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Cost-Benefit Analysis of Converting Wasp Class Landing Helicopter Dock (Lhd) Steam Propulsion Plants to Hybrid Propulsion

December 2019

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LT Richard Rodriguez, USN

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Prepared for the Naval Postgraduate School, Monterey, CA 93943.

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ABSTRACT

The purpose of this thesis is to conduct a cost-benefit analysis of converting steam-powered propulsion plants on-board Wasp-Class Landing Helicopter Dock (LHD) hulls 1 through 7 to hybrid propulsion. The objective of this research was to evaluate the net present value of conversion by weighing the cost-savings benefits of fuel savings, in-port utility consumption, and manpower against the cost of conversion. The results of the analysis conclude that LHDs 5 and 7 have a positive net present value; therefore, their conversion is recommended. LHD 6 can have a positive net present value with recommended complex overhaul schedule changes. Recommendations are made to maximize benefits to the Navy, considering potential changes in force structure and follow-on studies.

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ABOUT THE AUTHORS

LT Joseph G. Jablonski is a Surface Warfare Officer who graduated from Fairleigh Dickinson University in Madison, New Jersey, where he was awarded a Bachelor of Science in Chemistry and a minor in Mathematics. LT Jablonski then attended Clemson University in Clemson, South Carolina, where he was awarded a Master's of Science in Environmental Engineering.

After commissioning through the Nuclear Propulsion Officer Candidate program, LT Jablonski completed his first Division Officer tour onboard USS *Gravely* (DDG 107) as the Gunnery and Ordnance Officer. He was then assigned to Navy Nuclear Power Training Command, where he completed nuclear power school, followed by Nuclear Power Training Unit. LT Jablonski completed his nuclear Division Officer tour onboard USS *Dwight D. Eisenhower* (CVN 69) as the Electrical Division Officer for Number Two Reactor Plant, as well as the Assistant Main Propulsion Assistant following his successful completion of the Prospective Nuclear Engineering Officer exam.

After his NPS graduation, LT Jablonski will be attending SWO Department Dead school in Newport, Rhode Island with follow on orders to USS *James E. Williams* (DDG 95) as the Weapons Officer.

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Afloat, Lieutenant Rodriguez completed his division officer tours aboard the destroyer USS FORREST SHERMAN (DDG 98) as the Strike Officer and then aboard USS BAINBRIDGE (DDG 96) as the Fire Control Officer. During his sea tours he deployed to the Fifth Fleet area of operations in support of the Global War on Terrorism.

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Lieutenant Rodriguez's personal awards include the Navy and Marine Corps Achievement Medal with two Gold Stars as well as multiple service awards. He is married with two children.

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Joseph dedicates this thesis to his father, Joseph Gerard Jablonski, Sr., who passed away during Joseph's time at NPS. There was no father prouder of a son than Joseph Jablonski Sr. was. Thank you for the life lessons and memories we had together, Dad; you will be with me every day. Joseph would like to thank his wife, Rachele, for supporting him not only during the final months of thesis production but for the entirety of his naval career. Joseph would also like to thank his mother, Laurie, and brother, Anthony, for always being his backbone in life.

Richard dedicates this thesis to his family. To my wife, Magdielis, thank you for your endless patience and devotion. Your encouragement motivates me to be better every day, and I am excited to spend the rest of our lives together. Thank you for being the most loving and supporting wife a naval officer can ask for. To my children, Ricardo and Henry, thank you for giving me the endless inspiration that drives me to succeed every day. No one has been more important to me in the pursuit of this research than the three of you.

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Cost-Benefit Analysis of Converting Wasp Class Landing Helicopter Dock (Lhd) Steam Propulsion Plants to Hybrid Propulsion

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LIST OF ACRONYMS AND ABBREVIATIONS

AEO	Annual Energy Outlook
APM	Auxiliary Propulsion Motor
BTU	British Thermal Unit
BUPERS	Bureau of Naval Personnel
CAPE	Cost Assessment and Program Evaluation
CBA	Cost-Benefit Analysis
CBO	Congressional Budget Office
COA	Course of Action
CODLAG	Combined Diesel-Electric and Gas
COH	Complex Overhaul
DCARC	Defense Cost and Research Center
DDS	Design Data Sheet
DFM	Diesel Fuel Marine
DOD	Department of Defense
EIA	Energy Information Administration
FBCE	Fully Burdened Cost of Energy
FBCF	Fully Burdened Cost of Fuel
FY	Fiscal Year
GTE	Gas Turbine Engine
JIC	Joint Inflation Calculator
LHA	Landing Helicopter Assault
LHD	Landing Helicopter Dock
NAVFAC	Naval Facilities Engineering Command
NAVSEA	Naval Sea Systems Command
NCCA	Navy Center for Cost Analysis
NDAA	National Defense Authorization Act
NEC	Naval Enlisted Classification
NEURS	Navy Energy Usage and Reporting System
NPS	Naval Postgraduate School
NPV	Net Present Value

O&MN	Operations and Maintenance, Navy
O&S	Operations and Support
OMB	Office of Management and Budget
OPN	Other Procurement, Navy
OPNAV	Office of the Chief of Naval Operations
OSD	Office of the Secretary of Defense
PCS	Permanent Change of Station
PV	Present Value
ROM	Rough Order of Magnitude
SDR	Social Discount Rate
SMD	Ship Manpower Document
TAD	Temporary Additional Duty
TOC	Total Ownership Cost
VAMOSC	Visibility and Management of Operating and Support Costs
WH	Watt-Hour
WTA	Work Task Assignment

EXECUTIVE SUMMARY

PURPOSE

Steam-powered *Wasp*-class Landing Helicopter Dock (LHD) utilize an aging steam propulsion system that yields poor underway fuel economy, increased pier-side utility consumption, and increased manning compared to their gas turbine counterparts. Furthermore, reliance on steam-powered LHD-class ships is expected well past 2030 due to lifetime extensions for older ships and production gaps in the *America*-class program. These steam ships require costly, dedicated maintenance and infrastructure, which is distinct from all other non-nuclear Navy vessels. Until now, relatively little has been done to identify the costs and benefits of converting LHD 1–7 to a more advanced, fuel-efficient propulsion platform (Gingras, Scarborough, Howard, & McCleery, 1998). The purpose of this thesis is to provide the Navy with a conservative estimate of the net present value (NPV) of this conversion.

ORGANIZATIONAL IMPORTANCE

The National Defense Authorization Act (NDAA) for Fiscal Year 2018, Pub. L. No. 115-91, stated that "it shall be the policy of the United States to have available, as soon as practicable, not fewer than 355 battle force ships, comprised of the optimal mix of platforms" (p. 267). However, the 355-ship requirement is being reviewed by the ongoing 2019 force structure assessment (FSA). The former Chief of Naval Operations, Admiral John M. Richardson, discussed the FSA by stating "While data-driven analysis may ultimately change the details of our long-term fleet architecture, all force structure analyses agree in one respect: we must build a bigger Navy" (Office of the Chief of Naval Operations [OPNAV], 2019b, p. 6). The pending results of the newest force structure assessment (FSA) introduces uncertainty to the current balance of forces and future procurements plans. This thesis provides the flexibility for the Navy to plan for a larger, more capable fleet while accounting for the unknown future requirements.

BACKGROUND

Converting steam-powered LHD hulls to hybrid propulsion is not a new discussion topic for the U.S. Navy. Previous studies have identified fuel and manpower cost-savings, as well as determining that conversion is feasible (Gingras et al., 1998; Hatcher, S., Oswald, A., Boughner, A., 2002; Naval Sea Systems Command 05L/PMS 377, 2001). Furthermore, the hybrid-powered USS *Makin Island* (LHD 8) has proven these engineering concepts, namely the reduced fuel costs, through operational experience (USS Makin Island (LHD 8), 2012). Current studies propose a complex overhaul (COH) and conversion plan for LHD 1–8 that will extend LHD lifetimes from 40 years to 50 years (OPNAV N953, 2018; OPNAV N95, 2019). The steam-to-hybrid conversion will result in an engineering plant similar to LHD 8 being installed on LHD 1–7. Converted ships will also have the benefit of increased interoperability and lethality by modernizing command and control systems when coupled with the COH (OPNAV N953, 2018).

METHODOLOGY

This thesis uses the standard for performing cost-benefit analysis (CBA) on government programs, Circular A-94, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*, produced by the Office of Management and Budget (OMB, 1992). The goal for the CBA is to determine if the benefits offered from conversion outweigh the cost incurred, resulting in a positive NPV. The four primary benefits (cost-savings) are identified as underway fuel economy, not underway (auxiliary steaming) fuel economy, pier-side utility consumption, and manning, while the principle cost is incurred from the conversion process. Historical cost data for fuel and manpower is retrieved from Navy Visibility and Management of Operating and Support Costs (VAMOSC), while utility cost data is retrieved from Naval Facilities Engineering Command (NAVFAC).

Manpower cost-savings are calculated by taking the historical class average for LHD 1–7 and comparing it to the average of LHD 8 for all available years of operation. Utility cost-savings are determined by developing annual in-port usage rates at Naval Station Norfolk as well as Naval Base San Diego and comparing the total average cost of LHD 1–7 to the in-port cost of LHD 8. The primary consideration for utility consumption is based on the removal of all steam from LHD 1–7 by converting to all-electric auxiliaries.

This results in converted ships incurring higher electric costs than non-converted LHDs, however, it eliminates steam consumption and subsequent steam costs. Fuel cost-savings are determined by comparing the LHD 1–7 class average barrel (BBL) usage for underway, as well as not underway (auxiliary steaming) to LHD 8 average BBL usage.

Fuel price volatility is accounted for by using NAVSEA's (2012) Design Data Sheet (DDS) 200–2, *Calculation of Surface Ship Annual Energy Usage, Annual Energy Cost, and Fully Burdened Cost of Energy.* DDS 200–2 uses the Energy Information Administration's (EIA) annual outlook to model fuel price changes until the year 2050. The model outputs three different scenarios for fuel price, a reference case (baseline), a high oil price, and a low oil price. In addition to fuel price volatility, this thesis also accounts for the fully burdened cost of fuel (FBCF). Historical studies, such as the re-engining of the Boeing B-52H that have not considered the FBCF, failed to fully account for the cost-savings gained from improved fuel efficiencies (Office of the Under Secretary of Defense For Acquisition, Technology and Logistics, 2004). This thesis uses both the DDS 200–2, as well as a 2009 Naval Postgraduate School (NPS) thesis that studied the *Arleigh Burke*-class destroyer FBCF to develop a rough order of magnitude LHD FBCF (Corley, 2009).

KEY FINDINGS

The results for the CBA, performed using a 30-year nominal discount rate of 3.6% derived from OMB Circular A-94 and the reference fuel price, conclude that LHD 5 and 7 have a positive NPV for conversion when homeported in San Diego. LHD 6 would have a positive NPV if its conversion and overhaul can be accelerated and its homeport remains in San Diego. Norfolk does not yield any positive NPVs for conversion. This is mainly due to shore steam pricing, which is nearly ten times higher in San Diego as compared to Norfolk. The low cost of steam in Norfolk results in the conversion having a negative PV for utility consumption, thus becoming a cost rather than a benefit. Therefore, all converted LHD ships are recommended to be in San Diego. A combination of the COH timeline and remaining service life results in LHD 1–4 having a negative NPV for conversion. Additionally, the concurrent OPNAV N95 (2019) conversion study has determined that

LHD 1–4 are not convertible until further studies are conducted to address vessel center of gravity concerns.

CONCLUSIONS

Conclusion #1: *Convert LHD 5 and 7 to hybrid propulsion.* The primary conclusion is that LHD 5 and 7 should be converted from steam to hybrid propulsion and homeported in San Diego following the complex overhaul plan proposed by OPNAV N953 (2018). Due to the difference in shore steam costs, converted ships should be homeported in San Diego, and steamships should be homeported in Norfolk. This course of action requires shifting homeports in order to preserve the number of large-deck amphibious ships on each coast.

Conclusion #2: *Optimize the COH schedule for LHD 6 conversion.* The current COH timeline does not schedule LHD 6 for conversion until FY 2037, resulting in a negative NPV for Norfolk and San Diego. As a result, this thesis has analyzed potential conversion starting dates, which would result in a positive NPV for LHD 6 conversion. These dates are FY 2023 and FY 2025, with an NPV of $33.8 million FY 2019 and $1.1 million FY 2019, respectively. Norfolk retained a negative NPV during this analysis, therefore, LHD 6 must remain in San Diego if converted.

Conclusion #3: *Future demand considerations are uncertain.* Different factors of Navy policy, such as the emerging great power competition, fiscal situation, employment method, and capabilities shortfall, indicate possible changes in Navy policy for LHDs. These policy changes will be developed in the results of the 2019 force structure assessment (FSA), which will determine the future demand for big deck amphibious ships. This will result in one of three alternatives when considering the large deck amphibious force.

First, if the Navy increases the number of large-deck amphibious ships required, there will be benefits in extending and converting steam-powered LHDs. This is because the Navy may need to operate LHDs past the current 40-year service life to meet force size requirements. When coupled with the COH, converted ships will have the added benefit of increased interoperability and lethality by modernizing command and control systems

(OPNAV N953, 2018). Second, if the FSA reduces the requirement, LHD life extension and conversion may not be required to meet the large deck amphibious fleet size when compared to current LHD decommissioning and LHA construction planning.

In the third scenario, the number of ships required remains the same. In this case, the Navy has the option to either convert steam-powered LHDs or to decommission LHDs at the current 40-year service life and replace them with the *America*-class Flight 1. If the Navy chooses the latter, then this thesis recommends that the current LHA Flight 1 production schedule be expedited to meet changing demand as well as reduce production costs incurred via the long production break.

FOLLOW-ON STUDIES

The results of a CBA can yield changes to policies, operations, and procedures. These changes can cause unintended second- and third-order effects. Therefore, policy changes should be carefully analyzed before implementation. This thesis also recommends that future research be conducted in the following areas: LHD 1–4 stability modifications, steam infrastructure dependability reduction, engineering plant and shipyard maintenance reductions, and base case estimation of the FBCF for the LHD 1 class ship.

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I. INTRODUCTION

Chapter I introduces the problem this thesis intends to solve. The scope of this thesis is limited to the research questions and purpose stated herein. This chapter is written to highlight the fact that this type of conversion has never had a cost-benefit analysis (CBA) performed by the U.S. Navy and that the Navy is extending hull lifetimes due to fleet expansion. An outline of the organization of the rest of the thesis is also provided.

A. PROBLEM STATEMENT

Steam propulsion powered *Wasp*-class Landing Helicopter Dock (LHD) ships 1–7 serve as the majority "big-deck" amphibious assault ships in the U.S. Navy. Unlike the currently commissioned *America*-class Landing Helicopter Assault (LHA), LHD 1–7 have a submersible well deck, which is utilized to launch amphibious craft in support of U.S. Marine Corps operations. Steam LHDs, however, utilize an aging steam propulsion system that yields poor underway fuel economy, increased pier-side utility consumption, and increased manning compared to their gas turbine counterparts USS *Makin Island* (LHD 8), USS *America* (LHA 6), and USS *Tripoli* (LHA 7). Additionally, continued reliance on steam-powered LHD-class ships is expected well past 2030 due to lifetime extensions as well as production gaps in the *America*-class program.

The National Defense Authorization Act (NDAA) for Fiscal Year 2018, Pub. L. No. 115-91, stated that "it shall be the policy of the United States to have available, as soon as practicable, not fewer than 355 battle force ships, comprised of the optimal mix of platforms, with funding subject to the availability of appropriations or other funds" (p. 267). The most recent response to the NDAA's 355-ship policy is the *Report to Congress on the Annual Long-Range Plan for Construction of Naval Vessels for Fiscal Year 2020* (Office of the Chief of Naval Operations [OPNAV], 2019a), published in March 2019. This report discusses, in part, both the short-term and long-term construction and disposal plans for U.S. Navy ships. Considering LHD hulls specifically, the planned decommissioning of LHD 1 will not commence until Fiscal Year (FY) 2029, while LHD 7 is slated to decommission in FY 2046.

Furthermore, in his last statement before the House Committee on Appropriations, the 31st Chief of Naval Operations, Admiral John M. Richardson, stated, “An ongoing force structure assessment will conclude by the end of 2019. While data-driven analysis may ultimately change the details of our long-term fleet architecture, all force structure analyses agree in one respect: we must build a bigger Navy” (OPNAV, 2019b, p. 6). The implications of this strategic guidance show that the Navy plans to increase the size of its surface force.

Although fleet size requirements are increasing along with the age of propulsion plants, relatively little has been done to identify the costs and benefits of converting LHD 1–7 to a more advanced, fuel-efficient propulsion platform (Gingras, Scarborough, Howard, & McCleery, 1998). Previous studies have analyzed the feasibility of conversion, of which the primary and most technically relevant concluded that converting LHD 7 before commissioning to a combined diesel-electric and gas (CODLAG) was feasible (Gingras et al., 1998). However, the conversion was not accomplished. Additionally, a complex overhaul (COH) plan is being proposed for LHD 1–8 that will extend LHD lifetimes from 40 years to 50 years, as seen in Figure 1.

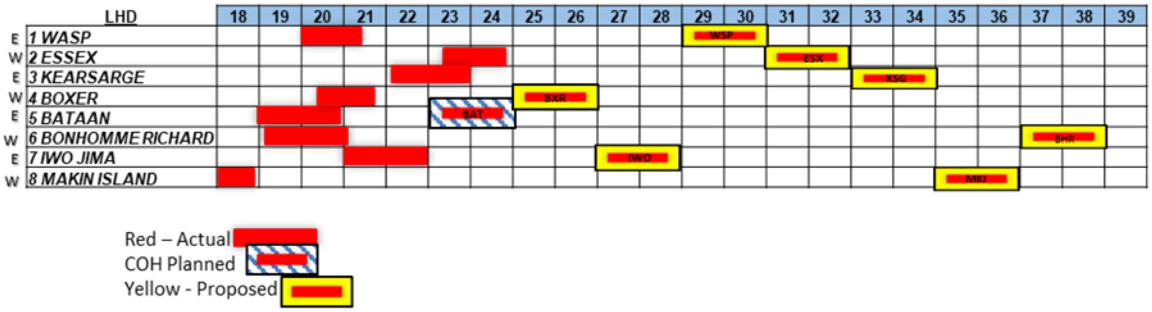

Figure 1. Notional LHD COH Timeline. Adapted from Navy Amphibious Warfare Branch (OPNAV N953; 2018).

Due to both the timing of the COHs and the optimal time to perform the CODLAG conversion, as well as the time remaining before disposal (i.e., how to optimize the ship’s remaining time after CODLAG conversion), each ship will have inherent differences in lifetime cost savings. Additionally, it is assumed that the conversion will be completed during the time each ship is undergoing its proposed COH period; therefore, this thesis utilizes the full 50-year lifetime when calculating costs and benefits. Due to these factors, this thesis identifies the need for a cost-benefit analysis (CBA) to be performed.

B. RESEARCH QUESTIONS

This thesis completes a CBA by identifying the major cost-savings elements involved in converting LHD steam propulsion ships. This thesis' primary research questions are as follows:

1. What are the costs and benefits when deciding whether to convert existing steam-powered LHD hulls to a CODLAG propulsion system?
2. What is the resultant net present value (NPV) for conversion?

This thesis' secondary research questions are as follows:

1. What is the optimal number of steam propulsion LHDs to convert when considering hull lifetime and ship modification requirements?
2. Is hybrid propulsion conversion desirable when compared to the construction costs of new LHA ships outfitted with well decks and hybrid propulsion standard?

C. PURPOSE

The purpose of this study is to construct a CBA that evaluates converting LHD 1–7 to hybrid propulsion. This is accomplished by identifying the significant monetary benefits and comparing them to conversion costs. This thesis has identified four primary, quantifiable elements in cost savings that are functions of propulsion plant conversion:

1. Underway fuel economy
2. Not underway fuel economy
3. Pier-side utility consumption
4. Manning

The cost-saving elements are then applied to the class average of LHD 1–7 and LHD 8 to estimate a rough order of magnitude (ROM) based on the difference between the cost of LHD 1–7 and LHD 8. Benefits will fluctuate per year due to inherent changes in the ship's schedule, such as maintenance periods, work-up periods, and deployments. This thesis assumes that the sum of actual long-term conversion cost savings will be similar to the total sum of the yearly average.

These cost-savings elements are then used to study two potential courses of action (COAs):

1. COA 1: Convert LHD 1–7 to CODLAG propulsion
2. COA 2: Status quo (LHD 1–7 remain steam-powered throughout the remainder of their lifetimes)

Sensitivity analysis is then performed to analyze COA 1 feasibility. It is likely, if not practical, that several LHDs will follow COA 2 based on their remaining lifetimes and potential engineering feasibility.

Concurrently with this thesis, the Director of Expeditionary Warfare for the Chief of Naval Operations (Navy Amphibious Warfare Branch [OPNAV N95], 2019) is conducting a cost-conversion study that has identified various propulsion plant line-ups, including the CODLAG system found on LHD 8. The OPNAV N95 study ended the rough order of magnitude Phase I in May 2019 and has entered Phase II, feasibility. Therefore, this thesis compares the conversion cost results from Phase I with the conversion benefits to compute the net present value (NPV) for LHD 1–7.

