2022-12

ANALYZING THE COSTS TO RECONFIGURE THE U.S. NAVY PLATFORM TO SUPPORT THE SINGLE FUEL CONCEPT - JP5

Zheng, Lin Lin; Ventura, Barry L.

Monterey, CA; Naval Postgraduate School

https://hdl.handle.net/10945/71592

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

MBA PROFESSIONAL PROJECT

ANALYZING THE COSTS TO RECONFIGURE THE U.S. NAVY PLATFORM TO SUPPORT THE SINGLE FUEL CONCEPT—JP-5

December 2022

By:	**Lin Lin Zheng** **Barry L. Ventura**
Advisor:	**Geraldo Ferrer**
Co-Advisor:	**Bryan J. Hudgens**

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** December 2022	**3. REPORT TYPE AND DATES COVERED** MBA Professional Project

4. TITLE AND SUBTITLE ANALYZING THE COSTS TO RECONFIGURE THE U.S. NAVY PLATFORM TO SUPPORT THE SINGLE FUEL CONCEPT—JP-5	**5. FUNDING NUMBERS**
6. AUTHOR(S) Lin Lin Zheng and Barry L. Ventura	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A	**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release. Distribution is unlimited.	**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

This research analyzes the reconfiguration costs of U.S. Navy amphibious assault vessels along with fuel depots at Defense Fuel Support Point (DFSP) to support the Single Fuel Concept (SFC). Previous research confirms that SFC would further improve military objectives and missions in a contested environment. The reconfiguration from F-76 to JP-5 would benefit logistic support, maintenance requirement, time on stations, and fuel posture. We gathered the most recent maintenance repair contracts and analyzed the data to determine the cost of reconfiguration. Using a Gantt chart, we show the series of actions that various stakeholders need to take prior to a ship entering the maintenance availability cycle as well as future actions to ensure maintenance is planned, executed, and completed. Since the energy content of JP-5 is lower than F-76, we analyze the total cost of using JP-5 in the deployment phase of operation. Furthermore, we conduct regression analysis on both fuel prices to estimate the delta percentage between both fuel products. This thesis recommends that stakeholders consider the overall long-term benefit of reconfiguration as the cost of conversion is reasonable, but transition to JP-5 requires time.

14. SUBJECT TERMS Single Fuel Concept, SFC, F-76, JP-5, reconfiguration, cost, constraints, conversion	**15. NUMBER OF PAGES** 73
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

ANALYZING THE COSTS TO RECONFIGURE THE U.S. NAVY PLATFORM TO SUPPORT THE SINGLE FUEL CONCEPT—JP-5

Lin Lin Zheng, Lieutenant Commander, United States Navy
Barry L. Ventura, Lieutenant Commander, United States Navy

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF BUSINESS ADMINISTRATION

from the

NAVAL POSTGRADUATE SCHOOL
December 2022

Approved by: Geraldo Ferrer
Advisor

Bryan J. Hudgens
Co-Advisor

Rene G. Rendon
Academic Associate
Department of Defense Management

THIS PAGE INTENTIONALLY LEFT BLANK

ANALYZING THE COSTS TO RECONFIGURE THE U.S. NAVY PLATFORM TO SUPPORT THE SINGLE FUEL CONCEPT—JP-5

ABSTRACT

This research analyzes the reconfiguration costs of U.S. Navy amphibious assault vessels along with fuel depots at Defense Fuel Support Point (DFSP) to support the Single Fuel Concept (SFC). Previous research confirms that SFC would further improve military objectives and missions in a contested environment. The reconfiguration from F-76 to JP-5 would benefit logistic support, maintenance requirement, time on stations, and fuel posture. We gathered the most recent maintenance repair contracts and analyzed the data to determine the cost of reconfiguration. Using a Gantt chart, we show the series of actions that various stakeholders need to take prior to a ship entering the maintenance availability cycle as well as future actions to ensure maintenance is planned, executed, and completed. Since the energy content of JP-5 is lower than F-76, we analyze the total cost of using JP-5 in the deployment phase of operation. Furthermore, we conduct regression analysis on both fuel prices to estimate the delta percentage between both fuel products. This thesis recommends that stakeholders consider the overall long-term benefit of reconfiguration as the cost of conversion is reasonable, but transition to JP-5 requires time.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ACRONYMS AND ABBREVIATIONS

CNO	Chief of Naval Operations
CuNi	copper nickel
DFSP	Defense Fuel Support Point
DLA	Defense Logistics Agency
DLA-E	Deference Logistics Agency-Energy
DMO	distributive maritime operations
DOD	Department of Defense
DON	Department of the Navy
D-SRA	dry dock—ships repair availability
FY	fiscal year
F-76	Naval Distillate Fuel
JET A/A1	aviation fuel
JFMM	Joint Fleet Maintenance Manual
JP-4	jet propellant-4
JP-5	jet propellant-5
JP-8	jet propellant-8
LHA	Landing Helicopter Assault
LHD	Landing Helicopter Dock
MGO	marine gas oil
MSC	Military Sealift Command
NATO	North Atlantic Treaty Organization
NAVSEA	Naval Sea Systems Command
SFC	Single Fuel Concept
SRA	ships repair availability
SWRMC	Southwest Regional Maintenance Center

T-AKE	fleet ordnance and dry cargo
T-AO	fleet replenishment oiler
USNS	United States Naval Ship

ACKNOWLEDGMENTS

With our sincere appreciation, we would like to thank our advisors, Professor Geraldo Ferrer and Professor Bryan Hudgens, for their patience and guidance on getting our thesis project to the finish line. Also, we would like to thank the following individuals who helped us gather all the pertinent information that supported our thesis: LCDR Jason Holmes, Chief Engineer onboard USS Tripoli (LHA 7); Mr. Doug Foote P.E., Senior Port Engineer at San Diego, CA; Mr. Conrad Calpito, Port Engineer at San Diego, CA; and Mr. Jeffery Hancock, Point Loma Fuel Department Facility Operations Supervisor. Lastly, we would like to thank our families, who provided us their constant support, sacrifice and dedication throughout our military career.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

A. OBJECTIVE AND RESEARCH QUESTIONS

There has not been much in-depth analysis on the costs to reconfigure amphibious assault vessels and DFSP's to support a single-fuel concept across the entire U.S. Navy. Once reconfiguration costs have been thoroughly analyzed, the SFC would open doors to change current DON policies with another transformative solutions to support the warfighter. The following are the research questions that this research project seeks to answer:

1. What are the costs, constraints, and timeline to reconfigure U.S. Navy amphibious assault vessels, specifically LHA/LHDs, to use only JP-5 to support the NDS and CNO objectives, removing F-76 from the naval supply chain?
2. What are the costs, constraints, and timeline of converting fuel depot at Defense Fuel Support Points' F-76 fuel tanks to JP-5 fuel tanks?

B. PRIOR RESEARCH

Fuel is a necessity for any type of operations as it brings ships into a fight and supplies critical materials needed into the battle space. The use of two types of fuel, F-76 and JP-5, presents logistical inefficiencies for the U.S. Navy. The following research concluded that there are clear advantages of adopting the Single Fuel Concept (SFC) to the Department of Navy (DON).

Tosh, Moulton, and Moses (1992) report concluded that "all shipboard systems, including boilers, turbine engines, and diesel engines should continue to operate satisfactorily, and in some instances, with increased efficiency with JP-5" (p. 4).

Sermarini (2000) concluded its finding that it would take time and effort to increase refineries' supply of JP-5 to meet the needs of a universal fuel at sea concept of operation; also, by doing so, SFC would enhance "simplicity, flexibility, interoperability, lower maintenance costs, and reduce infrastructure" (p. 94) to all key stakeholders.

Guimond (2007) research concluded that replacing F-76 with JP-5 would have no detrimental impact on most diesel engines. However, there are a small number of rotary type fuel injection pump engines used by Special Warfare (SPECWAR) that presented lubricity issues. Nevertheless, modification or redesign of the injection pump to support JP-5 fuel can be achieved via industries that are standing by to support.

Jimenez, Walters, and Lessner (2020) concluded that there was a noticeable operational benefit in fuel logistics support by Combat Logistic Force (CLF) assets' capacity to meet fleet demands using the SFC. By applying an Inventory Pooling Model, they showed that the afloat storage facilities would have an increased capacity if they adopted a single fuel. In a high intensity operation such as dual fuel concept of operations (CONOPS), tankers and oilers would expose in a much lesser capacity than status quo.

Kube and Kinser (2021) research concluded that implementing phased rollout plan to gradually convert to the SFC would give supply chains time to adjust to the new demands placed on refineries. The authors recommended a five-phase rollout plan that provides an ideal strategy to execute the SFC as it would reduce risks to the fleet. In addition, Giannini et al. (2002) research concluded that it would take five to 10 years to fully convert to JP-5 as this would give sufficient time for refineries to adjust to the demand.

As the above research concluded, SFC would further improve military objectives and missions. However, there has not been any research on the reconfiguration costs of U.S. Navy amphibious assault vessels and fuel depots at Defense Fuel Support Point (DFSP) to support SFC. The reconfiguration from F-76 to JP-5 would benefit logistic support, maintenance requirement, time on stations, and fuel posture; also, it would adhere to National Defense Strategy (NDS) to "think differently about how we deploy, employ, and sustain forces with the energy needed to conduct worldwide missions" (Office of the Under Secretary Defense for Acquisition and Sustainment, 2020, p. 9). We gathered the most recent maintenance repair contracts and analyzed the data to determine the cost of reconfiguration. Prior to ship entering maintenance availability cycle to support reconfiguration, we utilized a Gantt chart to show series of actions required by various stakeholders that need to be addressed and require future enhancement to ensure maintenance is planned, executed, and completed. Since JP-5 energy content is lower than

F-76, we analyze the total cost of using JP-5 in the deployment phase of operation. Our research will benefit the Joint Petroleum Doctrine “minimize the types of bulk petroleum products that must be stocked and distributed … and minimize the military-unique characteristics of DOD (Department of Defense) fuels” (Joint Publication 4-03, p. I1-I2) by adopting JP-5 as the single fuel for its naval platforms.

C. OVERVIEW OF METHODS

We gathered the most recent maintenance repair contracts and analyzed the data to determine the cost of reconfiguration. Using a Gantt chart, we show the series of actions that various stakeholders need to take prior to a ship entering the maintenance availability cycle as well as future actions to ensure maintenance is planned, executed, and completed. Since the energy content of JP-5 is lower than F-76, we analyze the total cost of using JP-5 in the deployment phase of operation. Furthermore, we conduct regression analysis on both fuel prices to estimate the delta percentage between both fuel products.

D. THESIS OUTLINE

Our thesis is outlined in the following orders: Chapter II covers the background. Chapter III provides the Literature Review. Chapter IV covers the methodology. Chapter V covers analysis and results. Chapter VI covers conclusions and recommendations.

THIS PAGE INTENTIONALLY LEFT BLANK

II. BACKGROUND

This chapter provides introductory information about types of fuel, fuel characteristics and descriptions, vital key operational concepts, maritime fuel logistic stakeholders, fuel supply chain management, and Navy Maintenance Organizations to support our research evaluation of the cost to implement the Single Fuel Concept (SFC).

A. TYPES OF FUEL

U.S. Navy uses several types of fuel to support its operations. The following types of fuel are introduced in this section: Naval Distillate Fuel (F-76), Marine Gas Oil (MGO), JP-5 (Jet Propellant-5), JP-8 (Jet Propellant-8), JP-4 (Jet Propellant-4), JET A1 and JET A (Commercial Jet Fuel).

1. Naval Distillate Fuel (F-76)

Naval Distillate Fuel, F-76, is a military-grade specification fuel per MIL-DTL-16884N, which is "intended for use in all naval shipboard boilers, gas turbines, and diesel engines" (Department of Defense [DOD], 2014, p. 8). The minimum flash point for F-76 is 140° F that meets U.S. Navy shipboard safety requirement. Its physical property is unique compared to commercial diesel fuel. It has storage stability additives which requires a minimum of 24 months and free of dyes to comply with Quality Surveillance for Fuels, Lubricants and Related Product, MIL-STD-3004 (DOD, 2016b).

2. Naval Jet Fuel: Turbine Fuel, Aviation (JP-5)

The U.S. Navy uses JP-5 on its aircrafts. This type of fuel contains 100% kerosene-blend that was developed in 1952 (Hemighaus et al., 2007). Due to its unique chemical property per MIL-DTL-5634T, there is no other alternative or substitute. JP-5 has a minimum flash point of 140° F that meets U.S. Navy shipboard safety requirement as the flight deck temperatures can exceed 100° F during flight operation. JP-5 is an alternative solution for both F-76 and JP-8.

3. Marine Gas Oil (MGO)

Marine Gas Oil is the main source of fuel for commercial vessel. It is a high-quality marine fuel. According to MIL-STD-3004, some grades of MGO may contain dye, but fuel that has Fatty Acid Methyl Ester (FAME) could cause damage to the ship's propulsion systems. Compared to F-76, stability additives for MGO are not a requirement in the commercial sector; nevertheless, MGO does meet a minimum flashpoint of 140° F. Due to a lack of stability additives, MGO must be consumed as soon as possible, no longer than 6 weeks. The process of procuring MGO goes through DLA Energy Bunkers Contract whenever F-76 is not available (DOD, 2016b).

4. Turbine Fuel, Aviation (JP-8)

JP-8 is a kerosene-based jet fuel that is similar to JET A1, commercial jet fuel. JET A1 can be converted into JP-8 by adding three additives: fuel system icing inhibitor, corrosion inhibitor, and electrical conductivity. JP-8 has been used by the U.S. armed forces: Army, Air Force and Marine aircrafts, vehicles and other ashore equipment. Per MIL-DTL-83133J specification, JP-8 has a flash point of 100° F, which does not meet shipboard safety requirement. According to McCord's memorandum (2022), JP-8 is less expensive than JP5. According to Deziel (2019), JP-8 is expected to phase out by 2025.

