprising representatives from the Army, Navy, and Air Force, issued a position statement in March 2006 supporting the current prohibition against the use of B20 for tactical applications. It identified the following critical issues associated with the use of B20 in such application:

1. Stability
2. High temperature properties
3. Low temperature properties
4. Water affinity
5. Material compatibility and solvency

The Tri-Service POL Users Group concluded that these issues must be addressed before B20 can be used in tactical vehicles. Tactical vehicles must be capable of deployment immediately and of performing mission-critical tasks with minimal fuel-related maintenance and related risks. This demonstration resulted in the following responses to each of the Tri-Service POL Users Group issues:

1. *Stability.* B20 oxidation stability, as measured by the Rancimat test, is a property that changes during storage. The rate of oxidation of any given blend will depend on numerous factors including the feedstock used to make the B100, the amount of exposure to oxygen, storage temperatures, storage conditions, and others. Because of these factors, it is difficult to predict the expected useful time period (storage life) of any given B20 in storage. (This is also true for petroleum fuels but to a much lesser degree.) For this reason, the storage of B20 in tanks and the use of B20 in any vehicle, either non-tactical or tactical, must include steps to:

    a. Try to ensure a high Rancimat level at the start; this may require increased stringency in the Statement of Work for the purchase of B20. (Based on the test results which show that vehicles running on B20 with Rancimat measurements exceeding 12 hours (Crane and 29 Palms) had no fuel breakdown in vehicle tanks. Vehicles running on B20 that just met the required Rancimat measured minimum of 6 hours (Moody and NBVC) each had evidence of fuel breakdown). This will increase the cost of the fuel substantially.

    b. Avoid high humidity climate zones, minimize exposure to high and low temperatures as much as possible.

    c. Avoid using B20 in vehicles that consume less than one tank of fuel per month, particularly in climate with high relative humidity.

2. *High Temperature Properties.* Based on our test observations, problems arose only when the B20 is exposed to both high temperatures and high relative humidity conditions which can affect oxidative stability. The 29 Palms Test Vehicle, running in high temperature, low relative humidity conditions did not have the same rate of oxidative breakdown and particulate contamination as vehicles running in a high temperature, high relative humidity climate.

3. *Low Temperature Properties.* As with stability, the low-temperature properties of biodiesel are very dependent on the feedstock and processing of the biodiesel. Most fuel suppliers are cognizant of the needed low-temperature properties of a fuel to be used in a given region during a given time of the year. They typically use a variety of methods to ensure that the fuel they sell will meet the near-term requirements regarding low-temperature operability. Most problems arise when ambient temperatures are lower than expected or when fuel is purchased during warm weather and not used until colder times of the year. (This can also happen with petroleum fuels.) Any user of B20 should be cognizant of these potential problems and take steps to avoid them. B20 used at a cold site installation (NSWC Crane) was automatically switched to B10 in the winter months, however only one test vehicle received B10 fuel. The vehicle running 15 minutes per month, AVGP P-6, filled with B20 at the start of the demonstration, used the same fuel for the duration of the test. This seems to indicate that B20 exceeding the Rancimat specification of 6 hours, is a better indication that the fuel will not breakdown than the climate zone that the vehicle operates in. Low temperature properties of biodiesel improved during the demonstration by the addition of the Cold Soak Filtration Test to the ASTM International D6751 for B100 specification in 2008.
4. *Water Affinity.* Biodiesel is known to be more susceptible to water emulsification to a much higher degree than petroleum diesel fuel. For this reason, any user of B20 should strive to keep fuel storage tanks and vehicle tanks as dry as possible. The test data does indicate that B20 in vehicles will degrade faster in a humid climate than a dry climate.
5. *Material Compatibility and Solvency.* Addition of B20 to fuel systems that have high levels of contamination and deposits will likely increase the occurrence of problems in the near term. This is because biodiesel will help loosen and suspend contaminants into the fuel. Maintaining clean fuel storage systems is the best method to prevent this potential problem. Some increase in filter usage rate may be encountered when biodiesel is first introduced into a given storage/vehicle tank. No additional maintenance costs occurred during the demonstration period that would be found during the duration of this test in general maintenance records, but there were costs associated with cleaning the tank and repairing the sending unit. Additionally, the incompatibility of the 1997 Bobtail fuel sending units is an indication that B20 fuel that becomes instable will cause damage to components within the fuel tank and it can be assumed, eventually downstream to the fuel filters and fuel injectors.