D. ORGANIZATION

This thesis is organized into six chapters. The problem, research questions, and purpose of the study are discussed in Chapter I. It is written to highlight both the fact that this type of conversion has never had a CBA performed by the U.S. Navy, as well as the fact that the Navy is extending hull lifetimes due to fleet expansion. The remaining chapters are discussed in the following paragraphs.

Chapter II discusses the background for the LHD class, as well as the history and evolution of LHD propulsion. The purpose of this chapter is to reinforce the reader with the fundamental purposes and utilities of LHD ships and explain the benefits and inner workings of the CODLAG propulsion system.

The purpose of Chapter III is to perform a literature review of the data utilized in this thesis. The literature review helped both to identify that the thesis was viable, in that the conversion was technically feasible, and to identify the four cost-savings elements that form the core of the CBA. Additionally, the literature review helped to organize the background and to ensure that the most recent literature regarding Navy force structure assessment as well as Marine Commandant guidance was included in the CBA.

The purpose of Chapter IV is to describe the methodology of the thesis. Chapter IV discusses the production of a CBA, the outline of data discovery and analysis methodology, and how the data was analyzed. Chapter IV also conducts the data portion of the literature review in greater detail.

The purpose of Chapter V is to formulate the results calculated from Chapter IV into a broader analysis of steam-powered LHD conversion and then discuss how these results factor into the CBA. Chapter V tabulates the results from the four primary cost-savings elements as compared to the conversion cost for each specific LHD's estimated lifetime at both Naval Base San Diego and Naval Station Norfolk. Chapter V then conducts a sensitivity analysis on these results.

Chapter VI has two purposes. First, it discusses the conclusions and recommendations that this thesis has derived from the results of performing the CBA. Second, it discusses follow-on studies recommended by the thesis that have the potential to both improve existing data as well as uncover potentially discovered benefits not identified.

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II. BACKGROUND

Chapter II discusses the background for both the LHD classes as well as the history and evolution of LHD propulsion. The purpose of this chapter is to reinforce for the reader the fundamental purposes and utilities of LHD ships. This chapter highlights the benefits and inner workings of the CODLAG propulsion system.

A. HISTORY OF LANDING HELICOPTER DOCK PROPULSION

Amphibious warships support the United States Marine Corps mission as a ready force with the ability to embark, transport, deploy, command, and support all attached elements (U.S. Navy, 2019b). Amphibious forces are at the center of the Navy's multi-mission competency with the ability to project power, maintain a presence, and provide humanitarian relief and other contingency operations on short notice (Forecast International, 2010). LHDs have been a part of every major operation the Navy has undertaken since its inception, often playing the role of small carriers to launch attack aircraft against the enemy. Furthermore, all previous LHA- and LHD-class ships employed steam propulsion until the revolutionary CODLAG engineering plant was designed and installed on LHD 8 (U.S. Navy, 2019b).

1. Transition from Steam

The first steamships made their maiden voyage early in the 19th century, and several advancements throughout their lifetimes revolutionized the industry (National Geographic, 2011). Steam boilers with water tubes were invented, giving way to ship hulls made from iron rather than wood. Early paddlewheel designs were replaced with screw propellers, further improving efficiency. Producing steam, however, requires high temperatures and pressures, resulting in the requirements for double-lined and watertight bulkheads. By the mid-20th century, steam turbine engines had become the most efficient prime mover for a ship; this is the same type of propulsion on amphibious ships today (National Geographic, 2011).

The steam propulsion plant used on the *Wasp* class is identical to the *Tarawa*-class steam turbine engines from the 1960s. *Wasp*-class LHDs were commissioned from 1989 to 2001 even though the Navy began phasing out steam systems in the 1990s due to the high maintenance and manning costs involved. LHD 7 was the last ship of the *Wasp* class and the last conventional steamship to be constructed by the Navy (Forecast International, 2010). Before commissioning LHD 7, the Navy commissioned a study to analyze the feasibility of converting the ship from steam to gas turbine propulsion (Gingras et al., 1998). This study concluded that converting the ship was entirely feasible and would even produce significant cost savings to the Navy.

2. Technological Advances Pave the Way

The first generation of the *Wasp* class (LHD 1–7) has two steam turbine engines, which are powered by two boilers, each driving one shaft with fixed propellers. The engines can cross-connect to drive the other shaft. Five ship service turbine generators provide power, with auxiliary power provided through two diesel engine generators (Forecast International, 2010). This aging technology is not as efficient as modern propulsion systems. As a result, steam is considered too labor-intensive and requires too many maintenance hours to fit into the current Navy fiscal environment (Dalton, T., Boughner, A., Mako, D., & Doerry, 2008).

In an attempt to modernize the fleet, an early study into the conversion of LHD 7 suggested employing one gas turbine per shaft; however, this suggestion was quickly identified as unappealing due to “unattractive low-speed fuel efficiency” (Hatcher, Oswald, & Boughner, 2002, p. 2). Additionally, Hatcher et al. (2002) found that the Navy’s desire to remove all steam-producing equipment during conversion led to an increase in power generation requirements due to new electric heating systems. This requirement eventually resulted in the concept of a low-speed electric propulsion system powered by an electric propulsion motor. Hatcher et al. also stated that “independent cost studies indicate a payback period of less than two years versus the design with no electric propulsion and a predicted life cycle fuel savings of over $21 million dollars” (Hatcher et at., 2002, p. 3).

At this point, conversion became a much more viable option, and the Navy stated the intent to outfit the next LHD ship with a gas turbine propulsion and all-electric auxiliary systems in place of a steam plant (Dalton et al., 2008). Since the 1970s, the Navy had been operating General Electric LM2500 engines, which were first used on the *Spruance*-class destroyers and rated at 21,000 bhp. The engines have evolved to a higher rating of 32,000 bhp and are now used on the Military Sealift Command ships. Based on the LM2500, General Electric designed the LM2500+ by adding a stage to increase the airflow and temperature of the engine. The LM2500+ has a 25% power increase from the original turbine. The new engine made it possible to have a propulsion plant powered by only one gas turbine per shaft with the inclusion of an auxiliary electric motor to improve efficiency at lower speeds. All the technological advances yielded a new type of propulsion system (Hatcher et al., 2002).

B. COMBINED DIESEL-ELECTRIC AND GAS PROPULSION

The engineering plant configuration was deemed the CODLAG propulsion system, a revolutionary design that allowed the Navy to advance propulsion technology towards higher efficiency and responsiveness. When integrated with a higher capacity electrical distribution system, CODLAG gives the equipped platform an edge in employing high voltage equipment and weapons.

1. System Requirements

Early designs to convert LHD 7 into a CODLAG ship called for two loitering motors rated at 800 bhp each for a total of 1,600 bhp per shaft (Gingras et al., 1998). However, Gingras et al. identified that there were concerns that these motors were not going to provide the necessary power outputs. A solution to this problem was to employ a 4160V electrical production and distribution system, which can provide power to an electric motor that meets required performance specifications.

In an American Society of Naval Engineers (ASNE) report titled LHD 8: A Step Toward the All-Electric *Warship* (Dalton et al., 2008), the authors discussed the expected total ownership costs (TOC) savings and go on to list the design, construction costs, and constraints placed on the design:

> In preparation for the design and construction of LHD 8, the Navy initiated a series of feasibility studies aimed at developing a gas turbine propulsion concept and reducing Total Ownership Costs (TOC) over the expected 40-year service life of the ship. Early results of this study showed that TOC could be drastically reduced simply through the predicted reduction in crew

size of at least 80 personnel and decreased maintenance requirements associated with the removal of steam turbine engines and boilers. To minimize design and construction costs, a number of constraints were placed on the design:

- Maintain the existing shaft line rake and skew of the steam propulsion plant to retain the same Wasp (LHD 1) class hull hydrodynamic characteristics
- Limit design changes to the second stage of the reduction gear to maintain the manufacturing lead time needed to support the ship construction schedule
- No Marine Corps missions could be degraded
- Minimize the impact to adjacent non-machinery spaces and
- Allow only reasonable machinery arrangement changes. (Dalton et al., 2008, p. 3)

2. The Combined Diesel-Electric and Gas Design

The Navy analyzed several design iterations considering the endurance, efficiency, and feasibility of combining gas turbines and electric motors with the existent reduction gears (Dalton et al., 2008). The Navy eventually decided to construct LHD 8 using an LM2500+ engine rated at 35,000 bhp with a variable speed electric motor rated at 5,000 bhp for each shaft. The two were coupled with the existing reduction gears after modifying the first pinion to accept the electric motor. The propellers were modified from fixed to controllable pitch. Power is generated by five ship service diesel generators and distributed over a 4160V distribution system. The electrical distribution system can provide all the power necessary to operate the two electric motors, also known as auxiliary propulsion motors (APMs), for speeds up to 12 knots. This allows the ship to achieve greater fuel efficiency. Once speeds higher than 12 knots are required, the LM2500+ gas turbine engines (GTEs) are used (Naval Sea Systems Command [NAVSEA], 2016). Figure 2 shows the power train arrangement for LHD 8 and follow-on ships.

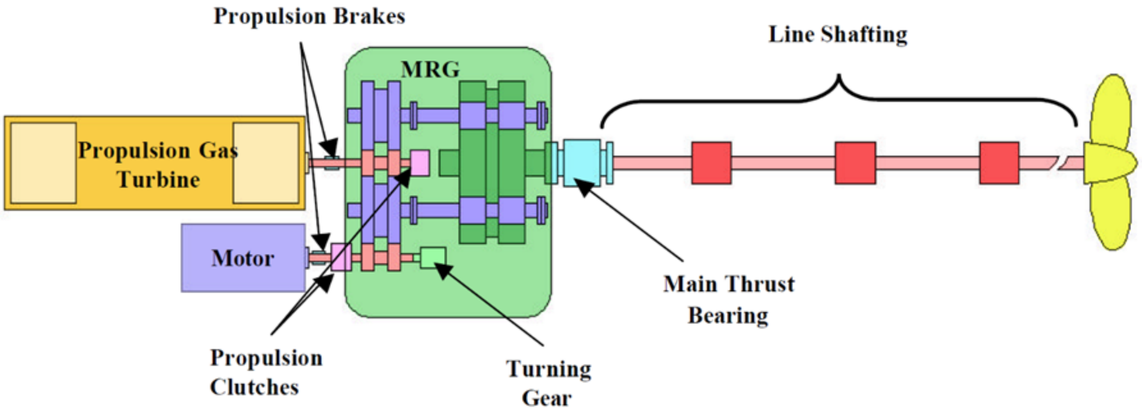

Figure 2. Conceptual Diagram of Shaft Propulsion Power Train Arrangement for LHD 8. Source: Dalton et al. (2008).

Propulsion may be provided by either GTEs or APMs, but not both at the same time (Dalton et al., 2008). The GTEs can drive one shaft at a time, also known as trail-shaft, to a maximum speed of 18 knots. Using both GTEs to drive both shafts simultaneously, also known as full power, renders the maximum speed of 20 knots. The APMs must operate both shafts simultaneously. Every time the ship has to go faster than 12 knots or slow below 12 knots, it must transition from APMs to GTEs or vice versa, a fully automated process.

The Navy successfully implemented the CODLAG design on the USS *Makin Island* (LHD 8), which was commissioned in 2009, and tested it on her maiden deployment in 2012. Although there are no more LHDs being built, *America*-class ships share the same propulsion plant, electrical distribution, and auxiliary systems designed and built for LHD 8. The *America*-class (Flight 0 LHAs) have evolved into small aircraft carriers optimized for aviation operations with no well deck. However, the Flight 1 of the *America*-class will "reincorporate a well deck to enhance expeditionary warfighting capabilities while maintaining the principal aviation characteristics of the Flight 0 via a reduced island" (U.S. Navy, 2019b, p. 5), effectively returning to the LHD 8 design.

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III. LITERATURE REVIEW

The literature review performed to construct this thesis is broken down into distinct categories based on the timeline of LHD conversion literature. First, historical conversion literature is discussed. This literature mainly focuses on the *feasibility* of conversion vice the *cost-estimation*. Second, cost-savings literature and data sources are discussed, including fuel consumption and performance data from steam propulsion LHDs as well as LHD 8. Finally, current considerations for LHD conversion are discussed, namely, the study being performed by OPNAV N95 (2019).

A. HISTORICAL CONVERSION FEASIBILITY AND COST SAVINGS

Converting steam-powered LHD hulls to hybrid propulsion is not a new discussion topic for the U.S. Navy. The primary study that analyzed the feasibility of installing gas turbine propulsion and all-electric auxiliaries into the current LHD hull form, Work Task Assignment (WTA) 17, did not discuss the impacts to out-of-plant spaces, nor did it altogether remove the need for steam on the ship (Gingras et al., 1998). WTA 17.1, the follow-on study to WTA 17, addressed the need for total steam removal as well as the conversion to all-electric auxiliaries (Gingras et al., 1998).

In September 1998, a study titled *Gas Turbine Propulsion Installation LHD 7* (WTA 2204–024) was performed to explore, in a high level of fidelity, the viability of installing and converting LHD 7 to hybrid propulsion and all-electric auxiliaries during initial ship construction (Gingras et al., 1998). This study researched similar equipment and designs that were eventually utilized in the USS *Makin Island* (LHD 8); however, the conversion was not performed for LHD 7. For this thesis, the *Gas Turbine Propulsion Installation* study is referenced as the primary research proving conversion feasibility as well as the basis for choosing the four cost-savings elements, which are discussed later in more detail.

Gas Turbine Propulsion Installation (Gingras et al., 1998) accomplished many new milestones during its conversion review. Firstly, the study extensively examined all of the systems required to be installed or modified, including the engineering plant (gas turbines with required ducting systems and machinery room arrangements), electric plant (diesel generators and 450V alternatives), machinery control systems, and auxiliary systems to support plant operation (notably seawater, freshwater, and lube oil). The study also identified the resulting impacts, if any, and discussed what would be required to facilitate a conversion. This thesis utilized those requirements to ensure that plant conversion would be feasible.

Secondly, *Gas Turbine Propulsion Installation* (Gingras et al., 1998) identified the major cost-savings elements this thesis ultimately employs for further analysis. Manpower savings were estimated to be $214 million in FY 1998 due to a reduction of 88 sailors, while endurance calculations noted a reduction in fuel consumption for gas turbines in a wide range of ship operations (Gingras et al., 1998). In addition to *Gas Turbine Propulsion Installation*, this thesis also identified in-port utility consumption as a potential cost-savings factor, which was not identified in the study. In-port utilities are now possible to investigate due to LHD 8 producing useable data for over ten years, which was not possible during the period in which *Gas Turbine Propulsion Installation* was being written. In addition to *Gas Turbine Propulsion Installation*, a 2001 study titled *LHD-8 Conversion Manpower Impact Analysis* reviewed *Gas Turbine Propulsion Installation* and determined that it "correctly estimated the manpower reduction achievable from the conversion" (NAVSEA, 2001, p. 9).

Hatcher et al. (2002) presented a conference paper titled *U.S. Navy Large Deck Amphibious Assault Ship: Steam to Gas Turbine Conversion.* This paper, using data provided from *Gas Turbine Propulsion Installation* as well as newly provided information, determined that converting the LHD hull to gas turbine propulsion would "greatly reduce crew size and operating costs" (Hatcher et al., 2002, p. 10). This study also discussed propulsion plant design history, potential issues faced with conversion, and references the designs that are utilized in LHD 8, including the first-ever application of the LM2500+ gas turbine engine in a U.S. Navy ship.

To improve the understanding of the cost-savings elements identified by this thesis for LHD 8, a 2012 LHD 8 maiden deployment report titled *USS Makin Island: Transforming the Fleet* (USS *Makin Island* [LHD 8], 2012) was analyzed to review previously generated, empirically determined data. This report detailed a hybrid propulsion overview, which showed a $15 million FY 2012 fuel cost savings of LHD 8 compared to LHD 4 during the six-month deployment. The report also noted that the manning "does not meet maintenance demand" (USS *Makin Island* [LHD 8], 2012, p. 6) for LHD 8, which may help explain future manning increases, and thus a reduction in cost savings for manpower in follow-on years. Furthermore, this report was also able to compare the predicted fuel economy against real-life fuel economy for both gas turbines as well as the electric drive motor. The result was improved performance over what was initially estimated.

Although not a U.S. Navy ship conversion, the U.S. Air Force has been conducting studies on replacing its B-52 fleet with a new, upgraded engine since 1996 (Office of the Under Secretary of Defense For Acquisition, Technology and Logistics [OUSD(AT&L)], 2004). The first three studies conducted found that re-engining was not economically feasible, namely, due to using a constant fuel price determined solely by the DLA energy price. Newer studies, however, have determined that not considering the associated costs in addition to DLA standard fuel prices, which are considered to be burdened costs of delivery, results in an underestimation of the economic value of re-engining, and these studies are now recommending the Air Force proceed in conversion without delay. Thus, this thesis has reviewed and determined that the cost of delivering fuel to ships is integral, in addition to the DLA standard energy price, which must be determined and considered in an analysis. Further discussion on fully burdened cost is found in Chapter III.

B. COST-SAVINGS DATA COLLECTION

After identifying the four cost-savings elements, this thesis performed data collection by researching numerous DOD cost databases, including the Naval Center for Cost Analysis (NCCA), Defense Cost and Research Center (DCARC), and operation and support databases including the Navy Visibility and Management of Operating and Support Costs (VAMOSC). For fuel cost savings, this thesis utilizes VAMOSC as the source for all fuel consumption data. Boardman, Greenberg, Vining, & Weimer (2010) is utilized as the source for constructing the CBA. For manpower savings, VAMOSC is utilized for historical data, while the Ship Manpower Document (SMD) for LHD 1–7 and LHD 8 were applied to calculate theoretical cost savings using the DOD composite pay rates. In-port cost savings were collected via the Naval Facilities Engineering Command (NAVFAC). All the data is calculated in or converted to FY 2019 dollars. Future cost-savings data is then adjusted for inflation (manpower and in-port utilities) or modeled for changes in cost (fuel). The methodology section discusses each one of these cost-savings elements in intricate detail.

C. CURRENT CONSIDERATIONS FOR LHD CONVERSION

In order to analyze current considerations in the feasibility and cost of LHD conversion, this thesis reviewed reports on the current state of LHD conversion, the current state of U.S. Navy shipbuilding, as well as the current state of technology (Dalton et al., 2008; Forecast International, 2019; Naval Power and Energy Systems [NPES], 2019; OPNAV N95, 2019). This thesis utilizes the OPNAV N953 (2018) complex overhaul (COH) report discussed in Chapter I to establish a timeline of potential conversion. The purpose of using this report is to identify the potential dates available for conversion, as well as what systems the COH is upgrading, and thus the number of potential cost savings possible. The preliminary reports have stated that various components of the steam propulsion, namely main propulsion boilers, the main feed system, and ship service turbine generators, will require an overhaul, and therefore would be identified as cost-savings elements if conversion is approved (since they are subsequently removed). The current FY 2019 estimated overhaul cost of the significant steam system overhauls mentioned previously is $27 million.

The primary study that is used to determine the cost factors is the OPNAV N95 (2019) propulsion study titled *Propulsion Options Study For LHD 1 Class Ships*. Although this report has not yet been published, this thesis analyzes the following preliminary findings:

1. Conversion cost estimates
2. Study assumptions and approach
3. Conversion impacts on weight and stability
4. Risks associated with conversion

This thesis compares the ROM findings from Phase I of this study to conduct the CBA. Further discussion on CBA is found in Chapter IV.

A 2019 Congressional Budget Office (CBO) report titled *An Analysis of the Navy's Fiscal Year 2019 Shipbuilding Plan* was utilized to better understand the requirements of maintaining LHD-class ships for an extended lifetime and the current state of the LHA (LHD replacement), and thus provide a reason to (i.e., have standing to) convert. The CBO report concluded:

> Under the 2019 plan, a seven-year gap separates that ship and the next one, slated to be purchased in 2024, which in CBO's estimation would effectively eliminate any manufacturing learning gleaned from building the first 3 ships of the class. As a result, CBO's estimate is higher than the Navy's, at $3.9 billion per ship. (CBO, 2019, p. 26).

Due to the expected cost increase reported by the CBO, this thesis determined that if conversion costs are outweighed by the benefits (cost savings), the Navy should give standing in the process of conversion. Namely, the conversion may, in the long-term, reduce the lifetime costs of the LHD class, which may result in the ability to transfer the cost savings onto future programs such as LHA construction.