5. Jet Propellant (JP-4)

In Deziel's (2019) article, "The Differences Between Kerosene & Jet Fuel," composition of JP-4 is a mixture of 70% gasoline and 30% kerosene. It is lighter than kerosene due to its liquid hydrocarbon chains. These characteristics make it highly desirable for aviation fuel. According to the DOD (2016a), *MIL-DTL-5624W*, JP-4 has a low flash point fuel characteristic of –9° F, which makes it hazardous to handle. Nevertheless, JP-4 has a low freezing point fuel characteristic of –72° F and realistic to use in extremely cold environments (Deziel, 2019, para. 12).

6. Commercial Jet Fuel (JET A1 and JET A)

According to Exxon Mobil (n.d.), JET A1 is the commercial industry standard aviation fuel, and it is available worldwide. JET A1 and JP-8 are identical fuels except for the three additives required in JP-8. U.S. domestic aircraft uses JET A as it is the industry standard, which is a variant of JET A1. JET A has a -40° F freeze point while JET A1 has a -47° F freeze point (ExxonMobil, n.d.). According to JP-8 the Single Fuel Forward (1997) research report, JET A1 is a common substitute for JP-8 for DOD ashore forces and was used during the Operation Desert Storm as a Single Fuel.

B. FUEL CHARACTERISTICS AND DESCRIPTIONS

Each type of fuel is different to one another, and it has different hazardous element when it is exposed. The following fuel characteristics that need to be cognizant are flash point, explosive range, and jet fuel additives.

1. Flash Point

According to Naval Sea Systems Command (2019), flash point is defined as the temperature needed for the fuel to produce vapor and ignite once the spark is presented. JP-5 and F-76 have a minimum flash point of 140° F due to the required policy to be used onboard Navy ships.

2. Explosive Range

Explosive Range is defined as the range between the Lower Explosive Limit (LEL) and the Upper Explosive Limit (UEL) for that specific gas or vapor (Department of the Army [DA], 2015). A combination of air and fuel can create an explosive or flammable mixture once the mixture has reached the Upper Explosive Limit (UEL) value for gas/vapor is too rich to ignite and explode and vice versa for Lower Explosive Limit (LEL) (DA, 2015, p. 77).

3. Jet Fuel Additives

According to DA (2015) report, jet fuel additives are military-grade additives and can be injected during the refining process, pipeline transfer, or transfer at the DFSP. The report noted, the Fuel System Icing Inhibitor (FSII), Static Dissipative Additive (SDA), and Corrosive Inhibitor/Lubricity Improver (CI/LI) are the three common military-grade additives blended into the DOD’s jet fuel. The report continues to state the ice crystals would restrict the flow of fuel to the engine; therefore, the anti-icing additive, FSII, prevents the formation of ice crystals in the fuel lines as it also helps remove water molecules through filtration. The report also states SDA improves fuel's electrical conductivity to prevent electrostatic buildup and explosive risks. SDA plays a significant role on rotary-wing aircraft during "hot" refueling. The report continues to mention that CI/LI adds lubricity when pumping fuel and an anti-corrosion agent in the fuel line tubing.

C. VITAL KEY OPERATIONAL CONCEPTS

Two vital key operational concepts can put the SFC to the test, which are Distributed Maritime Operations (DMOs) and Naval Refueling Behavior.

1. Distributed Maritime Operations (DMOs)

DMO is a warfighting concept that focuses on the Navy's and Marine Corps' capability to conduct maritime control and power projection missions to win a high-end fight at sea (Lundquist, 2021, para. 10). The Navigation Plan 2020 and Tri-Service Maritime Strategy state the U.S. is "involved in a long-term competition that threatens our security and our way of life. Russia and China are both undermining the free and open conditions that have enabled the world to largely prosper since the end of World War II" (Lundquist, 2021, para. 3). To combat this long-term competition, the Large Scale Exercise (LSE) was to test the "Navy's Distributed Maritime Operations, the Marines' Expeditionary Advanced Base Operations and Littoral Operations in a Contested Environment at a scale that spans 17 time zones, three global combatant commands, and more than a dozen command staffs" (LaGrone, 2021, para. 2).

Under DMO concept of operation, logistics were an element that was mentioned as an important factor. We see the opportunity that SFC would be a new unexploited capability that would provide multiple advantages especially in sustainment phase of operation. As then Navy Vice Admiral Phil Sawyer states: "[n]ew capabilities are important. But while the fleet waits for the introduction of these capabilities, we are moving out and exercising with what we have" (Lundquist, 2021, para. 18).

2. Naval Refueling Behavior

Operational Order (OPORD) is the heart of Navy refueling behavior. Per OPORD 201–15, Fleet Commanders' directives provide guidelines to ensure sufficient fuel levels are managed in a way to best accomplish mission objectives. The exact fuel levels are not disclosed due to the sensitivity of the information, but OPORD 201 Annex D (2015) is similar to Fleet Commanders' OPORD guidelines regarding fuel management as it states that naval vessels must refuel their fuel tanks at every opportunity that is given. This creates two benefits for maritime operation: first, it allows the fleet and CLF oilers to maintain high level of fuel readiness onboard. Second, it increases the proficiency during the most dangerous Underway Replenishment at sea (UNREP) evolution. Therefore, in a contested environment, these skill sets are proven beneficial. This also demonstrates the Navy must have the agility and lethality in the fuel logistic supply chain.

D. MARITIME FUEL LOGISTIC STAKEHOLDERS

This section captures the roles and responsibilities of Defense Logistics Agency-Energy (DLA-E) and Military Sealift Command (MSC) stakeholders managing fuel. These supporting actors play an important role in SFC as they are the one who streamline fuel contracts and contract management to support and deliver to the fleet.

1. Defense Logistics Agency-Energy

DLA-E is responsible for providing robust energy solutions globally to the warfighter. The following operational supplier directorates under DLA-E, which manage critical fuel to meet the DOD's mission requirement.

a. DLA-E Bulk Petroleum Products Division

The DLA-E Bulk Petroleum Products Division "provides the Military Services, DOD activities and designated federal agencies with worldwide comprehensive Class III Bulk Petroleum acquisition support" (DLA-E, 2021, p. 16).

b. DLA-E Bulk Petroleum Supply Chain Services

The DLA-E Bulk Petroleum Supply Chain Services "provides contract support for the bulk petroleum supply chain, including the worldwide acquisition of fuel-related services such as government-owned, contractor-operated (GOCO) DFSPs, contractor-owned and contractor-operated (COCO) DFSPs, alongside aircraft fuel contracted delivery, lab testing and environmental compliance, assessment, and remediation" (DLA-E, 2021).

c. DLA-E Direct Delivery Fuels Division

The DLA-E Direct Delivery Fuels Division "provides worldwide acquisition and integrated materiel management of commercial fuels delivered directly to the military and federal civilian customers" (DLA-E, 2021).

d. DLA-E Supply Chain Management Division

The DLA-E Supply Chain Management Division "provides enterprise-level management for both defense fuel support point operations and the DLA Energy-owned bulk petroleum inventory" (DLA-E, 2021, p. 17).

These four operational supplier directorates under DLA-E play a critical role in fuel management.

2. Military Sealift Command (MSC)

MSC is the DOD leading provider of ocean transportation, operating approximately 125 ships across the world. MSC's function is to deliver agile logistics, sealift, and special assignments across the globe. All its ships are staffed and fully trained for immediate tasking to synchronize with the fleet and joint force missions in contested environment.

a. Fleet Replenishment Oiler (T-AO)

T-AO is the largest workhorse of the Navy's Combat Logistics Force (Figure 1). They deliver Class I (subsistence), Class III (petroleum, oils, and lubricants), and Class XI (repair parts and components) materials to the fleet. It has a total of 15 Henry J. Kaiser class fleet replenishment oilers with two class variants, single and double hull (Military

Sealift Command, n.d.b). According to Naval Sea Systems Command (2021), Henry J. Kaiser class oilers are being replace with the new John Lewis class oilers. The first of its class, USNS John Lewis (T-AO 205), was commissioned in July 2021. As of 2021, there are three John Lewis-class oilers under construction: Harvey Milk (T-AO 206), Earl Warren (T-AO 207), and Robert F. Kennedy (T-AO 208). One special capability that T-AO can perform is to conduct fuel consolidated logistics (CONSOL) operations with other tankers resulting in significantly extending fuel support with a top speed of 20 knots (Military Sealift Command, n.d.b).

Figure 1. USNS Big Horn (T-AO 198). Source: Arciaga (2015).

b. Fleet Ordnance and Dry Cargo (T-AKE)

T-AKE's primary role is to provide provisions, parts, and ammunition to the fleet (Figure 2). T-AKE is a multi-product ship design which integrate combat stores and ammunition ships into one. T-AKEs can be preposition in "key ocean areas to ensure rapid availability during a major theater war, a humanitarian operation, or other contingency" (Military Sealift Command, n.d.c). There are currently 14 T-AKEs in the inventory. For Fast Combat Support ships (T-AOEs), USNS Arctic and USNS Supply are the only two ships that can also deliver parts, supplies, and fuel at sea.

Figure 2. USNS Medgar Evers (T-AKE 13). Source: Mesta (2017).

c. Dry Cargo and Tankers

According to Military Sealift Command (n.d.a), MSC has short-term and long-term chartered commercial tankers in its support program. It also states its mission is to “transport refined petroleum products between commercial refineries and DOD storage and distribution facilities worldwide for Defense Logistics Agency-Energy, which procures and manages fuel for all of DOD.” Dry Cargo and Tankers play a different role. Dry cargo ships (Figure 3) transport sizable items, i.e., engineering and construction equipment, military vehicles, aircraft, and ammunitions, during wartime and other contingencies operations. In addition, Tanker (Figure 4) is a long-term charter that transports refined petroleum products to DOD via commercial refineries to distribution storage facilities worldwide.

Figure 3. MT SLNC Corsica. Source: Schuyler Line (2022).

Figure 4. MT Empire State. Source: Wright (n.d.).

Without MSC's Combat Logistics Force and Combatant Command Support, DOD would not have the strength, agility, flexibility, and interoperability to delivery critical materials and fuels to the warfighter need in peacetime or contingency environment.

E. FUEL SUPPLY CHAIN MANAGEMENT

Fuel supply chain management enables the delivery of fuels at the right place and at the right time to support the mission. Five key enablers are acquisition strategy, logistics strategy, operational strategy, tactical strategy, and host nation support strategy.

1. Acquisition Strategy

Bulk petroleum supply chain contract support is managed by DLA Energy Bulk Petroleum Products Division. It focuses on worldwide commercial and military specification fuel requirements. There are four regions in charge of the fuel purchase programs: (1) Inland/East/ Gulf Coast, (2) Rocky Mountain/West Coast, (3) Atlantic/ European/Mediterranean, and (4) Western Pacific. The division oversees purchasing bulk additives, i.e., fuel system icing inhibitors, corrosion lubricity additives, and lubricity improver additives. The solicitation is available through System for Award Management (SAM) program. As of September 30, 2021, active multi-year contract data, ships' bunkers contracts consist of 32 ports supported, 13 contracts, 2.2M barrels, and a value of $258M contract value; in addition, overseas consists of 70 ports supported in 26 countries, 27 contracts, 11.5M barrels and value of $988M contract value (DLA-E, 2021).

2. Logistics Strategy

Our unique naval logistics strategy focuses on sealift and fuel support points to move fuels from storage to the area of operation.

a. Sealift

According to Military Sealift Command (n.d.e), more than 90% of our equipment and supplies supporting the warfighters travel through the sea. In addition, MSC Sealift Program (PM5) supports DLA-E mission providing "high-quality, efficient, and cost-effective ocean transportation for the Department of Defense and other federal agencies during peacetime and war." MSC would contract additional commercial tankers and foreign-flagged ships or activate Ready Reserve Force (RRF) tankers to support warfighter demand (Military Sealift Command, n.d.e).

b. Fuel Support Points

DFSP receives fuels from pipeline, MSC tankers, and Navy oilers. Bulk Petroleum Supply Chain Services are the only entities that draft, negotiate, conclude, and amend international fuel agreements with foreign governments supporting worldwide DOD Operations. In FY 2021, Bulk Petroleum Supply Chain Services awarded 599 contract actions with total business unit award dollars of $298.8M. DOD owns 597 DFSPs around the globe; of those, 117 are operated by DON. DFSPs are operated by Government-Owned Government Operated (GOGO), GOCO, COCO, and floating storage facility (DLA-E, 2021). DFSP is usually the main source of military-grade fuels delivered to warfighters' via PM1 and PM6 unless otherwise arranged.

1. Operational Strategy

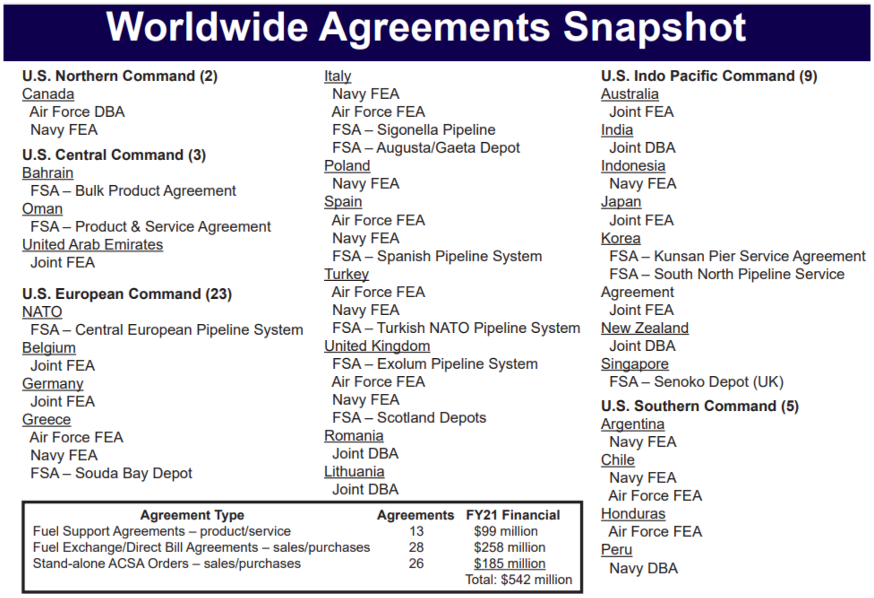
To support fuel requirements for the fleet, MSC's T-AOs and T-AKEs transport fuels from the DFSP sites to the contingency operating area. Oiler and tankers are considered high-value assets but defenseless; therefore, it is necessary to coordinate escorts to ensure safe passage.