Based on the results of this demonstration project, the use of B20 in selected locations can be recommended for expanded testing only under certain conditions:

- Use B20 fuel that meets or exceeds ASTM International Specifications. The fuels used by successful test vehicles significantly exceeded the oxidation stability requirement by Rancimat (6 hours) at Crane (Average 14.4 hours) and 29 Palms (Average 16.6 hours). This may not be implementable.
- Use vehicles that are refueled at least once a month. The one failure in the test was a vehicle that was used only 1/10th the amount of time as another test vehicle at the same location with the same fuel.

Blanket approval for the use of B20 in all tactical vehicles would not be advised because the potential for problems over and above those typically encountered with petroleum fuels is higher with the use of biodiesel. The annual fuel savings and diverted oil based fuel only make a tiny impact on overall DoD fuel usage, and the fuel cost savings are quickly negated by a small percentage of vehicles having maintenance issues. Major engine manufacturers may require certification of the fuel blend percentage to honor the warranty of the vehicle. OEM will not honor warranty for vehicles that use a biodiesel blend of greater that 5% (GSA. 2007).

Finally, system performance as documented in Table 7 is a critical aspect affecting user acceptance. Technologies that offer environmental advantages must also be capable of meeting the user's performance acceptance criteria. Most end-users expect high reliability from fueling stations with minimal maintenance and operator attention. Liquid fuel dispensing systems are relatively simple in design with few moving parts. Although B20 can use existing fuel storage tanks and pumps, there may be additional requirements such as a periodic visual inspection of fueling facilities to ensure storage tanks do not contain deposits, contaminants, or materials compatibility degradation that may be carried into vehicle fuel systems.

Table 7. Performance of vehicles at the five installations.

Performance Criteria	**Expected Performance Metric (pre demo)** *Examples*	**Performance Confirmation Method** *Examples*	**Actual Performance (post demo)** *Future*
Vehicle Component Testing (fuel pump, fuel pump gasket, fuel injector, fuel injector o-ring, fuel lines, and fuel filter) • Scorching • Deposits • Scarring	No difference between vehicles run on B20 and vehicles run on petroleum diesel fuel	Visible observation of component with the naked eye and under microscope	Moody AFB 1997 Bobtail resulted in heavy deposits in the fuel tank. Although the fuel tank and fuel sending unit were not cleaned and repaired during the demonstration, maintenance action would be required to prevent these solids from moving downstream affecting the fuel injectors and other fuel wetted parts.
Vehicle Oil Inspection	Within JOAP specification	Laboratory testing	Initial NBVC test vehicle oil was OEM off spec oil from a rebuild. Oil was changed and further testing met all JOAP standards.
Reliability	No statistically significant change in engine failure related to fuel system for vehicles running on B20 versus vehicles running on diesel or JP-8	Record keeping	At MCBH, the test TRAM required a new fuel filter; however a definitive cause for replacement was not determined. No variation in standard maintenance in other vehicles occurred. No vehicle failure, although it is expected that the 1997 Bobtail would have eventually had a major engine problem.

Initiating the use of B20 at military installations should appear seamless for the end user and should not create any changes in the fueling process. This demonstration showed an increase in

the cost of fleet tactical vehicle O&M when using B20 within specific fuel quality and operational parameters. In addition, tri-service operational parameters (fuel quality, vehicle age, vehicle usage rate, maximum fuel storage limits, and climate conditions) for using B20 in DoD ground tactical vehicles and equipment were investigated, and validated.