In addition to analyzing if LHD conversion has standing and how the conversion can be coordinated with the COH timeline, this thesis also analyzed the 2019 Naval Power and Energy Systems (NPES) report titled *Naval Power and Energy Systems Technology Development Roadmap: The Navy Power & Energy Leap Forward.* This report provides another reason why conversion may have standing: improving legacy power systems with next-generation systems capable of utilizing "directed energy weapons such as lasers and stochastic electronic warfare systems radiated energy systems such as the Air and Missile Defense Radar, and advances in kinetic energy weapons, including electro-magnetic railguns" (NPES, 2019, p. 5). Steam-powered LHDs still rely on legacy 450V systems, which are limited in capability when comparing newer systems such as the 4160V electric plant on LHD 8. As a result, this thesis determined that by converting to hybrid propulsion, and as a result upgrading the electric plants on converted ships, there may be notable national defense benefits found in the application of the advanced energy systems discussed (NPES, 2019).

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IV. METHODOLOGY

Chapter IV discusses how the thesis develops the CBA, as well as how the data is processed and analyzed. The outline section is utilized as a faster reference due to the length of the data analysis section. Additionally, the methodology dives further into a literature review of the data sources, discussing how each of the cost-savings elements was obtained and analyzed. Finally, this section discusses the limitations this thesis had on the data analysis.

A. COST-BENEFIT ANALYSIS

A cost-benefit analysis (CBA) is a helpful tool for decision-makers in any profession. Boardman et al. (2010) state that "the broad purpose of CBA is to help social decision making and to make it more rational. More specifically, the objective is to have a more efficient allocation of society's resources" (p. 2).

The two principal types of CBAs are *ex-ante* and *ex-post,* where *ex-ante* analysis (the standard CBA) analyzes a project that is under consideration, and an *ex-post* analysis analyzes a project at completion. For this thesis, all CBA discussion is completed utilizing an *ex-ante* CBA approach.

The benefit a CBA provides to a government program, such as LHD ship conversion, is that it allows for the analysis of benefits from competing alternatives where a policy decision must be made. This thesis utilizes the standard for performing CBA on government programs, Circular A-94, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*, produced by the Office of Management and Budget (OMB, 1992). Circular A-94 states that "The goal of this Circular is to promote efficient resource allocation through well-informed decision-making by the Federal Government. It provides general guidance for conducting benefit-cost and cost-effectiveness analyses" (OMB, 1992, pp. 2–3).

This thesis addresses the nine steps of a CBA by over-valuing costs while under-valuing benefits to develop a conservative net present value (NPV) estimate. The results of the CBA can be directly employed by policymakers to make decisions on whether or not to convert LHDs.

1. Steps of a Cost-Benefit Analysis

In order to lay the foundation of a CBA, the nine steps are briefly explained per Boardman et al. (2010). Some steps also relate the LHD conversion to the discussion Boardman et al. introduce, while other steps are more general due to further discussion in the following chapters.

a. Specify the Set of Alternative Projects

In order to complete step one, all alternative projects must be identified. This thesis is only concerned with the cost-benefits of conversion to one specific propulsion plant, CODLAG, as compared to maintaining the status quo (steam propulsion).

b. Decide Whose Benefits and Costs Count (Standing)

Step two analyzes whose costs and benefits from the project are most important or relevant. This thesis has identified that standing involves the relationship between the taxpayers and the government that will be completing the conversion. The taxpayers have standing due to the potential monetary gain from conversion. The government has standing due to having control of the ships, as well as gaining from conversion benefits (such as improved fuel efficiency) as well as the cost of having to budget the money.

c. Identify the Impact Categories, Catalog Them, and Select Measurement Indicators

Step three identifies the impacts or inputs and outputs that the project contains. The benefit impact categories for LHD conversion are mainly found in the cost savings of conversion. These impacts, which were identified in Chapter I, are fuel savings, manpower savings, and in-port utility savings. Additionally, there are inherent benefits that are related, or directly derived from, the main benefit impact categories, such as longer time on station before refueling, less frequent evolutions involving refueling, an updated and more efficient propulsion system that should require fewer maintenance hours and parts, and reduced emissions from converted ships.

The cost impact categories for LHD conversion are conversion costs (the most extensive cost and one that is required upfront), research and development costs of conversion (OPNAV N95, 2019), time spent converting ships (which may impact the time the ship could be on mission), and unknown factors that will arise after converting a steam propulsion ship to a hybrid system for the first time in U.S. Navy history.

d. Predict the Impacts Quantitatively Over the Life of the Project

The purpose of step four is to have the analyst develop a strategy that best estimates the long-term costs of the project. In the case of LHD conversion, benefits over ship life will have to outweigh the upfront conversion cost for the project to be beneficial. This means that any converted LHD will have to have enough active service time following conversion to ensure the appropriate amount of benefits are received. This thesis uses both the current estimated time that conversion may happen as well as the cost savings per year, which can be discounted to present value (PV) to determine project viability.

e. Monetize (Attach Dollar Values to) All Impacts

In order to understand the relationship between cost and benefit in the CBA, each of the impact categories must be monetized (given a value in dollars) for comparison. This thesis can monetize the main benefit categories of fuel, manpower, and in-port utility consumption savings; however, it is unable to monetize derivative benefits such as national defense and maintenance savings associated with conversion. Additionally, the cost of conversion is monetized through the OPNAV N95 study.

f. Discount Benefits and Costs to Obtain Present Values

The purpose of step six is to "aggregate the benefits and costs that arise in different years" (Boardman et al., 2010, p. 12). This is done by discounting the future benefits and costs to PV, allowing for a better understanding of the opportunity costs involved in performing the project. Present value is determined by calculating the benefits and costs, where t is the time the benefit or cost is inherited, and s is the social discount rate for the project (Boardman et al., 2010).

$$PV(B) = \sum_{t=0}^{n} \frac{B_t}{(1+s)^t}$$

$$PV(C) = \sum_{t=0}^{n} \frac{C_t}{(1+s)^t}$$

Social discount rates (SDR) should be chosen such that they are appropriate for the project. For government programs, the social discount rate is derived from OMB Circular A-94 (1992) for internal government investment. This thesis uses the nominal 30-year SDR of 3.6% found in OMB Circular A-94 Appendix C (2018) because the cost and benefits discussed are solely borne by the government. Additionally, this thesis uses SDR based on current nominal treasury rates to perform sensitivity analysis.

g. Compute the Net Present Value of Each Alternative

The NPV is the difference between the PV of the benefits and the PV of the costs. A project is typically only considered when the PV of the benefits is larger than the PV of the costs for projects like LHD conversion since it is a single alternative project (convert or maintain status quo). Therefore, LHD conversion should only occur if the NPV is positive.

h. Perform Sensitivity Analysis

Due to the uncertainty in calculating long-term benefits, especially in a project such as LHD conversion, where fuel prices behave unpredictably, sensitivity analysis aims to address these uncertainties. This thesis performs a full sensitivity analysis in Chapter V. In addition to NPV as the CBA decision rule, this thesis utilizes inflation-adjusted costs and benefits, along with nominal interest rates in order to produce final, consistently quantified numbers. Inflation-adjusted impacts were determined to be a more conservative estimation due to each ship being converted throughout a long time span, with funding not occurring until close to the conversion date.

i. Make a Recommendation

All CBAs require analysts to determine the NPV of a project, then make their recommendation whether the project should go forward. For this thesis, LHD conversion is only recommended if there is a positive NPV. This requires that the full cost of conversion be known, along with the cost of performing the research and development study. Once this data is available, the information provided by this thesis can be used to finalize the PV of costs and determine the NPV.

B. GENERAL APPROACH IN IDENTIFYING COST-SAVINGS ELEMENTS

Chapter I, Section I.C, identified the four main cost-savings elements this thesis is investigating. The procedure developed to quantify these factors utilized various sources of data as well as measurement techniques that were considered best suited to each specific cost-savings factor. This procedure was developed as follows:

1. Identify the primary cost-savings factors that will be seen directly following the conversion of steam-powered LHDs
    - Literature review
    - On-site ship tours on both steam-powered LHDs as well as LHD 8
    - Ships Manpower Document (SMD)
2. Select the most feasible naval stations for analysis
3. Collect data applicable to the previously identified cost-savings factors and provide observations and recommendations from analysis
4. Collect underway and in-port steaming fuel economy data and analyze
    - Utilize Visibility and Management of Operating and Support Costs (VAMOSC) database for historical cost
    - Identify the best approach for normalizing data
    - Analyze relevant time segments for both propulsion types
    - Develop a method to predict future cost
    - Report the cost savings as both yearly savings from FY 2019 through 2050 as well as cost savings for specific hull lifetime
5. Collect pier-side utility consumption data and analyze
    - Utilize Naval Facilities Engineering Command (NAVFAC) databases at both San Diego and Norfolk for historical cost
    - Identify the best approach for normalizing data
    - Analyze all data collected and predict future cost by utilizing the Naval Center for Cost Analysis (NCCA) Joint Inflation Calculator (JIC) Operations and Maintenance (O&M) for purchases' inflation rate
    - Report the cost savings as both yearly savings from FY 2019 through 2050 as well as cost savings for specific hull lifetime

6. Collect manpower data and analyze

- Utilize SMD for LHD 1–7 as well as LHD-8 for the class cost
- Utilize VAMOSC database for historical cost
- Identify the best approach for normalizing data
- Analyze data and predict future cost by utilizing the NCCA JIC Military Pay only (OSD Cost Escalation Element)
- Report the cost-savings as both yearly savings from FY 2019 through 2050 as well as cost savings for specific hull lifetime

C. DATA ANALYSIS

The purpose of the data analysis section is to provide the basis for how each of the cost-savings elements was calculated. Analysis of the data is provided in follow-on chapters. Data received from the Navy's VAMOSC database was interpreted with the help of the VAMOSC user manual for ships, version 18.2 (U.S. Navy, 2019a).

1. Fuel Economy Data

The Navy's VAMOSC system was used to provide historical fuel data for LHD 1–8. LHD 1–7 utilized a 20-year (1999–2018) period in order to establish a class baseline, whereas LHD 8 utilized all available data since commissioning (2010–2017). Due to being in-port for all of 2018, no fuel economy data was generated for LHD 8 during that time. The data was then aggregated into tables by year, which is displayed in Appendix D.

VAMOSC receives its fuel data from the Standard Accounting and Reporting System, which comes from both the Defense Finance and Accounting Service as well as the Navy Energy Usage Reporting System (NEURS). These systems are reported via the Fleet Commander monthly. Steaming hours are reported to VAMOSC via NEURS and are broken down into the sub-elements of steaming underway, steaming not underway, and cold iron. Underway fuel consumption is defined as diesel fuel marine (DFM) consumed while underway for propulsion and regular ship service, while not underway is defined as DFM consumed while not underway for propulsion and regular ship service (U.S. Navy, 2019a). Not underway for propulsion is also called auxiliary steaming, or "aux steaming." For consistency, the term "not underway" is used throughout the remainder of this thesis.

Fuel consumption was calculated via the method described in the VAMOSC user manual (U.S. Navy, 2019a), which involves dividing fuel consumption in barrels (BBL) by the number of hours underway and not underway.

$$\text{Fuel Economy}\left(\frac{\text{BBL}}{\text{hr}}\right) = \frac{\text{Number Barrels Consumed}}{\text{Hours of Operation}}$$

This was done for both underway as well as not underway consumption during each year of LHD 1–8 operation and is included in Appendix D with the aggregated yearly data discussed previously. The purpose of this calculation method is to normalize the differences between ship schedules throughout the year of operation. If only yearly BBL consumption were considered, there would be an inherent deviation from the average due to ship schedule differences. Finally, each year of fuel economy data was averaged per LHD to determine eight ship-specific, lifetime average fuel economies for both underway and not underway operation. In addition to the ship-specific averages, an LHD 1–7 class average was established for fuel calculations when determining fuel usage cost savings of steam-powered LHDs compared to LHD 8. The results of the fuel economy averages are displayed in Figure 3.

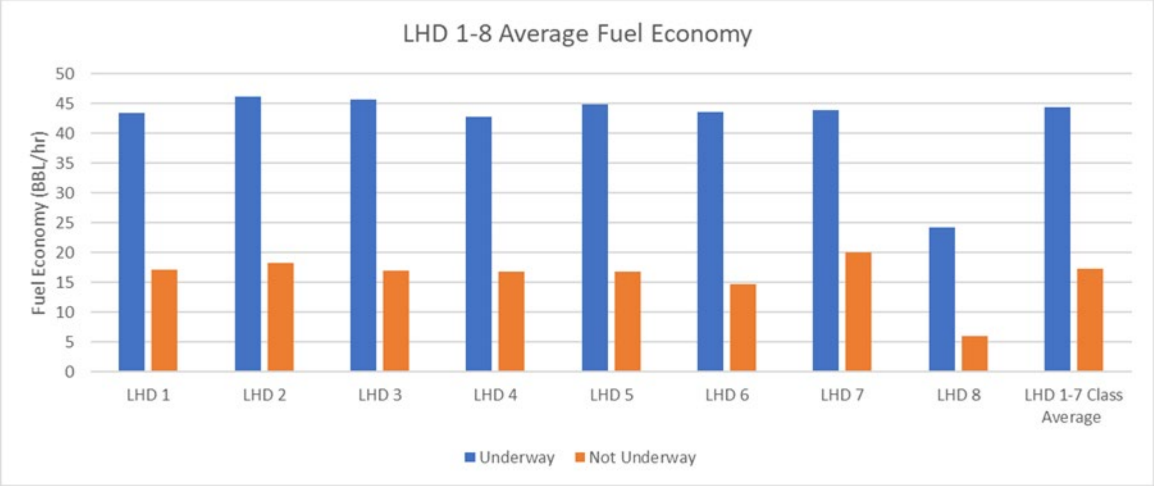


Figure 3. LHD 1–8 Average Fuel Economy Calculations. Adapted from U.S. Navy (2019b).

When analyzing the yearly fuel consumption data, this thesis identified that LHD 1–7 data has a relatively low deviation from the mean for both underway and not underway. During LHD 8 analysis, however, it was noticed that 2014 not underway BBL consumption did not correlate with any previous year, resulting in extremely high fuel consumption. Due to the high uncertainty of the legitimacy of this data point, 2014 was not included in the final average for not underway fuel economy. This was the only data point rejected for establishing class averages.

In order to determine the underway cost savings of LHD 8 as compared to the LHD 1–7 class average, the average amount of fuel consumed (in BBL) per year must be determined. Therefore, fuel consumption ratios must be multiplied by the average hours underway in a year. For LHD 1–7, the class-average hours underway were established using the same method as the class average for fuel economy. First, each ship's yearly underway hours were averaged. Finally, an LHD 1–7 class average was established by averaging the ship specific underway hours. For LHD 8, all available years of underway operation (2010–2017) were averaged to determine average hours underway. These results are displayed in Figure 4.

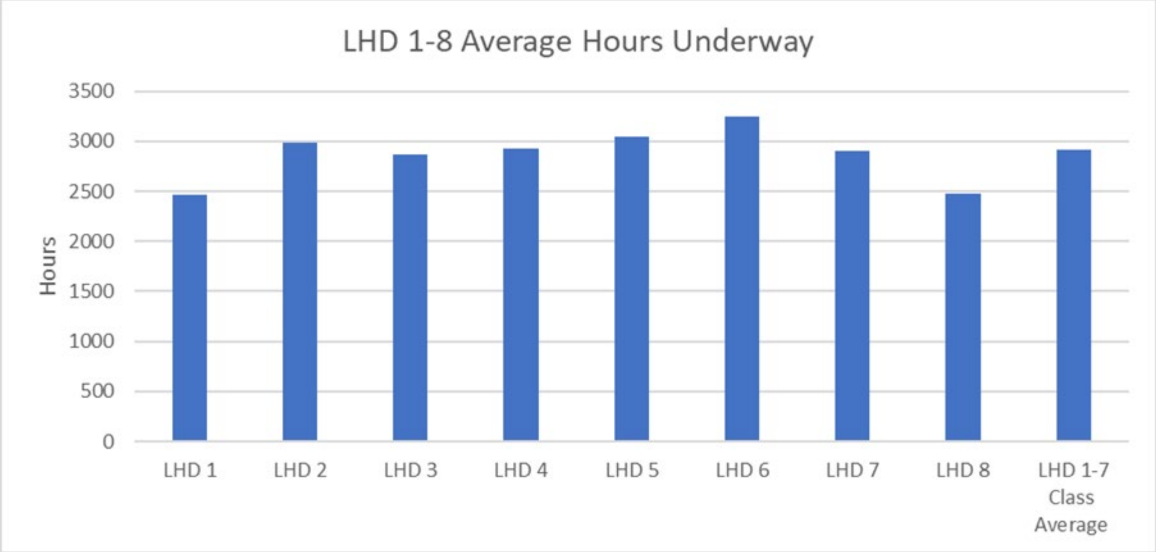


Figure 4. LHD 1–8 Average Hours Underway. Adapted from U.S. Navy (2019b).

The result of the average hours underway calculations shows that LHD 8 has spent, on average, fewer hours underway as compared to the LHD 1–7 class average. This is likely the result of reduced hours of operation (as compared to the class average) following the years directly after commissioning.

The combined LHD 1–7 average hours underway were then multiplied by the fuel economy numbers for LHD 1–7 to determine BBLs consumed in one year. LHD 8 fuel consumption was determined by multiplying average hours underway for LHD 8 by the average fuel economy for LHD 8. Both calculations were performed as shown in the following equation.

$$\text{Barrels Fuel Consumed Underway}\left(\frac{\text{BBL}}{\text{yr}}\right) = \text{Avg Fuel Economy}\left(\frac{\text{BBL}}{\text{hr}}\right) \text{ x Avg Yearly Hours Underway}$$

The result for LHD 8 was subtracted from LHD 1–7 to determine the total average number of BBLs saved in a year of underway LHD operation utilizing LHD 8 CODLAG propulsion.

In order to determine the not underway cost savings of LHD 8 as compared to the LHD 1–7 class average, the same method as underway fuel consumption was employed. LHD 1–7 not underway hours were averaged to establish a class average, while LHD 8 not underway hours were averaged separately. These results are displayed in Figure 5.

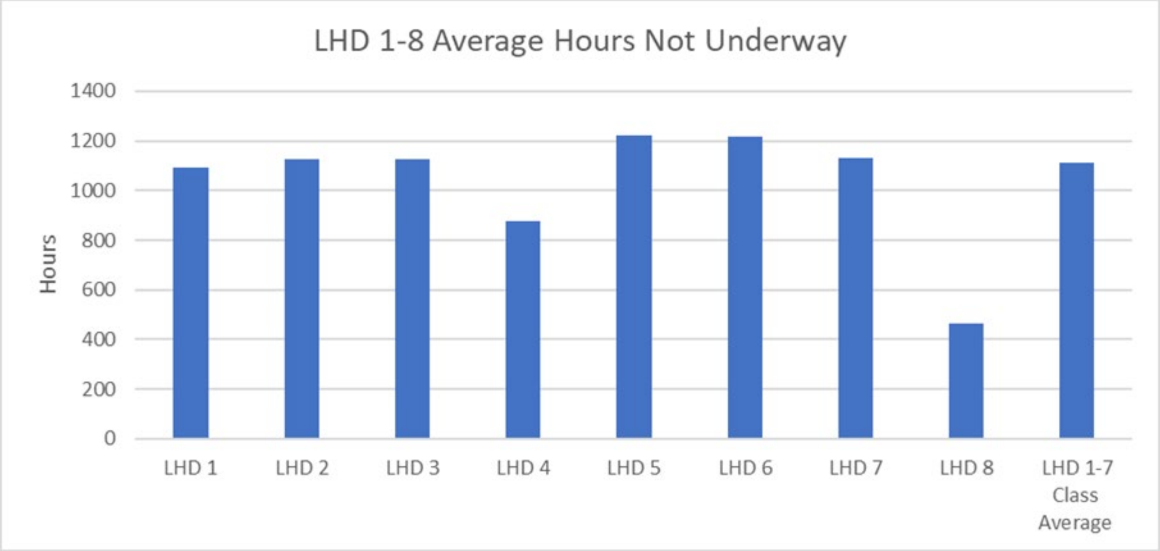


Figure 5. LHD 1–8 Average Hours Not Underway. Adapted from U.S. Navy (2019).

Results from the not underway hours' calculations show LHD 8 spent approximately half of the time in not underway status. This is not due to schedule differences, but rather due to the inherent plant design of LHD 8. Steam plants require long start-up times and are usually lit off one or more days before an underway. LHD 8's CODLAG propulsion system does not require this early light-off time, and thus this result is as expected.

The LHD 1–7 class average, as well as the LHD 8 average, was then multiplied by the fuel economy averages to determine average BBLs consumed in one year not underway, shown in the following equation.

$$\text{Barrels Fuel Consumed Not Underway }\left(\frac{\text{BBL}}{\text{yr}}\right) = \text{Avg Fuel Economy }\left(\frac{\text{BBL}}{\text{hr}}\right) \text{ x Avg Yearly Hours Not Underway}$$

The result for LHD 8 was subtracted from LHD 1–7 to determine the total average number of BBLs saved in a year of not underway LHD operation utilizing LHD 8 CODLAG propulsion.

