PUBLIC WORKS TECHNICAL BULLETIN 200-1-83
30 SEPTEMBER 2010

FEASIBILITY OF JP-8 RECYCLING AT FORT BRAGG, NC

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DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
441 G Street NW
Washington, DC 20314-1000

CECW-CE

Public Works Technical Bulletin 30 SEPTEMBER 2010

No. 200-1-83

FACILITIES ENGINEERING
ENVIRONMENTAL

FEASIBILITY OF JP-8 RECYCLING AT FORT BRAGG, NC

1. Purpose.

a. The purpose of this Public Works Technical Bulletin (PWTB) is to report the results of a JP-8 recycling feasibility study performed for Fort Bragg, NC.

b. All PWTBs are available electronically in Adobe® Acrobat® portable document format [PDF]) through the World Wide Web (WWW) at the National Institute of Building Sciences' Whole Building Design Guide (WBDG) Web page, which is accessible through this Universal Resource Locator (URL):

http://www.wbdg.org/ccb/browse_cat.php?o=31&c=215

2. Applicability. This PWTB is relevant to all U.S. Army facilities with engineering activities that are considering evaluating recycling options for JP-8. This report shows the results of one study at one installation that predicted recycling JP-8 at that installation would be cost effective. However, recycling options reported here are not necessarily applicable to other installations. This report is intended to be used as one source of information for installations that are considering JP-8 recycle. This single report does not eliminate the need to perform an installation-specific study at another installation.

3. References.

a. AR 200-1: Environmental Protection and Enhancement

b. PL 94-580 Resource Conservation and Recovery Act, and amendments.

4. Discussion.

a. AR 200-1 requires that Army installations comply with federal environmental regulations, including those that pertain to the disposal and recycling of hazardous wastes.

b. The Resource Conservation and Recovery Act requires the U.S. Environmental Protection Agency (USEPA) to promulgate regulations regarding the storage, processing, and disposal of solid and hazardous wastes. In 1984 the Act was augmented by the Hazardous and Solid Waste Amendments which included provisions that encourage the recycling and reuse of hazardous wastes.

c. The Waste Minimization and Pollution Prevention (WMPP) program was established by Congress to demonstrate promising off-the-shelf environmental technologies at Army installations. Funding for the WMPP program ended in FY 05. During the 12-year tenure of this program, many environmental technologies were evaluated and demonstrated on Army installations by the prime contractor for the WMPP program, MSE Technology Applications, Inc. (MSE). Unfortunately, the WMPP program did not include sufficient funds to produce a method for technology transfer of the results from many of the successful projects including this feasibility study of JP-8 recycling at Fort Bragg, NC.

d. JP-8 fuel that no longer met specifications (became off-spec) was being disposed as hazardous waste at Fort Bragg. A study identified methods to reuse off-spec JP-8 fuel, to reduce the amount of wastes disposed and to reduce the amount of fuels purchased at Fort Bragg. Implementation of effective reuse methods would result in cost avoidance and eliminate the compliance burden of removing contaminated fuel from the site. MSE first identified the contaminants that caused JP-8 fuel to become off-spec, and determined how off-spec JP-8 was being managed at Fort Bragg. MSE visited recycling systems being used at Fort Hood, Texas, and Fort Lewis, Washington, to obtain operating histories and note the "lessons learned.”

e. MSE then evaluated potential sites for processing JP-8 on Fort Bragg. The 82nd Heat Plant was determined to be the most feasible location because existing infrastructure could be used.

Several end-use options for recycling JP-8 fuel were investigated by MSE. A cost-benefit analysis was performed on those options to determine their economic feasibility. For each option, Net Present Value (NPV) was determined based on capital and initial start-up costs. MSE also determined the annual operations and maintenance (O&M) costs, and the annual cost avoidance for each option.

f. Results of the economic analysis are provided in Table 1 and Table 2. Based on that analysis, reusing reclaimed fuel in the 82nd Heat Plant (Option 1B in Table 1) would provide the greatest overall benefit for Fort Bragg. Note that the accuracy for a NPV cost analysis is from -15% to +30%.

Table 1. Ranked analysis for JP-8 fuel recycling at Fort Bragg.

Outputs	**Net Present Value (NPV)($)**	**Return on Investment (ROI) (%)**	**Payback Period (yr)**
Option 1B – Burn directly in boiler, replacing diesel #2	413,455	2,377	0.04
Option 4A – Use in ground vehicles, after Clarus	399,190	204	0.5
Option 4B – Use in ground vehicles, after Pall	384,503	53	1.9
Option 3A – Burn after Clarus*, replacing diesel #2	303,436	146	0.7
Option 3B – Burn after Pall*, replacing diesel #2	288,748	42	2.4
Option 1A – Burn directly in boiler, replacing natural gas	284,885	1,641	0.1 yr
Option 2A – Burn after Clarus, replacing natural gas	174,865	89	1.1 yr
Option 2B – Burn after Pall, replacing natural gas	160,178	29	3.5 yr
Option 5 – Sell off-spec JP-8*	76,382	N/A	N/A
Baseline – Give away to local universities	–	N/A	N/A

* Clarus and Pall are both companies that make fuel treatment systems to remove contamination of particulates and water. The Pall system used at Fort Hood is described in Section 2.1, and the Clarus system at Fort Lewis is described in Section 2.2.

Table 2. Cost options for capital, operations and maintenance, and cost avoidance.

Option	Capital/Startup Cost ($)	Annual O&M Cost ($)	Annual Cost Avoidance ($)
Baseline – Give away to local universities	—	—	—
Option 1A – Burn directly in boiler, replacing natural gas	2,060	—	33,811
Option 1B – Burn directly in boiler, replacing diesel #2	2,060	—	48,960
Option 2A – Burn after Clarus, replacing natural gas	26,560	10,077	33,811
Option 2B – Burn after Pall, replacing natural gas	112,060	1,733	33,811
Option 3A – Burn after Clarus, replacing diesel #2	26,560	10,077	48,960
Option 3B – Burn after Pall, replacing diesel #2	112,060	1,733	48,960
Option 4A – Use in ground vehicles, after Clarus	24,500	10,077	60,000
Option 4B – Use in ground vehicles, after Pall	110,000	1,733	60,000
Option 5 – Sell off-spec JP-8*	—	—	9,000

*for Option 5, the value in the annual cost avoidance column is actually an income stream.

g. Appendix A contains the body of the final July 2002 report submitted by MSE to ERDC-CERL (known as USACERL 27), edited for format and clarity. Appendices C–F contain supplementary information that supports or augments Appendix A.

h. A glossary is located after the table of contents that begins with Appendix A.

5. Points of Contact.

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Appendix A
FEASIBILITY OF JP-8 RECYCLING AT FORT BRAGG, NC
TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY

Term	Definition
APC	U.S. Army Petroleum Center
API	American Petroleum Institute
AR	Army regulation
AST	Above ground storage tank
Btu	British thermal unit
Coalescer	A device used to consolidate (coalesce) small droplets of a liquid that are suspended within another liquid.
CU	Conductivity units
DCI-4A	A corrosion inhibitor/lubricity enhancer
DF2	#2 diesel fuel
DiEGME	Diethylene glycol monomethyl ether
DPW	Department of Public Works
DOL	Directorate of Logistics
ERDC/CERL	Engineer Research and Development Center/ Construction Engineering Research Laboratory
FSII	Fuel system icing inhibitor
gpm	Gallons per minute
HEMTT	Heavy expanded mobility tactical truck
HMMV	High-mobility multi-purpose vehicle
HQUSACE	Headquarters, U. S. Army Corps of Engineers
JP–8	Jet propellant 8
LCC	Life-cycle cost
MOGAS	Motor gasoline
MW	Megawatt
NATO	North American Treaty Alliance
NPV	Net present value
O&M	Operations and maintenance
PAC	Pall Aeropower Corporation
ppm	Parts per million
SOP	Standard operating procedure
Stadis 450	A static dissipater (the only one approved for military use)
Surfactant	Any substance dissolved in aqueous solution to reduce the surface tension between it and another liquid.
TARDEC	(U.S. Army) Tank Automotive Research Development and Engineering Center
USEPA	U.S. Environmental Protection Agency
WWTP	Waste water treatment plant

1 INTRODUCTION

1.1 Background

JP-8 fuel is used in both aircraft and ground vehicles at all Army installations. Often, this fuel becomes “off-spec” because of contamination by water and solid particulate matter. Approximately 60,000 gal of off-spec fuel is generated annually at Fort Bragg. Similar fuel contamination scenarios are present at both Fort Hood and Fort Lewis.

This study evaluated the existing fuel recycle management in place at Fort Hood, Texas, and Fort Lewis, Washington. Lessons learned from these systems and a study of Fort Bragg's requirements were used to develop recommendations (see Section 6) for a fuel recycling system to be installed at DoD installations.

1.2 JP-8 Fuel

JP-8 is a kerosene-based fuel (>99% by weight) that is very similar to commercial Jet A-1 fuel with an additive package (see Appendix B). JP-8 is classified under North Atlantic Treaty Organization (NATO) Code F-34 as an acceptable alternative to diesel fuel #2 (DF2 or NATO Code F-54). JP-8 has volumetric energy content (heat of combustion) that ranges from approximately 123,100–125,800 British thermal units per gallon (Btu/gal).