2. Tactical Strategy

To ensure fuels are at the right place and at the right time to support each strike group, there is usually an organic CLF oiler that is attached to the strike group to deliver stocks replenishment, such as fuels, ammunition, parts, and provisions. Without the replenishment oiler station in a contested environment, the shuttle oiler would require frequent replenishment at sea.

3. Host Nation Support Strategy

DLA Energy has 43 Fuel Exchange Agreements (FEA) with United States allies around the globe (Figure 5). According to Braesch's article (2021), FEA enables our "partners the opportunity to explore ways to strengthen interoperability, discuss mutual fuel support efforts, and troubleshoot challenges" (para. 4). The article also states the agreements "not only during routine and emerging requirements but also international exercises" (para. 13) i.e., RIMPAC, Vigilant Shield, and the Defender Exercises in Europe. The article continues to note it would be "vital not only to DLA Energy, but to all of NATO's partner and allied countries as we collectively posture forces to deter adversarial aggression and build readiness for the next fight" (para. 7).



Worldwide Agreements Snapshot

U.S. Northern Command (2)
Canada
Air Force DBA
Navy FEA

U.S. Central Command (3)
Bahrain
FSA – Bulk Product Agreement
Oman
FSA – Product & Service Agreement
United Arab Emirates
Joint FEA

U.S. European Command (23)
NATO
FSA – Central European Pipeline System
Belgium
Joint FEA
Germany
Joint FEA
Greece
Air Force FEA
Navy FEA
FSA – Souda Bay Depot
Italy
Navy FEA
Air Force FEA
FSA – Sigonella Pipeline
FSA – Augusta/Gaeta Depot
Poland
Navy FEA
Spain
Air Force FEA
Navy FEA
FSA – Spanish Pipeline System
Turkey
Air Force FEA
Navy FEA
FSA – Turkish NATO Pipeline System
United Kingdom
FSA – Exolum Pipeline System
Air Force FEA
Navy FEA
FSA – Scotland Depots
Romania
Joint DBA
Lithuania
Joint DBA

U.S. Indo Pacific Command (9)
Australia
Joint FEA
India
Joint DBA
Indonesia
Navy FEA
Japan
Joint FEA
Korea
FSA – Kunsan Pier Service Agreement
FSA – South North Pipeline Service Agreement
Joint FEA
New Zealand
Joint DBA
Singapore
FSA – Senoko Depot (UK)

U.S. Southern Command (5)
Argentina
Navy FEA
Chile
Navy FEA
Air Force FEA
Honduras
Air Force FEA
Peru
Navy DBA

Agreement Type	Agreements	FY21 Financial
Fuel Support Agreements – product/service	13	$99 million
Fuel Exchange/Direct Bill Agreements – sales/purchases	28	$258 million
Stand-alone ACSA Orders – sales/purchases	26	$185 million
		Total: $542 million

Figure 5. International Fuel Agreements. Source: Defense Logistics Agency-Energy (2021).

F. NAVY MAINTENANCE ORGANIZATIONS

Figure 6 shows Naval Sea Systems Command (NAVSEA) Office. It is the lead agency for the Surface Ship Repair, Maintenance, and Modernization. Regional Maintenance Centers and Naval Shipyards have full capability to conduct extensive tank cleaning conversion and preservation on all types of combatant naval vessels across the globe. Their roles and responsibilities are “to deliver technical excellence and skilled craftsmanship to maintain and modernize our Navy’s fleet” (Naval Sea Systems Command, 2022, para. 1).

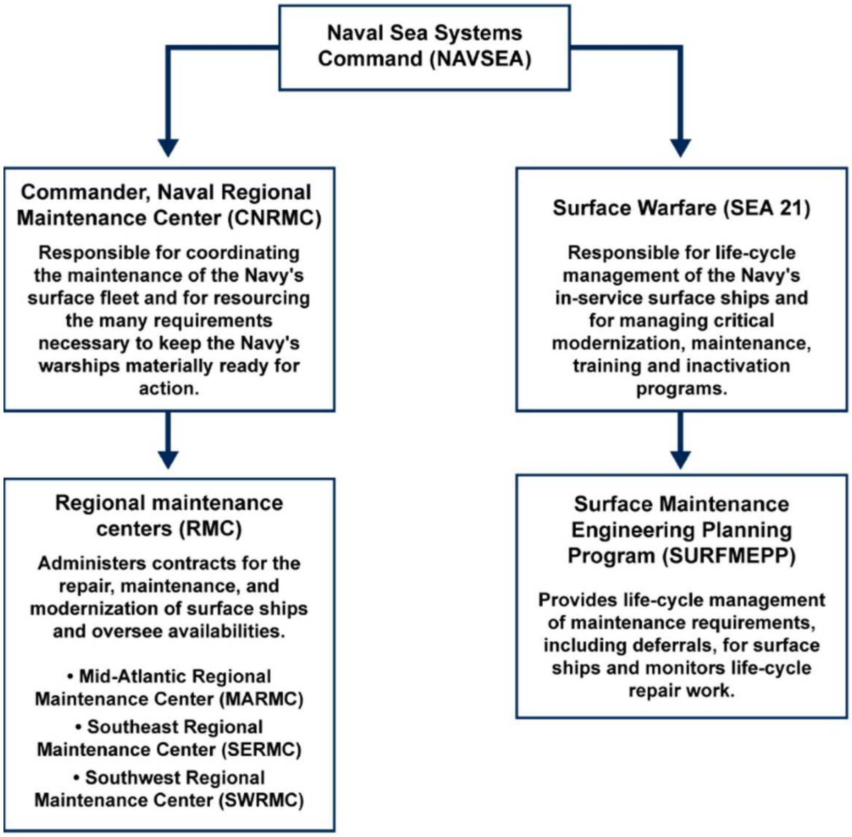


Figure 6. NAVSEA Offices Responsible for Surface Ship Repair, Maintenance, and Modernization. Source: Mackin (2016).

1. Yokosuka, Japan Ships Repair Facility and Japan Regional Maintenance Center (SRF-JRMC)

SFR-JRMC is located in Seventh Fleet AOR that provides ship repair and modernization effort. SRF-JRMC is aligned with the local national ships companies and Naval Supply Systems Command (NAVSUP) Fleet Logistic Industrial Support for contracting acquisition management within the region of Forward Deployed Naval Forces - Japan.

2. Regional Maintenance Center (RMC)

According to Naval Sea Systems Command (2022), RMC’s mission is to provides surface ships maintenance, modernization, and technical expertise in support of the ships of the U.S. Navy. In addition, it supports all of the NAVSEA capability from

Organizational level, Integrated level to Depot level related maintenance. The website also noted the RMCs are located in three regional areas in the United States excluding overseas: Southwest Regional Maintenance Center-San Diego, CA (SWRMC), Southeast Regional Maintenance Center-Mayport, FL (SERMC), and Mid-Atlantic Regional Maintenance Center-Norfolk, VA (MARMC).

3. Naval Shipyard

According to Naval Sea Systems Command (n.d.), naval shipyard is responsible for providing logistic support and tasks in conjunction with "ship construction, conversion, overhaul, repair, alternation, dry docking, outfitting, manufacturing research, re-development and test work." Furthermore, NAVSEA established "One Shipyard" concept of operation, which provides "naval shipyards balance the workload and mobilize the workforce across the yards to best ready the fleet and stabilize a vital industrial base for our nation's defense." There are currently four shipyards in the United States: Norfolk Naval Shipyard, Pearl Harbor Naval Shipyard and Intermediate Maintenance Facility, Portsmouth Naval Shipyard, and Puget Sound Naval Shipyard and Intermediate Maintenance Facility.

III. LITERATURE REVIEW

In this chapter, we examine the areas of prior research testing the SFC as a sole source of fuel supporting the fleet. Prior research studies include *Tactical and Operational Effects of the Single Fuel Concept* (Jimenez et al., 2020), *Universal Fuel at Sea* (Sermarini, 2000), *Implementation of the SFC: An Analysis of Long-Term Solutions* (Kube et al., 2021), *Single Fuel on the Battlefield* (Garrett, 1993), diesel fuel impact study (Guimond, 2007), *Single Naval Fuel At-Sea Feasibility Study-Phase One* (Giannini et al., 2002), and Technical Feasibility Concerns from various authors. These studies verified the technical and operational feasibilities of the SFC for the Navy.

A. TACTICAL AND OPERATIONAL EFFECTS OF THE SINGLE FUEL CONCEPT

Jimenez et al. (2020) focuses on the probable “operational benefits and force structure reductions” from CLF avenue via the SFC. The research used over 27,250 data points from the Naval Supply Systems Command (NAVSUP) and the Center of Naval Analyses (CNA). To evaluate past demand trend of replenishment at sea for fuels, F-76 and JP-5, they used inventory pooling analysis to calculate whether the SFC would increase “afloat storage capacity and increase refueling logistics responsiveness through demand variability reduction across fleets” (Jimenez et al., 2020). The authors predicted that adopting JP-5 as a single fuel would not only reduce the number of ships required for refueling operation and it would also increase maritime refueling capacity.

B. UNIVERSAL FUEL AT SEA

Sermarini (2000) concluded that implementing JP-5 as the universal fuel at sea is essential. To increase the JP-5 production industrial base, DOD should enable an adequate supply of JP-5 to support future contingencies. He also mentioned that it would take time and effort to increase refineries’ supply of JP-5 to meet the needs of a universal fuel at sea concept of operation. By doing so, SFC would enhance “simplicity, flexibility, interoperability, lower maintenance costs, and reduce infrastructure” to all key stakeholders. Furthermore, the author indicated the use of a single fuel product would be beneficial and provide additional flexibility in UNREP and CONSOLs between CLF assets as MSC's long-term chartered tankers.

The author also pointed out that during peacetime and contingency operations, there is an increase relying on foreign-flagged tankers to support strategic petroleum lift to DFSPs site; therefore, in future conflicts, these foreign assets could be constrained from U.S. use, so adopting the SFC would prove critical for future contingency operations.

C. IMPLEMENTATION OF THE SFC: AN ANALYSIS OF LONG-TERM SOLUTIONS

Kube and Kinser (2021) concluded that implementing phased rollout plan to gradually convert to the SFC would give supply chains enough time to anticipate the new demands placed on refineries. The authors recommended a five-phase rollout plan that provides an ideal strategy to execute the SFC as it considers the risk factors to the fleet. They found that the shift to JP-5 would generate a threefold increase in current refinery production to support the fleet based on the 30-Year Shipbuilding Plan, which is based on past consumption and pricing reports. Therefore, the authors concluded that their analysis on the current cost and pricing for F-76 and JP-5 would have significant savings for DOD to shift fuel to solely JP-5.

D. SINGLE FUEL ON THE BATTLEFIELD

Garrett (1993) concluded that JP-8 as a SFC on the battlefield was implemented by the USAF and U.S. Army. The author noted that there were two sets of advantages converting JP-4 and DF-2 to JP-8. The results show of converting JP-4 to JP-8 improved crash survivability, achievement of standardization with NATO member nations, promotion of NATO interoperability, and a 3–5% increase in aircraft range. The author stated that the advantages of converting DF-2 to JP-8 are simplified battlefield logistics, enhanced interoperability, and improved engine maintenance since JP-8 burns cleaner than DF-2. The author also addressed some disadvantages of using JP-8 which are higher acquisition cost, product availability, and potential power loss. Because the advantages outweigh disadvantages, the U.S. Army and USAF implemented JP-8 as their SFC in 1990.

Therefore, “a single fuel on the battlefield is indeed a viable option and one which DOD should continue to seek” (Garrett, 1993, p 30).

E. SINGLE NAVAL FUEL AT-SEA DIESEL ENGINE IMPACT STUDY

Guimond (2007) research found a potential impact on performance, maintenance, and cost while using JP-5 as the main source of fuel on diesel engines. The author points out there were a small number of engines that currently have a potential issue using JP-5, i.e., rotary-type fuel injection pump (mostly SPECWAR boats). Manufacturers are willing to work with the Navy to retrofit equipment into the engines to make it suitable for using JP-5. Therefore, Naval diesel engines will show no major degradation whenever JP-5 is used. The technical feasibility of the fuel properties’ area of analysis will be explained in the latter part of this chapter, which address lubricity, cetane number/cetane index, power, fuel consumption, and maintenance.