Once both underway and not underway BBLs saved were determined, the cost savings were calculated for each using the Defense Logistics Agency (DLA) F-76 standard fuel price of $126.00 FY 2019 for petroleum products, effective October 1, 2018 (Norquist, 2018). Due to the high volatility of fuel prices, this thesis determined it impractical to adjust each follow-on year after 2019 by inflation. Therefore, this thesis employs the instruction of the future fuel pricing model introduced in NAVSEA's (2012) Design Data Sheet (DDS) 200–2, *Calculation of Surface Ship Annual Energy Usage, Annual Energy Cost, and Fully Burdened Cost of Energy.* DDS 200–2 provides the use of the Energy Information Administration's (EIA) Annual Energy Outlook (AEO) report, which provides crude oil price predictions for a reference case (expected case), as well as high- and low-price cases. DDS 200–2 provides the following guidelines for future pricing:

> The great volatility of crude oil prices (AEO 2011 shows a 4 to 1 ratio of the long-term high oil price to low oil price projections) suggests that a simple projection of fuel price in the future will not be sufficient to gain the insight needed for many decisions. If better insight is needed, the impact of the variability of crude oil prices can be accounted for in several ways including:
>
> a. Use the current DLA Energy price as a baseline, then show the impact of varying this amount both upwards and downwards to reflect the anticipated volatility
>
> b. Use the AEO to predict future DLA Energy prices for the baseline, high price and low price to reflect the volatility

c. Use the AEO to develop a stochastic model of the DLA Energy price as a function of year. (NAVSEA, 2012, p. 12)

Following DDS 200–2 (NAVSEA, 2012), this thesis utilizes option c, or the DLA price of $126.00 FY 2019, as well as the AEO predictions of crude oil prices for years 2020 through 2050. The model adjusts the DLA standard fuel price by the percent change in crude oil price for both underway and not underway operations to determine the actual cost of fuel per year in FY 2019 dollars. The model output is displayed in Figure 6, starting at the FY 2019 DLA standard energy price of $126.00.

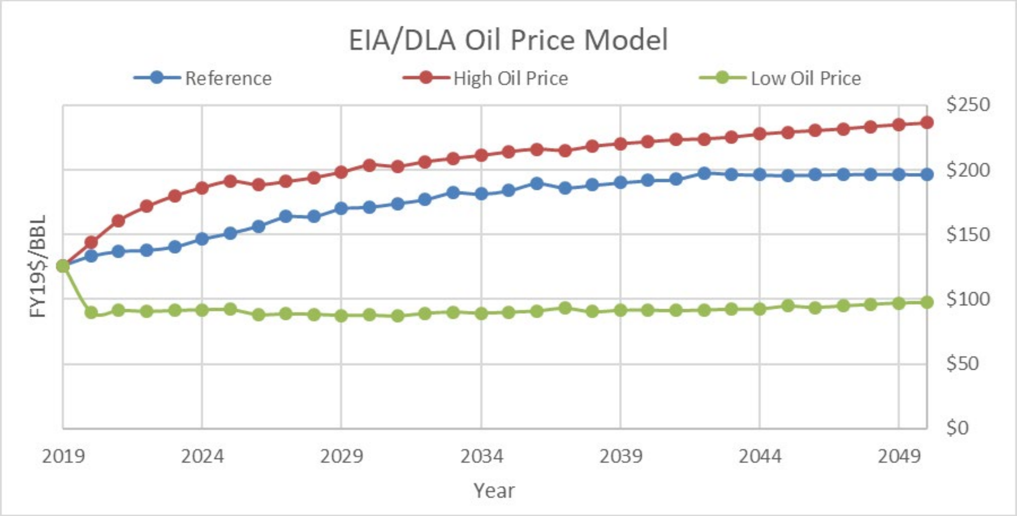


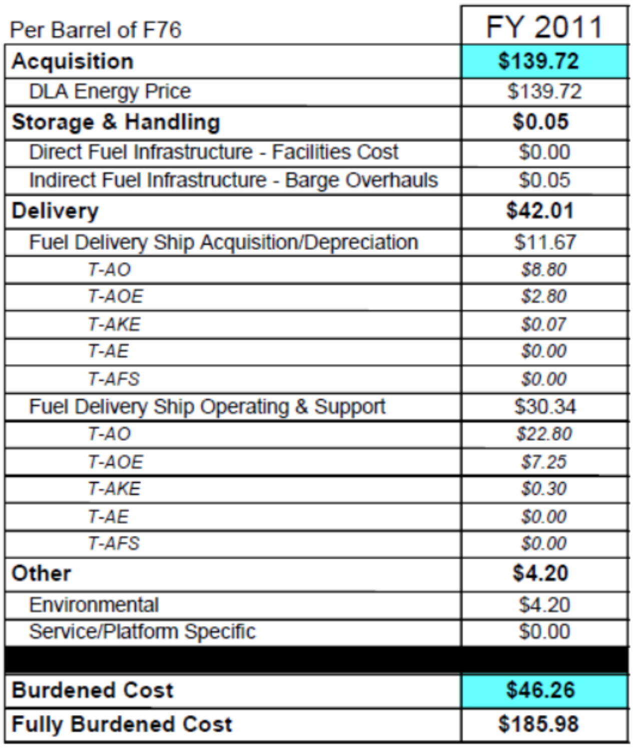
Figure 6. EIA Model to Predict DLA Fuel Price Change from 2020 to 2050. Adapted from EIA (2019).

The DLA standard fuel price, however, does not consider the fuel burden cost associated with delivering the fuel to U.S. Navy ships. The fuel burden cost referred to as the Fully Burdened Cost of Fuel (FBCF) is a component of the Fully Burdened Cost of Energy (FBCE), a topic introduced in the National Defense Authorization Act (NDAA) for FY 2009. The FBCE consists of both the cost burden of delivering the fuel to ships (FBCF) as well as the fully burdened cost of electricity (shore power). Electricity costs are discussed in Chapter IV, Section C.2.b. The NDAA for FY 2009 defines the FBCF as “the commodity price for fuel plus the total cost of all personnel and assets required to move and, when necessary, protect the fuel from the point at which the fuel is received from the commercial supplier to the point of use.”

Furthermore, the Defense Acquisition University (DAU; 2012) discusses the FBCE implications on defense acquisitions programs within their framework:

> FBCE, is used to inform the acquisition tradespace [*sic*] by quantifying the per gallon price of fuel (or per kilowatt price of electricity) used per day for two or more competing materiel solutions. The FBCE estimate includes apportioned costs of the energy logistics forces needed to deliver and protect the fuel in a scenario. Calculating the FBCE gives DOD decision makers a way to more accurately consider the cost of a system's energy logistics footprint when making trades between cost, schedule, and performance. (p. 1)

In order to determine the FBCE for U.S. Navy ships, this thesis utilizes the FBCF cost-estimation approach introduced in NAVSEA's (2012) Design Data Sheet (DDS) 200–2, *Calculation of Surface Ship Annual Energy Usage, Annual Energy Cost, and Fully Burdened Cost of Energy*. DDS 200–2 considers four primary factors to calculate the FBCF, acquisition costs (DLA energy price), storage and handling costs, delivery costs, and other costs. The FBCF derivation using DLA energy prices from FY 2011 is displayed in Figure 7.



Per Barrel of F76	FY 2011
Acquisition	**$139.72**
DLA Energy Price	$139.72
Storage & Handling	**$0.05**
Direct Fuel Infrastructure - Facilities Cost	$0.00
Indirect Fuel Infrastructure - Barge Overhauls	$0.05
Delivery	**$42.01**
Fuel Delivery Ship Acquisition/Depreciation	$11.67
T-AO	*$8.80*
T-AOE	*$2.80*
T-AKE	*$0.07*
T-AE	*$0.00*
T-AFS	*$0.00*
Fuel Delivery Ship Operating & Support	$30.34
T-AO	*$22.80*
T-AOE	*$7.25*
T-AKE	*$0.30*
T-AE	*$0.00*
T-AFS	*$0.00*
Other	**$4.20**
Environmental	$4.20
Service/Platform Specific	$0.00
Burdened Cost	**$46.26**
Fully Burdened Cost	**$185.98**

Figure 7. NAVSEA Example Calculation of FBCF. Source: NAVSEA (2012).

In order to determine the current FBCF in FY 2019, the burdened cost of $46.26 FY 2011 was adjusted for Operations and Maintenance, Navy (O&MN) inflation via the JIC index, resulting in $52.64 FY 2019. The FY 2019 adjusted burden amount was then added to the DLA standard energy price to total $178.64 FY 2019. For years 2020–2050, the inflation-adjusted burdened cost was added to the DLA modeled price of fuel to determine a yearly FBCF. This process was performed for each fuel case, resulting in a yearly cost savings, corrected by modeled volatility, starting in 2020 and ending in 2050.

The expected decommissioning date for LHD 7, however, is 2051. Therefore, for LHD 7 specifically, one additional year of the model was added by using the same percent change for 2050 as 2051. The EIA does not currently have a model that predicts dates past 2050.

2. In-Port Utility Cost Savings

This thesis focuses on the conversion cost savings for steam and electric consumption during in-port operations. It is assumed that conversion will accompany full-electric auxiliaries' conversion, similar to the engineering design of LHD 8. As a result, in-port electric consumption (and therefore cost) is expected to increase on converted ships to accompany the electric auxiliaries. San Diego and Norfolk were chosen due to these locations being significant fleet concentration areas for LHD-class ships. Currently, LHD 1 and LHD 7 are stationed in Sasebo, Japan, and Mayport, FL, respectively. Due to similar billing rates for electric between Mayport and Norfolk, this thesis did not identify the need to include Mayport separate from Norfolk. Therefore, LHD 7 data is reported under Norfolk results. Additionally, data for LHD 1 was included only before the homeport shift to Japan in 2018.

a. Steam Cost Savings

NAVFAC in San Diego and Norfolk were contacted, and each provided five years (2015–2019) of steam consumption data for all available ships (Raymon Leyeza and Chris Roberts, unpublished data, 2019). The data is metered for each ship and is reported as a monthly amount for each year. Due to differences in consumption, both Norfolk and San Diego were analyzed separately. Each ship had cost savings reported for both locations.

Unlike fuel data, which is recorded and billed through the same provider (see the previous section for details), steam utilities cannot be adjusted by simply dividing by the cold iron hours due to different billing locations (shipyard versus naval base). Therefore, to normalize the available data, this thesis averaged the monthly steam consumption (in MBTU) for both Norfolk and San Diego for each month of the reported FY for each of the five years of data. Ships that did not consume any steam in a month were not included in the average. The monthly average totals were then summed to produce a yearly, class-averaged steam consumption number for both Norfolk and San Diego.

Since each ship, on average throughout its lifetime, spends some amount of time in port and at sea, this thesis calculated the average hours cold iron each year (1999–2018) for LHD 1–7 using the same method that was employed for fuel consumption data. LHD 8 cold iron hours are not required for steam data due to all-electric auxiliaries but are still included in the data for electrical analysis. The results are displayed in Figure 8.

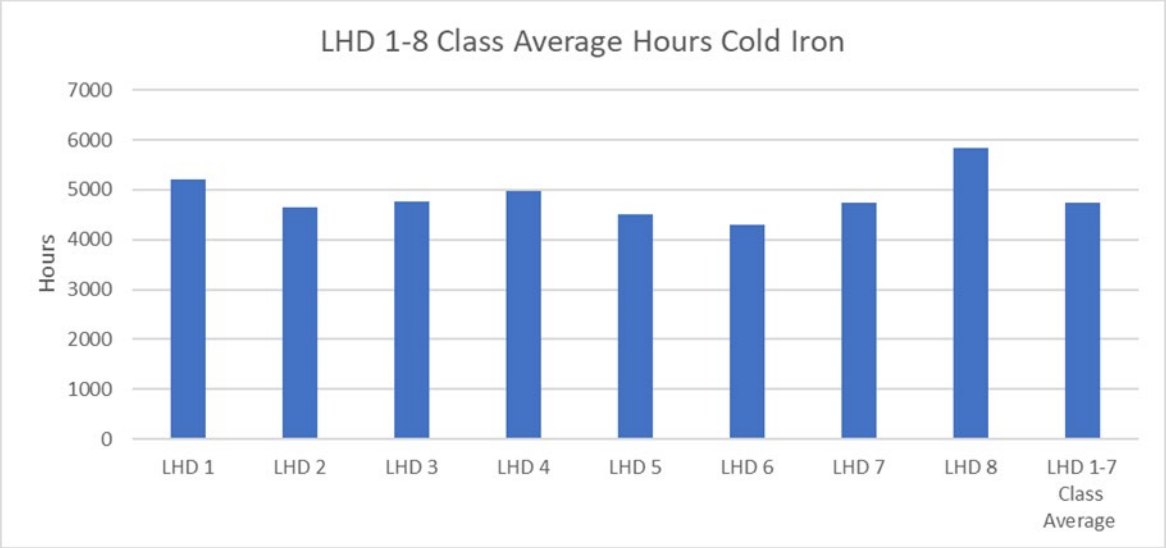


Figure 8. Average LHD In-port Hours. Adapted from U.S. Navy (2019b).

This was necessary to determine how many BTU, based on average time spent cold iron, an LHD uses in a year. Average steam consumption in MBTU was calculated by the following equation:

$$\text{Yearly Steam Usage}\left(\frac{\text{MBTU}}{\text{Year}}\right) = \left(\frac{\text{Class-Average Hours Cold Iron}}{\text{Year}}\right) \text{x} \left(\frac{\text{Average MBTU}}{\text{Year}}\right) \text{x} \left(\frac{\text{Year}}{\text{8766 Hrs}}\right)$$

Finally, average yearly steam consumption in MBTU was converted to a FY 2019 dollar amount by multiplying consumption by the service billing rate in Norfolk and San Diego. Analysis of steam consumption data is discussed in Chapter V. One notable difference for steam utilities is the cost of the steam for San Diego and Norfolk. The FY 2019 steam billing rate in San Diego is $297.82/MBTU, while the steam production price in Norfolk is $31.90/MBTU.

b. Electric Cost Savings

The Commander, Naval Surface Force, U.S. Pacific Fleet (COMNAVSURFPAC), as well as the Commander, Naval Surface Force, Atlantic (COMNAVSURFLANT), Fleet Energy Managers (FEM), were contacted and provided five years (2015–2019) of electric consumption for all available ships. The data is metered for each ship and is reported as a daily usage rate in kilowatt-hours (kWh) per month for each FY. Similar to the steam data, differences in electrical usage required Norfolk and San Diego to be reported separately. As a result, each ship has cost reported at both locations. NAVFAC in San Diego meters ships based on eight different service types: peak consumption surcharge, base consumption, semi-peak consumption surcharge, and non-coincident demand charge (this is done in winter and summer, resulting in a total of eight categories). NAVFAC in Norfolk reported data as one service charge per ship.

The FBCE component for electric usage (shore power) was determined solely by the energy price derived from NAVFAC. NAVSEA (2012) Design Data Sheet (DDS) 200–2, *Calculation of Surface Ship Annual Energy Usage, Annual Energy Cost, and Fully Burdened Cost of Energy,* states that "The major element of the fully burdened cost of shore power is the commodity price for electricity. The Naval Facilities Engineering Command (NAVFAC) tracks the usage and cost of electricity by naval facilities" (NAVSEA, 2012, p. 18).

Therefore, the burdened cost of delivering electricity through the Navy-owned electrical infrastructure was determined by DDS 200–2 (NAVSEA, 2012) to be negligible and therefore is not included in this thesis.

In order to compare the two different locations, this thesis calculates the average daily usage rate for both LHD 1–7–class ships and LHD 8 in San Diego, as well as LHD 1–7-class ships in Norfolk. Norfolk has never had an all-electric auxiliaries LHD- or LHA-class ship. Therefore, the cost increase, determined by the difference in LHD 1–7 and LHD 8 electrical consumption in San Diego, is applied in the same proportion in Norfolk. The daily usage rate for each location (in kWh/day) was then converted to a yearly energy usage rate in MWh by the following equation.

$$\text{Average Electric Usage}\left(\frac{\text{MWh}}{\text{Year}}\right) = \text{Average Consumption}\left(\frac{\text{kWh}}{\text{Day}}\right) \text{ x } \left(\frac{\text{365 Day}}{\text{Year}}\right) \text{ x } \left(\frac{\text{MWh}}{\text{1000 kWh}}\right)$$

The average electric average yearly cost was then determined by the following equation.

$$\text{Avg Electric Cost}\left(\frac{\$}{\text{Year}}\right) = \text{Avg Consumption}\left(\frac{\text{MWh}}{\text{Year}}\right) \text{ x } \left(\frac{\text{Avg Hours Cold Iron}}{\text{Year}}\right) \text{ x } \left(\frac{\text{Year}}{\text{8766 Hours}}\right) \text{ x Utility Rate}\left(\frac{\$}{\text{MWh}}\right)$$

The average hours cold iron is the same for steam and electric, as seen in Figure 8. To allow for a direct comparison of San Diego to Norfolk, only the base consumption rate for San Diego was used in the equation to calculate the average electric cost. In order to determine the cost of electric conversion for each location, the cost of LHD 1–7 was subtracted from the cost of LHD 8 (LHD 8 has a higher usage), resulting in a net cost increase for conversion. Analysis of electric consumption data is discussed in Chapter V.

3. Manpower Data

Two separate methods were employed to determine manpower savings: historical analysis utilizing the VAMOSC database (U.S. Navy, 2019a), as well as reviewing the Ship Manpower Document (SMD) for both ship types. The two approaches were employed to better understand the actual (historical) cost savings of LHD 8 as compared to what the Navy has determined manpower should cost, based on the SMD differences in LHD 1–7 and LHD 8. The goal is to establish a range of all potential cost- savings in manpower for future sensitivity analysis. The early historical cost data (2010–2014) has been hypothesized to be inconsistent because LHD 8 was the first-in-class ship, and likely had a more extensive range in manning during the first years following commissioning.

a. Historical Manpower Cost Savings

Historical analysis from VAMOSC (U.S. Navy, 2019a) was only possible using San Diego manpower costs since all similar CODLAG propulsion ships (LHD 8 and LHA 6 and 7) have remained homeported in San Diego since commissioning. Additionally, due to homeport shifts of steam-powered LHD 2 and 6 to Sasebo, Japan, data for LHD 2 is analyzed between 2013 to 2018, while data from LHD 6 is analyzed between 2010 to 2011. Data from the year 2012 is not included for LHD 2 or 6 due to the homeport shift. This thesis uses the cost savings between the steam-powered ships and LHD 8 due to the reduction in manpower. Therefore, the cost savings is the same when comparing the cost of a converted ship to a steamship in the same location (the identical SMD changes are shared regardless of ship homeport), even though the total cost to man an LHD is higher in San Diego as compared to Norfolk due to basic allowance for housing (BAH), permanent change of station (PCS), and other factors.

This thesis utilizes the yearly actual cost (from VAMOSC; U.S. Navy, 2019a) of the personnel that is analogous to the military composite standard pay and reimbursement rate, including basic pay, allowances (housing, sustenance, and other expenses), bonuses, Medicare-eligible retiree health care, retired pay accrual, PCS, and entitlements, adjusted to FY 2019 dollars. In order to relate the total pay to the actual manpower, VAMOSC total personnel numbers (officer and enlisted) were plotted from 2010 to 2018 and are displayed in Figure 9 and Figure 10.

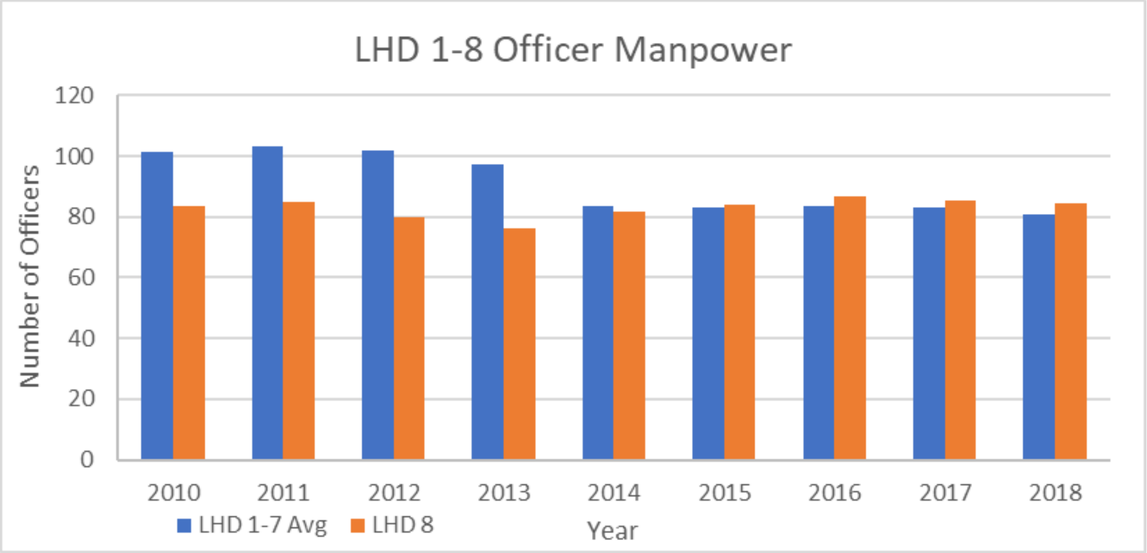


Figure 9. Officer Manning LHD 1–7 and LHD 8. Adapted from U.S. Navy (2019a).