1.3 Fuel Additives

The additives contained in JP-8 are a corrosion inhibitor / lubricity enhancer (DCI-4A) and static dissipater (Stadis 450). In addition, a fuel system icing inhibitor (FSII) additive, diethylene glycol monomethyl ether (DiEGME), is put in at the bulk terminal, before delivery of the fuel mixture to Fort Bragg. The following describes the effects or benefits each additive provides to the fuel.

1.3.1 Corrosion Inhibitor (DCI-4A)

Corrosion inhibitors are required to prevent water and oxygen in the fuel from rusting uncoated metallic components that come in contact with the fuel. This additive also adds lubricity for fuel-lubricated rotary injection pumps in ground units, although the effects are minimal.

1.3.2 Static Dissipater (Stadis 450)

Static charge may be generated during the rapid movement of fluid through hoses or fuel lines. Pure hydrocarbons (i.e., JP-8) are essentially nonconductors, and thus, they require an additive to eliminate static charge accumulation. Conductivity of JP-8 must be between 50-450 conductivity units (CU)[1] to dissipate static charge.[2] At the time of this writing, Stadis 450 was the only static dissipater approved for military use. It is important to note that clay filters can easily remove Stadis 450, and they should not be used in a fuel reclamation system.

1.3.3 Fuel System Icing Inhibitor (DiEGME)

The amount of dissolved water present in jet fuel is typically dependent on the temperature and humidity of ambient air. DiEGME, when combined with water, lowers the freezing point of the mixture to ensure that no ice crystals are formed. The additive is only slightly soluble in fuel; however, it is quite soluble in water. When fuel containing FSII comes in contact with large amounts of free water, the DiEGME will separate from the fuel, resulting in a gelatinous layer that may plug the fuel filter. When fuel is clean and "dry,"[3] the DiEGME additive will remain in the fuel solution. However, high concentrations of undissolved residual deicer could affect some filters and epoxy linings.[4]

All of the additives listed above are surfactants, which are defined as any substance dissolved in aqueous solution to reduce the surface tension between it and another liquid. Surfactants reduce coalescer efficiency by emulsifying the fuel and causing the coalescing media to be ineffective, allowing contaminants to pass through.

2 Evaluation of Existing Processes

2.1 Fort Hood, TX

Fort Hood annually generates approximately 60,000 gal of JP-8 fuel that is contaminated with high amounts of water and particulates (Ref. 1). This fuel is primarily generated by Fort Hood's motor pools during routine maintenance duties.

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[1] One CU is equivalent to 1 pico Siemens/meter (1pS/m) = 1 x 10^{-12} ohm^{-1} $meter^{-1}$.
[2] Chevron aviation fuel bulletin acquired from Internet search.
[3] "Dry" fuel may still contain trace amounts of dissolved water.
[4] Phillips 66 aviation tech tips acquired from Internet search.

Fort Hood has initiated a cost savings to the installation by using the reclaimed JP-8 fuel in Department of Public Works (DPW) and Directorate of Logistics (DOL) vehicles, thereby avoiding new fuel costs for those vehicles. The JP-8 fuel recycle program was initiated in February 2000, but it was not operational at the time of MSE’s evaluation (July 2001). Modifications were under investigation at that time, so no reclaimed fuel was being used in any vehicles.

Contaminated fuel is generated in the motor pools when fuel is drained from vehicles during routine maintenance. The contaminated fuel is transferred and stored in aboveground storage tanks (ASTs) at the individual motor pools throughout Fort Hood. DPW personnel collect the contaminated fuel from the ASTs using vacuum trucks and transfer the fuel to 5,000-gal tankers at the recycle/storage facility.

Fort Hood installed a Pall Aeropower Corporation (PAC) Aquasep Fuel Contamination Removal System, Model GE01090. The system operates in three stages. In the first stage, a filter removes particulate matter. In the second stage, water is coalesced and allowed to separate from the JP-8. In the third stage, water is removed from the JP-8. The reclaimed JP-8 is then transferred to a 10,000-gal storage tank; the water is discharged to the sanitary sewer. This system can remove up to 3% water by weight.

In addition to the filtration equipment, the closed-loop system included ASTs, interconnecting piping, biocide injection, pumps, and bulk loading and unloading connections. The two ASTs are equipped for bulk loading and unloading of JP-8 via quick-connect hose couplers. The skid-mounted filtration system was also equipped with a biocide injection system to eliminate biological growth that could occur as a result of insufficient water removal.

The site investigation and subsequent conversations with both Fort Hood and PAC personnel revealed a major design deficiency of the overall recycling system. The flat-bottom storage tanks have no provisions for draining "bottom water" from the tanks. The design allowed a large amount of water contamination to remain in the fuel being transferred for processing, probably exceeding the 3% water limit of the Pall equipment.

Fort Hood personnel have since discussed adding a centrifuge as a pretreatment step to the original process. The addition of a centrifuge should effectively remove gross amounts of free water and benefit the overall process. Centrifuging will also greatly reduce the amount of free water that comes in contact with the coalescing filter, improving the filter’s effective life cycle.

2.2 Fort Lewis, WA

Off-spec fuel is placed into 55-gal drums at multiple locations and then collected by DPW. Contents of the drums are sampled to determine fuel type and contaminants present. Compatible fuels are consolidated at the fuel processing area in a system of ten, 500-gal poly-type totes.

Fort Lewis uses a Clarus Titan 100 series system to reclaim the contaminated fuel by removing particulates[5] and water. Water removal is achieved using a coalescing filter that can remove 99% of the water at flow rates up to 15 gal per minute (gpm). The filter/separator meets American Petroleum Institute (API) 1581 requirements.[6] The system is designed with redundancies that allow continuous operation of the filtration/separation equipment. The system is supplied using an onboard variable-speed pump that allows flow control up to 15 gpm.

Processed fuel is consumed in tactical vehicles at Fort Lewis. Each unit must contact the DPW to make arrangements for fuel pickup and processing. If the unit desires to use the fuel after processing is complete, fuel return is coordinated with DPW personnel. There is no cost to the unit for fuel reclamation; costs are absorbed by the DPW.

Over 3 years, Fort Lewis reclaimed over 250,000 gal of JP-8 fuel. However, the volume reclaimed is now smaller because the quantity of contaminated fuel generated has been reduced.

The Clarus system used a primary collection tank for initial fluid separation. Fuel was pumped from the phase containing fuel and dissolved water (top layer) to the Clarus Titan unit. After the fuel was pumped off, the remaining water phase (bottom layer) was then transferred to conical tanks for further separation. The liquid sent to the conical tanks separates into three fractions: (1) fuel/water emulsion, (2) water, and (3) settled solids.

[5] Particulates are removed to the one-half micron size.

[6] API 1581 provides the minimum performance and mechanical requirements, and the testing and qualification procedures for aviation fuel filters/separators.

The top layer of fuel was skimmed from the conical tank and processed through the Clarus Titan unit to further remove water. The bottom two layers (the water and solids layers) were drained and discharged to the sanitary sewer[7].

Fort Lewis personnel monitor fuel quality by visual inspection. A sight glass allows the operator to see the fuel as it is processed. Clear, amber fluid in the sight glass indicates the fuel stream is sufficiently clean; cloudy fluid indicates the presence of water contamination. A cloudy stream is re-circulated through the Clarus Titan unit until it becomes clear. The water removed by the Clarus unit is disposed, as required, via Fort Lewis' sanitary sewer.

Samples of "clean" fuel were sent to the U.S. Army Petroleum Center (APC) laboratory in New Cumberland, PA, for certification as JP-8 with a "ground-use only" designation. Before fuel is used in military vehicles it must be approved for use by APC. The fuel is issued only after it is deemed suitable by APC for “ground use only”.

According to personnel at Fort Lewis, a difficult issue in recycling fuel is the segregation and management of the waste stream.[8] Improper segregation of off-spec JP-8 containing small quantities of diesel fuel or even smaller quantities of gasoline that end up being processed in the fuel recycling system will result in JP-8 recycled fuel batches failing the JP-8 specifications as determined by the APC. For example, gasoline present in recycled fuel will fail the JP-8 fuel specification due to the lower flashpoint associated with gasoline, and diesel fuel present in recycled fuel will fail the JP-8 fuel specification due to the high sulfur content associated with diesel fuel.

Fort Lewis used a system of 10 totes to segregate the fuel to be recycled. Fuel was visually graded upon receipt and assigned to a tote according to the visual grade. The best fuel went in tote #1 while the most contaminated fuel went into tote #10. This allowed the lower numbered totes to be recycled at lower costs. Fuel costs were related to the amount of fuel cleaned and the amount of processing required.

[7] An electroflocculation process was originally part of the Fort Lewis processing system. It was discontinued because wastewater from the Clarus unit could be discharged directly to the sanitary sewer system.

[8] Telecom with James Lee, Fort Lewis

The fuel reclamation program originally started as a performance-based contract with a contracted recycler. DPW personnel performed fuel collection, while the contractor conducted recycling operations. The service-based contract allowed Fort Lewis personnel to obtain confirmation from the APC that the fuel was suitable for use prior to the contractor receiving payment. Only fuel approved by the APC was purchased from the contractor.