The vehicle that had significant problems while using B20 is the 1997 Bobtail. This vehicle has a history of problems at Moody AFB. The low use rate (75 hours/year), the climate (high temperature/high humidity), and the vehicle age and design contributed to a faster breakdown of fuel then the other vehicles operating on the same fuel in the same conditions. Climate did seem to play a role in fuel breakdown the fuel breakdown in the 1997 Bobtail, but not as much as the initial fuel quality and vehicle usage. The initial sample of the fuel going into the 1997 Bobtail had a Rancimat of 8.5 hours, which met the specification, but was well below the initial Rancimat readings for Crane (18.92 hours). The operation times for the Crane test vehicles (54.6 hours and 6.4 hours) were run the same or less than the Moody vehicle (47 hours) but did not have the same fuel breakdown, even though the relative humidity was virtually the same. The 2008 Bobtail used the same fuel in the same climate, but did not have the same breakdown because the vehicle was used 10 times more frequently than the 1997 Bobtail.

The data gathered by this demonstration validates the March 2006 Tri-Service Biodiesel Position Paper, although it has been demonstrated that under certain circumstances (higher Rancimat, high vehicle usage) vehicles running on B20 did not have vehicle maintenance issues that were different than vehicles running on JP-8. The Tri-Service POL membership and DLA Energy have also stated that increasing the oxidative requirement for biodiesel is not feasible and limiting the use of B20 to a limited number of CONUS operations is logistically impossible. Another important fact to consider is OEM will not honor warranties on engine breakdowns for vehicles running on biodiesel blends above 5%, so even if the engine breakdown cannot be directly tied to the use of B20, warranties on DoD vehicles will be voided due to use of B20.

Any cost savings calculated in this demonstration could also be achieved by switching from JP-8 to DS2 without any of the risks associated with B20 use. Cost savings should not be a factor when determining if CONUS operations should be switched from JP-8 to B20.

Demonstration results will be distributed to the Tri-Service POL Users Group, the Joint Group on Pollution Prevention (JG-PP) and shared with the NREL for nationwide distribution. The Tri-Service POL Users Group consists of fuels experts from each of the armed services. POL members set standards for fuel procurement for their respective branches. The JG-PP will host demonstration information on the JG-PP website to facilitate program awareness, communications and technology transfer.

9.0 REFERENCES

Alleman, T.; McCormick, R.L. 2009. 2008 B20 Survey Results (Presentation). 24 pp.; NREL Report No. PR-540-45184. www.nrel.gov/docs/fy09osti/45184.pdf

Barker, T.L. 2009. Green to Greener--Is Biodiesel a Feasible Alternative Fuel for U.S. Army Tactical Vehicles? Master's Thesis presented to the U.S. Army Command and General Staff College of the University of Motevallo.

Defense Energy Support Center. 2009. Interim Implementation Plan Regarding Section 526 of the Energy Independence and Security Act of 2007. August 2009.

Defense Logistics Agency Energy. 2011. DLA Energy Standard Prices. http://www.energy.dla.mil/DLA_finance_energy/Pages/dlafp03.aspx

Department of Defense (DoD). 2005. Joint Oil Analysis Program Manual Volume II Spectrometric And Physical Test Laboratory Operating Requirements And Procedures. http://www.tinker.af.mil/shared/media/document/AFD-061220-064.pdf

House of Representatives (H.R.) 6 (110th Congress). 2007. Energy Security and Independence Act of 2007, Section 526: Procurement and Acquisition of Alternate Fuels.

Engine Manufacturers Association. 2006. 2006 Test Specifications for Biodiesel Fuel.

Environmental Protection Agency (EPA). 2013. Renewable and Alternative Fuels. U.S. http://www.epa.gov/oms/fuels/alternative-renewablefuels/

EPA. 2002. A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions. Environmental Protection Agency Draft Technical Report, EPA420-P-02-001.