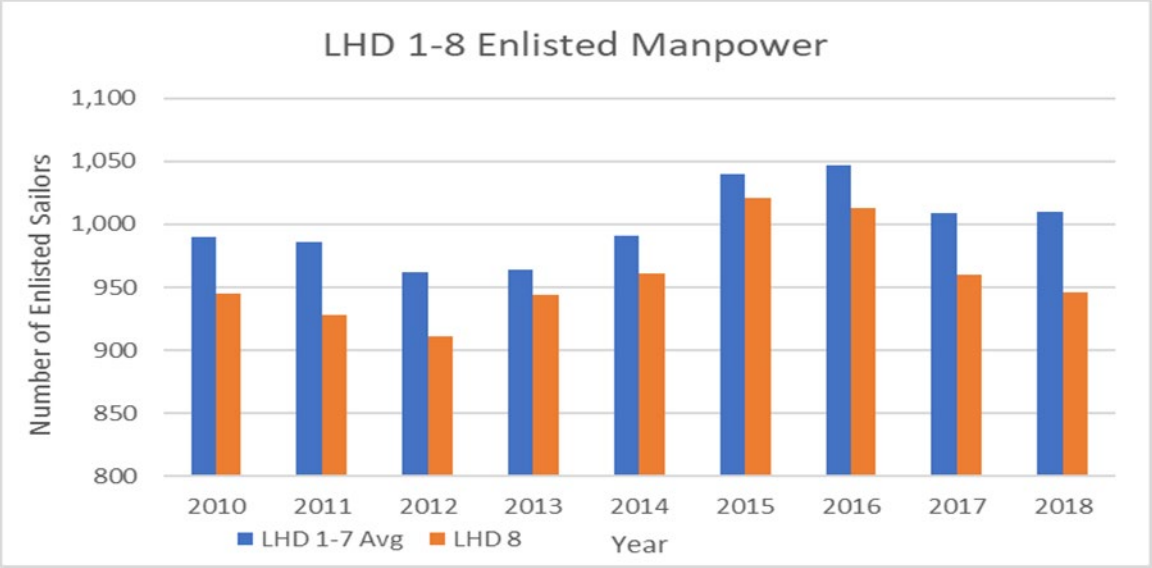
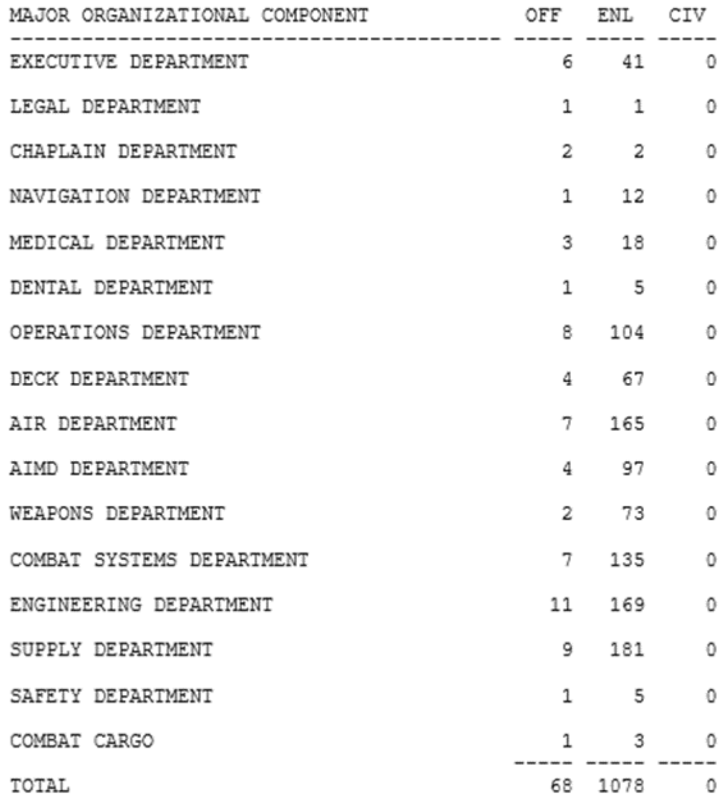


Figure 10. Enlisted Manning LHD 1–7 and LHD 8. Adapted from U.S. Navy (2019a).

These results show that savings in manpower have decreased for LHD 8 in years after commissioning. Historical cost-savings amounts are tabulated and displayed in Chapter V.

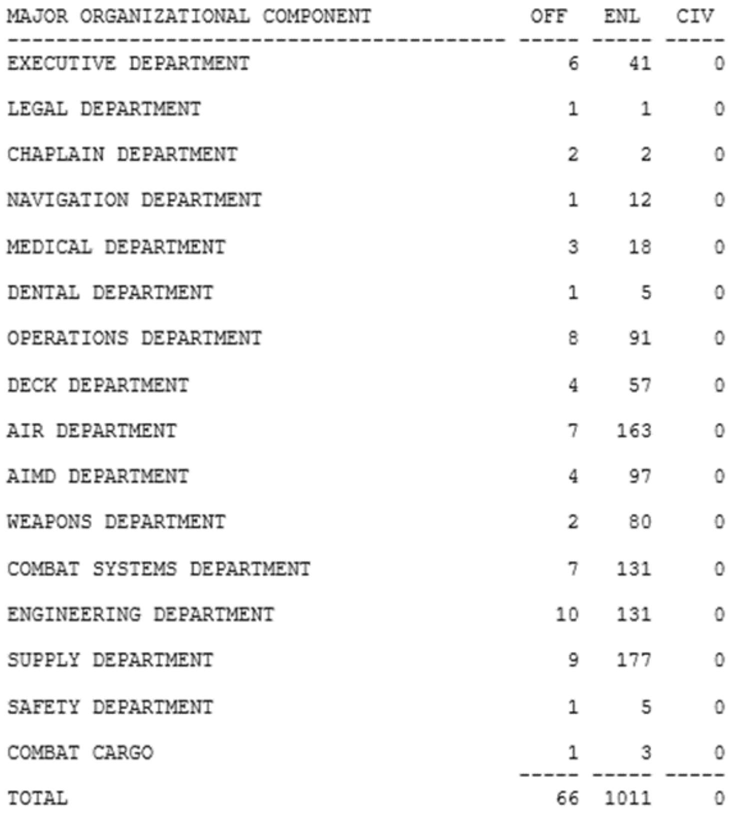
b. Ship Manpower Document Cost Savings

The SMD for both LHD 1–7 and LHD 8 were compared to determine the reduction of total personnel on LHD 8. This thesis assumes that all converted LHDs will use the same SMD as LHD 8. This assumption should be validated following the full cost-estimation study release. Additionally, unlike the historical manpower cost savings, the SMD comparison utilized by this thesis presents the average cost of manpower in the Navy, vice the cost in San Diego alone. Figure 11 and Figure 12 display the current SMD for LHD 1–7 and LHD 8, respectively.



```
MAJOR ORGANIZATIONAL COMPONENT            OFF   ENL   CIV
----------------------------------------- ----- ----- -----
EXECUTIVE DEPARTMENT                          6    41     0

LEGAL DEPARTMENT                              1     1     0

CHAPLAIN DEPARTMENT                           2     2     0

NAVIGATION DEPARTMENT                         1    12     0

MEDICAL DEPARTMENT                            3    18     0

DENTAL DEPARTMENT                             1     5     0

OPERATIONS DEPARTMENT                         8   104     0

DECK DEPARTMENT                               4    67     0

AIR DEPARTMENT                                7   165     0

AIMD DEPARTMENT                               4    97     0

WEAPONS DEPARTMENT                            2    73     0

COMBAT SYSTEMS DEPARTMENT                     7   135     0

ENGINEERING DEPARTMENT                       11   169     0

SUPPLY DEPARTMENT                             9   181     0

SAFETY DEPARTMENT                             1     5     0

COMBAT CARGO                                  1     3     0
                                          ----- ----- -----
TOTAL                                        68  1078     0
```

Figure 11. Ship Manpower Document (SMD) Manpower Summary for LHD 1–7. Source: Navy Manpower Analysis Center (2014).



```
MAJOR ORGANIZATIONAL COMPONENT            OFF   ENL   CIV
----------------------------------------- ----- ----- -----
EXECUTIVE DEPARTMENT                          6    41     0

LEGAL DEPARTMENT                              1     1     0

CHAPLAIN DEPARTMENT                           2     2     0

NAVIGATION DEPARTMENT                         1    12     0

MEDICAL DEPARTMENT                            3    18     0

DENTAL DEPARTMENT                             1     5     0

OPERATIONS DEPARTMENT                         8    91     0

DECK DEPARTMENT                               4    57     0

AIR DEPARTMENT                                7   163     0

AIMD DEPARTMENT                               4    97     0

WEAPONS DEPARTMENT                            2    80     0

COMBAT SYSTEMS DEPARTMENT                     7   131     0

ENGINEERING DEPARTMENT                       10   131     0

SUPPLY DEPARTMENT                             9   177     0

SAFETY DEPARTMENT                             1     5     0

COMBAT CARGO                                  1     3     0
                                          ----- ----- -----
TOTAL                                        66  1011     0
```

Figure 12. Ship Manpower Document (SMD) Manpower Summary for LHD 8. Source: Navy Manpower Analysis Center (2015).

The result of comparing the reduction of manpower between LHD 1–7 and LHD 8 is one officer and 64 enlisted. The total row for LHD 1–7 includes the combat cargo personnel, whereas the total row for LHD 8 does not, accounting for a discrepancy between what this thesis reports (one officer and 64 enlisted) and what the total column reports.

This thesis utilizes the Annual DOD Composite Rate from the FY 2019 Department of Defense (DOD) Military Personnel Composite Standard Pay and Reimbursable Rates memorandum to estimate cost savings for the total number of personnel listed previously. The composite rate includes average basic pay, housing allowance, subsistence allowance, incentive pay, special pay, PCS pay, and miscellaneous pay (Office of the Under Secretary of Defense, 2018). This rate was chosen so that a proper comparison can be drawn between the VAMOSC historical cost savings and the SMD implied cost savings. Additionally, the SMD was compared for each department, and each loss or gain with respect to LHD 8 was recorded by rank.

The ranks were then multiplied by the applicable composite pay rates to determine total cost savings (reduction in manning for LHD 8) in FY 2019 dollars. These cost savings were then adjusted for inflation from the year 2020 to the year 2050 using the JIC inflation rate for military pay only (OSD Cost Escalation Element) to build a database of manpower cost savings. This database is displayed in Appendix D. A discussion of the results is found in Chapter V.

D. LIMITATIONS

One limitation to cost-savings estimation was the calculations for in-port pier utilities, both steam and electric, due to limited daily usage data availability used to determine the class averages for steam and electric usage. Additionally, utility usage is a function of both manning as well as environmental factors. As a result, this thesis considers the utility usage cost estimations as the most volatile assessment and recommends that further study be performed to monitor the energy usage comparisons for LHD-class ships.

A second limitation was the quantity of historical manpower and fuel data for LHD 8, which was only available from VAMOSC (U.S. Navy, 2019a) starting in 2009. This thesis recognizes that the first years of a ship's life cycle are likely not entirely representative of manning or fuel consumption due to testing and other post-commissioning activities. Additionally, LHD 8 was the first hybrid large-deck amphibious ship the U.S. Navy commissioned, which conceivably resulted in more significant manpower numbers than previously observed. Therefore, the potential exists that current manpower savings are less than what has been historically observed by employing the LHD 8 lifetime average, or a reduction in the NPV for conversion. A sensitivity analysis is performed using the last five years of historic VAMSOC data for LHD 8, which may better represent the actual cost savings of the conversion.

A third limitation for this thesis on cost-savings estimation was seen in the monetizing of maintenance on the propulsion systems discussed in Chapter III. While not quantitatively proven by this thesis, it is likely that maintenance costs will be reduced on hybrid-powered LHD ships when compared to the steam propulsion system. These cost savings would likely be found in both the reduction in quantity and cost of repair parts as well as availability costs. Therefore, it is likely that there will be a further increase in cost savings, seen as an increase in the NPV for conversion. Chapter VI discusses future analysis recommendations for monetization.

V. RESULTS

Chapter V of this thesis presents the results of the CBA for converting steam-powered LHD ships. The results are presented in two parts; the first displays the results from the CBA that was performed, while the second shows the results of the sensitivity analysis that was performed using various cost-driving factors. This thesis provides a conservative, rough order of magnitude approach to cost savings by using historic class averages and employing fuel predictions from the EIA. Manpower calculations are performed using historical VAMOSC data (U.S. Navy, 2019a). SMD data was only used as a comparison tool and is therefore not used in any cost-savings calculations due to the inherent differences in actual manning compared to Navy SMD predicted manning.

Additionally, the concurrent OPNAV N95 (2019) conversion study has determined that LHD 1–4 are not currently feasible for conversion due to vessel center of gravity concerns. Because a cost estimate for the modifications to correct these stability issues has not yet been completed, this thesis carries out a CBA on LHD 1–7. As a result of the on-going conversion study, however, this thesis recommends that the required modifications needed to modify LHD 1–4 be added to the cost of conversion once they are determined. If it is determined that LHD 1–4 are not feasible for conversion, the CBA performed on LHD 5–7 remains unaffected.

A. COST-BENEFIT ANALYSIS DETERMINATION

The results for the CBA, performed using a 30-year nominal discount rate of 3.6%, derived from OMB Circular A-94 Appendix C, are displayed in Tables 1–6. The tabulated results are presented separately for Norfolk and San Diego due to the inherent differences in utility billing rates as well as utility consumption at each port location. Additionally, each location has three distinct fuel cases determined by the fuel price model discussed in Chapter IV. The completed data tables from FY 2019 to FY 2051 used to formulate these results are found in Appendix D for future consideration. NPV figures that are greater than zero are highlighted in green, while figures that are within $1 million of having a positive NPV are highlighted in yellow.

Table 1. NPV Calculation for San Diego – Reference Fuel Price

Reference Fuel Case - San Diego			
LHD	PV Benefits	PV Cost	NPV
1	$177,309,809.77	$386,439,183.30	-$209,129,373.53
2	$187,578,385.80	$374,595,010.42	-$187,016,624.62
3	$163,624,129.49	$363,113,855.68	-$199,489,726.19
4	$366,848,418.41	$411,262,858.89	-$44,414,440.49
5	$443,223,459.70	$424,266,418.11	$18,957,041.59
6	$164,740,901.01	$341,196,436.29	-$176,455,535.28
7	$409,764,426.00	$398,657,852.44	$11,106,573.55

Table 2. NPV Calculation for San Diego – High Fuel Price

High Oil Price - San Diego			
LHD	PV Sum Benefits	PV Cost	NPV
1	$193,196,624.57	$386,439,183.30	-$193,242,558.73
2	$203,791,123.50	$374,595,010.42	-$170,803,886.92
3	$177,534,972.52	$363,113,855.68	-$185,578,883.15
4	$400,075,978.73	$411,262,858.89	-$11,186,880.16
5	$485,118,300.28	$424,266,418.11	$60,851,882.17
6	$178,881,142.32	$341,196,436.29	-$162,315,293.96
7	$446,761,653.69	$398,657,852.44	$48,103,801.25

Table 3. NPV Calculation for San Diego – Low Fuel Price

Low Oil Price - San Diego			
LHD	PV Sum Benefits	PV Cost	NPV
1	$138,787,107.89	$386,439,183.30	-$247,652,075.41
2	$146,592,431.39	$374,595,010.42	-$228,002,579.03
3	$127,890,889.48	$363,113,855.68	-$235,222,966.20
4	$288,588,518.74	$411,262,858.89	-$122,674,340.16
5	$350,983,683.15	$424,266,418.11	-$73,282,734.96
6	$129,786,563.15	$341,196,436.29	-$211,409,873.14
7	$323,098,048.41	$398,657,852.44	-$75,559,804.03

Table 4. NPV Calculation for Norfolk – Reference Fuel Price

Reference Fuel Case - Norfolk			
LHD	PV Sum Benefits	PV Cost	NPV
1	$152,879,710.46	$386,439,183.30	-$233,559,472.84
2	$161,464,769.15	$374,595,010.42	-$213,130,241.27
3	$140,668,622.03	$363,113,855.68	-$222,445,233.65
4	$315,926,695.12	$411,262,858.89	-$95,336,163.77
5	$381,476,941.21	$424,266,418.11	-$42,789,476.89
6	$140,955,552.32	$341,196,436.29	-$200,240,883.97
7	$351,744,904.76	$398,657,852.44	-$46,912,947.68

Table 5. NPV Calculation for Norfolk – High Fuel Price

High Oil Price - Norfolk			
LHD	PV Sum Benefits	PV Cost	NPV
1	$168,766,525.26	$386,439,183.30	-$217,672,658.04
2	$177,677,506.84	$374,595,010.42	-$196,917,503.58
3	$154,579,465.06	$363,113,855.68	-$208,534,390.61
4	$349,154,255.45	$411,262,858.89	-$62,108,603.45
5	$423,371,781.79	$424,266,418.11	-$894,636.31
6	$155,095,793.63	$341,196,436.29	-$186,100,642.66
7	$388,742,132.45	$398,657,852.44	-$9,915,719.99

Table 6. NPV Calculation for Norfolk – Low Fuel Price

Low Oil Price - Norfolk			
LHD	PV Sum Benefits	PV Cost	NPV
1	$114,357,008.58	$386,439,183.30	-$272,082,174.72
2	$120,478,814.73	$374,595,010.42	-$254,116,195.69
3	$104,935,382.01	$363,113,855.68	-$258,178,473.66
4	$237,666,795.45	$411,262,858.89	-$173,596,063.44
5	$289,237,164.66	$424,266,418.11	-$135,029,253.45
6	$106,001,214.45	$341,196,436.29	-$235,195,221.83
7	$265,078,527.17	$398,657,852.44	-$133,579,325.27

The result of the CBA shows that using the OMB A-94 30-year nominal discount rate, Norfolk does not yield any positive NPVs for conversion. This is mainly due to steam pricing in Norfolk as compared to San Diego, which was discussed in Chapter IV. The low cost of steam in Norfolk results in the conversion having a negative PV for utility consumption, thus becoming a cost rather than a benefit. Therefore, if considering conversion at a 3.6% SDR, all converted LHD ships are recommended to be located in San

Diego. Additionally, based on the current schedule for complex overhauls, LHD 6 does not have a positive NPV for conversion. This thesis addresses and makes recommendations considering the COH scheduling in Chapter VI.

B. SENSITIVITY ANALYSIS

Sensitivity analysis is performed to "determine how sensitive outcomes are to changes in the assumptions" (OMB, 1992, p. 11). The purpose of this section is to discuss the primary factors that can affect the NPV results for the CBA. This thesis has identified three primary factors: social discount rate (SDR), fuel costs, and LHD 8 manpower cost savings. The following sections discuss each of these factors in-depth.

1. Social Discount Rate

This thesis initially employed the OMB Circular A-94 Appendix C (2018) 30-year nominal rate of 3.6% based on OMB forecast recommendations. Another approach, however, is to employ an SDR that is representative of the current treasury bond rates. This allows for the planner to consider the opportunity cost of the alternative COA, no conversion. This thesis has determined a 30-year nominal treasury interest rate of 2.6% by taking the average of all 2019 daily 30-year nominal treasury rates. This rate was then applied to the NPV calculations performed in the previous section to determine the NPV for Norfolk and San Diego. The results for the reference (expected) fuel price are displayed in Tables 7 and 8. Tabulated results for the high and low fuel price cases are found in Appendix A.

Table 7. SDR Adjusted NPV Calculation for San Diego – Reference Fuel Price

Reference Fuel Case - San Diego			
LHD	PV Benefits	PV Cost	NPV
1	$206,878,243.57	$386,439,183.30	-$179,560,939.73
2	$224,161,711.44	$374,595,010.42	-$150,433,298.98
3	$198,447,972.64	$363,113,855.68	-$164,665,883.04
4	$430,763,153.19	$411,262,858.89	$19,500,294.30
5	$519,487,452.97	$424,266,418.11	$95,221,034.86
6	$208,634,497.67	$341,196,436.29	-$132,561,938.62
7	$498,842,119.07	$398,657,852.44	$100,184,266.63

Table 8. SDR Adjusted NPV Calculation for Norfolk – Reference Fuel Price

Reference Fuel Case – Norfolk			
LHD	PV Sum Benefits	PV Cost	NPV
1	$178,366,570.45	$386,439,183.30	-$208,072,612.85
2	$192,942,347.70	$374,595,010.42	-$181,652,662.72
3	$170,597,411.68	$363,113,855.68	-$192,516,444.00
4	$370,899,822.23	$411,262,858.89	-$40,363,036.67
5	$447,003,868.18	$424,266,418.11	$22,737,450.07
6	$178,494,659.67	$341,196,436.29	-$162,701,776.62
7	$428,039,241.63	$398,657,852.44	$29,381,389.19

When adjusting the SDR to reflect nominal 30-year treasury interest rates, two significant changes appear in the NPV calculations. First, based on the current COH schedule, LHD 4 becomes suitable for conversion when considering San Diego as its homeport. Second, Norfolk becomes a suitable location for converted LHD 5 and 7, considering the reference and high fuel price cases. Therefore, this thesis has determined that the SDR must be considered carefully by decision-makers when considering both quantity and location of ship conversion.