2.3 Fort Bragg, NC

Off-spec fuel is generated at Fort Bragg through a variety of sources. Regulations require fuel removal from equipment undergoing routine maintenance and/or storage, which is the main source of contaminated JP-8. Additional off-spec fuel can be generated as a result of mission stand-downs associated with alerts for disaster relief missions (e.g., hurricanes). All mission-critical vehicles are fully fueled in advance to prepare for disaster relief. If disaster relief missions are not deployed, fuel tank levels of the associated motor vehicles must be reduced below the three-quarters level in preparation for potential rapid deployment missions.

Off-spec fuel is collected by DPW personnel and transferred to a 20,000-gal AST located near the Fort Bragg 82nd Heating Plant. The contaminated fuel is allowed to separate via gravity in this tank until transferred off site. The main contaminants are water and particulate.

Gross amounts of water are drained from the bottom of the tank -- visual inspection is used to determine when the majority of water has been drained. This water is directed to an underground drain leading to an oil-water separator. The separator removes residual amounts of fuel prior to discharge to the waste water treatment plant (WWTP). Oil/water separator effluent is typically clear, indicating that emulsified fuel is not present.

Area universities have accepted the recycled fuel for use in heat plants. Fort Bragg imposes no charge on the universities for the fuel. However, the universities are required to provide their own transport of the fuel.

3 JP-8 Management at Fort Bragg

To effectively administer a JP-8 reclamation program, a standard operating procedure (SOP) must be developed for the collection, transfer, and storage of off-spec JP-8 fuel at Fort Bragg. An accepted, effective, and seamless SOP will result if representatives from all affected parties (motor pools, heat plant, environmental contractors, DPW personnel, etc.) are involved in creating the SOP. Along with this SOP, changes to the equipment and facilities used may be necessary. The following section describes recommendations for the equipment and processes associated with contaminated JP-8 at Fort Bragg.

3.1 Suggested Modifications to Current Process

The reclaimed fuel program process should properly segregate off-spec fuel from other contaminants such as antifreeze, diesel fuel, gasoline, hydraulic oil, etc. DPW would pick up the off-spec fuel, transfer fuel into an existing bulk storage tank, reclaim (remove excess water and particulate) from the off-spec fuel, and submit test samples from the reclaimed fuel to the APC for testing and certification as ground-use JP-8. [9]

The tanks located at the 82nd Heat Plant, which are currently used for off-spec JP-8 fuel storage, are suitable for a JP-8 reclaiming system, and should continue to be used. However, it is recommended that these tanks be drained of all existing contents, cleaned (as required), and inspected for structural integrity. These steps will ensure that the tanks are sufficient for a long-term program and that additional contaminants (i.e., gasoline, diesel fuel) from past contents are not introduced into a reclaimed JP-8 fuel stream.

Also, as a final measure, a second, existing 10,000-gal storage tank should be modified to include (1) a vent/breather apparatus that can prevent moisture due to ambient humidity from entering the tank and (2) an easy-to-read tank level indicator. The apparatus should consist of a one-way vent valve to allow the tank to vent to atmosphere during increased volumetric effects. The inlet breather should be drawn through an air-drying apparatus such as a desiccant bed, which would aid in reducing the effects of humidity on the fuel. The tank-level indicator should be easy to read and maintain, while allowing an operator to see the tank’s current fuel storage capacity at a glance.

[9] Information gathered from internet search - Aviation Fuel Reclamation System; *Preproduction Initiative - NELP;* NAS North Island

3.2 Segregation

Fluid segregation is important in a fuel recycle program. A very small quantity of motor gasoline (MOGAS) and small quantities of diesel fuel can ruin a large quantity of JP-8. No consensus exists regarding how many gallons of JP-8 will be ruined with the addition of 1 gal of gasoline. In the literature, estimates for such quantity range from a low of 1,000 gal,[10] a median of 3,000 gal,[11] and a maximum of 5,000 gal.[12] Additionally, APC laboratory personal commented that reclaimed fuel fails the JP-8 certification test when it tests positive for a low flashpoint (MOGAS contamination) and a high sulfur concentration (DF2 contamination). Therefore, it is extremely important that all MOGAS and DF2 contamination is completely eliminated from any JP-8 fuel destined for reclamation.

The most appropriate method of successfully accomplishing this is through the education of troops and personnel responsible for off-spec JP-8 collection and recycling. Also, as a means of maintaining overall fuel integrity, fuel collection for reclamation should be assigned to a single organization such as the DPW. Any off-spec JP-8 that is too contaminated for beneficial reuse would be rejected from reclamation and disposed appropriately following all local, state, and federal guidelines for the disposal of hazardous waste.

3.3 Equipment

Existing tanks located at Fort Bragg's 82nd Heat Plant may be used as initial and final holding tanks for the fuel. The 20,000-gal horizontal tank would serve as the initial stabilization tank, allowing gravity separation of a multi-phase fluid.

4 Options for Reuse of Reclaimed JP-8

Proper collection and reclamation of JP-8 fuel will render a fuel useful to various applications at Fort Bragg. This next section addresses the options to use reclaimed fuel at the 82nd Heat Plant and in ground vehicles.

[10] Telecom with Conoco Refinery Laboratory
[11] Telecom with Montana Refining Corporation
[12] Conversation with Fort Hood environmental branch personnel.

4.1 Heat Plant Reuse

Section 1.2 describes JP-8 fuel properties in detail. The heating value and the flashpoint of JP-8 are slightly lower than that of DF2[13] (see Table D-1 in Appendix D).

In October 1999, the 8th U.S. Army completed the conversion of a heating plant from DF2 to JP-8 in Korea. This conversion was completed without incident, and enhanced the military's one-fuel readiness posture by eliminating the need for DF2 (Ref. 2). Similarly, a metropolitan airport in Minnesota recently completed a Detroit Stoker heat plant conversion from DF2 to aviation fuel for similar reasons.

Fort Bragg's 82nd Heat Plant uses Detroit Stoker burners to provide steam heat throughout the installation. Currently, the burners are configured to use either natural gas or DF2. Because Fort Bragg is an industrial user of natural gas, supply may be reduced or cut off periodically to meet residential demands. As a result of the potential interruption in natural gas supply, Fort Bragg uses DF2 as a secondary combustion fuel for the heat plant. Heat plant personnel are warned of an interrupted service by the natural gas supplier and have time to change over to DF2, which is stored onsite.

Conversations with heat plant personnel indicated that Burner #5 (a D-frame style heat exchanger) might best be suited for use of JP-8. The configuration of this burner is similar to the type that was converted to JP-8 at a Minnesota civilian airport. Conversations with Detroit Stoker personnel confirmed that the use of JP-8 would not result in any adverse effects to the burners of the heat plant. However, due to the slightly lower viscosity of the JP-8, it is recommended that all fittings within the piping system be tightened to prevent fuel leaks.

It appeared that a misconception regarding the use of JP-8 in Heat Plant applications existed. It has been stated that JP-8 burns hotter than DF2, and high temperature could damage the existing tube bundles in the #5 boiler. The tubes are made from SA-178 Grade A material. Referring to the maximum flame temperatures that may result from combustion, natural gas has a higher adiabatic flame temperature than JP-8 and a higher energy content (see Table D-1 in Appendix D). Therefore, it is

[13] DF2 referred to in this report is equivalent to fuel oil #2, a high-sulfur, non-taxed diesel fuel.

reasonable to assume that damage will not occur to the boiler tubes.

Off-spec JP-8 is currently being stored near the heating facility. Therefore, much of the existing infrastructure can be used for the additional reclamation equipment required. There are two horizontal storage tanks that may be used to store both unprocessed and processed fuel. The 20,000-gal tank is suitable for unprocessed fuel storage. The larger capacity of that tank is well-suited for large accumulations of off-spec fuel that contain bulk water contamination. Off-spec fuel transferred to this tank will undergo a preliminary gravity-separation process, i.e. heavier contaminants (solids and water) present in the mixture will settle to the bottom of the tank while the lighter fluid (JP-8) will rise to the top. Water and particulate contamination can be drained to the existing oil/water separator.

Following successful removal of gross contamination in the large storage tank, the JP-8 could be burned directly in the heat plant, though it may require processing through a fuel-recycling unit to become an acceptable fuel for the heat plant. Fuel filtration may be required according to personnel with the Detroit Stoker Company (heat plant burner manufacturer). A normal fuel specification for DF2 combusted in a Detroit Stoker burner specifies a very low percentage (approaching 0%) for both water and sediment. Gums and oxidants present in fuel are less critical to satisfactory burner operation. Bulk quantities of reclaimed fuel may then be stored in the existing 10,000-gal tank until it is needed.

The 82nd Heat Plant could realize a decrease in fuel cost as a result of replacing the fuel in the boilers with reclaimed JP-8. Expenses and cost avoidance data associated with the different options for burning reclaimed JP-8 in the boilers are provided in Section 5 of this report.