Gerpen, J. Van, B. Shanks, R. Pruszko, D. Clements, and G. Knothe. 2004. Biodiesel Production Technology NREL/SR-510-36244.

Global Security. 2010A. Twenty-nine Palms, California Military Facilities. http://www.globalsecurity.org/military/facility/29palms.htm

Global Security. 2010B. Kaneohe Bay Military Facilities http://www.globalsecurity.org/military/facility/kaneohe-bay.htm

GSA. 2007. Biodiesel Fuel. General Services Administration. http://www.gsa.gov/portal/content/104135

GSA. 2004. Commercial Item Description, Diesel Fuel, Biodiesel Blend (B20). General Services Administration. A-A-59693A.

Heck, D.A. 2007. The 2 Million Mile Haul. Iowa Central Community College. http://www.2millionmilehaul.com/news/2mmhaul.doc

Lucas, W. 1995. Summary Test Report for the Biodiesel Fuel Evaluation for the U.S. Army Tactical Wheeled Vehicles. U.S. Army Yuma Proving Ground TECOM Project No. 1-eg-095-000-028. www.biodiesel.org/reports/19950401_fle-020.pdf

Moody Air Force Base. 2010A. 23rd Wing, Fact Sheets. http://www.moody.af.mil/library/factsheets/factsheet.asp?id=3450

Moody Air Force Base. 2010B. 93rd Air Ground Operations Wing, Fact Sheets. http://www.moody.af.mil/library/factsheets/factsheet.asp?id=17358

National Biodiesel Board. 2012. Biodiesel Emissions. www.biodiesel.org/docs/ffs-basics/emissions-fact-sheet.pdf?sfvrsn=4

National Biodiesel Board, 2011. Biodiesel Industry Producing Record Volumes, Fueling Job Creation. http://www.biodieselmagazine.com/articles/7975/biodiesel-industry-producing-record-volumes-fueling-job-creation

Proc, K., R. Barnitt, R. Hayes, M. Ratcliff, R. McCormick, L. Ha, and H. Fang. 2006. 100,000 Mile Evaluation of Transit Buses Operated on Biodiesel Blends (B20). SAE International. NREL/CP-540-40128.

Schneller, E., and V. Gatto. 2008. Stabilizing Biodiesel Blends from Multiple Feedstocks, March 17, 2008, http://www.biodieselmagazine.com/articles/2218/stabilizing-biodiesel-blends-from-multiple-feedstocks

Schumacher, L.G., J.A. Weber, M.D. Russell, and J.G. Krahl. 1995. An Alternative Fuel for Urban Buses - Biodiesel Blends http://www.biodiesel.org/resources/reportsdatabase/reports/fle/19950821_fle-024.pdf

Tyson, K.S., and R.L. McCormick. 2009. Biodiesel Handling and Use Guide, Fourth Edition. U.S. Department of Energy, Office of Science and Technical Information. NREL Report NREL/TP-540-43672.

Tyson, K.S., and R.L. McCormick. 2006. Biodiesel Handling and Use Guidelines, Third Edition. U.S. Department of Energy, Office of Science and Technical Information. Report DOE/GO-102006-2358.

U.S. Climate Data. 2010A. Climate Crane - Indiana. http://www.usclimatedata.com/climate.php?location=USIN0137

U.S. Climate Data. 2010B. Climate - Kaneohe Bay. http://www.usclimatedata.com/climate.php?location=USHI0064

U.S. Navy. 2010A. Naval Base Ventura County. https://www.cnic.navy.mil/VENTURA/About/index.htm

U.S. Navy. 2010B. NSWC Crane Internet Home. http://www.navsea.navy.mil/nswc/crane/default.aspx

This page left blank intentionally.