F. SINGLE NAVAL FUEL AT-SEA FEASIBILITY STUDY-PHASE ONE

Giannini et al. (2002) concluded that there should be sufficient JP-5 suppliers to support naval aircraft, ship’s propulsion systems and U.S. Marine Corps (USMC) ground forces equipment based on FY 2000 historical fuel data, solicitations, and fuel supplier surveys. It would take five to ten years to fully convert to JP-5 as this would give sufficient time for refineries to adjust to the new demand. Also, the six cost-saving efforts would benefit the initial conversion costs which comprise the following:

> 1. Reduced shipboard maintenance from handling and consuming an inherently cleaner fuel, infrastructure savings from handling one less fuel in transportation systems, and in downstream distribution terminals, economies of scale from procuring larger quantities of JP-5.
> 2. Fewer fuel rotation requirements due to the more storage-stable characteristics of JP-5.
> 3. Rising diesel fuel costs which will result from the U.S. EPA’s mandatory ultra-low sulfur diesel requirements.
> 4. Greater flexibility for scheduling underway replenishment events.
> 5. Reduced fuel supply and transportation risks, improved readiness.
> 6. Enhanced naval capability to sustain major contingency operations. (Giannini et al., 2002, p. 8)

G. TECHNICAL FEASIBILITY CONCERNS

According to reports from Guimond (2007), Putnam (2018), Tosh et al. (1992), and Naval Air Systems Command (NAVAIR) (2006), there are six specific area of concerns that will need to be address: engine performance, preventive maintenance, copper-nickel contamination, fuel consumption, power, and cetane number/cetane index.

1. Engine Performance

Guimond (2007) stated there are no signs of lubricity issues using JP-5 on most Navy diesel engines. There are minor problems identified with SPECWAR engines, rotary fuel injection pumps, which would need to be retrofitted. There is a lower fuel sulfur content that is related to hydrotreatment, which is an area of concern for lubricity characteristics. However, there is currently no minimum lubricity specification for Navy fuel. The Naval Fuels and Lubricants Integrated Product Team is currently working on a plan to establish a minimum fuel lubricity level that would be added to all Navy fuel specifications (Guimond, 2007).

2. Preventive Maintenance

Guimond (2007) noted that Navy diesel engines has shown that fuel injection system-related maintenance costs are a minor part of overall diesel engine maintenance costs, and no data indicates any differences in these costs when using JP-5 vs. F-76. Furthermore, Jimenez et. al. summarized from NAVAIR (2006) reported that JP-5 usage in ship’s propulsion gas turbine engines resulted in “significant savings in consumable components within the filtration system” (p. 48); also, it exhibited a minimal “decrease in the number of filter changes in centrifugal purifier system” (p. 48), a “68% reduction in pre-filter element changes” (p. 48) and a “72% reduction in filter/particle separator element changes” (p. 48).

3. Copper Nickel (CuNi) Contamination

Putnam (2018) stated that CuNi can be found onboard maritime vessels on its piping unions and joints. CuNi would cause harmful effects on thermal stability and potential issue of the Jet Fuel Thermal Oxidation Test (JFTOT) per ASTM 3241 test methods. Putnam further mentioned that JFTOT failure in CuNi contamination is more commonly detected in JP-5 stored onboard CVNs (Carrier Vessel Nuclear) than oilers due to decreased contact time onboard refueling ships and high turnover of fuel (Putnam, 2018). Putnam concluded to combat CuNi contamination upon the SFC implementation, fuel can be blended back into JP-5 stocks as there is no onboard mitigation program that exists.

4. Fuel Consumption

Guimond (2007) stated laboratory testing and manufacturer data indicated an increase in fuel consumption when using JP-5; however, there was no data collection done on fuel consumption onboard actual Navy ships while the diesel engines operated with JP-5. Furthermore, Army Field Assessment concluded there were no differences in fuel procurement cost and consumption when using JP-8 vice diesel fuel. Guimond (2007) recommends long-term shipboard "at-sea" evaluations to capture fuel consumption using JP-5.

5. Power

Tosh (1992) concluded there is data showing reductions in rated power when using JP-5 during laboratory testing, and the effects vary with the type of engine and engine-mounted fuel injection system. However, the author stated adjusting the "thermal efficiency can offset in some diesel engines" (Tosh, 1992, p. 32). In addition, the Navy seldom operates Main Propulsion Diesel Engine (MPDE) and Ship Service Diesel Generator (SSDG) engines at full power. Furthermore, no data indicates that the Navy diesel engine would not attain full power when operating on JP-5 (Guimond, 2007).

6. Cetane Number/Cetane Index

Guimond (2007) stated cetane number measures the quality of ignition of the fuel, which plays a significant role in diesel engine starting and operation during engine warm-up cycle. Cetane index lower than 33 could lead to difficulty starting and improper operation due to the excessive ignition delay period. The ignition delay would cause the rate of cylinder pressure to rise, and the peak pressure that occurs in the combustion chamber would result in a potential effect on the reliability and durability of components such as pistons and bearings. There is currently no cetane specification required for JP-5, and diesel engine manufacturers are working on commercial fuel specifications that will include a minimum cetane requirement to warrant proper engine operation. Guimond (2007) recommends a minimum requirement for cetane index and lubricity to be potentially incorporated into the JP-5 specification to synchronize with current and future technology diesel engines.

H. SUMMARY

Overall, our literature review examined tactical effect, operational effect, phased replacement plan, engine performances, and technical constraints supporting SFC. Our study examines another knowledge gap. We analyze the costs of conversion for the amphibious ships (LHA/LHD) fuel tanks and fuel depot. In the next chapter, we discuss the most recent maintenance repair contracts to develop our data analysis and to determine the costs of reconfiguration. We utilized a Gantt chart to show the actions required by various stakeholders to pinpoint the bottlenecks. By addressing to reduce the bottlenecks, it will enhance future maintenance as it is planned, executed, and completed prior to ship entering SRA or D-SRA maintenance cycle to support reconfiguration. Since JP-5 energy content is lower than F-76, we analyzed the potential total cost of using JP-5 in the deployment phase of operation. Furthermore, we conducted a regression analysis on both fuel price costs to determine how strong the price of JP-5 impacts the price of F-76.

IV. METHODOLOGY

This chapter captures procedures to conduct our analysis of this research project for the reconfiguration costs. The outlines cover types of data and the assumptions made to streamline our analysis. The sources of data we used to analyze are repair contracts from USS Boxer (LHD 4) and DFSP Point Loma, Joint Fleet Maintenance Manual, DLA-E Fiscal Year Fact Books, DLA-E Current Standard Prices for Petroleum Products, and NAVSEA *U.S. Navy Surface Ship Fuel Consumption Data* report.

A. TYPES OF DATA

1. LHD CNO Availability Contract

To calculate the average cost of tank cleaning in support of reconfiguration cost of LHA/LHD SFC, we examined USS Boxer (LHD 4) maintenance operation via Southwest Regional Maintenance Center (SWRMC) class desk Port Engineer in San Diego, CA under Contract SSP number TPPC-HLD4-SWRMC20-CN01. There are a total of 526 work specification line items, and the data was filtered to remove all non-fuel tank cleaning line items. To compute the Average Cleaning Cost per Tank, the following formula was used in Microsoft Excel:

$$= \text{Average } (1^{st} \text{ tank cost, 2nd tank cost, } 3^{rd}\ldots)$$

Once the Average Tank Cleaning Cost are computed, we calculate the total cost of converting F-76 fuel tanks to support the SFC while adhering to all work specification requirements for tank cleaning: NAVSEA Standard Item (NSI) 009–32 for cleaning and painting requirements, NSI 009–25 for structural boundary test requirements, and NSI 009–12 for weld, fabricate, and inspecting requirements. To calculate the Total Cost of Fuel Tank conversion, the following formula was used in Excel:

$$=\text{Average Tank Cleaning Cost} * \text{Total number of F76 Fuel Tanks}$$

2. DFSP Point Loma Fuel Tank Maintenance Contract

The primary source of data to calculate the average cost of tank cleaning in support of reconfiguration costs of fuel terminals at DFSP sites are from the facility operation manager at NAVSUP FLC San Diego Fuel Farm located at Point Loma. The repair contract data that was analyzed was from DFSP Point Loma, Contract Number N39430-20D-2225, under task order N39430-20F-4031, which encompasses cleaning, inspection, and repair of two fuel tanks.

3. Surface Ship Availability Milestone Flowchart

The Joint Fleet Maintenance Manual (JFMM) is an established guideline that standardized minimum requirements used by all Type Commander (TYCOM) and subordinate commands. The JFMM provides detailed "technical instructions to ensure maintenance is planned, executed, completed, and documented" (Department of the Navy, 2022) within each fleet command. The JFMM provides a timeline of events that we used to create a Gantt chart, to study bottlenecks, and to evaluate potential issues corresponding to the events timeline. The Gantt chart breaks down all stakeholders and action requirements in the timeline prescribed, establishing a clear picture of the processes of surface ship availability. In addition, it also focuses on risks in contracting, funding, policy, culture, priorities, personnel, and workforce. The Gantt chart is discussed in next chapter.

4. DLA-E Fiscal Year Fact Books

DLA-E publishes fact books on each fiscal year basis. It provides a snapshot of DLA-E business operations. One section of the fact book provides information on facts and statistics, which consists of DLA-E Enterprise snapshot, energy summary, statement of financial conditions, statement of sales, net sales by category, product cost, purchases by category, and worldwide bulk fuel ending inventory. The 2012–2022 fact books were used to analyze the SFC costs in terms of industry impact, economies of scale, and formulate correlation and regression models between the costs of F-76 and JP-5.

5. DLA-E Current Standard Prices for Petroleum Products

Every fiscal year, there is a release of Standard Fuel Price Change memorandum that is signed by the Under Secretary of Defense for Acquisition and Sustainment. Our research used the current standard prices of fuel of F-76 and JP-5 (FY 2012–2022) to examine data on both fuel consumption and deployment costs from current status quo operation to the SFC operation while using NAVSEA *U.S. Navy Surface Ship Fuel Consumption Data Report* (2016) of optimum transit speed with its specific plant configurations.

6. NAVSEA U.S. Navy Surface Ship Fuel Consumption Data Report

The NAVSEA *U.S. Navy Surface Ships Fuel Consumption Data Report* (2016) provides a fuel burn rate curve in gallons per hour based on the class of the ship's plant configurations along with its speeds. The following formula was used to convert the burn rate to gallons used per day to support our calculation requirement in Chapter 5:

Total Gallons Per Day = Burn Rate Gallons Per Hours * 24 Hours.

B. ASSUMPTIONS

To bring the Single Fuel Concept to the execution phase, there were several assumptions made to minimize the errors estimating the reconfiguration costs.

1. SRA/D-SRA Maintenance Availability Period

It is assumed that LHA/LHD will enter its SRA or D-SRA timeline window from the commissioning date. This assumption is made to streamline all the amphibious ships' schedules of depot level maintenance availabilities. Also, the shipyard is assumed to be operating at 100%.

2. Number of Fuel Tanks

The total number of F-76 fuel tanks data were captured from USS Tripoli (LHA-7) Chief Engineer, and USS Bonhomme Richard (LHD-6) *Ship Information Book Volume 2, Part 2 Machinery Plant: Auxiliary Machinery, Piping, Air Conditioning, Ventilation and*

Heating Systems (S9LHD-AF-SIB-070/LHD-6). The F-76 fuel tanks consist of compensating tanks, fuel/ballast tanks, receiving tanks, and overflow tanks.

3. Congressional Budget

It is assumed that Congress will appropriate the funding to support the conversion costs for LHA/LHD platforms starting with the FY24 budget requirement, not accounting for inflation adjustment. The assumption is made so that no other repair costs are needed in each of the fuel tanks during availability.

4. Diesel/Distillate Fuel

The *DLA-E Fact Book* states Diesel/Distillate fuel is F-76, which we assume for this analysis, and it is widely used in the DON.

5. Fuel Burn Rate

Since speed of the ship will influence the fuel burn rate, this research uses the optimum transit speed along with the ship's plant configuration to streamline fuel consumption based on the NAVSEA *U.S. Navy Surface Ship Fuel Consumption Data* report (2016).

V. ANALYSIS AND RESULTS

This chapter provides the analysis that was described in previous chapter. It covers LHA/LHD tank cleaning and reconfiguration costs, DFSP tank cleaning and reconfiguration costs, surface ship availability milestones, industry impact, fuel consumption, and regression analysis.

A. LHA/LHD TANK CLEANING AND RECONFIGURATION COSTS

According to The Editorial Team (2019, para. 4) article “IMO 2020 & Tank Cleaning: What you need to know,” the primary purpose of tank cleaning onboard a vessel is to remove coatings of substances containing sediments and sludge before loading a new type of fuel. Cost data was gathered from USS Boxer (LHD 4), currently in maintenance availability. There are 235 tanks that need to be opened, ventilated, defueled, repaired, cleaned, and/or inspected prior to exiting the yard period. The overall contract for tank maintenance alone is over $3.7M according to contract SSP number TPPC-LHD4-SWRMC20-CN01. Of the 235 tanks, 46 of the tanks are fuel tanks. By combining the 46 fuel tanks’ costs, the average total cost per tank is $26,552.76. It takes an average of seven days to clean each tank and flush pipelines according to the Editorial Team (2019, para. 10). Preservation of fuel tanks must adhere to NSI 009–32 for cleaning and painting requirements, NSI 009–25 for structural boundary test requirements, and NSI 009–12 for welding, fabrication and inspection requirements. Time required to clean the fuel tank depends on tank size, number of tanks, and how long each tank has been previously cleaned. Fuel tanks must be cleaned throughout the life span of the vessel to preserve its stability; otherwise, it will be much more costly if maintenance is deferred or ignored. Table 1 shows the total cost of cleaning all the F-76 fuel tanks and pipelines per ship is approximately $1,274,532.48 and would take about 336 days to complete. Transitioning to the SFC will need to take at least two maintenance availabilities to successfully reconfigured into the SFC operation.