2. Fuel Costs

Although the price of fuel based on market volatility is addressed by this thesis by the employment of the DDS 200–2 and EIA model, the possible ranges in the price of fuel burden are not. As discussed in Chapter IV, the FBCF is the DLA standard energy price plus the burdened cost. Up until this point, this thesis has utilized the burdened cost developed in DDS 200–2 and has only adjusted the cost for inflation. Other studies, however, have shown that the burdened cost can be higher than what this thesis has employed. The primary thesis that has looked at the FBCF for U.S. Navy surface ships was a 2009 Naval Postgraduate School (NPS) thesis titled *Evaluating the Impact of the Fully Burdened Cost of Fuel* (Corley, 2009). In his thesis, Corley identified the fuel burden cost of fueling the DDG-51 fleet by employing a calculating method introduced by the Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics (OUSD[AT&L]). This method is similar to the one employed by DDS 200–2 (NAVSEA, 2012), which is used by this thesis.

One primary difference employed by Corley (2009), however, was the determination of the commodity price. Corley calculated and determined that the commodity price, or the price paid by the Navy based on historical VAMOSC data, was higher than that of the DLA standard energy price. This thesis reperformed the calculation method used to calculate commodity price using LHD 1–8 historical VAMOSC data for FY 2018 and determined there was no difference in the DLA standard price and the commodity price introduced by Corley. The result of Corley's analysis is shown in Figure 13.

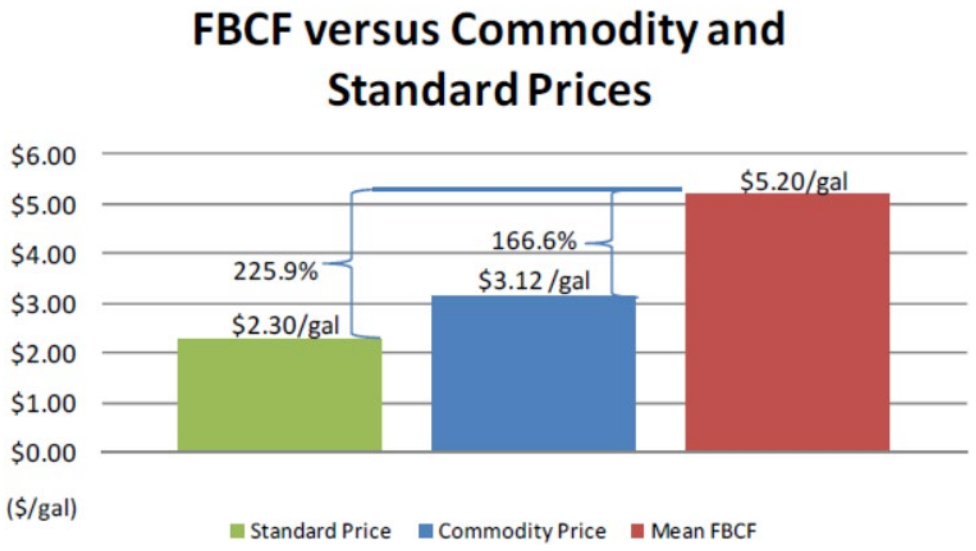


Figure 13. FBCF Determined for DDG-51 Class Ships. Source: Corley (2009).

The result from Corley's (2009) analysis shows that there was a mean FBCF price increase that was 166.6% of the total, or 66.6% higher than the price of fuel paid by the Navy. The burdened price determined by DDS 200–2 and used in this thesis resulted in 141.8% of the total, or a 41.8% increase over the commodity price. Therefore, this thesis has determined that modifying the total cost of fuel by the mean FBCF presented by Corley will provide an upper range to the cost savings provided by fuel consumption reduction. The results from a 66.6% increase, or a 166.6% total, using the more conservative SDR of 3.6%, are displayed in Tables 9 and 10 for the reference (expected) fuel price. Tabulated data for high and low fuel prices are found in Appendix B.

Table 9. Burdened Cost Adjusted NPV Calculation for San Diego – Reference Fuel Price

Reference Fuel Case - San Diego			
LHD	PV Benefits	PV Cost	NPV
1	$195,699,367.62	$386,439,183.30	-$190,739,815.68
2	$207,235,197.59	$374,595,010.42	-$167,359,812.83
3	$180,903,700.36	$363,113,855.68	-$182,210,155.32
4	$405,179,329.97	$411,262,858.89	-$6,083,528.93
5	$489,702,647.49	$424,266,418.11	$65,436,229.38
6	$182,645,128.09	$341,196,436.29	-$158,551,308.20
7	$453,405,147.61	$398,657,852.44	$54,747,295.17

Table 10. Burdened Cost Adjusted NPV Calculation for Norfolk – Reference Fuel Price

Reference Fuel Case - Norfolk			
LHD	PV Sum Benefits	PV Cost	NPV
1	$171,269,268.31	$386,439,183.30	-$215,169,914.99
2	$181,121,580.93	$374,595,010.42	-$193,473,429.49
3	$157,948,192.90	$363,113,855.68	-$205,165,662.78
4	$354,257,606.68	$411,262,858.89	-$57,005,252.21
5	$427,956,129.00	$424,266,418.11	$3,689,710.90
6	$158,859,779.40	$341,196,436.29	-$182,336,656.89
7	$395,385,626.37	$398,657,852.44	-$3,272,226.07

The results from the modification of burdened price show a substantial enough NPV increase to have conversion possible for Norfolk-based ships, even at the more conservative SDR of 3.6% and reference fuel pricing. This result demonstrates that, when determining conversion CBA, fuel burdened costs must be accurately determined. This thesis, therefore, recommends that future analysis be performed using a method similar to the one introduced by Corley (2009) for LHD class ships in order to provide updated and accurate costs of the FBCF.

3. LHD 8 Manning Considerations

This thesis has determined that there is potential for reduced manpower savings for LHD 8 as compared to LHD 1–7 due to both the limited years of available LHD 8 data as well as the assumption that the initial years following commissioning were comprised of different manning levels than average. Chapter IV displays the historical manpower numbers for both officers and enlisted in Figure 9 and Figure 10, respectively. This thesis has identified that, while officer manning has trended higher for LHD 8 in the previous four years, enlisted manning has had the opposite result potentially due to the ship's life cycle. Additionally, due to officer manning being approximately identical for LHD 1–7 and LHD 8, this thesis determined that is has a negligible change to overall manpower cost savings. The nine-year cost-savings results for LHD 8 in San Diego are displayed in Table 11.

Table 11. Five- and Nine-Year LHD 8 Manpower Cost Savings

Year	LHD 8 Cost Savings in Manpower
2010	$9,433,916.00
2011	$7,916,829.50
2012	$6,697,723.00
2013	$10,577,700.00
2014	$5,816,030.50
2015	$3,389,807.50
2016	$2,693,694.00
2017	$5,049,585.50
2018	$4,505,944.50
Five-Year Average	$4,291,012.40
Nine-Year Average	$6,231,247.83

Therefore, in order to establish a lower bound on potential cost savings for manpower, this thesis has performed the CBA using the most recent five-year average for historical VAMOSC manpower cost savings. The results for the reference (expected) fuel case using the more conservative 3.6% SDR are displayed in Tables 12 and 13. The high and low fuel price cases are found in Appendix C.

Table 12. Manpower Cost Adjusted NPV Calculation for San Diego – Reference Fuel Price

Reference Fuel Case - San Diego			
LHD	PV Benefits	PV Cost	NPV
1	$163,686,135.76	$386,439,183.30	-$222,753,047.54
2	$173,015,882.55	$374,595,010.42	-$201,579,127.87
3	$150,822,775.45	$363,113,855.68	-$212,291,080.23
4	$338,451,441.81	$411,262,858.89	-$72,811,417.09
5	$408,789,934.53	$424,266,418.11	-$15,476,483.58
6	$151,476,778.22	$341,196,436.29	-$189,719,658.07
7	$377,409,295.79	$398,657,852.44	-$21,248,556.65

Table 13. Manpower Cost Adjusted NPV Calculation for Norfolk – Reference Fuel Price

Reference Fuel Case - Norfolk			
LHD	PV Sum Benefits	PV Cost	NPV
1	$139,256,036.45	$386,439,183.30	-$247,183,146.86
2	$146,902,265.89	$374,595,010.42	-$227,692,744.53
3	$127,867,267.99	$363,113,855.68	-$235,246,587.69
4	$287,529,718.52	$411,262,858.89	-$123,733,140.37
5	$347,043,416.04	$424,266,418.11	-$77,223,002.07
6	$127,691,429.53	$341,196,436.29	-$213,505,006.76
7	$319,389,774.56	$398,657,852.44	-$79,268,077.88

These results show that at the conservative 3.6% SDR conversion is not recommended due to all NPVs being negative. The OPNAV N95 conversion study, in progress during the production of this thesis, has estimated the annual manpower cost savings at $5.8 million FY 2019, and this thesis concurs.

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VI. CONCLUSIONS AND FOLLOW-ON STUDIES

Chapter VI of this thesis discusses the conclusions and implications from the results presented in Chapter V. Additionally, this thesis offers recommendations to maximize the benefits to the Navy. Lastly, areas for future research are proposed to develop on the analysis conducted.

A. CONCLUSIONS

There are a few considerations to bear in mind when considering the conclusions and recommendations presented. In the late 1990s, the Navy was debating extending the service life of the *Tarawa*-class. The primary argument in opposition was that the high cost of modernization, at about $1.5 billion FY 1999, was too high for a ship that would only be in service another 15 years. Then there is the negative stereotype that “modernized” ships are still old hulls that cannot be upgraded to a revolutionary new design. Furthermore, upgrading the *Tarawa*-class was going to require that one or two ships be kept in maintenance and out of service for over ten years (Forecast International, 2010).

These are the same arguments that we must evaluate when considering modernizing the *Wasp*-class LHD. This thesis only analyzes the cost savings directly involved in the conversion of the propulsion and electrical systems. The cost of the COH proposed by OPNAV N953 (2018) is not considered. If the Navy approves the complex overhaul plan, the COH cost should be combined with the conversion costs to determine the full cost of extending the life of an LHD with hybrid propulsion. The highest estimate for the complex overhaul proposed by OPNAV N953 (2018) is $700 million FY 2019 per ship. The cost of hybrid conversion is estimated at $450 million FY 2019 (OPNAV N95, 2019). Therefore, the highest expected cost to convert and overhaul an LHD to hybrid propulsion is $1.15 billion FY 2019 before any benefits are received. Therefore, the total cost should be evaluated against the cost of building a new LHA estimated at $4.1 billion FY 2019 (Congressional Research Service, 2019).

Lastly, the complex overhaul and the propulsion plant conversion on LHDs are projects that have never been accomplished by the Navy. This type of project carries high risks and has been historically known to cause delays and budget overruns in other platforms. The complexity of these projects results in extensive planning and budgeting processes, which should be acknowledged and accounted for in the schedule. This thesis provides all the required data to perform a CBA on any conversion starting year in the appendix sections. If there is a considerable change in the fleet composition based on the ongoing Force Structure Assessment, this thesis recommends that the Navy optimizes a maintenance schedule that includes hybrid conversion for as many LHDs as required.

With these considerations in mind, there are specific conclusions from the results discussed in Chapter V:

1. Convert LHD 5 and 7 to Hybrid Propulsion

The primary conclusion is that LHD 5 and 7 should be converted from steam to hybrid propulsion and homeported in San Diego following the complex overhaul plan proposed by OPNAV N953 (2018). This conclusion is based on the expected values for the four primary cost-saving elements evaluated. When modifying the discount rates, fuel costs, and manpower costs, the analysis for LHD 4 also yields a positive NPV when homeported in San Diego. However, LHD 4 requires additional stability modifications to convert. Therefore, the conversion is recommended if the additional costs for stability modifications are lower than the NPV calculated.

Another significant finding is that Norfolk is the preferable location for homeporting steam LHDs due to the low cost of steam compared to San Diego. The cost of steam in Norfolk is \$31.90/MBTU, while the cost of steam in San Diego is \$297.82/MBTU. Therefore, any converted ship should be homeported in San Diego, and steamships should be homeported in Norfolk. This course of action requires shifting homeports in order to preserve the number of large-deck amphibious ships on each coast.

2. Optimize the Schedule for LHD 6

The current COH timeline proposed by OPNAV N953 (2018) does not schedule LHD 6 until FY 2037, resulting in a negative NPV for all conversion scenarios. As a result, this thesis has analyzed potential conversion starting dates, which would result in a positive NPV for LHD 6 conversion. The results, calculated as reference fuel price, homeported in San Diego, and using the expected 3.6% SDR, concluded that there are only two possible starting dates where LHD 6 could enter a COH period and yield a positive NPV. These dates are FY 2023 and FY 2025, with an NPV of $33.8 million FY 2019 and $1.1 million FY 2019, respectively. Norfolk retained a negative NPV during this analysis.

This result indicates that the Navy has a potential for receiving conversion benefits in LHD 6 if the COH timeline is changed to benefit the conversion and homeported in San Diego. Additionally, if LHD 6 were shifted earlier in the schedule to start in FY 2025, the COH schedule would allow for converting LHD 5, 6, and 7 back-to-back. Furthermore, the ongoing conversion study being conducted by OPNAV N95 concluded that the weight distribution on LHD 1–4 requires additional modifications and further study to preserve the ship's center of gravity (OPNAV N95, 2019). This process may not be completed in time for a 2025 conversion of LHD 4.

This thesis recommends that the COH plan be optimized to convert LHD 6 between FY 2023 to FY 2025, which will allow the Navy to maximize the benefits of hybrid propulsion on capable hulls. If the industry base and the Navy can only support having one LHD in the shipyards at a time as displayed in Figure 1, LHD 5 should be converted to hybrid propulsion when it enters the yards in 2023. Then LHD 6 can follow with its conversion in 2025, assuming a two-year conversion schedule. Lastly, LHD 7 would follow with conversion, on schedule, in 2027. The optimized schedules proposed by this thesis would benefit the fleet regardless of whether the Navy desires to reduce or increase the number of amphibious ships based on the pending results of the FSA.

3. Future Demand Considerations

Different factors of Navy policy will determine the future demand for big deck amphibious ships. The Navy is conducting a new Force Structure Assessment concurrent with this thesis and results from the assessment may change the number of amphibious ships the Navy is required to maintain (CBO, 2019). The Vice Chief of Naval Operations (VCNO) Admiral Robert P. Burke alluded to a possible reduction in fleet size from that of the previous 355-ship requirement imposed by the 2018 NDAA (Werner, 2019). Admiral Burke stated, "I think with today's fiscal situation, where the Navy's top line is right now, we can keep around 305 to 310 ships whole, properly manned, properly maintained, properly equipped, and properly ready" (Werner, 2019, p. 3). Though the Navy may reduce the total number of ships in the force, neither the specific breakdown amongst platforms nor the demand for large deck amphibious ships will be known until the FSA is published.

Additionally, the Navy is signaling a change in the way in which LHDs and LHAs are employed, which may drive up the demand for big deck amphibious ships. Former Secretary of the Navy Richard V. Spencer indicated a possible change in the employment of large deck amphibious ships by embracing the "lightning carrier" concept (Eckstein, 2019). Speaking about the USS America, he stated, "Why don't we load this thing up with F-35 Bravos, put 20 F-35 Bravos on this, and make it quote/unquote a lightning carrier" (Eckstein, 2019, p. 13). In addition to the "lightning carrier" concept, there is a demand in the fleet for newer and better large deck amphibious ships (Eckstein, 2019). Former Director of Expeditionary Warfare (OPNAV N95) Maj. Gen. David Coffman stated, "I don't want to bring Marine Aviation down to third- and fourth-gen; I want to bring the rest of the Marine Air-Ground Task Force up to fifth-gen and exploit that technical expertise and have a fifth-gen MAGTF. The problem is, we're having to embark a fifth-gen MAGTF on a third-gen ship, and we have to fix that" (Eckstein, 2019, p. 9).

The aggregate of the fiscal situation, employment method, and capabilities shortfall indicate possible changes in Navy policy. This will result in one of three alternatives when considering the large deck amphibious force. First, if the Navy increases the number of large deck amphibious ships required there will be benefits in extending and converting steam powered LHDs. This is because the Navy may need to operate LHDs past the current 40-year service life to meet force size requirements. When coupled with the COH, converted ships will have the added benefit of increased interoperability and lethality by modernizing command and control systems (OPNAV N953, 2018). Second, if the FSA reduces the requirement, LHD life extension and conversion may not be required to meet the large deck amphibious fleet size when compared to current LHD decommissioning and LHA construction planning. These two scenarios, to a large extent, are driven by demand. The third scenario, however, is more complex and will be driven by policy.

In the third scenario, the Navy maintains the current requirement for 12 large deck amphibious ships directed by the 355-ship plan. This scenario poses the greatest freedom for the Navy to decide on a strategic solution that consists of some new and some converted ships. This scenario also benefits from the increased capability and lethality offered by the converted LHDs. The Navy has the option to either convert steam powered LHDs or to decommission LHDs at the current 40-year service life and replace them with the America-class Flight 1. If the Navy chooses the latter, then this thesis recommends that the current LHA Flight 1 production schedule be expedited to both meet changing demand and reduce production costs incurred via the long production break as discussed by the 2019 Congressional Research Service report on LHA production issues (Congressional Research Service, 2019).

B. FOLLOW-ON STUDIES

The results of a CBA can yield changes to policies, operations, and procedures. These changes can cause unintended second- and third-order effects. Therefore, policy changes should be carefully analyzed before implementation. This thesis also recommends the following three follow-on studies.

1. LHD 1–4 Stability

The Navy should conduct a study to determine the extent and cost of the modifications required to preserve the vessel's center of gravity of a converted hybrid ship. If the conversion is feasible, the cost of the stability modifications should be added to the cost of conversion for that ship. The Navy should only convert a ship if the resulting NPV is positive. In other words, the Navy should only convert a ship if the cost of the stability modifications is less than the NPV for the ship calculated in this thesis. The Navy should only conduct a stability modification study if it intends to extend the service life of any of these ships.

2. Steam Infrastructure Reduction

Converting ships from steam to hybrid propulsion and the resulting homeport shift has the potential to produce additional cost savings if accompanied by a reduction on shore steam infrastructure in San Diego. This thesis recommends a follow-on study be conducted to determine the potential for infrastructure reduction as a result of a significant reduction in steam usage. This new study could identify additional monetary benefits of converting ships.

3. Maintenance Requirement Reduction

This thesis expects a significant reduction in the maintenance requirements for converted ships. A hybrid ship should require different types of maintenance and in lesser quantities than a steamship. The reduced maintenance should result in a lower operational cost. This thesis recommends a study be conducted using LHD 8 to identify the potential cost savings of maintenance on converted ships. The study should also examine the impact on the maintenance community at large due to the decreased demand for steam plant support. This new study could identify additional monetary benefits of converting ships.

4. Fully Burdened Cost of Fuel

Fuel burden costs utilized by this thesis were derived from a combination of two sources, Corley (2009) and the NAVSEA (2012) DDS 200–2. Neither of these sources provided an explicit measurement for *Wasp*-class or *America*-class fuel burden cost. Therefore, this thesis recommends that a follow-on study be performed employing the framework constructed by Corley (2009) that focuses on LHD burdened costs. DDS 200–2 should also be updated to account for an increase in the FBCF. These updated cost analyses can then be applied to the fuel model utilized by this thesis to derive an LHD specific fully burdened cost of fuel.

5. Manpower

Manpower cost-savings calculations were based on the available data from LHD 8, starting from the year of commissioning. These historical costs are volatile due to inherent changes in a ship's schedule following commissioning, which results in changes in required manning. Therefore, this thesis recommends a follow-on study be performed that analyses the necessary manpower numbers to support the maintenance, basic, integrated, deployment, and sustainment phases of LHD 8's life-cycle support plan. These results can then be compared to both the historical costs derived by this thesis, as well as the SMD, to create an updated cost-savings for conversion.

6. Utilities

Utility cost-savings calculations were limited based on available data from NAVFAC. In order to improve the accuracy of these calculations, follow-on studies should focus on gathering data monthly from NAVFAC, starting as soon as possible. Ship schedule data should also be combined with the monthly consumption data in order to determine an exact monthly usage rate per ship. In order to account for external factors, such as environmental changes, this thesis recommends compiling monthly class averages, then totaling to determine annual consumption. Additionally, *America*-class LHAs can be incorporated into a monthly monitoring plan to better determine hybrid-propulsion in-port averages.