Prior to using JP-8 as a fuel in the heat plant, it should be confirmed that it will not affect the existing air quality permit for the Fort Bragg (see Appendix E). Emissions from JP-8 combustion have been shown to have a higher ash and sulfur content than from diesel fuel, which may be detrimental to the greater Fayetteville air-shed.

4.2 Use in Ground Vehicles

Studies have been performed to evaluate the use of JP-8 fuel in place of DF2 in ground vehicles throughout the Army. These studies have been performed in support of the Army's concept of using a single fuel on the battlefield (Ref. 2). As briefly noted in Section 1.2 JP-8 (NATO Code F-34) is an acceptable substitute for DF2 (NATO Code F-54). Studies indicate that JP-8 has had very little detrimental effects on vehicle performance. However, it should be noted that all of the data gathered in regard to JP-8 use in vehicles only involved the use of "new" JP-8 fuel. No data were gathered regarding the use of reclaimed JP-8 fuel in vehicles. However, because reclaimed JP-8 must be approved by the APC, it is logical that it will have virtually the same properties as new JP-8 fuel.

The following paragraphs are an attempt to clarify issues that arose during those investigations, including the effects on ground vehicles relating to horsepower, emissions, and viscosity. In addition, warranty claims and myths are clarified in the following text.

4.2.1 Horsepower

Referring to the net heat of combustion provided in Table D-1 in Appendix D, the heat content of JP-8 is slightly lower than DF2. The assortment of information gathered has shown that the variations of heat content between JP-8 and DF2 range from 2%-9%. It is assumed that this range is a function of both the quality of crude oil that is refined and the distillation process unique to the production of these crude oil fuel products.[10]

Due to the slightly lower volumetric heating content of JP-8 in comparison to diesel, there is a decrease in output horsepower while burning JP-8 in diesel engines. This decrease has typically been shown to be an approximately 2%-9% reduction in output horsepower at the top end of the performance curve.[14] Therefore, drivers conducting the study had to give more "rack" (throttle) while using JP-8 to meet mission objectives. As a result, higher fuel consumption rates are generated using JP-8. On a percentage basis, the increased fuel consumption is proportional to the decrease in horsepower (i.e., the 5%

[14] Studies have not clarified where horsepower determinations were measured. It is assumed the output horsepower is equivalent to the drawbar horsepower.

decrease in horsepower results in a 5% increase in fuel consumption) to meet mission objectives.

4.2.2 Emissions

The combustion characteristics of JP-8 and DF2 are nearly identical. Therefore, the emissions from both fuels are similar, resulting in USEPA approval of JP-8 substitution for DF2 (Ref. 3). However, the sulfur emissions are elevated with DF2 (e.g., off-highway and heating oil use) compared to JP-8.

Limited laboratory testing has shown that JP-8 produces significantly lower overall emissions and signature than DF2. Also, smoke generated using JP-8 is significantly less than that produced by DF2. This has caused problems with armored vehicles using the Vehicle Engine Exhaust Smoke Systems. The superheated vapor from JP-8 combustion does not cool as it exhausts, and without cooling, a fog is not formed as the JP-8 exhaust is dissipated into the atmosphere. Essentially, JP-8 is too clean to put out a good smoke screen.

4.2.3 Maintenance

As a result of the corrosion and lubricity additives in JP-8, deposits of carbon found in DF2 fuel systems are removed when JP-8 is introduced. This has resulted in short-term increased fuel filter consumption until the deposits are removed. After this period however, the inherent cleanliness of JP-8 and lack of significant particulate matter (1 milligram per milliliter [mg/mL]) compared to DF2 (10 mg/mL) actually increases the life of fuel filters (Ref. 2). Therefore, vehicles in transition from DF2 to JP-8 should be monitored for fuel filter performance. Past experience with JP-8 in DF2 engines has also revealed the need to pay attention to fuel injection systems following conversion. The lower viscosity of the JP-8 can result in leakage from the high-pressure regions of the fuel pump and injection nozzle.

4.2.4 Warranty Claims

Discussions with Army personnel reveal reluctance to using JP-8 in diesel engines because of the belief it would void the manufacturer’s warranty for the engine. This claim was proven false by contacting manufacturer representatives. Use of JP-8 in diesel-powered Caterpillar engines would not void the factory warranty.[15] Early Caterpillar engines equipped with a Stanadyne fuel delivery system had problems with a seal that was incompatible with JP-8 fuel. However, Caterpillar has since replaced this seal with a material that was compatible with JP-8 fuel. This resulted in newer manufactured engines no longer experiencing this problem. Also, it was revealed that the High Mobility Multi-Purpose Wheeled Vehicle (HMMV) had problems when initially converted from diesel to JP-8. This was probably caused by washing of engine components with this cleaner fuel, which resulted in frequent fuel filter changes until the engine had cleaned itself of DF2 deposits, as described previously.

It is important to note that although the use of JP-8 in ground vehicles is not entirely widespread throughout DoD, vehicles at Alaska installations have used Jet A-1 for the past three decades. There have been no reports of catastrophic failures in vehicles. These installations use Jet A-1 in place of DF2 due to better fuel characteristics at lowered temperatures. As noted previously, Jet A-1 and JP-8 are essentially identical fuels. Jet A-1 and JP-8 have a lower wax temperature than DF2; therefore, there is less susceptibility to wax formations in the fuel, resulting in plugging of the fuel filter. Additionally, the refueling of a fire truck with JP-8 has been observed at Fort Bragg. Subsequent conversation with the firemen who were refueling the truck revealed that particular fire truck was equipped with a Detroit diesel engine, and it had been fueled exclusively with JP-8 with no adverse effects.

4.2.5 Tactical Vehicles

Due to the operating nature and potentially risky environment of tactical vehicles, operators must have confidence in the reliability of their vehicles. This has caused some concern regarding the use of reclaimed fuel. However, as discussed in Section 2.2, Fort Lewis uses reclaimed fuel in tactical vehicles for training missions with no ill effects. Fuel used in military vehicles must be approved by the U.S. Army Petroleum Center (APC) in New Cumberland, Pennsylvania. The fuel can be issued only after it is deemed "Suitable for Ground Use Only" by the APC.

[15] Caterpillar Warranty Department, POC Allan Paden (309) 578-6491

4.2.6 Non-tactical Vehicles

Non-tactical vehicles are support or administrative vehicles that are not used for combat. Non-tactical vehicles are typically used in-garrison by groups such as logistics or public works. There is less reluctance regarding the use of reclaimed fuel in vehicles of this classification.

4.3 Use in Emergency Power Generation

Fort Bragg currently maintains five, 5-megawatt (MW) diesel-powered electrical generators to provide alternate electrical power. As previously discussed, JP-8 is a suitable replacement fuel for diesel engines. Therefore, it is conceivable to use JP-8 in the emergency generator units. However, a recent survey of the use of the Fort Bragg generators by MSE personnel revealed that the units are operated an average of 24 hours per year. Emergency generators are started weekly to ensure equipment functionality. As a result of the limited run time and fuel consumption, the generators would not be a significant user of the reclaimed JP-8 generated at Fort Bragg.

5 Cost Analysis

Life-cycle cost (LCC) analysis was completed for the JP-8 fuel reuse options being considered at Fort Bragg. For each option analyzed, the capital and upfront costs associated with the required equipment and startup costs for each system were obtained. In addition, the annual operations and maintenance (O&M) costs were determined. Along with these costs, any cost avoidance associated with each option was also determined, to complete the cost analysis. From this information, annual cash flows for each option being considered were calculated.

A project life of 10 years was used to compute the LCC for each option. To compare the total costs for each option in an equitable manner, the annual Net Present Value (NPV) was calculated for each option, using a discount rate of 3.1%. This discount rate was taken from the then-current U.S. Office of Management and Budget Circular no. A-94, which is used for cost-effectiveness, lease purchase, and related analyses for federal government capital projects. Using this method, the larger the NPV (net cash flow), the more cost-effective the option would be. Besides calculating the NPV, the rate of return on capital and the payback periods were also calculated for each option considered.

Not all possible costs were accounted for in this analysis. For instance, certain costs that are common to all options were not considered. Costs associated with collecting and handling off-spec JP-8, transferring it to the holding tanks, and removing gross water and sediments would fall into this category. Other costs not included are capital expenditures for items that had been purchased in the past. This included items such as the existing 20,000-gal holding tank and the 10,000-gal reclaimed JP-8 storage tank, along with the pumps, valves, and piping associated with these tanks.

There were minor differences among the reuse options in how reprocessed JP-8 was handled and transferred to the end user—whether it be a boiler, vehicle, or backup generator. Although these tasks may contribute to the overall cost for each of these options, they were considered small relative to the overall cash flow during a 10-yr period. Therefore, the cost avoidance was considered the same for replacing diesel regardless whether it is in a boiler, vehicle, or backup generator.

In addition to the baseline, five major options were considered. Options 1, 2, 3, and 4 each featured two alternative scenarios that are slightly different. The baseline and the four options are described in the following paragraphs.

5.1 Baseline: Donated to University

The baseline used in this JP-8 recycling project at Fort Bragg was to give the off-spec fuel away to local universities for use in their heat plants. The fuel would be bulked up in the 20,000-gal holding tank, periodically draining off excess water and sediment. Fort Bragg would provide no further processing. Transportation would be provided by the acquiring university, thereby allowing Fort Bragg to excess the off-spec fuel at no charge.