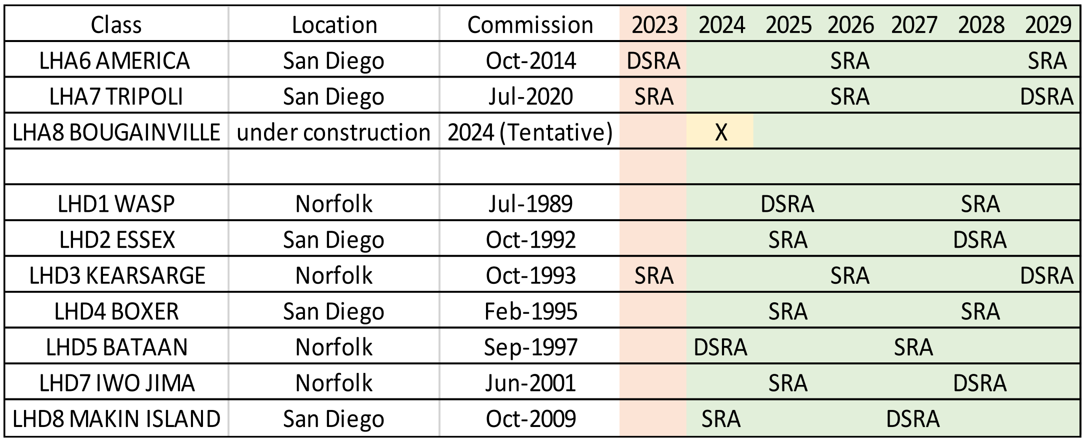
Table 1. Reconfiguration Cost

Days to Clean the Tank & Flush	7
Cost per tank	$26,552.76
Total Number of F76 Tanks	48
Results:	
Total days to clean	336
Total tank cost per ship	$1,274,532.48

Table 2 shows all LHA and LHD platforms can be fully reconfigured to JP-5 by calendar year 2029, accounting for the tank cleaning costs during upcoming FY2024 DOD budget submission to Congress. The total tank cost per ship is $1,274,532.48, so the total cost excluding inflation to reconfigure nine LHA/LHD (excluding USS Bougainville) is $11,470,792.30 in the next seven years. USS Bougainville (LHA 8) is excluded in this time table due to it is still under construction with an anticipated delivery in the year of 2024; therefore, no fuel tank cleaning required.

To include average inflation rate of 2.7% from the past ten years of consumer price index data (U.S. Bureau of Labor Statistics, n.d.), the total reconfiguration cost in the next seven years would accumulate to $13,642,976.74. The following are ships and year of reconfiguration to be completed: USS Bataan (LHD 5) and USS Makin Island (LHD 8) would be reconfigured by 2027. USS Wasp (LHD 1), USS Essex (LHD 2), USS Boxer (LHD 4), and USS Iwo Jima (LHD 7) would be reconfigured by 2028. USS America (LHA 6), USS Tripoli (LHA 7), and USS Kearsarge (LHD 3) would be reconfigured by 2029. The conversion of all 48 F-76 fuel tanks takes 336 days to convert. SRA and D-SRA have a maintenance availability of 270 days (nine months). Therefore, based on Table 2, each ship requires two maintenance availability to fully convert. Each maintenance availability (270 days) can complete up to 38 fuel tanks accounting seven days of cleaning and flushing each tank; however, the ship may experience growth work that would cause the ship to stay in the maintenance availability longer than schedule.

Table 2. CNO Availability Schedule



Class	Location	Commission	2023	2024	2025	2026	2027	2028	2029
LHA6 AMERICA	San Diego	Oct-2014	DSRA			SRA			SRA
LHA7 TRIPOLI	San Diego	Jul-2020	SRA			SRA			DSRA
LHA8 BOUGAINVILLE	under construction	2024 (Tentative)		X					
LHD1 WASP	Norfolk	Jul-1989			DSRA			SRA	
LHD2 ESSEX	San Diego	Oct-1992			SRA			DSRA	
LHD3 KEARSARGE	Norfolk	Oct-1993	SRA			SRA			DSRA
LHD4 BOXER	San Diego	Feb-1995			SRA			SRA	
LHD5 BATAAN	Norfolk	Sep-1997		DSRA			SRA		
LHD7 IWO JIMA	Norfolk	Jun-2001			SRA			DSRA	
LHD8 MAKIN ISLAND	San Diego	Oct-2009		SRA			DSRA		

B. DFSP POINT LOMA TANK CLEANING AND RECONFIGURATION COSTS

The initial cost for contract number N39430-20D-225 that covers Tanks 3 and 6 with Tanks 6 and 7 as an option, has a total of $1,150,581. The average return to service timeline is 239 days per tank. Table 3 shows the current cost to clean, inspect, and repair per tank. Based on historical trends, the constraints associated with tank cleaning after the inspection phase, generates a list of required repairs due to growth work, that prevents returning to service on time and an increase overall contract cost. Per Table 3, the total cost grew exponentially due to growth work to $3,001,938 for the four tanks with an average return to service increased to 271 days per tank. Tanks 7 and 8 are still waiting on Tank 3 and 6 to be completed, likely the cost would increase.

In conclusion, DFSP's above ground storage fuel tank to be reconfigured, it would take more than 270 days with an average cost of $750,484.82 per tank.

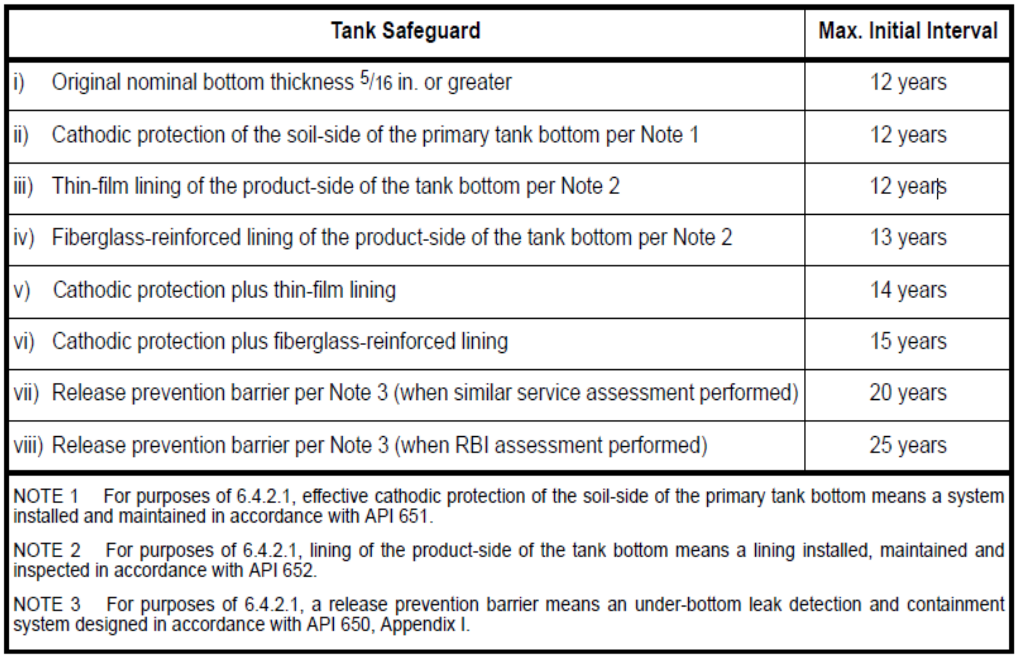
Table 3. DFSP Point Loma Contract. Adopted from NAVFAC Southwest (2020).

Contract # N39430-20D-2225		
Description	**Amount**	**Return to Service Timeline (days)**
Tank 3	$1,237,479	317
Tank 6	$1,237,479	318
Tank 7 (Option)	$262,090	222
Tank 8 (Option)	$264,891	228
Total	$3,001,939	
Average/Tank	$750,484.82	271

DFSP's tank cleaning requirement follows the API Standard 653 and Unified Facilities Criteria (UFC) 3–460-03 Petroleum Fuel Systems Maintenance. The API Standard 653 manual provides a clear guidance on the minimum maintenance requirements of the frequency needed to ensure fuels are clean and contamination-free. The Unified Facilities Criteria (UFC) 3–460-03 Petroleum Fuel Systems Maintenance manual provides inspection and preventive maintenance needed to avoid shutdowns, fuel contamination, and hazards.

The initial internal tank inspection must occur no later than 10 years after commission. Table 4 shows inspection time interval increases for fuel tank that has "one or more leak prevention, detection, corrosion mitigation, or containment safeguards" (API Energy, 2009), i.e., for tank bottom thickness of 5/16-inch or more, the initial internal tank inspection must occur no later than 12 years. Each of the DFSP Point Loma fuel tanks have 3/4-inch tank bottom with a release prevention barrier and a fiberglass lining with a service life of twenty-five years.

Table 4. Inspection Intervals. Source: API Energy (2009).



Tank Safeguard	Max. Initial Interval
i) Original nominal bottom thickness 5/16 in. or greater	12 years
ii) Cathodic protection of the soil-side of the primary tank bottom per Note 1	12 years
iii) Thin-film lining of the product-side of the tank bottom per Note 2	12 years
iv) Fiberglass-reinforced lining of the product-side of the tank bottom per Note 2	13 years
v) Cathodic protection plus thin-film lining	14 years
vi) Cathodic protection plus fiberglass-reinforced lining	15 years
vii) Release prevention barrier per Note 3 (when similar service assessment performed)	20 years
viii) Release prevention barrier per Note 3 (when RBI assessment performed)	25 years

NOTE 1 For purposes of 6.4.2.1, effective cathodic protection of the soil-side of the primary tank bottom means a system installed and maintained in accordance with API 651.

NOTE 2 For purposes of 6.4.2.1, lining of the product-side of the tank bottom means a lining installed, maintained and inspected in accordance with API 652.

NOTE 3 For purposes of 6.4.2.1, a release prevention barrier means an under-bottom leak detection and containment system designed in accordance with API 650, Appendix I.

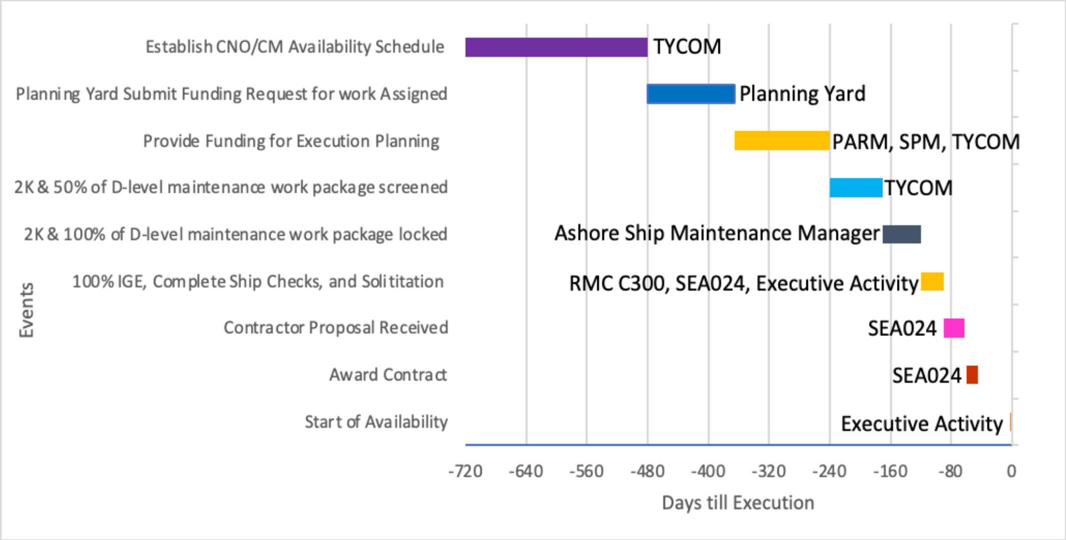
The following maintenance schedule (U.S. Army Corps of Engineers, Naval Facilities Engineering Command, & Air Force Civil Engineer Center, 2017) outlines the initial inspection of the fuel tanks would be executed by the tenth year after commissioning. The fiberglass lining inspection would be executed by the fifteenth years after commissioning. The release prevention barrier inspection would be executed by the twenty-fifth year after commissioning.

10 years (initial) + 5 Years (fiberglass lining) +10 years (release prevention barrier) = 25 years.

C. SURFACE SHIP AVAILABILITY MILESTONE

The SFC cannot be fully executed until all F-76 fuel tanks are clean, repaired (if applicable) and inspected for conversion. Table 5 is a Gantt chart that breaks down stakeholders' action requirements and timeline that establish a clear picture of each process of surface ship availability milestones, which include fuel tank cleaning for conversion. Maintenance availabilities are categorized in three areas: Ship Repair Availability (SRA), Drydocking Selected Restricted Availability (D-SRA), and Continuous Maintenance Availability (CMAV). SRA and D-SRA have a maintenance cycle of nine months, and CMAV is shorter than SRA and D-SRA maintenance cycle.

Table 5. Surface Ship Availability Gantt Chart. Source: Department of the Navy (2022).



Bottlenecks can be seen throughout the entire process of the surface ship availability milestone. Table 4 shows that planning takes place A-720 days (Availability minus 720 days) prior to the start of availability. TYCOM is the initial key player to establish CNO (Chief of Naval Operations) or CM (Continuous Maintenance) availability schedule based on Optimize Fleet Response Plan (O-FRP) maintenance cycle, which are published in Navy Data Environment (NDE) as it occurs.

Maintenance availability funds must be available by A-365 days as it would affect all levels of maintenances work packages. Since all work packages must be submitted no later than A-170 days, funding would impact the availability start date and the solicitation process if delayed.

Aside from funding concern, to minimize risk to the government, we recommend solicitation at A-120 and implementing a Multiple Award Contract-Multi Order (MAC-

MO) contracting strategy. Utilizing MAC-MO strategy, costs are controlled through firm-fixed price contracts and provides defined work specification with third-party planners, resulting in increased competition and small business set aside.