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APPENDIX A. SOCIAL DISCOUNT RATE SENSITIVITY ANALYSIS RESULTS

High Oil Price - San Diego

LHD	PV Sum Benefits	PV Cost	NPV
1	$225,401,319.38	$386,439,183.30	-$161,037,863.92
2	$243,520,262.94	$374,595,010.42	-$131,074,747.48
3	$215,303,206.17	$363,113,855.68	-$147,810,649.51
4	$469,642,307.35	$411,262,858.89	$58,379,448.46
5	$568,256,822.79	$424,266,418.11	$143,990,404.68
6	$226,555,571.90	$341,196,436.29	-$114,640,864.39
7	$543,842,084.30	$398,657,852.44	$145,184,231.86

Low Oil Price - San Diego

LHD	PV Sum Benefits	PV Cost	NPV
1	$161,928,426.49	$386,439,183.30	-$224,510,756.81
2	$175,181,246.24	$374,595,010.42	-$199,413,764.18
3	$155,108,933.83	$363,113,855.68	-$208,004,921.85
4	$338,773,776.16	$411,262,858.89	-$72,489,082.73
5	$411,101,360.43	$424,266,418.11	-$13,165,057.68
6	$164,407,050.60	$341,196,436.29	-$176,789,385.69
7	$393,536,849.83	$398,657,852.44	-$5,121,002.61

High Oil Price - Norfolk

LHD	PV Sum Benefits	PV Cost	NPV
1	$196,889,646.27	$386,439,183.30	-$189,549,537.03
2	$212,300,899.20	$374,595,010.42	-$162,294,111.22
3	$187,452,645.21	$363,113,855.68	-$175,661,210.47
4	$409,778,976.39	$411,262,858.89	-$1,483,882.51
5	$495,773,238.00	$424,266,418.11	$71,506,819.89
6	$196,415,733.90	$341,196,436.29	-$144,780,702.39
7	$473,039,206.86	$398,657,852.44	$74,381,354.42

Low Oil Price - Norfolk

LHD	PV Sum Benefits	PV Cost	NPV
1	$133,416,753.38	$386,439,183.30	-$253,022,429.92
2	$143,961,882.50	$374,595,010.42	-$230,633,127.92
3	$127,258,372.87	$363,113,855.68	-$235,855,482.81
4	$278,910,445.20	$411,262,858.89	-$132,352,413.70
5	$338,617,775.64	$424,266,418.11	-$85,648,642.47
6	$134,267,212.61	$341,196,436.29	-$206,929,223.68
7	$322,733,972.39	$398,657,852.44	-$75,923,880.05

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APPENDIX B. FUEL BURDENED PRICE SENSITIVITY ANALYSIS RESULTS

High Oil Price - San Diego			
LHD	PV Sum Benefits	PV Cost	NPV
1	$211,586,182.42	$386,439,183.30	-$174,853,000.88
2	$223,447,935.28	$374,595,010.42	-$151,147,075.14
3	$194,814,543.39	$363,113,855.68	-$168,299,312.28
4	$438,406,890.29	$411,262,858.89	$27,144,031.40
5	$531,597,488.07	$424,266,418.11	$107,331,069.96
6	$196,785,369.41	$341,196,436.29	-$144,411,066.88
7	$490,412,692.27	$398,657,852.44	$91,754,839.83

Low Oil Price - San Diego			
LHD	PV Sum Benefits	PV Cost	NPV
1	$157,176,665.74	$386,439,183.30	-$229,262,517.56
2	$166,249,243.17	$374,595,010.42	-$208,345,767.25
3	$145,170,460.34	$363,113,855.68	-$217,943,395.33
4	$326,919,430.30	$411,262,858.89	-$84,343,428.60
5	$397,462,870.94	$424,266,418.11	-$26,803,547.17
6	$147,690,790.23	$341,196,436.29	-$193,505,646.06
7	$366,744,726.09	$398,657,852.44	-$31,913,126.35

High Oil Price - Norfolk			
LHD	PV Sum Benefits	PV Cost	NPV
1	$187,156,083.11	$386,439,183.30	-$199,283,100.20
2	$197,334,318.63	$374,595,010.42	-$177,260,691.79
3	$171,859,035.93	$363,113,855.68	-$191,254,819.75
4	$387,485,167.01	$411,262,858.89	-$23,777,691.89
5	$469,850,969.58	$424,266,418.11	$45,584,551.48
6	$173,000,020.71	$341,196,436.29	-$168,196,415.57
7	$432,393,171.03	$398,657,852.44	$33,735,318.59

Low Oil Price - Norfolk			
LHD	PV Sum Benefits	PV Cost	NPV
1	$132,746,566.43	$386,439,183.30	-$253,692,616.87
2	$140,135,626.52	$374,595,010.42	-$234,459,383.90
3	$122,214,952.88	$363,113,855.68	-$240,898,902.79
4	$275,997,707.01	$411,262,858.89	-$135,265,151.88
5	$335,716,352.45	$424,266,418.11	-$88,550,065.66
6	$123,905,441.54	$341,196,436.29	-$217,290,994.75
7	$308,725,204.86	$398,657,852.44	-$89,932,647.58

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APPENDIX C. MANPOWER COST-SAVINGS SENSITIVITY ANALYSIS RESULTS

High Oil Price - San Diego			
LHD	PV Sum Benefits	PV Cost	NPV
1	$179,572,950.55	$386,439,183.30	-$206,866,232.75
2	$189,228,620.24	$374,595,010.42	-$185,366,390.18
3	$164,733,618.48	$363,113,855.68	-$198,380,237.20
4	$371,679,002.13	$411,262,858.89	-$39,583,856.76
5	$450,684,775.11	$424,266,418.11	$26,418,357.00
6	$165,617,019.54	$341,196,436.29	-$175,579,416.75
7	$414,406,523.49	$398,657,852.44	$15,748,671.05

Low Oil Price - San Diego			
LHD	PV Sum Benefits	PV Cost	NPV
1	$125,163,433.88	$386,439,183.30	-$261,275,749.42
2	$132,029,928.13	$374,595,010.42	-$242,565,082.29
3	$115,089,535.43	$363,113,855.68	-$248,024,320.24
4	$260,191,542.14	$411,262,858.89	-$151,071,316.76
5	$316,550,157.98	$424,266,418.11	-$107,716,260.13
6	$116,522,440.36	$341,196,436.29	-$224,673,995.93
7	$290,742,918.21	$398,657,852.44	-$107,914,934.23

High Oil Price - Norfolk			
LHD	PV Sum Benefits	PV Cost	NPV
1	$155,142,851.24	$386,439,183.30	-$231,296,332.06
2	$163,115,003.59	$374,595,010.42	-$211,480,006.83
3	$141,778,111.02	$363,113,855.68	-$221,335,744.66
4	$320,757,278.85	$411,262,858.89	-$90,505,580.05
5	$388,938,256.62	$424,266,418.11	-$35,328,161.49
6	$141,831,670.84	$341,196,436.29	-$199,364,765.45
7	$356,387,002.25	$398,657,852.44	-$42,270,850.19

Low Oil Price - Norfolk			
LHD	PV Sum Benefits	PV Cost	NPV
1	$100,733,334.56	$386,439,183.30	-$285,705,848.74
2	$105,916,311.48	$374,595,010.42	-$268,678,698.94
3	$92,134,027.97	$363,113,855.68	-$270,979,827.70
4	$209,269,818.85	$411,262,858.89	-$201,993,040.04
5	$254,803,639.49	$424,266,418.11	-$169,462,778.62
6	$92,737,091.67	$341,196,436.29	-$248,459,344.62
7	$232,723,396.97	$398,657,852.44	-$165,934,455.47

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APPENDIX D. COST ESTIMATION TABLES

Conversion Cost Table SDR at 3.6%

Year	SCN Inflation	Total Cost	Period	PV
2019	1.0000	$451,520,000.00	0	$451,520,000.00
2020	1.0200	$460,550,400.00	1	$444,546,718.15
2021	1.0404	$469,761,408.00	2	$437,681,131.77
2022	1.0612	$479,156,636.16	3	$430,921,577.61
2023	1.0824	$488,739,768.88	4	$424,266,418.11
2024	1.1041	$498,514,564.26	5	$417,714,040.99
2025	1.1262	$508,484,855.55	6	$411,262,858.89
2026	1.1487	$518,654,552.66	7	$404,911,308.95
2027	1.1717	$529,027,643.71	8	$398,657,852.44
2028	1.1951	$539,608,196.58	9	$392,500,974.41
2029	1.2190	$550,400,360.52	10	$386,439,183.30
2030	1.2434	$561,408,367.73	11	$380,471,010.59
2031	1.2682	$572,636,535.08	12	$374,595,010.42
2032	1.2936	$584,089,265.78	13	$368,809,759.30
2033	1.3195	$595,771,051.10	14	$363,113,855.68
2034	1.3459	$607,686,472.12	15	$357,505,919.68
2035	1.3728	$619,840,201.56	16	$351,984,592.74
2036	1.4002	$632,237,005.59	17	$346,548,537.25
2037	1.4282	$644,881,745.71	18	$341,196,436.29
2038	1.4568	$657,779,380.62	19	$335,926,993.26
2039	1.4859	$670,934,968.23	20	$330,738,931.59
2040	1.5157	$684,353,667.60	21	$325,630,994.42
2041	1.5460	$698,040,740.95	22	$320,601,944.31
2042	1.5769	$712,001,555.77	23	$315,650,562.93
2043	1.6084	$726,241,586.88	24	$310,775,650.76
2044	1.6406	$740,766,418.62	25	$305,976,026.81
2045	1.6734	$755,581,746.99	26	$301,250,528.33
2046	1.7069	$770,693,381.93	27	$296,598,010.52
2047	1.7410	$786,107,249.57	28	$292,017,346.26
2048	1.7758	$801,829,394.56	29	$287,507,425.86
2049	1.8114	$817,865,982.45	30	$283,067,156.73
2050	1.8476	$834,223,302.10	31	$278,695,463.19
2051	1.8845	$850,907,768.15	32	$274,391,286.15

Manpower Cost Table at 3.6%

Year	MPN Purchase Inflation	Average LHD 8 VAMOSC Manpower Savings	Period	PV
2019	1.0000	$6,231,247.83	0	$6,231,247.83
2020	1.0200	$6,355,872.79	1	$6,135,012.35
2021	1.0404	$6,482,990.25	2	$6,040,263.12
2022	1.0612	$6,612,650.05	3	$5,946,977.20
2023	1.0824	$6,744,903.05	4	$5,855,132.00
2024	1.1041	$6,879,801.11	5	$5,764,705.25
2025	1.1262	$7,017,397.14	6	$5,675,675.05
2026	1.1487	$7,157,745.08	7	$5,588,019.84
2027	1.1717	$7,300,899.98	8	$5,501,718.37
2028	1.1951	$7,446,917.98	9	$5,416,749.75
2029	1.2190	$7,595,856.34	10	$5,333,093.38
2030	1.2434	$7,747,773.47	11	$5,250,729.01
2031	1.2682	$7,902,728.93	12	$5,169,636.67
2032	1.2936	$8,060,783.51	13	$5,089,796.72
2033	1.3195	$8,221,999.18	14	$5,011,189.82
2034	1.3459	$8,386,439.17	15	$4,933,796.92
2035	1.3728	$8,554,167.95	16	$4,857,599.29
2036	1.4002	$8,725,251.31	17	$4,782,578.45
2037	1.4282	$8,899,756.34	18	$4,708,716.23
2038	1.4568	$9,077,751.46	19	$4,635,994.75
2039	1.4859	$9,259,306.49	20	$4,564,396.37
2040	1.5157	$9,444,492.62	21	$4,493,903.77
2041	1.5460	$9,633,382.47	22	$4,424,499.85
2042	1.5769	$9,826,050.12	23	$4,356,167.80
2043	1.6084	$10,022,571.13	24	$4,288,891.08
2044	1.6406	$10,223,022.55	25	$4,222,653.38
2045	1.6734	$10,427,483.00	26	$4,157,438.66
2046	1.7069	$10,636,032.66	27	$4,093,231.11
2047	1.7410	$10,848,753.31	28	$4,030,015.18
2048	1.7758	$11,065,728.38	29	$3,967,775.57
2049	1.8114	$11,287,042.95	30	$3,906,497.18
2050	1.8476	$11,512,783.81	31	$3,846,165.18
2051	1.8845	$11,743,039.48	32	$3,786,764.94

Utilities Cost Table at 3.6% - San Diego

Year	Inflation Index	Steam Cost	Additional Electric Cost	Total Savings	Period	PV
2019	1.0000	$3,635,264.87	$794,877.24	$2,840,387.63	0	$2,840,387.63
2020	1.0200	$3,707,970.17	$810,774.79	$2,897,195.38	1	$2,796,520.64
2021	1.0404	$3,782,129.57	$826,990.28	$2,955,139.29	2	$2,753,331.13
2022	1.0612	$3,857,772.16	$843,530.09	$3,014,242.08	3	$2,710,808.64
2023	1.0824	$3,934,927.61	$860,400.69	$3,074,526.92	4	$2,668,942.87
2024	1.1041	$4,013,626.16	$877,608.70	$3,136,017.46	5	$2,627,723.68
2025	1.1262	$4,093,898.68	$895,160.88	$3,198,737.80	6	$2,587,141.07
2026	1.1487	$4,175,776.66	$913,064.09	$3,262,712.56	7	$2,547,185.23
2027	1.1717	$4,259,292.19	$931,325.38	$3,327,966.81	8	$2,507,846.46
2028	1.1951	$4,344,478.03	$949,951.88	$3,394,526.15	9	$2,469,115.24
2029	1.2190	$4,431,367.59	$968,950.92	$3,462,416.67	10	$2,430,982.18
2030	1.2434	$4,519,994.94	$988,329.94	$3,531,665.00	11	$2,393,438.06
2031	1.2682	$4,610,394.84	$1,008,096.54	$3,602,298.30	12	$2,356,473.76
2032	1.2936	$4,702,602.74	$1,028,258.47	$3,674,344.27	13	$2,320,080.35
2033	1.3195	$4,796,654.80	$1,048,823.64	$3,747,831.16	14	$2,284,248.99
2034	1.3459	$4,892,587.89	$1,069,800.11	$3,822,787.78	15	$2,248,971.01
2035	1.3728	$4,990,439.65	$1,091,196.11	$3,899,243.53	16	$2,214,237.87
2036	1.4002	$5,090,248.44	$1,113,020.04	$3,977,228.41	17	$2,180,041.15
2037	1.4282	$5,192,053.41	$1,135,280.44	$4,056,772.97	18	$2,146,372.56
2038	1.4568	$5,295,894.48	$1,157,986.05	$4,137,908.43	19	$2,113,223.95
2039	1.4859	$5,401,812.37	$1,181,145.77	$4,220,666.60	20	$2,080,587.28
2040	1.5157	$5,509,848.62	$1,204,768.68	$4,305,079.93	21	$2,048,454.66
2041	1.5460	$5,620,045.59	$1,228,864.06	$4,391,181.53	22	$2,016,818.30
2042	1.5769	$5,732,446.50	$1,253,441.34	$4,479,005.16	23	$1,985,670.52
2043	1.6084	$5,847,095.43	$1,278,510.16	$4,568,585.27	24	$1,955,003.80
2044	1.6406	$5,964,037.34	$1,304,080.37	$4,659,956.97	25	$1,924,810.69
2045	1.6734	$6,083,318.09	$1,330,161.97	$4,753,156.11	26	$1,895,083.88
2046	1.7069	$6,204,984.45	$1,356,765.21	$4,848,219.23	27	$1,865,816.18
2047	1.7410	$6,329,084.14	$1,383,900.52	$4,945,183.62	28	$1,837,000.48
2048	1.7758	$6,455,665.82	$1,411,578.53	$5,044,087.29	29	$1,808,629.82
2049	1.8114	$6,584,779.14	$1,439,810.10	$5,144,969.04	30	$1,780,697.31
2050	1.8476	$6,716,474.72	$1,468,606.30	$5,247,868.42	31	$1,753,196.20
2051	1.8845	$6,850,804.21	$1,497,978.43	$5,352,825.79	32	$1,726,119.81

Utilities Cost Table at 3.6% - Norfolk

Year	Inflation Index	Steam Cost	Additional Electric Cost	Total Savings	Period	PV
2019	1.0000	$243,159.04	$882,019.69	-$638,860.65	0	-$638,860.65
2020	1.0200	$248,022.22	$899,660.08	-$651,637.86	1	-$628,994.07
2021	1.0404	$252,982.67	$917,653.28	-$664,670.62	2	-$619,279.88
2022	1.0612	$258,042.32	$936,006.35	-$677,964.03	3	-$609,715.71
2023	1.0824	$263,203.17	$954,726.47	-$691,523.31	4	-$600,299.25
2024	1.1041	$268,467.23	$973,821.00	-$705,353.77	5	-$591,028.22
2025	1.1262	$273,836.57	$993,297.42	-$719,460.85	6	-$581,900.37
2026	1.1487	$279,313.30	$1,013,163.37	-$733,850.07	7	-$572,913.49
2027	1.1717	$284,899.57	$1,033,426.64	-$748,527.07	8	-$564,065.41
2028	1.1951	$290,597.56	$1,054,095.17	-$763,497.61	9	-$555,353.97
2029	1.2190	$296,409.51	$1,075,177.08	-$778,767.56	10	-$546,777.08
2030	1.2434	$302,337.70	$1,096,680.62	-$794,342.91	11	-$538,332.64
2031	1.2682	$308,384.46	$1,118,614.23	-$810,229.77	12	-$530,018.63
2032	1.2936	$314,552.15	$1,140,986.51	-$826,434.37	13	-$521,833.01
2033	1.3195	$320,843.19	$1,163,806.24	-$842,963.05	14	-$513,773.81
2034	1.3459	$327,260.05	$1,187,082.37	-$859,822.31	15	-$505,839.08
2035	1.3728	$333,805.25	$1,210,824.02	-$877,018.76	16	-$498,026.90
2036	1.4002	$340,481.36	$1,235,040.50	-$894,559.14	17	-$490,335.36
2037	1.4282	$347,290.99	$1,259,741.31	-$912,450.32	18	-$482,762.61
2038	1.4568	$354,236.81	$1,284,936.13	-$930,699.33	19	-$475,306.82
2039	1.4859	$361,321.54	$1,310,634.85	-$949,313.31	20	-$467,966.17
2040	1.5157	$368,547.97	$1,336,847.55	-$968,299.58	21	-$460,738.90
2041	1.5460	$375,918.93	$1,363,584.50	-$987,665.57	22	-$453,623.24
2042	1.5769	$383,437.31	$1,390,856.19	-$1,007,418.88	23	-$446,617.47
2043	1.6084	$391,106.06	$1,418,673.32	-$1,027,567.26	24	-$439,719.91
2044	1.6406	$398,928.18	$1,447,046.78	-$1,048,118.60	25	-$432,928.87
2045	1.6734	$406,906.74	$1,475,987.72	-$1,069,080.98	26	-$426,242.71
2046	1.7069	$415,044.88	$1,505,507.47	-$1,090,462.60	27	-$419,659.81
2047	1.7410	$423,345.78	$1,535,617.62	-$1,112,271.85	28	-$413,178.58
2048	1.7758	$431,812.69	$1,566,329.98	-$1,134,517.28	29	-$406,797.44
2049	1.8114	$440,448.94	$1,597,656.57	-$1,157,207.63	30	-$400,514.85
2050	1.8476	$449,257.92	$1,629,609.71	-$1,180,351.78	31	-$394,329.30
2051	1.8845	$458,243.08	$1,662,201.90	-$1,203,958.82	32	-$388,239.27