5.2 Options 1A and 1B: Untreated Replacement of Heat Plant Fuels

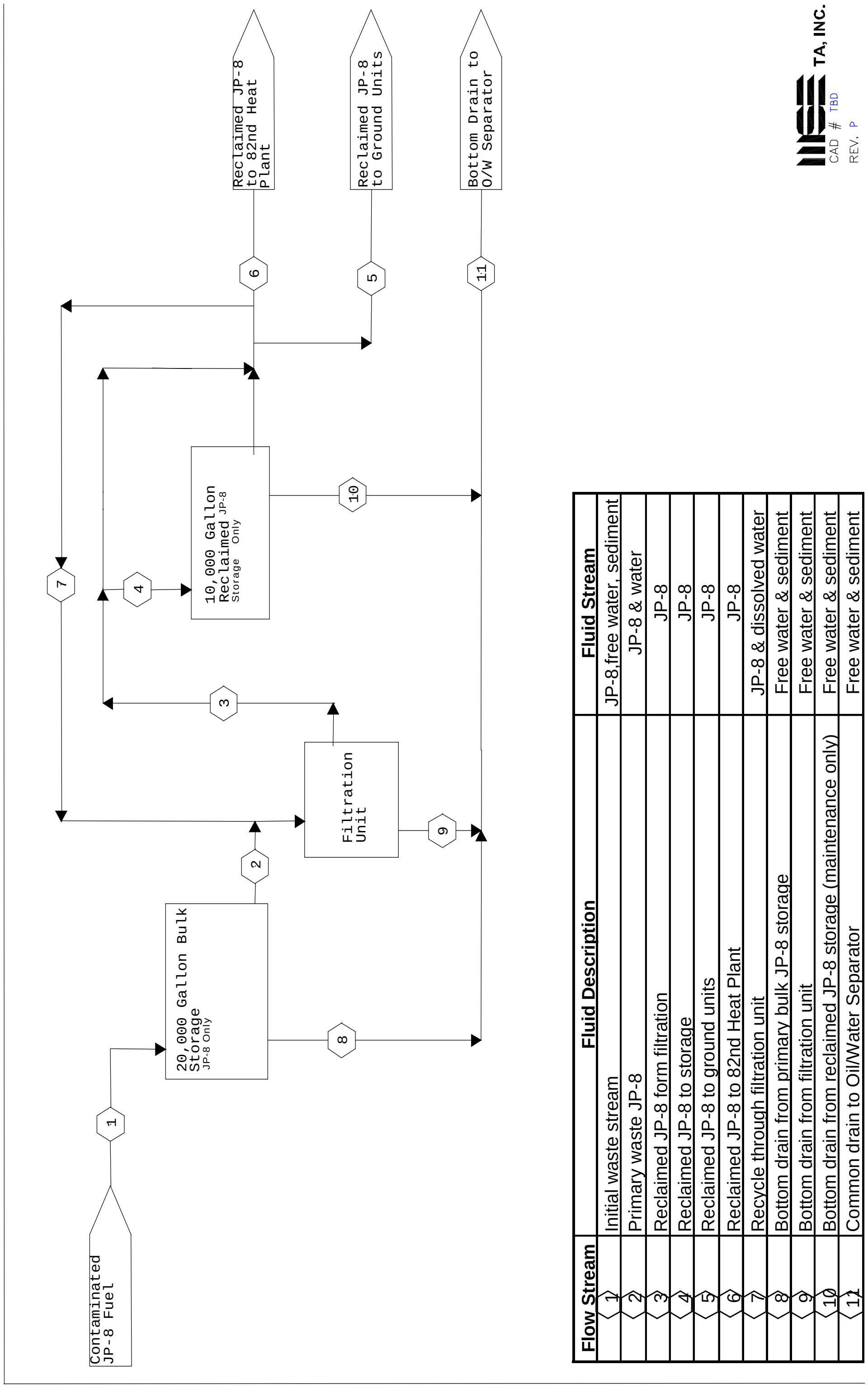
Option 1A

Option 1A considered disposing of off-spec JP-8 at Fort Bragg and using it as fuel burned in the 82nd Heat Plant. For this option, the handling currently performed by DPW personnel was not changed. Excess free water contained in the fuel would be settled out in an existing 20,000-gal storage tank (Figure A-1). After the water and any sediment contained in the off-spec fuel were settled out and removed, the fuel would be transferred and stored in a 10,000-gal holding tank. From this tank, it is assumed the fuel would be transferred to the boilers using existing systems. The only other expenses associated with directly burning the off-spec JP-8 without additional processing would be the addition of piping and valves to tie into the existing boiler feed lines.

It was assumed that the off-spec JP-8 would replace an equivalent amount of natural gas for firing the boilers. The cost of natural gas was calculated using a spreadsheet model constructed from data obtained from personnel at Fort Bragg and Piedmont Natural Gas of North Carolina. The natural gas energy equivalent in therms for JP-8 was calculated based on the energy conversion for DF2 and a de-rate factor for JP-8 of 0.96 relative to the DF2. Once the energy equivalent of natural gas was calculated, the cost avoidance was determined based on the amount of natural gas being replaced by the off-spec JP-8.

Option 1B

Option 1B is similar to Option 1A, except the off-spec JP-8 was assumed to replace an equivalent volume of DF2 instead of natural gas in the boilers. The cost of DF2 used in the cost model of $0.85/gal was obtained from Fort Bragg personnel. A de-rate factor for JP-8 of 0.96 relative to the DF2 was used to calculate the equivalent volume of diesel fuel that would be replaced. Using the cost of diesel and this volume, the annual cost avoidance was calculated.



Flow Stream	Fluid Description	Fluid Stream
1	Initial waste stream	JP-8,free water, sediment
2	Primary waste JP-8	JP-8 & water
3	Reclaimed JP-8 form filtration	JP-8
4	Reclaimed JP-8 to storage	JP-8
5	Reclaimed JP-8 to ground units	JP-8
6	Reclaimed JP-8 to 82nd Heat Plant	JP-8
7	Recycle through filtration unit	JP-8 & dissolved water
8	Bottom drain from primary bulk JP-8 storage	Free water & sediment
9	Bottom drain from filtration unit	Free water & sediment
10	Bottom drain from reclaimed JP-8 storage (maintenance only)	Free water & sediment
11	Common drain to Oil/Water Separator	Free water & sediment

Figure A-1. Conceptual process flow diagram.

5.3 Options 2A and 2B: Treated Replacement of Natural Gas In Heat Plant

Both Options 2A and 2B evaluated reprocessing the off-spec JP-8 by using a treatment system before burning it in the 82nd Heat Plant. In this case, it was assumed that the JP-8 would need to be cleaned up to remove trace amounts of water and solids before being fed to the boilers. This option would be considered only when required by the boiler manufacturer to prevent fouling of orifices or other possible equipment damage. The only difference between Options 2A and 2B was the treatment system used to reprocess the off-spec fuel. For Option 2A, a Clarus Titan Fuel Reclaiming system was used. For Option 2B, the Pall Fuel Recycler system was used.

After removing the excess water and sediments, the off-spec fuel would be processed using either the Clarus or Pall system. Once cleaned up, the reprocessed JP-8 is transferred to the 10,000-gal holding tank, where it is stored before being sent to the boilers (Figure A-1). Besides the cost of the treatment system, the only other capital expense is for the addition of piping and valves to tie into the existing lines to the boilers. This option also has O&M costs associated with reprocessing the off-spec fuel.

Like Option 1A, it was assumed that the reprocessed JP-8 would replace an equivalent amount of natural gas for firing the boilers. The cost of natural gas was calculated using a spreadsheet model constructed from data obtained from personnel at Fort Bragg and Piedmont Natural Gas of North Carolina. The natural gas energy equivalent in therms for JP-8 was calculated based on the energy conversion for DF2 and a de-rate factor for JP-8 of 0.96 relative to the DF2. Once the energy equivalent of natural gas was calculated, the cost avoidance was determined, based on the amount of natural gas being replaced by the off-spec JP-8.

5.4 Options 3A and 3B: Treated Replacement of Diesel Fuel in Heat Plant

In Options 3A and 3B, the reprocessed fuel would replace an equivalent amount of diesel fuel to run the boilers. The cost of DF2 was obtained from Fort Bragg. The energy equivalent of JP-8 for diesel was calculated using a de-rate factor. Option 3A assumed the Clarus system would be used to reprocess the off-spec fuel, while Option 3B assumed the Pall system is used. The procedure and costs associated with reprocessing the off-spec

JP-8 using this option were the same as for Option 2. The major difference between Option 2 and Option 3 was that cost avoidance varied, depending on whether the recycled JP-8 was assumed to replace natural gas or diesel fuel in the boilers.

5.5 Options 4A and 4B: Treated Replacement of Fuel for Ground Vehicles

Both Options 4A and 4B involved using the reprocessed fuel in ground vehicles after it was treated to remove trace amounts of water and sediment. If this reprocessed fuel were to be used in tactical ground vehicles, it would be required to be tested and certified by the APC. There would be no additional charge to Fort Bragg for this testing. For Option 4A, the off-spec fuel would be cleaned using the Clarus Titan reprocessing unit, while Option 4B would use the Pall system.