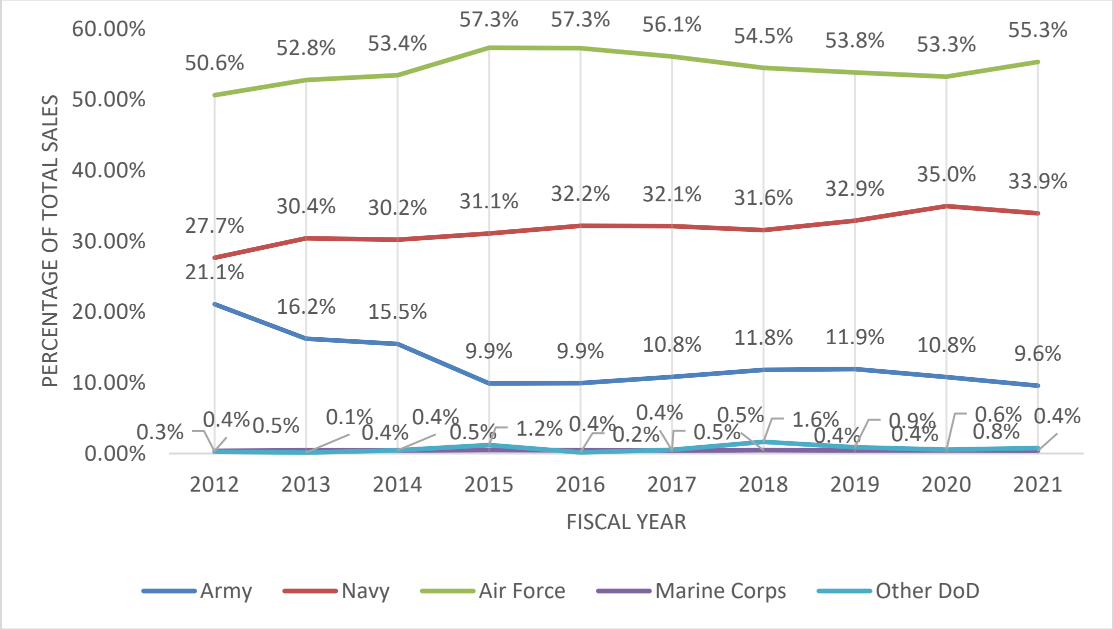
Personnel is another key constraint during the availability period. Most of the times, when a ship enters into the yard, contractor/subcontractor and the shipboard organization experience challenges to start the repair work immediately due to shortage of crew/shore-based workforce, high operational tempo scheduling, limited maintenance/repair training, and parts and materials shortages. The result of these challenges can lead to availability not being completed on time, and the remaining work items would be added to the CMAV.

We recommend the ship's staffing need to be at least 75% manned and trained during the availability period. Equipment and machinery needed during the conversion must be on standby, especially all the parts, anticipating all supply chain issues and challenges. All resources need to be synchronized ahead of time. Early planning and constant communication with the ship's chain of command and key subject matter experts are necessary to prevent delays.

D. INDUSTRY IMPACT AND ECONOMIES OF SCALE

Table 6 shows that the DON consumed on an average of 31% of the total DOD energy each year, ranked second place behind U.S. Air Force, based on Statement of Sales from DLA-E factbook between 2012–2022.

Table 6. Fuel Sales by Department. Source: Defense Logistics Agency Energy (2012-2021).



Based on Thomas' Single Product Jet Fuel White Paper (2021), JP-5 has been successfully sourced and tested as a single base jet fuel through additization. The fuel specification has been approved by DLA-Energy. It states that the concept of additization and using single base jet fuel would give the DON the leading technological advantage to streamline a sole product into various grades of products, which would reduce the processes and assets necessary to move bulk supply from vendors to DOD users. Logistical challenge would be simplified as it would give the supplier the ability to process and distribute bulk supply from source to ashore, afloat units and forward deployed assets.

The report concluded the single base jet fuel concept provides economic and operations advantages, such as simpler transportation and more efficient and inexpensive bulk storage (ashore or afloat), which would have smaller footprints of infrastructure requirements.

E. FUEL CONSUMPTIONS

To calculate daily demand, we use each ship's plant configuration using optimum transit speed from NAVSEA *U.S. Navy Surface Ship Fuel Consumption Data Report*, Table 7. To interpret Table 7 daily fuel consumption rate, we set to 0% gallons per day (GPD) as a baseline to identify status quo using F-76. Also, the 3% and 5% GPD fuel consumption percentage simulates JP-5 energy content, which is lower than F-76.

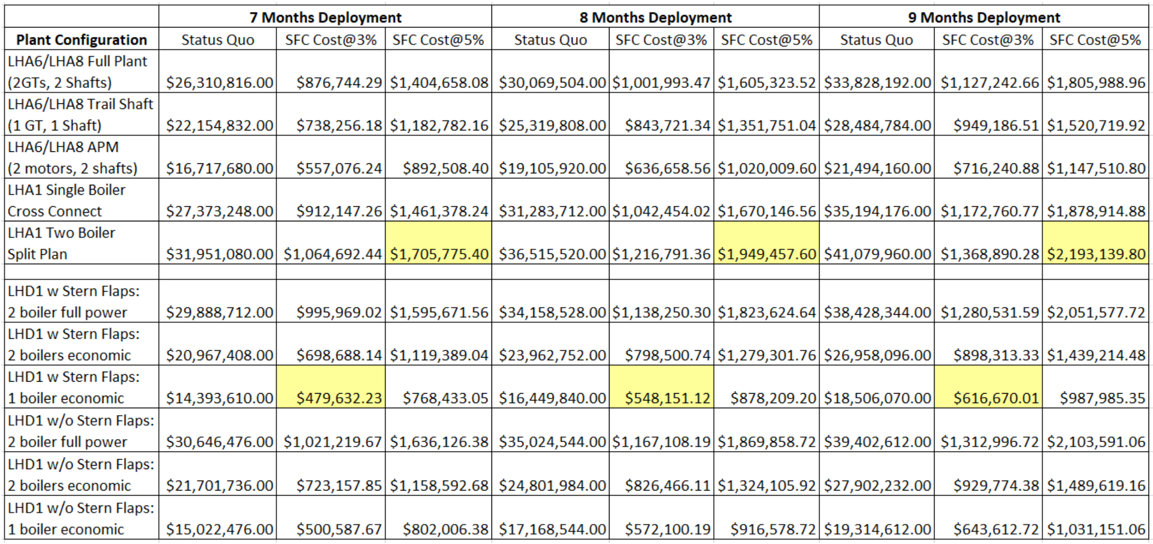
Therefore, based on LHA class ship's configuration, the daily demand for fuel consumption for 3%-5% GPD would have an additional consumption ranging from 770 GPD to 2,454 GPD. For an LHD, there would be an additional consumption ranging from 663 GPD to 2,354 GPD.

Table 7. Amphibious Ships Fuel Consumption Data. Adapted from NAVSEA U.S. Navy Surface Ship Fuel Consumption Data (2016).

		Consumption/Day		
Ship Class	Plant Configuration	0% (GPD)	3% (GPD)	5% (GPD)
LHA6/LHA8	LHA6/LHA8 Full Plant (2GTs, 2 Shafts)	40,416	1,212	2,021
	LHA6/LHA8 Trail Shaft (1 GT, 1 Shaft)	34,032	1,021	1,702
	LHA6/LHA8 APM (2 motors, 2 shafts)	25,680	770	1,284
LHA1	LHA1 Single Boiler Cross Connect	42,048	1,261	2,102
	LHA1 Two Boiler Split Plan	49,080	1,472	2,454
LHD 1 with Stern Flaps	LHD1 w Stern Flaps: 2 boiler full power	45,912	1,377	2,296
	LHD1 w Stern Flaps: 2 boilers economic	32,208	966	1,610
	LHD1 w Stern Flaps: 1 boiler economic	22,110	663	1,106
LHD1 without Stern Flaps	LHD1 w/o Stern Flaps: 2 boiler full power	47,076	1,412	2,354
	LHD1 w/o Stern Flaps: 2 boilers economic	33,336	1,000	1,667
	LHD1 w/o Stern Flaps: 1 boiler economic	23,076	692	1,154

So, costs for deployment and based on optimum transit speed of plant configurations ranges from $479K to $2.1M as depicted in Table 8 of the seven to nine months' deployment calculation. The benefit of implementing the SFC far exceeds the cost of remaining status quo as it increases operational flexibility along with logistics support.

Table 8. Deployment Cost. Adapted from NAVSEA U.S. Navy Surface Ship Fuel Consumption Data (2016).

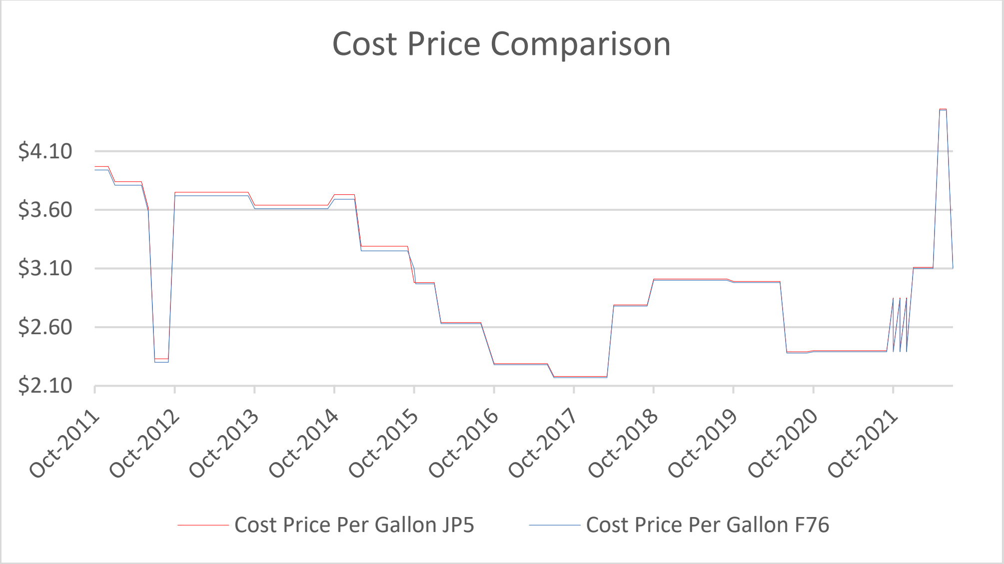


	7 Months Deployment			8 Months Deployment			9 Months Deployment		
Plant Configuration	Status Quo	SFC Cost@3%	SFC Cost@5%	Status Quo	SFC Cost@3%	SFC Cost@5%	Status Quo	SFC Cost@3%	SFC Cost@5%
LHA6/LHA8 Full Plant (2GTs, 2 Shafts)	$26,310,816.00	$876,744.29	$1,404,658.08	$30,069,504.00	$1,001,993.47	$1,605,323.52	$33,828,192.00	$1,127,242.66	$1,805,988.96
LHA6/LHA8 Trail Shaft (1 GT, 1 Shaft)	$22,154,832.00	$738,256.18	$1,182,782.16	$25,319,808.00	$843,721.34	$1,351,751.04	$28,484,784.00	$949,186.51	$1,520,719.92
LHA6/LHA8 APM (2 motors, 2 shafts)	$16,717,680.00	$557,076.24	$892,508.40	$19,105,920.00	$636,658.56	$1,020,009.60	$21,494,160.00	$716,240.88	$1,147,510.80
LHA1 Single Boiler Cross Connect	$27,373,248.00	$912,147.26	$1,461,378.24	$31,283,712.00	$1,042,454.02	$1,670,146.56	$35,194,176.00	$1,172,760.77	$1,878,914.88
LHA1 Two Boiler Split Plan	$31,951,080.00	$1,064,692.44	$1,705,775.40	$36,515,520.00	$1,216,791.36	$1,949,457.60	$41,079,960.00	$1,368,890.28	$2,193,139.80
LHD1 w Stern Flaps: 2 boiler full power	$29,888,712.00	$995,969.02	$1,595,671.56	$34,158,528.00	$1,138,250.30	$1,823,624.64	$38,428,344.00	$1,280,531.59	$2,051,577.72
LHD1 w Stern Flaps: 2 boilers economic	$20,967,408.00	$698,688.14	$1,119,389.04	$23,962,752.00	$798,500.74	$1,279,301.76	$26,958,096.00	$898,313.33	$1,439,214.48
LHD1 w Stern Flaps: 1 boiler economic	$14,393,610.00	$479,632.23	$768,433.05	$16,449,840.00	$548,151.12	$878,209.20	$18,506,070.00	$616,670.01	$987,985.35
LHD1 w/o Stern Flaps: 2 boiler full power	$30,646,476.00	$1,021,219.67	$1,636,126.38	$35,024,544.00	$1,167,108.19	$1,869,858.72	$39,402,612.00	$1,312,996.72	$2,103,591.06
LHD1 w/o Stern Flaps: 2 boilers economic	$21,701,736.00	$723,157.85	$1,158,592.68	$24,801,984.00	$826,466.11	$1,324,105.92	$27,902,232.00	$929,774.38	$1,489,619.16
LHD1 w/o Stern Flaps: 1 boiler economic	$15,022,476.00	$500,587.67	$802,006.38	$17,168,544.00	$572,100.19	$916,578.72	$19,314,612.00	$643,612.72	$1,031,151.06

F. ANALYSIS OF THE PRICE OF F-76 AND JP-5'S CORRELATION AND REGRESSION

Table 9 graph shows the cost price comparison between JP-5 and F-76 based on data collected from Fiscal Year 2012 to 2022 in the DLA-E Current Standard Prices for Petroleum Products Memorandum. By running a correlation analysis, there is a strong correlation relationship, 99.9%, between JP-5 and F-76 price change. Furthermore, it shows that there is an average of 0.45% delta differentiation comparing JP-5 price to F-76 price. During the first quarter of FY2015, there was a period of 7 days that the F-76's price was 3.87% higher than that of JP-5. The regression analysis indicates strong comparison between JP-5 and F-76 fuel cost price.