APPENDIX A

POINTS OF CONTACT

Point of Contact	Organization	Phone Fax E-Mail	Role In Project
David Cook	NAVFAC EXWC 1100 23rd Avenue, Code EV426 Port Hueneme, CA 93043	Phone: (805) 982-3477 Fax: (805) 982-4832 E-Mail: david.j.cook@navy.mil	Primary Investigator
David Chavez	NAVFAC EXWC 1100 23rd Avenue, Code EV11 Port Hueneme, CA 93043	Phone: (805) 982-5314 Fax: (805) 982-4832 E-Mail: david.chavez1@navy.mil	Co-Primary Investigator
Richard Kamin	Naval Fuels and Lubricants Cross Functional Team 22229 Elmer Road, Building 2360 Patuxent River, MD 20670	Phone: (301) 757-3408 Fax: (301) 757-3614 E-Mail: richard.kamin@navy.mil	Navy Subject Matter Expert
Sherry Williams	Naval Fuels and Lubricants Cross Functional Team 22229 Elmer Road, Building 2360 Patuxent River, MD 20670	Phone: (301) 757-3380 Fax: (301) 757-3614 E-Mail: sherry.williams@navy.mil	Navy CFT Technical Lead
George Handy	NDCEE/CTC 341 Magnolia Lake Court Aiken, SC 29803	Phone: (803) 641-0203 Fax: (803) 480-0303 E-Mail: handyg@ctc.com	Co-Investigator
William Thomas	NDCEE/CTC Suite 500 1225 S. Clark Street Arlington, VA 22202	Phone: (703) 298-2358 Fax: (703) 310-5655 E-Mail: ThomasW@CTC.com	Program Coordinator
Leanne Debias	NDCEE/CTC 100 CTC Drive Johnstown, PA 15904	Phone: (814) 269-6830 E-Mail: debiasl@ctc.com	Laboratory Lead
Kevin Merichko	NDCEE/CTC 100 CTC Drive Johnstown, PA 15904	Phone: (814) 269-2530 E-Mail: merichko@ctc.com	Program Support
Emilio Alfaro	AFPET AFPET/PTPT 2430 C Street, Bldg 70, Area B Wright-Patterson AFB, OH 45433-7632	Phone: (937) 255-8020 Fax: (937) 255-8051 E-Mail: Emilio.Alfaro@wpafb.af.mil	Air Force Subject Matter Expert
Benet Curtis	AFPET AFPET/PTPT 2430 C Street, Bldg 70, Area B Wright-Patterson AFB, OH 45433-7632	Phone: (937) 255-8039 Fax: (937) 255-8051 E-Mail: Benet.Curtis@wpafb.af.mil	Air Force Subject Matter Expert
Omar Mendoza	Air Force Research Laboratory AFRL/MLSC Bldg 652, Room G-10 2179 12th Street Wright Patterson AFB, OH 45433	Phone: (937) 255-2247 Fax: (937) 656-4378 E-Mail: omar.mendoza@wpafb.af.mil	Air Force Sponsor
Luis Villahermosa	TARDEC 6501 E. 11 Mile Road Warren, MI 48397	Phone: (586) 574-4207 E-Mail: luis.a.villahermosa@us.army.mil	Army Subject Matter Expert
Bob Appleton	Marine Corp System Command 6501 E. 11 Mile Road	Phone: (586) 574-9039 Fax: (586) 574-5472	Marine Corps LAV Program

APPENDIX A (continued)

POINTS OF CONTACT

Point of Contact	Organization	Phone Fax E-Mail	Role In Project
	Warren, MI 48397	E-Mail: bob.appleton@us.army.mil	
Robert McCormick	NREL 1617 Cole Blvd. Golden, CO 80401	Phone: (303) 275-4432 Fax: (303) 275-4415 E-Mail: robert_mccormick@nrel.gov	Industry Partner

ESTCP Office
4800 Mark Center Drive
Suite 17D08
Alexandria, VA 22350-3605

(571) 372-6565 (Phone)

E-mail: estcp@estcp.org
www.serdp-estcp.org