After running the JP-8 through the reprocessing unit, it would be transferred to the 10,000-gal reclaimed JP-8 tank, similar to the process used in Option 2 and Option 3 (Figure A-1). From this tank, the reprocessed fuel would be transferred into fuel tankers, pods, or blivets for storage and subsequent dispensing into ground vehicles. If the fuel were to be used in non-tactical vehicles, service trucks would fill up at the 10,000-gal tank and subsequently fuel public works trucks and equipment. If the reclaimed fuel were used in tactical ground vehicles, the same process would occur with the exception that Heavy Expanded Mobility Tactical Truck (HEMTT) tankers would likely be used to transfer of JP-8 from the holding tank to the vehicles.

Costs for Option 4 consist of the capital along with O&M cost for the reprocessing system used to clean the fuel. For this option, it was assumed the reclaimed JP-8 would be tested and certified by the APC to replace an equivalent amount of new JP-8 being used to fuel ground transport vehicles. The cost of new JP-8 fuel was obtained from Fort Bragg. From this information, the net cost avoidance was determined for Option 4. If the reclaimed JP-8 were used to replace DF2 in non-tactical vehicles, the overall cost-effectiveness would be very comparable to that for Option 3, where the recycled JP-8 replaced DF2 in the boilers.

5.6 Option 5: Fort Bragg is paid for off-spec JP-8

Option 5 is similar to the baseline except Fort Bragg would be paid for the off-spec JP-8 fuel. The fuel would be handled in the same manner as for the other options. Off-spec JP-8 would be transferred to the 20,000-gal holding tank where the excess water and sediments would be drained off periodically (Figure A-1). From this point, a vendor would load a transport tanker to remove it from the Fort Bragg site. There would be no additional costs to Fort Bragg for disposing of the fuel. In addition, the vendor would pay Fort Bragg a specified amount for the JP-8, resulting in an annual income stream.

5.7 Life-Cycle Cost Model

A Life-Cycle Cost (LCC) model was constructed to compare all options considered for recycling the off-spec JP-8 fuel to determine which option would be most cost-effective. This comparison is illustrated in the model shown in Table A-1. The first section shows the inputs to the model. Those inputs reflect then-current trends at Fort Bragg. From these inputs and other data used in this cost model, the outputs were calculated and shown in (Table A-2), which compares the cost-effectiveness for each option including the NPV, return on investment, and payback period. The equations used for this cost analysis are given in Appendix F.

In this use of the LCC model, the NPV represents the present value of cash flows over a 10-year life cycle for each option. The cash flows are the result of either cost avoidance or income streams; therefore, the higher the NPV, the more favorable the option. A large return on initial investment is also a positive indicator for each option evaluated. The payback period indicates the length of time required to recover the initial capital expenditure, with the shorter time being better. Also, a higher rate of return and shorter payback period reduces the risk associated with the option due to the quicker recovery of the initial cash outlay.

Table A-1. Cost-effectiveness of JP-8 fuel recycling options.

Inputs	**Value[16]**		
Volume of off-spec JP-8	60,000 gal/yr		
Cost of JP-8	$1.00/gal		
Cost of new diesel #2	$.85/gal		
Average natural gas consumption	472,039 therms/month		
Project life	10 yr		
Outputs	**Net Present Value (NPV) ($)**	**Return on Investment (ROI) (%)**	**Payback Period (years)**
Baseline – Give away to local universities	–	N/A	N/A
Option 1A – Burn directly in boiler, replacing natural gas	284,885	1,641	0.1 yr
Option 1B – Burn directly in boiler, replacing diesel #2	413,455	2,377	0.04
Option 2A – Burn after Clarus, replacing natural gas	174,865	89	1.1 yr
Option 2B – Burn after Pall, replacing natural gas	160,178	29	3.5 yr
Option 3A – Burn after Clarus, replacing diesel #2	303,436	146	0.7
Option 3B – Burn after Pall, replacing diesel #2	288,748	42	2.4
Option 4A – Use in ground vehicles, after Clarus	399,190	204	0.5
Option 4B – Use in ground vehicles, after Pall	384,503	53	1.9
Option 5 – Sell off-spec JP-8*	76,382	N/A	N/A

[16] The original MSE report was prepared in 2002. Costs in all tables are in 2002 dollars, and reflect fuel costs at that time.

Table A-2. Economic analysis results ranked by NPV.

Outputs	Net Present Value (NPV) ($)	Return on Investment (ROI) (%)	Payback Period (years)
Option 1B – Burn directly in boiler, replacing diesel #2	413,455	2,377	0.04
Option 4A – Use in ground vehicles, after Clarus	399,190	204	0.5
Option 4B – Use in ground vehicles, after Pall	384,503	53	1.9
Option 3A – Burn after Clarus, replacing diesel #2	303,436	146	0.7
Option 3B – Burn after Pall, replacing diesel #2	288,748	42	2.4
Option 1A – Burn directly in boiler, replacing natural gas	284,885	1,641	0.1 yr
Option 2A – Burn after Clarus, replacing natural gas	174,865	89	1.1 yr
Option 2B – Burn after Pall, replacing natural gas	160,178	29	3.5 yr
Option 5 – Sell off-spec JP-8*	76,382	N/A	N/A
Baseline – Give away to local universities	–	N/A	N/A

From Table A-2, we see that overall, Option 1B had the highest NPV, the greatest return on investment, and the shortest payback period. This option was the most cost-effective because there was little additional investment involved with using the off-spec JP-8 to replace an energy-equivalent volume of diesel burned in the boilers. Also, there were no additional operating costs because the off-spec JP-8 is handled and treated the same way regardless of its ultimate use. Also, it was assumed there would be no additional labor cost because the same steps required for switching the boilers over from natural gas to diesel would be required for switching over to JP-8. Although

Options 1A and 1B are similar, Option 1B is more cost-effective than 1A because the energy-equivalent of DF2 costs more than the equivalent of natural gas.

Following Option 1B, Options 4A and 4B are the next most cost-effective, based on the NPV for each. Although there was some difference in the NPV of the cash flows for these options, the accuracy for this type of cost analysis is from -15% to +30%. Therefore with this range of error, the difference in present value for options 1B, 4A, and 4B is not significant. However, option 1B has a higher return on initial investment and a shorter payback period. This is because the small capital expenditure to implement this option will result in a higher rate of return and quicker payback.

Options 1A, 3A, and 3B are similarly grouped together, with NPV of cash flows of approximately $300,000 each. With these three options, the NPV for Option 1A is the lowest at approximately $285,000. However, this option has the highest return on investment and shortest payback period due to the low upfront capital expenditures. For this reason, this option may be considered more attractive compared to the other two options, because of the reduced risk associated with shorter capital recovery times.

The next two options with close NPV values are for Options 2A and 2B with NPV cash flows of approximately $175,000 and $160,000, respectively. Between these two, Option 2A has a higher return and shorter payback period due to the lower cost of the Clarus reprocessing system compared to the Pall system.

Selling the off-spec JP-8 without any further processing is only favorable when compared to the baseline. Selling the fuel results in a present value of cash flows over a 10-yr period of approximately $76,000 compared to no cash flow for giving the fuel away. Option 5 and the baseline require no initial cash outlay and therefore, there is no return on investment or payback period.

Table A-3 lists the associated capital and startup costs, annual O&M costs, and annual cost avoidance values for each of the options evaluated. The capital and startup costs include the expenses to get the applicable system in place and start it up. The O&M costs are those associated with keeping the system going and, in this case, included items such as labor, electricity, and expendables. The cost avoidance values were calculated based on the amount and the cost of fuel being replaced by the off-spec JP-8. A cost avoidance value was calculated for every option except Option 5, in which case an income stream is derived from selling the off-spec JP-8.

Table A-3. Capital, O&M, and cost avoidance comparisons.

Option	**Capital & Startup Costs ($)**	**Annual O&M Cost ($)**	**Annual Cost Avoidance ($)**
Baseline – Give away to local universities	—	—	—
Option 1A – Burn directly in boiler, replacing natural gas	2,060	—	33,811
Option 1B – Burn directly in boiler, replacing diesel #2	2,060	—	49,960
Option 2A – Burn after Clarus, replacing natural gas	26,560	10,077	33,811
Option 2B – Burn after Pall, replacing natural gas	112,060	1,733	33,811
Option 3A – Burn after Clarus, replacing diesel #2	26,560	10,077	48,960
Option 3B – Burn after Pall, replacing diesel #2	112,060	1,733	48,960
Option 4A – Use in ground vehicles, after Clarus	24,500	10,077	60,000
Option 4B – Use in ground vehicles, after Pall	110,000	1,733	60,000
Option 5 – Sell off-spec JP-8*	—	—	9,000
*for Option 5, the value in the annual cost avoidance column is actually an income stream.			