Table 9. Cost Price Comparison. Adopted from: Defense Logistics Agency Energy (2012-2021).



THIS PAGE INTENTIONALLY LEFT BLANK

VI. CONCLUSIONS AND RECOMMENDATIONS

This chapter outlines our conclusion and recommendations to expand the horizon of the Navy's future of the Single Fuel Concept in the U.S. Navy. We have concluded our findings to our research questions on the costs, constraints, and timeline requirements of implementing the conversion costs to the Amphibious Class ships and fuel depot.

A. CONCLUSION

Based on our findings for the costs, constraints, and timeline to reconfigure the U.S. Navy amphibious assault vessels, the average cost per ship of reconfiguration would be a total of $1,274,532.48 for all 48 F-76 fuel tanks. Of note, there would be around an average of 20% of tank cleaning and repair requirement already identified during SRA and more than 20% of tank cleaning and repair requirement during D-SRA per class desk Port Engineer SWRMC in San Diego.

The reconfiguration is targeted to take two maintenance availabilities with an approximate 336 maintenance total days to clean all 48 fuel tanks. Several constraints that we have identified, such as funding is a principal factor in executing the SFC. In addition, equipment and machinery needed for the conversion must be on standby, especially all the parts and materials required, anticipating all supply chain issues and challenges. Scheduling challenges would be experienced due to competing priorities as the amphibious ships have various requirements that could impact operational commitments and operational commander's demand. Furthermore, growth work is expected and would cause the ship to stay in the maintenance availability longer than anticipated, which could impact funding, manning, scheduling, and contracting support. Therefore, all the available resources need to be synchronized ahead of time. Early planning and constant communication with the ship chain of command and key subject matter experts are necessary to prevent delays.

Based on our findings for the costs, constraints, and timeline of converting fuel depot's F-76 fuel tanks, the average reconfiguration cost would be $750,484.82 per tank (based on 125,000 barrels fuel tank), which includes cleaning and maintenance repairs. The average timeline would take 271 days per fuel tank. Growth work is the biggest constraint that would impact the reconfiguration effort.

B. RECOMMENDATIONS

Implementing the SFC would require an extensive phased rollout plan. There would be a need to balance maintenance repairs and tank cleaning during the time of availability. Aligning all the available resources, including depot-level maintenance services, would require a wide range of planning, communication, and coordination.

Industry impact would be at a minimum to support the SFC. There is a vendor, i.e., Crowley Government Services, Inc, could supply the DOD requirement as it has tested and fielded its JP-5 for the past five years. DLA-E has fully supported the initiative and confirmed the product specification meets the DON standards. Eventually, the DON should implement the SFC as the costs would be significantly lower due to utilizing one type of military-grade fuel, JP-5.

Based on our research, the following are topic areas that need attention to deliver the SFC into the implementation phase: test platforms, NATO fleet readiness, MGO application, industrial preparedness, and ready reserve reconfiguration.

1. Test Platform

DON would need to establish a test platform. This research recommends USS Wasp (LHD 1) to be a testing platform as the ship was commissioned in July 1989, and it is close to the end of its service life. Data gathered regarding wear and tear, fuel consumption, and engine performance will provide valuable insight on the transition to the SFC. On the other hand, to save reconfiguration costs, USS Bougainville (LHA 8) is currently under construction, commissioning around calendar year 2024 and will be a great candidate as another test platform implementing the SFC.

2. NATO Fleet Readiness

If the DON agrees to the phased rollout plan of implementing the SFC, it might have an impact on NATO fleet readiness. Currently, our allies use F-76 for their propulsion by exercising the FEAs, and there have not been studies done on the impact of our SFC to our allies' fleet forces where 28 countries are participating in the FEAs. Shifting to JP-5 might impact business and operational readiness, which will diminish the readiness of their fleets for military exercise or contingency operations. With that said, there would be a need to study the impact of SFC on our allied forces around the globe.

3. MGO Application

Since JP-5 is not readily available in the marketplace while MGO is, this research recommends that DON continue using MGO during deployment to ensure our fleet will be at the highest readiness status when called upon. To minimize the risk of fuel tanks contamination, the fuel tanks would need to be designated for the use of MGO, and policies and procedures must be set in place to prevent any incident. This may provide cost savings, as it is not necessary to have all the fuel tanks cleaned for the SFC adoption.

4. Industrial Preparedness

If the Department of the Navy continues to support the reconfiguration of all platforms supporting the phased rollout plan, the DON must create a mass of expertise and adequate engineering resources required to bring the fleet to its fullest capability. All regional maintenance centers must be equipped with adequate machinery to provide timely configuration of different platforms of Naval vessels. The industry must be ready to staff personnel that have requisite technical skills to conduct independent engineering analysis.

5. Ready Reserve Reconfiguration

We recommend further research on reconfiguration costs on all DFSP locations to increase the inventory capacity of JP-5 fuel in support of the reconfiguration of all Navy vessels. In addition, we recommend creating a long-term bulk fuel contract on fleet-concentrated Naval bases including overseas forward deployed Naval bases such as Yokosuka, Japan and Rota, Spain. Increasing inventory capacity would establish advance preparedness of requirements of deployed forces, especially during contingency missions.

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF REFERENCES

API Energy. (2009, April). *Tank inspection, repair, alteration, and reconstruction* (Fourth edition). https://www.coursehero.com/file/58971765/Tank-Inspection-Repair-Alteration-and-Repdf/.

Arciaga. R. (2015). *USNS Big Horn.* Military Sealift Command. https://www.msc.usff.navy.mil/Press-Room/Photo-Gallery/igphoto/2002476570/.

Braesch, C. (2021, December 07). *16th annual international DLA Energy Europe and Africa fuel Exchange Agreements Forum*. DLA. https://www.dla.mil/AboutDLA/News/NewsArticleView/Article/2864574/16th-annual- international-dla-energy-europe-and-africa-fuel-exchange-agreements/.

Commander, U.S. Pacific Fleet. (2015). *Operations order* (OPORD 201–15). Department of the Navy.

The Editorial Team. (2019, July 23). *IMO 2020 & tank cleaning: what you need to know*. Safety4Sea. https://safety4sea.com/cm-imo-2020-tank-cleaning-what-you-need-to-know/.

Defense Logistics Agency Energy. (2012). *Defense Logistics Agency Energy fiscal year 2012 fact book*. DLA Energy Library. Retrieved October 12, 2022, from https://www.dla.mil/Portals/104/Documents/Energy/Publications/DLA%20Energy%20Fact%20Book%202012_small.pdf?ver=2019-05-24-140601-670.

Defense Logistics Agency Energy. (2013*). Defense Logistics Agency Energy fiscal year 2013 fact book*. DLA Energy Library. Retrieved October 12, 2022, from https://www.dla.mil/Portals/104/Documents/Energy/Publications/DLA%20Energy%20Fact%20Book%202013_small.pdf?ver=2019-05-24-140027-470.

Defense Logistics Agency Energy. (2014). *Defense Logistics Agency Energy fiscal year 2014 fact book*. DLA Energy Library. Retrieved October 12, 2022, from https://www.dla.mil/Portals/104/Documents/Energy/Publications/E_Fiscal2014FactBookLowResolution_150911.pdf.

Defense Logistics Agency Energy. (2015). *Defense Logistics Agency Energy fiscal year 2015 fact book*. DLA Energy Library. Retrieved October 12, 2022, from https://www.dla.mil/Portals/104/Documents/Energy/Publications/E_Fiscal2015FactBookLowResolution_160707.pdf.

Defense Logistics Agency Energy. (2016). *Defense Logistics Agency Energy fiscal year 2016 fact book*. DLA Energy Library. Retrieved October 12, 2022, from https://www.dla.mil/Portals/104/Documents/Energy/Publications/E_Fiscal2016FactBookWebResolution_170706.pdf?ver=2017-07-06-103854-863.

Defense Logistics Agency Energy. (2017*). Defense Logistics Agency Energy fiscal year 2017 fact book*. DLA Energy Library. Retrieved October 12, 2022, from https://www.dla.mil/Portals/104/Documents/Energy/Publications/E_Fiscal2017FactBookLowRes2.pdf?ver=2018-03-29-073051-897.

Defense Logistics Agency Energy. (2018). *Defense Logistics Agency Energy fiscal year 2018 fact book*. DLA Energy Library. Retrieved October 12, 2022, from https://www.dla.mil/Portals/104/Documents/Energy/Publications/E_Fiscal2018FactBookLowRes.pdf?ver=2019-03-08-101941-663.

Defense Logistics Agency Energy. (2019). *Defense Logistics Agency Energy fiscal year 2019 fact book.* DLA Energy Library. Retrieved October 12, 2022, from https://www.dla.mil/Portals/104/Documents/Energy/Publications/FactBookFiscalYear2019_lowres.pdf?ver=RZopJ1Us3tPFWiiWbc1qtg%3d%3d.

Defense Logistics Agency Energy. (2020). *Defense Logistics Agency Energy fiscal year 2020 fact book*. DLA Energy Library. Retrieved October 12, 2022, from https://www.dla.mil/Portals/104/Documents/Energy/Publications/DLAEnergyFactBookFY20_lowres2.pdf?ver=VE-mCUImzFiKKnG1uajkxg%3d%3d.

Defense Logistics Agency-Energy. (2021). *Defense Logistics Agency Energy fiscal year 2021 fact book*. DLA Energy Library. Retrieved October 12, 2022, from https://www.dla.mil/Portals/104/Documents/Energy/Publications/DLAEnergyFactBook2021_2.pdf?ver=NJ0NwnrAlbjZSxxhrPjnHA%3d%3d.

Department of the Army. (2015). *Petroleum supply operations, army techniques publication No.4-43* (ATP 4-43). https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/atp4_43.pdf.

Department of the Navy. (2022, March 31). *Joint fleet maintenance manual volume II integrated fleet maintenance (*COMUSFLTFORCOMINST 4790.3). https://www.navsea.navy.mil/Portals/103/Documents/SUBMEPP/JFMM/Volume%20II.pdf.

Director, Fleet Readiness Division (OPNAV N83). (2022, June 06). Representative intervals, durations, and repair man-days for depot level maintenance availabilities of U.S. Navy ships. Department of Defense.

Deziel. C. (2019, March 8). *The differences between kerosene & jet fuel*. Itstillruns. https://itstillruns.com/the-differences-between-kerosene-jet-fuel-12003828.html.

Department of Defense. (2016a). *MIL-DTL-5624W, detail specification: turbine fuel, aviation, grades JP-4 and JP-5*. Everyspec. http://everyspec.com/MIL-SPECS/MIL-SPECS-MIL-DTL/MIL-DTL-5624W_55741/.

Department of Defense. (2016b). *Department of Defense standard practice quality assurance/surveillance for fuels, lubricants, and related products* (MIL-STD-3004D). https://www.dla.mil/Portals/104/Documents/Energy/Quality%20and%20Technical%20S upport/E_MilSTD3004_1603.pdf.

Department of Defense. (2015). MIL-DTL-83133J, detail specification: turbine fuel, aviation, kerosene type, JP-8 (NATO F-34), NATO F-35, and JP-8+100 (NATO F-37). Everyspec. http://everyspec.com/MIL-SPECS/MIL-SPECS-MIL-DTL/MIL-DTL-83133J_53582/.

Department of Defense (2014). *MIL-DTL-16884N, detail specification: fuel, naval distillate*. Everyspec. http://everyspec.com/MIL-SPECS/MIL-SPECS-MIL-DTL/MIL-DTL-16884N_50645/.

Exxon Mobil. (n.d.). *Aviation lubricants, greases, fluids, oils & fuels*. Exxon Mobile. Retrieved October 11, 2022, from https://www.exxonmobil.com/en/aviation/products-and-services/products/product-wildcard.

Foote, D. (2022). *SSP number: TPPC-LHD4-SWRMC20-CN01* [Unpublished manuscript].

Garrett, R. K. (1993). *Is a single fuel on the battlefield still a viable option?* The Industrial College of the Armed Forces. https://apps.dtic.mil/dtic/tr/fulltext/u2/a276757.pdf.

Giannini, R.M., Martin, C.J., & Strucko, R. (2002). *Single naval fuel at-sea feasibility study—phase one* (NAVAIRSYSCOM Report 445/02-004). Naval Air Systems Command. Naval Fuels & Lubricants IPT.

Global Security. (n.d.). *Fuel oil*. Global Security.org. Retrieved October 11, from https://www.globalsecurity.org/military/systems/ship/systems/fuel-oil.htm.

Guimond, D.P. (2007). *Single naval fuel at-sea diesel engine impact study* (NSWCCD-98-TR-2004/22). Naval Surface Warfare Center Carderock Division Report.

Hale, R. (2011, October 01). Fiscal Year (FY) *2012 standard fuel price change [Memorandum]*. Under Secretary of Defense. https://www.dla.mil/Portals/104/Documents/Energy/Standard%20Prices/Petroleum%20Prices/E_2011Oct1PetroleumStandardPrice_160112.pdf.

Hale, R. (2012, January 01). Fiscal Year (FY) *2012 standard fuel price change [Memorandum]*. Under Secretary of Defense. https://www.dla.mil/Portals/104/Documents/Energy/Standard%20Prices/Petroleum%20Prices/E_2012Jan1PetroleumStandardPrice_160112.pdf.

Hale, R. (2012, June 01). Fiscal Year (FY) *2012 standard fuel price change [Memorandum]*. Under Secretary of Defense. https://www.dla.mil/Portals/104/Documents/Energy/Standard%20Prices/Petroleum%20Prices/E_2012June1PetroleumStandardPrice_160112.pdf.