Underway Fuel Cost at 3.6% - Reference Case

Year	Fuel Price / BBL	Cost LHD 1–7	Cost LHD 8	Difference Between LHD 1–7 and LHD 8	Period	Present Value
2019	178.64	$23,129,581.95	$10,729,950.26	$12,399,631.70	0	$12,399,631.70
2020	187.37	$24,260,616.04	$11,254,643.68	$13,005,972.36	1	$12,554,027.38
2021	192.15	$24,879,903.74	$11,541,934.91	$13,337,968.82	2	$12,427,111.28
2022	194.17	$25,141,041.81	$11,663,078.41	$13,477,963.40	3	$12,121,182.95
2023	198.03	$25,640,195.31	$11,894,638.68	$13,745,556.63	4	$11,932,276.53
2024	205.63	$26,624,885.94	$12,351,442.51	$14,273,443.43	5	$11,959,967.00
2025	211.43	$27,376,136.95	$12,699,952.30	$14,676,184.64	6	$11,870,107.02
2026	218.39	$28,276,325.33	$13,117,555.04	$15,158,770.30	7	$11,834,384.74
2027	227.30	$29,431,070.42	$13,653,248.13	$15,777,822.29	8	$11,889,648.54
2028	228.79	$29,623,843.92	$13,742,676.90	$15,881,167.02	9	$11,551,665.76
2029	236.42	$30,611,549.22	$14,200,879.25	$16,410,669.97	10	$11,522,023.52
2030	238.90	$30,931,868.59	$14,349,477.30	$16,582,391.29	11	$11,238,021.26
2031	243.19	$31,487,657.53	$14,607,311.09	$16,880,346.44	12	$11,042,420.74
2032	247.59	$32,058,097.70	$14,871,941.67	$17,186,156.03	13	$10,851,803.72
2033	254.53	$32,956,718.22	$15,288,817.06	$17,667,901.16	14	$10,768,330.72
2034	254.87	$33,000,374.11	$15,309,069.28	$17,691,304.82	15	$10,407,910.15
2035	258.94	$33,526,971.88	$15,553,361.11	$17,973,610.77	16	$10,206,556.54
2036	266.32	$34,482,163.75	$15,996,480.29	$18,485,683.46	17	$10,132,571.34
2037	264.44	$34,239,852.12	$15,884,070.49	$18,355,781.64	18	$9,711,745.33
2038	267.98	$34,697,283.38	$16,096,275.56	$18,601,007.82	19	$9,499,508.21
2039	271.54	$35,158,689.20	$16,310,324.46	$18,848,364.75	20	$9,291,344.64
2040	274.79	$35,578,990.70	$16,505,304.81	$19,073,685.88	21	$9,075,692.29
2041	277.27	$35,900,683.45	$16,654,539.99	$19,246,143.46	22	$8,839,528.49
2042	283.86	$36,753,984.65	$17,050,391.48	$19,703,593.18	23	$8,735,163.89
2043	284.78	$36,872,351.02	$17,105,302.34	$19,767,048.68	24	$8,458,779.46
2044	285.77	$37,000,958.04	$17,164,963.90	$19,835,994.15	25	$8,193,323.19
2045	287.37	$37,208,518.70	$17,261,252.52	$19,947,266.18	26	$7,952,977.29
2046	289.41	$37,472,974.13	$17,383,934.96	$20,089,039.17	27	$7,731,179.73
2047	291.59	$37,754,201.82	$17,514,398.15	$20,239,803.66	28	$7,518,533.58
2048	293.60	$38,015,024.65	$17,635,395.41	$20,379,629.24	29	$7,307,408.26
2049	295.40	$38,248,396.23	$17,743,657.87	$20,504,738.36	30	$7,096,783.72
2050	297.16	$38,475,917.21	$17,849,206.20	$20,626,711.01	31	$6,890,925.68
2051	296.82	$38,431,723.66	$17,828,704.56	$20,603,019.11	32	$6,643,832.77

Underway Fuel Cost at 3.6% - High Oil Price

Year	Fuel Price / BBL	Cost LHD 1–7	Cost LHD 8	Difference Between LHD 1–7 and LHD 8	Period	Present Value
2019	$178.64	$23,129,581.95	$10,729,950.26	$12,399,631.70	0	$12,399,631.70
2020	$200.24	$25,927,436.19	$12,027,891.43	$13,899,544.76	1	$13,416,549.00
2021	$221.31	$28,655,198.70	$13,293,316.64	$15,361,882.06	2	$14,312,810.31
2022	$234.41	$30,350,791.98	$14,079,912.42	$16,270,879.56	3	$14,632,945.81
2023	$244.62	$31,673,379.22	$14,693,468.48	$16,979,910.74	4	$14,739,962.59
2024	$252.57	$32,701,962.73	$15,170,634.48	$17,531,328.26	5	$14,689,805.46
2025	$259.01	$33,536,819.66	$15,557,929.56	$17,978,890.11	6	$14,541,337.20
2026	$257.38	$33,325,848.01	$15,460,058.55	$17,865,789.45	7	$13,947,742.59
2027	$261.20	$33,820,025.88	$15,689,310.60	$18,130,715.28	8	$13,662,711.40
2028	$265.61	$34,391,134.36	$15,954,251.21	$18,436,883.15	9	$13,410,646.18
2029	$271.49	$35,152,380.55	$16,307,397.84	$18,844,982.72	10	$13,231,168.17
2030	$278.62	$36,075,186.79	$16,735,493.12	$19,339,693.67	11	$13,106,667.48
2031	$278.99	$36,123,883.17	$16,758,083.66	$19,365,799.51	12	$12,668,300.79
2032	$284.13	$36,788,619.78	$17,066,458.92	$19,722,160.86	13	$12,453,105.76
2033	$288.05	$37,297,000.99	$17,302,299.98	$19,994,701.01	14	$12,186,481.64
2034	$291.94	$37,800,090.04	$17,535,685.97	$20,264,404.07	15	$11,921,681.24
2035	$296.39	$38,376,720.60	$17,803,188.31	$20,573,532.29	16	$11,682,956.94
2036	$300.09	$38,854,829.20	$18,024,985.72	$20,829,843.48	17	$11,417,477.50
2037	$300.53	$38,912,128.38	$18,051,567.15	$20,860,561.23	18	$11,036,983.44
2038	$305.38	$39,540,512.27	$18,343,078.17	$21,197,434.10	19	$10,825,499.42
2039	$308.97	$40,005,344.69	$18,558,716.69	$21,446,628.01	20	$10,572,164.47
2040	$312.19	$40,421,726.01	$18,751,878.45	$21,669,847.56	21	$10,311,004.89
2041	$315.44	$40,843,150.21	$18,947,379.63	$21,895,770.58	22	$10,056,471.22
2042	$317.61	$41,123,982.68	$19,077,659.48	$22,046,323.20	23	$9,773,762.81
2043	$320.79	$41,535,176.74	$19,268,414.84	$22,266,761.89	24	$9,528,464.83
2044	$324.96	$42,074,868.80	$19,518,781.19	$22,556,087.60	25	$9,316,866.82
2045	$328.38	$42,517,636.06	$19,724,183.55	$22,793,452.51	26	$9,087,752.10
2046	$331.32	$42,898,411.23	$19,900,827.41	$22,997,583.82	27	$8,850,520.54
2047	$334.55	$43,317,582.21	$20,095,283.32	$23,222,298.90	28	$8,626,449.00
2048	$338.30	$43,802,769.98	$20,320,364.80	$23,482,405.18	29	$8,419,953.06
2049	$341.72	$44,246,098.16	$20,526,027.37	$23,720,070.79	30	$8,209,624.97
2050	$344.98	$44,667,458.44	$20,721,498.90	$23,945,959.53	31	$7,999,812.84
2051	$346.86	$44,911,490.72	$20,834,706.92	$24,076,783.79	32	$7,764,013.82

Underway Fuel Cost at 3.6% - Low Fuel Price

Year	Fuel Price / BBL	Cost LHD 1–7	Cost LHD 8	Difference Between LHD 1–7 and LHD 8	Period	Present Value
2019	$178.64	$23,129,581.95	$10,729,950.26	$12,399,631.70	0	$12,399,631.70
2020	$151.70	$19,642,574.18	$9,112,306.67	$10,530,267.51	1	$10,164,350.88
2021	$154.40	$19,991,639.99	$9,274,240.37	$10,717,399.62	2	$9,985,502.25
2022	$154.62	$20,019,737.77	$9,287,275.10	$10,732,462.68	3	$9,652,062.39
2023	$156.58	$20,273,962.29	$9,405,211.36	$10,868,750.94	4	$9,434,971.99
2024	$158.28	$20,494,089.95	$9,507,329.88	$10,986,760.06	5	$9,205,997.72
2025	$159.62	$20,667,932.31	$9,587,976.38	$11,079,955.92	6	$8,961,475.06
2026	$156.74	$20,293,926.95	$9,414,473.08	$10,879,453.87	7	$8,493,541.39
2027	$158.68	$20,545,685.95	$9,531,265.57	$11,014,420.38	8	$8,300,105.34
2028	$159.45	$20,644,848.11	$9,577,267.49	$11,067,580.62	9	$8,050,352.47
2029	$159.84	$20,696,206.37	$9,601,092.89	$11,095,113.48	10	$7,789,941.47
2030	$161.29	$20,884,118.69	$9,688,266.53	$11,195,852.16	11	$7,587,519.94
2031	$161.93	$20,965,953.43	$9,726,230.15	$11,239,723.28	12	$7,352,559.61
2032	$165.59	$21,440,139.38	$9,946,207.83	$11,493,931.56	13	$7,257,579.24
2033	$168.02	$21,755,119.09	$10,092,328.78	$11,662,790.31	14	$7,108,302.34
2034	$168.44	$21,810,054.23	$10,117,813.52	$11,692,240.71	15	$6,878,621.56
2035	$170.75	$22,107,999.53	$10,256,032.11	$11,851,967.42	16	$6,730,299.06
2036	$173.14	$22,418,308.91	$10,399,986.47	$12,018,322.44	17	$6,587,611.96
2037	$177.02	$22,920,450.35	$10,632,932.86	$12,287,517.49	18	$6,501,125.52
2038	$175.55	$22,729,700.73	$10,544,442.98	$12,185,257.75	19	$6,222,993.78
2039	$178.51	$23,113,465.87	$10,722,473.91	$12,390,991.96	20	$6,108,167.91
2040	$180.07	$23,315,125.24	$10,816,024.89	$12,499,100.35	21	$5,947,355.40
2041	$181.28	$23,472,374.73	$10,888,973.86	$12,583,400.87	22	$5,779,408.78
2042	$183.50	$23,759,246.27	$11,022,055.27	$12,737,191.00	23	$5,646,759.45
2043	$185.80	$24,057,306.96	$11,160,327.39	$12,896,979.57	24	$5,518,917.25
2044	$187.66	$24,297,553.49	$11,271,779.18	$13,025,774.31	25	$5,380,339.30
2045	$191.82	$24,836,931.02	$11,521,999.61	$13,314,931.40	26	$5,308,664.66
2046	$192.52	$24,927,138.44	$11,563,847.37	$13,363,291.07	27	$5,142,804.70
2047	$195.72	$25,341,626.34	$11,756,130.77	$13,585,495.57	28	$5,046,640.10
2048	$198.75	$25,734,298.65	$11,938,293.78	$13,796,004.87	29	$4,946,755.35
2049	$201.87	$26,138,293.93	$12,125,709.59	$14,012,584.34	30	$4,849,819.52
2050	$204.04	$26,419,083.69	$12,255,969.62	$14,163,114.07	31	$4,731,581.61
2051	$204.59	$26,489,583.35	$12,288,674.83	$14,200,908.52	32	$4,579,351.25

Not Underway Fuel Cost at 3.6% - Reference Case

Year	Fuel Price / BBL	Cost LHD 1–7	Cost LHD 8	Difference Between LHD 1–7 and LHD 8	Period	Present Value
2019	$178.64	$3,432,864.71	$505,418.54	$2,927,446.18	0	$2,927,446.18
2020	$187.37	$3,600,731.43	$530,133.45	$3,070,597.98	1	$2,963,897.67
2021	$192.15	$3,692,645.37	$543,665.88	$3,148,979.49	2	$2,933,933.87
2022	$194.17	$3,731,403.17	$549,372.17	$3,182,031.00	3	$2,861,706.83
2023	$198.03	$3,805,486.93	$560,279.47	$3,245,207.45	4	$2,817,107.65
2024	$205.63	$3,951,633.52	$581,796.55	$3,369,836.98	5	$2,823,645.13
2025	$211.43	$4,063,133.29	$598,212.59	$3,464,920.71	6	$2,802,429.96
2026	$218.39	$4,196,738.17	$617,883.15	$3,578,855.02	7	$2,793,996.24
2027	$227.30	$4,368,124.05	$643,116.19	$3,725,007.86	8	$2,807,043.55
2028	$228.79	$4,396,735.26	$647,328.60	$3,749,406.66	9	$2,727,248.73
2029	$236.42	$4,543,329.29	$668,911.55	$3,874,417.74	10	$2,720,250.45
2030	$238.90	$4,590,870.71	$675,911.04	$3,914,959.67	11	$2,653,199.96
2031	$243.19	$4,673,360.23	$688,055.92	$3,985,304.31	12	$2,607,020.37
2032	$247.59	$4,758,024.27	$700,520.95	$4,057,503.32	13	$2,562,017.33
2033	$254.53	$4,891,396.45	$720,157.26	$4,171,239.19	14	$2,542,310.08
2034	$254.87	$4,897,875.80	$721,111.21	$4,176,764.60	15	$2,457,217.89
2035	$258.94	$4,976,032.81	$732,618.22	$4,243,414.60	16	$2,409,680.03
2036	$266.32	$5,117,801.24	$753,490.69	$4,364,310.55	17	$2,392,212.77
2037	$264.44	$5,081,837.64	$748,195.80	$4,333,641.84	18	$2,292,859.37
2038	$267.98	$5,149,729.04	$758,191.40	$4,391,537.63	19	$2,242,752.02
2039	$271.54	$5,218,210.33	$768,273.86	$4,449,936.47	20	$2,193,606.39
2040	$274.79	$5,280,590.98	$777,458.13	$4,503,132.85	21	$2,142,692.73
2041	$277.27	$5,328,336.23	$784,487.63	$4,543,848.60	22	$2,086,936.49
2042	$283.86	$5,454,982.16	$803,133.63	$4,651,848.53	23	$2,062,296.91
2043	$284.78	$5,472,549.96	$805,720.13	$4,666,829.83	24	$1,997,044.93
2044	$285.77	$5,491,637.66	$808,530.40	$4,683,107.26	25	$1,934,372.99
2045	$287.37	$5,522,443.56	$813,065.93	$4,709,377.63	26	$1,877,629.40
2046	$289.41	$5,561,693.72	$818,844.71	$4,742,849.01	27	$1,825,264.90
2047	$291.59	$5,603,433.19	$824,989.98	$4,778,443.21	28	$1,775,060.98
2048	$293.60	$5,642,144.20	$830,689.38	$4,811,454.82	29	$1,725,216.11
2049	$295.40	$5,676,780.93	$835,788.93	$4,840,992.00	30	$1,675,489.47
2050	$297.16	$5,710,549.32	$840,760.63	$4,869,788.70	31	$1,626,888.16
2051	$296.82	$5,703,990.17	$839,794.93	$4,864,195.24	32	$1,568,551.66

Not Underway Fuel Cost at 3.6% - High Oil Price

Year	Fuel Price / BBL	Cost LHD 1–7	Cost LHD 8	Difference Between LHD 1–7 and LHD 8	Period	Present Value
2019	$178.64	$3,432,864.71	$505,418.54	$2,927,446.18	0	$2,927,446.18
2020	$200.24	$3,848,118.87	$566,556.15	$3,281,562.72	1	$3,167,531.59
2021	$221.31	$4,252,970.10	$626,162.14	$3,626,807.96	2	$3,379,131.16
2022	$234.41	$4,504,628.01	$663,213.58	$3,841,414.43	3	$3,454,712.39
2023	$244.62	$4,700,924.82	$692,114.24	$4,008,810.58	4	$3,479,978.13
2024	$252.57	$4,853,585.95	$714,590.44	$4,138,995.51	5	$3,468,136.47
2025	$259.01	$4,977,494.41	$732,833.41	$4,244,661.00	6	$3,433,084.39
2026	$257.38	$4,946,182.25	$728,223.34	$4,217,958.91	7	$3,292,941.82
2027	$261.20	$5,019,527.53	$739,021.92	$4,280,505.62	8	$3,225,648.41
2028	$265.61	$5,104,290.77	$751,501.56	$4,352,789.21	9	$3,166,137.98
2029	$271.49	$5,217,274.01	$768,136.01	$4,449,138.00	10	$3,123,764.77
2030	$278.62	$5,354,235.80	$788,300.81	$4,565,934.99	11	$3,094,371.23
2031	$278.99	$5,361,463.26	$789,364.90	$4,572,098.36	12	$2,990,876.63
2032	$284.13	$5,460,122.67	$803,890.46	$4,656,232.20	13	$2,940,070.94
2033	$288.05	$5,535,576.00	$814,999.41	$4,720,576.58	14	$2,877,123.29
2034	$291.94	$5,610,243.87	$825,992.72	$4,784,251.15	15	$2,814,606.19
2035	$296.39	$5,695,826.68	$838,593.02	$4,857,233.66	16	$2,758,245.44
2036	$300.09	$5,766,786.98	$849,040.46	$4,917,746.52	17	$2,695,568.04
2037	$300.53	$5,775,291.26	$850,292.54	$4,924,998.72	18	$2,605,736.67
2038	$305.38	$5,868,555.24	$864,023.74	$5,004,531.50	19	$2,555,807.11
2039	$308.97	$5,937,545.11	$874,181.07	$5,063,364.03	20	$2,495,996.91
2040	$312.19	$5,999,343.92	$883,279.67	$5,116,064.25	21	$2,434,339.39
2041	$315.44	$6,061,891.19	$892,488.47	$5,169,402.72	22	$2,374,246.18
2042	$317.61	$6,103,572.01	$898,625.11	$5,204,946.90	23	$2,307,501.16
2043	$320.79	$6,164,600.94	$907,610.36	$5,256,990.58	24	$2,249,588.42
2044	$324.96	$6,244,701.38	$919,403.50	$5,325,297.88	25	$2,199,631.96
2045	$328.38	$6,310,416.37	$929,078.68	$5,381,337.69	26	$2,145,539.95
2046	$331.32	$6,366,930.56	$937,399.23	$5,429,531.33	27	$2,089,531.62
2047	$334.55	$6,429,143.41	$946,558.79	$5,482,584.63	28	$2,036,630.26
2048	$338.30	$6,501,154.40	$957,160.92	$5,543,993.48	29	$1,987,878.35
2049	$341.72	$6,566,952.63	$966,848.35	$5,600,104.28	30	$1,938,221.70
2050	$344.98	$6,629,490.42	$976,055.75	$5,653,434.67	31	$1,888,686.86
2051	$346.86	$6,665,709.40	$981,388.25	$5,684,321.15	32	$1,833,016.75

Not Underway Fuel Cost at 3.6% - Low Oil Price

Year	Fuel Price / BBL	Cost LHD 1–7	Cost LHD 8	Difference Between LHD 1–7 and LHD 8	Period	Present Value
2019	$178.64	$3,432,864.71	$505,418.54	$2,927,446.18	0	$2,927,446.18
2020	$151.70	$2,915,327.22	$429,221.81	$2,486,105.40	1	$2,399,715.64
2021	$154.40	$2,967,135.14	$436,849.46	$2,530,285.68	2	$2,357,491.02
2022	$154.62	$2,971,305.38	$437,463.44	$2,533,841.94	3	$2,278,768.74
2023	$156.58	$3,009,037.08	$443,018.66	$2,566,018.42	4	$2,227,515.57
2024	$158.28	$3,041,708.16	$447,828.80	$2,593,879.36	5	$2,173,456.72
2025	$159.62	$3,067,509.64	$451,627.54	$2,615,882.10	6	$2,115,727.03
2026	$156.74	$3,012,000.21	$443,454.92	$2,568,545.29	7	$2,005,251.92
2027	$158.68	$3,049,365.98	$448,956.26	$2,600,409.72	8	$1,959,583.34
2028	$159.45	$3,064,083.51	$451,123.11	$2,612,960.40	9	$1,900,618.84
2029	$159.84	$3,071,706.04	$452,245.37	$2,619,460.67	10	$1,839,138.04
2030	$161.29	$3,099,595.76	$456,351.56	$2,643,244.20	11	$1,791,348.06
2031	$161.93	$3,111,741.57	$458,139.78	$2,653,601.80	12	$1,735,875.96
2032	$165.59	$3,182,119.68	$468,501.50	$2,713,618.18	13	$1,713,451.91
2033	$168.02	$3,228,868.59	$475,384.31	$2,753,484.28	14	$1,678,208.92
2034	$168.44	$3,237,022.00	$476,584.74	$2,760,437.26	15	$1,623,983.27
2035	$170.75	$3,281,242.68	$483,095.32	$2,798,147.36	16	$1,588,965.60
2036	$173.14	$3,327,298.42	$489,876.08	$2,837,422.35	17	$1,555,278.41
2037	$177.02	$3,401,825.65	$500,848.68	$2,900,976.98	18	$1,534,859.71
2038	$175.55	$3,373,514.82	$496,680.49	$2,876,834.33	19	$1,469,195.20
2039	$178.51	$3,430,472.78	$505,066.37	$2,925,406.41	20	$1,442,085.80
2040	$180.07	$3,460,402.83	$509,472.96	$2,950,929.87	21	$1,404,119.35
2041	$181.28	$3,483,741.60	$512,909.11	$2,970,832.49	22	$1,364,468.60
2042	$183.50	$3,526,318.73	$519,177.71	$3,007,141.02	23	$1,333,151.24
2043	$185.80	$3,570,556.54	$525,690.82	$3,044,865.72	24	$1,302,968.80
2044	$187.66	$3,606,213.64	$530,940.59	$3,075,273.05	25	$1,270,251.74
2045	$191.82	$3,686,267.41	$542,726.86	$3,143,540.55	26	$1,253,329.97
2046	$192.52	$3,699,655.88	$544,698.04	$3,154,957.85	27	$1,214,171.87
2047	$195.72	$3,761,173.68	$553,755.26	$3,207,418.42	28	$1,191,468.23
2048	$198.75	$3,819,453.63	$562,335.78	$3,257,117.85	29	$1,167,886.30
2049	$201.87	$3,879,414.12	$571,163.73	$3,308,250.39	30	$1,145,000.59
2050	$204.04	$3,921,088.60	$577,299.44	$3,343,789.17	31	$1,117,085.64
2051	$204.59	$3,931,552.08	$578,839.97	$3,352,712.11	32	$1,081,145.36

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