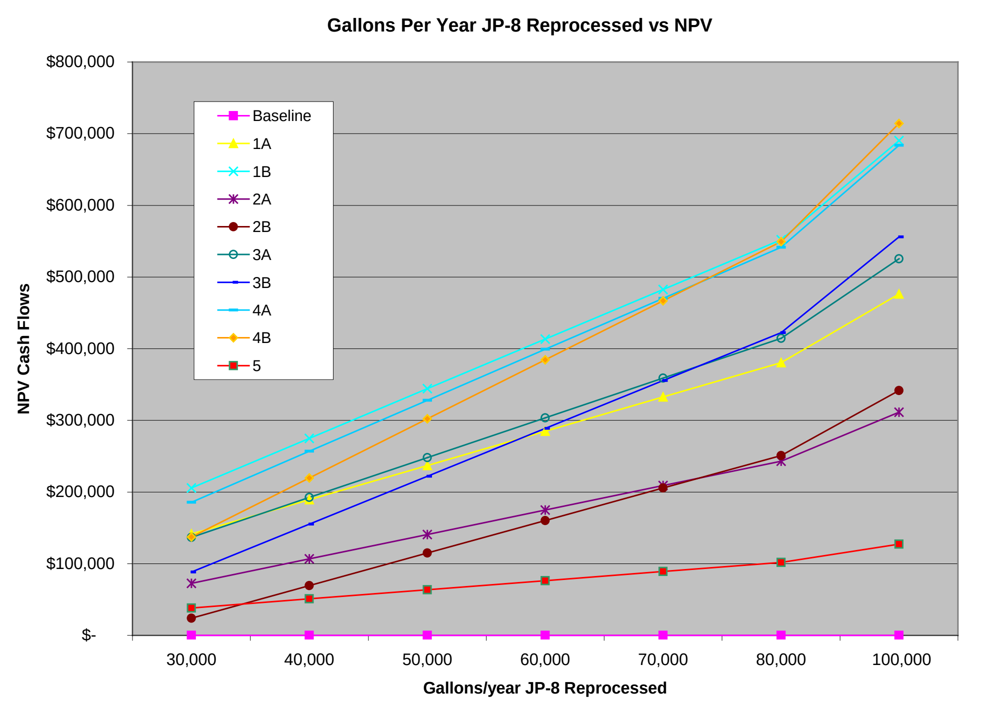
Recommended options for reprocessing the off-spec JP-8 fuel at Fort Bragg are based on fixed inputs, considered to be the best data available at the time (Table A-1). To determine how variations to these inputs can affect the NPV cash flow outcomes of the model, various sensitivity analyses were completed.

The first analysis was completed by using a range of possible gallons of off-spec fuel that may become available annually. This input was varied from 30,000–100,000 gal. This sensitivity analysis confirmed that Options 1B, 4A, and 4B are still the most cost-effective throughout this range of volumes to be reprocessed (Figure A-2). As this chart shows, from 30,000–80,000 gal, Option 1B shows a higher NPV cash flow than Options 4A and 4B. However, at 80,000 gal, Options 4A and 4B overtake Option 1B because the recycled fuel replaces the higher-cost JP-8 rather than the lower costing DF2. Beyond 80,000 gallons, Option 4B also becomes more cost-effective than option 4A, even though the Pall system is initially more costly than the Clarus.

This is because the Pall recycler has lower O&M costs than the Clarus Titan.

Project duration also has an effect similar to varying the volume processed on the NPV cash flows. This is because the longer the project period, the effect the higher upfront capital costs have on the NPV is diminished. For this particular sensitivity analysis, the project period was varied from 3–20 yr (see Figure A-3). In this case, the option ranking is very similar to the ranking of options based on varying the volume processed. In this case, the options with the lower operating cost and higher valued end product become more economical as the time period of the project increases. Again, Options 1B, 4A, and 4B showed the highest NPV cash flows for a project life of 5 yr and greater.

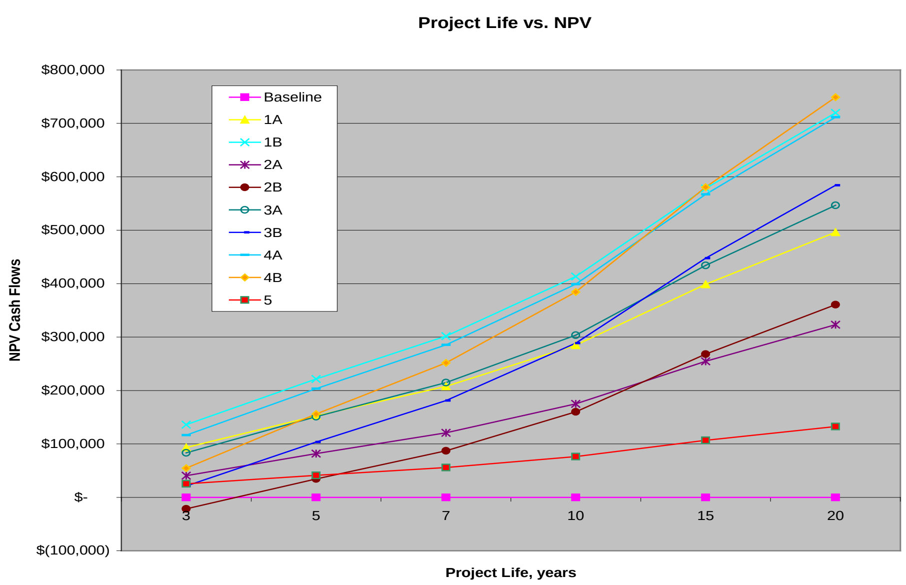
A sensitivity analysis was also completed by varying the "per gallon" cost of JP-8 and DF2 fuels. The purpose of this analysis was to determine what effect a decrease or increase in fuel would have on the cost-effectiveness of each option. Because the JP-8 and DF2 are both petroleum-derived products, it was assumed that the price of both would likely move in tandem. Therefore, it was assumed that a percent increase or decrease in price for one will result in an equivalent change for the other. For this sensitivity analysis, the cost of both JP-8 and DF2 fuel ranged from 70% to 175% of the original price of $1.00 per gallon and $0.85 per gallon, respectively (see Figure A-4).



Legend:

Baseline = Baseline
1A = Off-spec JP-8 is burned directly in boilers, replacing natural gas.
1B = Off-spec JP-8 is burned directly in boilers, replacing DF2.
2A = Off-spec JP-8 is burned in boilers after processing with Clarus, replacing natural gas.
2B = Off-spec JP-8 is burned in boilers after processing with Pall, replacing natural gas.
3A = Off-spec JP-8 is burned in boilers after processing with Clarus, replacing DF2.
3B = Off-spec JP-8 is burned in boilers after processing with Pall, replacing DF2.
4A = Off-spec JP-8 is used in ground vehicles after processing with Clarus, replacing new JP-8.
4B = Off-spec JP-8 is used in ground vehicles after processing with Pall, replacing new JP-8.
5 = Sell off-spec JP-8.

Figure A-2. Volume of off-spec JP-8 reprocessed annually versus NPV cash flows.



Legend

Baseline = Baseline

1A = Off-spec JP-8 is burned directly in boilers, replacing natural gas.

1B = Off-spec JP-8 is burned directly in boilers, replacing DF2.

2A = Off-spec JP-8 is burned in boilers after processing with Clarus, replacing natural gas.

2B = Off-spec JP-8 is burned in boilers after processing with Pall, replacing natural gas.

3A = Off-spec JP-8 is burned in boilers after processing with Clarus, replacing DF2.

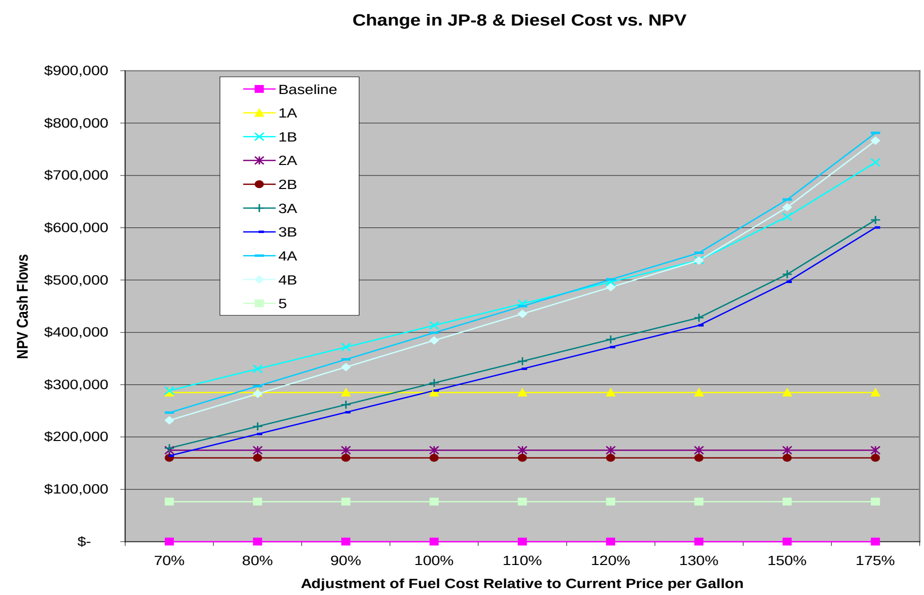
3B = Off-spec JP-8 is burned in boilers after processing with Pall, replacing DF2.