Hale, R. (2012, July 01). Fiscal Year (FY) *2012 standard fuel price change [Memorandum]*. Under Secretary of Defense. https://www.dla.mil/Portals/104/Documents/Energy/Standard%20Prices/Petroleum%20Prices/E_2012July1PetroleumStandardPrice_160112.pdf.

Hale, R. (2012, October 01). Fiscal Year (FY) *2013 standard fuel price change [Memorandum]*. Under Secretary of Defense. https://www.dla.mil/Portals/104/Documents/Energy/Standard%20Prices/Petroleum%20Prices/E_2012Oct1PetroleumStandardPrice_160112.pdf.

Harker, T. (2020, September 17). Fiscal Year (FY) *2021 standard fuel price change [Memorandum]*. Under Secretary of Defense. https://www.dla.mil/Portals/104/Documents/Energy/Standard%20Prices/Petroleum%20Prices/E_2020Oct1PetroleumStandardPrices_200930.pdf.

Hemighaus, G., Boval, T., & Bacha, J. (2007). *Aviation fuel technical review*. Chevron. https://www.chevron.com/-/media/chevron/operations/documents/aviation-tech-review.pdf.

Jimenez, E. F., Walters, J. T., Lessner, D. P. (2020). Single fuel concept for maritime operations: effects on tactical and operational readiness and sustainment through simulation and analysis. [Master's thesis, Naval Postgraduate School]. NPS Archive: Calhoun. https://calhoun.nps.edu/bitstream/handle/10945/65555/20Jun_Jimenez_Walters_Lessner.pdf?sequence=1&isAllowed=y.

Joint Publication 4-03. (2017). *Joint bulk petroleum and water doctrine*. https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp4_03.pdf?ver=aia3pcpu3661VCMhrjc_FQ%3d%3d.

JP-8 the single fuel forward: an information compendium. (1997, May) U.S. Army Tank-Automotive and Armaments Command Research, Development and Engineering Center, Warren, Michigan.

Kube, C. L. & Kinser, C. J. (2021). *Implementation of the single fuel concept for the navy's surface fleet: an analysis of long-term solutions*. [Master's thesis, Naval Postgraduate School]. NPS Archive: Calhoun. https://calhoun.nps.edu/bitstream/handle/10945/68727/21Dec_Kube_Kinser.pdf?sequence=1&isAllowed=y.

LaGrone, S. (2021, August 9). *Large scale exercise 2021 tests how navy, marines could fight a future global battle*. USNI. https://news.usni.org/2021/08/09/large-scale-exercise-2021-tests-how-navy-marines-could-fight-a-future-global-battle.

Lundquist, Edward. (2021, February 2). *DMO is the navy's operational approach to winning the high-end fight at sea*. *Seapower*. https://seapowermagazine.org/dmo-is-navys-operational-approach-to-winning-the-high-end-fight-at-sea/.

Mackin, M. (2016). Navy ship maintenance: action needed to maximize new contracting strategy's potential benefits (GAO-17-54). Government Accountability Office.

Maurer, D. (2022). Navy ship maintenance: action needed to monitor and address the performance of intermediate maintenance periods (GAO-22-104510). Government Accountability Office.

McCord, M. (2013, October 01). Fiscal Year (FY) *2014 standard fuel price change* [Memorandum]. Under Secretary of Defense. https://www.dla.mil/Portals/104/Documents/Energy/Standard%20Prices/Petroleum%20Prices/E_2013Oct1PetroleumStandardPrice_160112.pdf.

McCord, M. (2014, October 01). Fiscal Year (FY) *2015 standard fuel price change* [Memorandum]. Under Secretary of Defense. https://www.dla.mil/Portals/104/Documents/Energy/Standard%20Prices/Petroleum%20Prices/E_2014Oct1PetroleumStandardPrice_160112.pdf.

McCord, M. (2015, February 01). Fiscal Year (FY) *2015 standard fuel price change* [Memorandum]. Under Secretary of Defense. https://www.dla.mil/Portals/104/Documents/Energy/Standard%20Prices/Petroleum%20Prices/E_2015Feb1PetroleumStandardPrice_160112.pdf.

McCord, M. (2015, October 01). Fiscal Year (FY) *2016 standard fuel price change* [Memorandum]. Under Secretary of Defense. https://www.dla.mil/Portals/104/Documents/Energy/Standard%20Prices/Petroleum%20Prices/E_2015Oct1PetroleumStandardPrice_160112.pdf.

McCord, M. (2016, February 02). Fiscal Year (FY) *2016 standard fuel price change* [Memorandum]. Under Secretary of Defense. https://www.dla.mil/Portals/104/Documents/Energy/Standard%20Prices/Petroleum%20Prices/E_2015Oct8PetroleumStandardPrice_151013.pdf.

McCord, M. (2016, October 01). Fiscal Year (FY) *2017 standard fuel price change* [Memorandum]. Under Secretary of Defense. https://www.dla.mil/Portals/104/Documents/Energy/Standard%20Prices/Petroleum%20Prices/E_16Oct1PetroleumStandardPricesFY17_160929.pdf.

McCord, M. (2021, September 29). Fiscal Year (FY) *2022 standard fuel price change* [Memorandum]. Under Secretary of Defense. https://www.dla.mil/Portals/104/Documents/Energy/Standard%20Prices/Petroleum%20Prices/E_2021Oct1PetroleumStandardPrices_210930.pdf?ver=CcNB9kPinpjen3Q6GC5a5w%3d%3d.

McCord, M. (2021, December 20). Fiscal Year (FY) *2022 standard fuel price change* [Memorandum]. Under Secretary of Defense. https://www.dla.mil/Portals/104/Documents/Energy/Standard%20Prices/Petroleum%20Prices/E_2022Jan1PetroleumStandardPrices_211231.pdf?ver=QGvZ9AUBYkHMAC3Mt PF8Pw%3d%3d.

McCord, M. (2022, April 01). Fiscal Year (FY) *2022 standard fuel price change* [Memorandum]. Under Secretary of Defense. https://www.dla.mil/Portals/104/Documents/Energy/Standard%20Prices/Petroleum%20Prices/E_2022May1PetroleumStandardPrices_220427.pdf?ver=Z6RNl2NXDKasW1z_Yk 4zwg%3d%3d.

McCord, M. (2022, July 15). Fiscal Year (FY) *2022 standard fuel price change* [Memorandum]. Under Secretary of Defense. https://www.dla.mil/Portals/104/Documents/Energy/Standard%20Prices/Petroleum%20Prices/E_2022Aug01PetroleumStandardPrices_220729.pdf?ver=s0fOY2AHCJB-dwChg3w61w%3d%3d.

McCusker, E. (2019, September 24). Fiscal Year (FY) *2020 standard fuel price change* [Memorandum]. Under Secretary of Defense. https://www.dla.mil/Portals/104/Documents/Energy/Standard%20Prices/Petroleum%20Prices/E_2019Oct1PetroleumStandardPrices_190928.pdf?ver=2019-09-30-072433-663.

McCusker, E. (2020, June 01). Fiscal Year (FY) *2020 standard fuel price change* [Memorandum]. Under Secretary of Defense. https://www.dla.mil/Portals/104/Documents/Energy/Standard%20Prices/Petroleum%20Prices/E_2020Jun1PetroleumStandardPrices_200529.pdf?ver=LKorUk872sSFi0TYRWD26Q%3d%3d.

Mesta, B. (2017). *USNS Medgar Evers.* Military Sealift Command. https://www.msc.usff.navy.mil/Press-Room/Photo-Gallery/igphoto/2002484482/.

Military Sealift Command. (n.d.a). *Dry cargo and tankers*. Military Sealift Command. Retrieved October 11, 2022, from https://www.msc.usff.navy.mil/Ships/Dry-Cargo-and-Tankers/.

Military Sealift Command. (n.d.b). *Fleet oiler (PM1)*. Military Sealift Command. Retrieved October 11, 2022, from https://www.msc.usff.navy.mil/Ships/Fleet-Oiler-PM1/.

Military Sealift Command. (n.d.c). *Fleet ordnance and dry cargo (PM6)*. Military Sealift Command. Retrieved October 11, 2022, from https://www.msc.usff.navy.mil/Ships/Fleet-Ordnance-and-Dry-Cargo-PM6/.

Military Sealift Command. (n.d.d). *Preposition (PM3)*. Military Sealift Command. Retrieved October 11, 2022, from https://www.msc.usff.navy.mil/Ships/Prepositioning-PM3/.

Military Sealift Command. (n.d.e). *Sealift program* (PM5). Military Sealift Command. Retrieved October 11, 2022, from https://www.msc.usff.navy.mil/Ships/Sealift-Program-PM5/.

Naval Air Systems Command. (2006). Impact on shipboard fuel handling equipment: JP-5 single naval fuel at-sea feasibility study phase two (NAVAIRSYSCOM Report 445/05-007). Naval Fuels & Lubricants IPT.

Naval Sea Systems Command. (n.d.). *Building the shipyards the nation needs.* Naval Sea Systems Command. Retrieved Oct 11, 2022, https://www.navsea.navy.mil/Home/Shipyards/.

Naval Sea Systems Command. (2016). U.S. Navy Surface Ship Fuel Consumption Data.

Naval Sea Systems Command. (2019). Ship fuel and fuel systems in naval ships' technical Manual.

Naval Sea Systems Command. (2021). *Future fleet replenishment oiler T-AO*. https://www.navsea.navy.mil/Home/Team-Ships/PEO-Ships/T-AO/

Naval Sea Systems Command. (2022). *Command Philosophy*. Naval Sea Systems Command. Retrieved Oct 11, 2022, https://www.navsea.navy.mil/Home/Shipyards/Norfolk/.

NAVFAC Southwest. (2020, February 19). *Order for supplies or services (*Contract Agreement Number N3943020D2225 & Delivery Order N3943020F4031). NAVFAC EXWC.

Norquist, D. (2018, March 29). Fiscal Year (FY) *2018 standard fuel price change* [Memorandum]. Under Secretary of Defense. https://www.dla.mil/Portals/104/Documents/Energy/Standard%20Prices/E_PetroleumStandardPricesFY18_180402.pdf?ver=2018-04-02-103836-967.

Norquist, D. (2018, September 28). Fiscal Year (FY) *2019 standard fuel price change* [Memorandum]. Under Secretary of Defense. https://www.dla.mil/Portals/104/Documents/Energy/Standard%20Prices/Petroleum%20Prices/E_PetroleumStandardPricesFY19_181001.pdf?ver=2018-10-01-131358-203

Office of the Under Secretary Defense for Acquisition and Sustainment. (2020). *Fiscal year 2020 operational energy annual report*. https://www.acq.osd.mil/eie/Downloads/OE/FY20%20OE%20Annual%20Report.pdf.

Putnam, D. (2018). *Eliminating adverse impact of copper contamination in jet propellant 5 (JP-5)*. [SBIR 2018.1 – Topic N181-071]. Navy Small Business Innovation Research Program Office.

Roth, J. (2017, June 19). Fiscal Year (FY) *2017 standard fuel price change [Memorandum]*. Under Secretary of Defense. https://www.dla.mil/Portals/104/Documents/Energy/Standard%20Prices/Petroleum%20Prices/E_17Jul1PetroleumStandardPricesFY17_170622.pdf?ver=2017-06-22-140920-933.

Roth, J. (2017, September 27). Fiscal Year (FY) *2018 standard fuel price change [Memorandum]*. Under Secretary of Defense. https://www.dla.mil/Portals/104/Documents/Energy/Standard%20Prices/Petroleum%20Prices/E_PetroleumStandardPricesFY18_171205.pdf?ver=2017-12-05-154339-333.

Schuyler Line. (2022). *MV SLNC Corsica.* Schuyler Line. https://www.schuylerline.com/mv-slnc-corsica/.

Sermarini, J. T. (2000). *The universal fuel at sea: Replacing F-76 with JP-5*. [Master's thesis, Naval Postgraduate School]. NPS Archive: Calhoun. http://hdl.handle.net/10945/7730.

Thomas, S. P. (2021). *Single product jet fuel white paper*. Crowley Government Services, Inc. [Unpublished White Paper].

Tosh, J. D., Moulton, D. S., & Moses, C. A. (1992). *Navy Fuel Specifications Standardization Interim Report* (Interim Report No. 225). Belvoir Fuels and Lubricants Research Facility. https://apps.dtic.mil/dtic/tr/fulltext/u2/a248542.pdf.

U.S. Army Corps of Engineers, Naval Facilities Engineering Command, & Air Force Civil Engineer Center. (2017). *Unified Facilities Criteria (UFC) petroleum fuel systems maintenance* (UFC 3–460-03). Department of Defense. https://wbdg.org/FFC/DOD/UFC/ufc_3_460_03_2017_c1.pdf.

U.S. Bureau of Labor Statistics. (n.d.). *Consumer price index for all urban consumers (CPI-U).* Retrieved October 25, 2022, from https://www.bls.gov/regions/mid-atlantic/data/consumerpriceindexhistorical_us_table.htm.

U.S. Navy Photo. (n.d.). *MT SLNC Corsica*. Military Sealift Command. https://www.msc.usff.navy.mil/Press-Room/Photo-Gallery/igphoto/2002484438/.

USS Bonhomme Richard (LHD 6). (2016). Volume 2, part 2 machinery plant: auxiliary machinery, piping, air conditioning, ventilation and heating systems chapters 20 through 26 (S9LHD-AF-SIB-070/LHD-6). Department of the Navy.

Wright. K. (n.d.). *MT Empire State*. Military Sealift Command. https://www.msc.usff.navy.mil/Press-Room/Photo-Gallery/igphoto/2002484463/.

THIS PAGE INTENTIONALLY LEFT BLANK

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California