4A = Off-spec JP-8 is used in ground vehicles after processing with Clarus, replacing new JP-8.

4B = Off-spec JP-8 is used in ground vehicles after processing with Pall, replacing new JP-8.

5 = Sell off-spec JP-8.

Figure A-3. Project life versus NPV cash flows.



Legend

Baseline = Baseline
1A = Off-spec JP-8 is burned directly in boilers, replacing natural gas.
1B = Off-spec JP-8 is burned directly in boilers, replacing DF2.
2A = Off-spec JP-8 is burned in boilers after processing with Clarus, replacing natural gas.
2B = Off-spec JP-8 is burned in boilers after processing with Pall, replacing natural gas.
3A = Off-spec JP-8 is burned in boilers after processing with Clarus, replacing DF2.
3B = Off-spec JP-8 is burned in boilers after processing with Pall, replacing DF2.
4A = Off-spec JP-8 is used in ground vehicles after processing with Clarus, replacing new JP-8.
4B = Off-spec JP-8 is used in ground vehicles after processing with Pall, replacing new JP-8.
5 = Sell off-spec JP-8.

Figure A-4. Change in JP-8 and DF2 cost versus NPV cash flows.

Option 1B is the most cost-effective option with the cost of fuel in the price range at the time. However, with an approximately 20% increase in JP-8 and DF2, Options 4A and 4B become more economical because of the higher-priced JP-8 fuel. Options 3A and 3B also become more cost-effective as fuel prices increase, due to the options’ dependency on DF2. As the cost of fuel decreases, Option 1A or burning the JP-8 without first reprocessing to replace natural gas, becomes the option of choice from an economic standpoint. However, this assumes the price of natural gas is independent of the price of petroleum.

Completing these sensitivity analyses further confirms that Option 1B is the most cost-effective considering a range of volumes of JP-8 reprocessed, project duration, and fuel costs. However, certain conditions (such as with an increase in fuel costs) improve the cost-effectiveness of Options 4A and 4B, due to increased cash flows covering the initial capital costs. From an economic standpoint, the final recommendation to Fort Bragg is either to burn the off-spec JP-8 fuel in the boilers to replace an energy equivalent of DF2 or to reprocess the off-spec fuel and use it to replace an equivalent amount of JP-8 in the ground vehicles. Regardless of which of these recommended options is chosen, the economic benefits would be greater than the current baseline.

6 Conclusions and Recommendations

Based on the cost analysis and evaluation of various options for recycling off-spec JP-8 at Fort Bragg, the recommended option is 1B -- the off-spec JP-8 replaces DF2 as boiler fuel without any further treatment other than the removal of excess water and sediment. Although Options 4A and 4B are very comparable to Option 1B from the NPV cash flow standpoint, Option 1B requires little initial capital outlay and therefore has a higher return on investment, shorter payback period, and poses less risk associated with the initial investment recovery.

If for some reason Option 1B is not feasible, it is recommended that option 4A be the alternate method for treating the off-spec fuel. With this option, the off-spec JP-8 would be treated using the Clarus Titan, tested to ensure it meets the proper specifications, and ultimately used to fuel ground transport vehicles. Options 4A and 4B both provide a good return on investment and high NPV values due to the cost avoidance associated with treating the off-spec JP-8 and using it in ground vehicles to replace new JP-8. Between these two choices, Option 4A would be more favorable than 4B because of the higher return on investment and shorter payback period due to the lower initial cost of reprocessing equipment.

Appendix B
References

References

1. U.S. Army, Fort Hood Recycling Program. *Fort Hood forges into the future with fuel filtration*. Fort Hood, North Carolina.
2. U.S. TARDEC. 2001. *JP-8: The single fuel forward*. May 2001.
3. U.S. Army. 1997. A single fuel for the battlefield. *Quartermaster Professional Bulletin*, PB 10-97-3: Autumn 1997.

Appendix C
Thermal Stabilizer (+100) Fuel Additive

Thermal stabilizer (+100): Thermal stabilizer is added to the fuel to increase the thermal stability from 325 °F to 425 °F, or +100 °F over the original temperature. The stabilizer package consists of 25 ppm antioxidant, 70 ppm dispersant/ detergent, and 3 ppm metal activator. The increased stability is achieved by the dispersant in the additive package that aids in preventing a solution of potential insolubles from precipitating, which could form gum or sediment.

However, the dispersant/detergent component has also been suspected of permanently disabling some types of coalescing filters and thus, allowing free water to enter fuel tanks. Fuel which contains this additive is designated as JP-8+100, and is typically designated only for aviation units. Normally, the +100 additive is injected by the refuelers at particular locations for aviation units only. As noted in Section 1.1, the JP-8 fuel provided to the installation is supplied as "ground use only", as there is a "no use policy" of fuel containing the +100 additive in ground units. Therefore, it is assumed the thermal stabilizer additive is not present, and will not interfere with coalescer performance.

Appendix D
Fuel Comparison Data

Table D-1, shown below, lists the heating values of diesel fuel and JP-8 in relation to the primary heating fuel, which is natural gas. Diesel and JP-8 are very comparable in both heating value and Wobbe Index. The Wobbe Index is a measure of fuel energy flow rate through a fixed orifice under given inlet conditions. It is used to match a replacement fuel to a primary fuel. Two fuels with similar Wobbe indices will produce comparable amounts of heat from combustion. In this case, the Wobbe Index values for both diesel and JP-8 are considerably lower than the primary fuel, natural gas. However, the real comparison lies between diesel and JP-8. As previously stated, diesel is currently used as a secondary fuel for the 82nd Heat Plant. It could be easily replaced, however, with reclaimed JP-8 and cause very little change in the heat output.

Table D-1. Fuel property comparison and exchangeability index.

Fuel Property Comparisons			
Fuel	**Methane**	**DF2**	**JP-8**
Trade Name	Nat. Gas	Diesel	Jet Fuel A
Heat Content (Btu/gal)	–	130,319	123,138
Heat Content (Btu/cf)	1,012	–	–
Heating Value (MJ/kg)	50.03	42.70	42.90
Heating Value (Btu/lb)	21,513	18,361	18,447
Flashpoint (°F)	N/A	140	100
° API Gravity[17]	103.30	34.50	45.40
Specific Gravity	0.60	0.85	0.80
Wobbe Index	64.59	46.31	47.96
Fuel Exchangeability Index			
Wobbe Index	64.59	46.31	47.96
% Difference than Methane	–	-28.29%	-25.74%
% Difference than Diesel	39.46%	–	3.56%

[17] Crane Technical Paper 410, pg. 1-3.

Appendix E
Air Discharge Permit[18]

According to North Carolina Division of Air Quality (DAQ) regulations for permitting the combustion of recycled fuels, the Permittee is allowed to combust recycled No. 2 fuel oil as follows:

(a) The Permittee is responsible for ensuring that the recycled No. 2 fuel oil meets the approved criteria for unadulterated fuel. Each delivery of the used oil shall have a corresponding laboratory analysis for the criteria below. As an alternative, the Permittee himself may sample and analyze the recycled oil. The Permittee is held responsible for any discrepancies discovered by DAQ as a result of sampling and analysis. The recycled No. 2 fuel oil shall be equivalent to unadulterated fossil fuel by meeting the following criteria:

Constituent/Property	Allowable Level
Arsenic	1 ppm maximum
Cadmium	2 ppm maximum
Chromium	5 ppm maximum
Lead	100 ppm maximum
Total Halogens	1000 ppm maximum
Flash Point	100 °F maximum
Ash	1.0% maximum

(b) Record keeping Requirements

(i) The Permittee shall maintain accurate records of the actual amount of recycled No. 2 fuel oil delivered to, and combusted at the facility on an annual basis. These records shall be maintained at the facility for a minimum of three (3) years, and shall be made available to representatives of the Division of Air Quality upon request.

(ii) The Permittee shall maintain records of the results of the analytical testing of the recycled No. 2 fuel oil. These records shall be maintained at the facility for a minimum of three (3) years, and shall be made available to representatives of the Division of Air Quality upon request.

(c) Reporting Requirements - Within thirty (30) days after each calendar year, the Permittee must submit in writing to the Regional Supervisor, Division of Air Quality, the following:

(i) A summary of the results of the analytical testing for the previous twelve (12) months (calendar year).

[18] North Carolina State, Division of Air Quality.

(ii) The total number of gallons of recycled fuel oil combusted at the facility for the previous twelve (12) months (calendar year).

(d) The Division of Air Quality reserves the right to require additional testing and/or monitoring of the recycled No. 2 fuel oil on an annual basis or without notice.

Appendix F
Cost Analysis Key Equations

The equations used for the cost analysis in Section 5.7 Cost Model follow:

Net Present Value (NPV) = $[P*(1-(1+i)^{-t})/i]-C$

Return on Original Investment (ROI) = $(P/C)*100$

Payback Period = (C/P)

Where:

P = Net annual cash flow

i = Discount rate

t = Period

C = Capital and upfront costs

In this case, it is assumed the net annual cash flow is the same for all periods.